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Spillover effects of the United States economic slowdown induced by COVID-19 pandemic on energy, economy, and environment in other countries

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ABSTRACT

The United States has become the country hardest hit by the COVID-19 pandemic. This pandemic has not only led to the largest decline in economic output but also caused a sharp decline in carbon emissions and energy consumption in the United States after World War II. This study aims to evaluate how to spillover effects of the US economic slowdown caused by the COVID-19 pandemic on the 3E (Energy Economy Environment) in other countries. To this end, the international 3E for 2000 and 2014, and nine indicators based on network analysis to dynamically study the changes in the degree of 3E impact between countries. And then, we analyzed the impact of the epidemic on the 3E of various countries, with focusing on the interaction between the United States and other countries. The results show that the internal carbon emission density and internal energy consumption density of the United States declined during 2010–2014, whereas the internal carbon emission density and internal energy consumption density of developing countries increased. Next, changes in US carbon emissions induced by the epidemic have a more significant impact on Canada, China, Mexico, the European Union, and Russia. Finally, the internal and external carbon emission indexes of most countries have decreased, which indicates that most countries are affected by the carbon reduction and energy consumption caused by the pandemic in the US. This information provides a new perspective for assessing the impact of 3E between countries suffered from the COVID-19 Pandemic.

1. Introduction

As announced by the World Health Organization (WHO) on March 11, the COVID-19 has constituted a global pandemic and has brought challenges to the global healthcare system (WHO, 2020). To effectively curb the spread of the COVID-19, most countries have adopted strict non-pharmaceutical public health interventions, including stay-at-home, non-essential business closures, interstate travel restriction, gathering ban, lockdowns, etc. (Flaxman et al., 2020; Lai et al., 2020; Liu et al., 2020). However, except for the global health system, the global pandemic of COVID-19 seriously impacts the world economy. According to the World Economic Outlook issued by the International Monetary Fund (IMF), under the influence of the COVID-19, global economic output is expected to decline by 4.4% compared with 2019, with the economic output of developed economies projected to decline by 5.8%, output in emerging market and developing economies is

expected to decline by 3.3%, and world trade volume (goods and services) projected to fall by 10.4%, with the import volume of developed economies is expected to decline by 11.5%, the export volume is expected to decline by 11.6%, the import volume of emerging markets and developing economies is expected to decline by 9.4%, and the export volume is expected to decline by 7.7%. However, the global pandemic of COVID-19 has great uncertainty in the economic impact, mainly in two aspects: the suddenness and enormity of the massive job losses and the severity of the economic contraction relative to the size of the mortality shock (Altig et al., 2020). In fact, the global pandemic of COVID-19 is more serious than expected in the first half of 2020. We underestimated the impact of the outbreak and other crises on the economy (Fernandes, 2020). Meanwhile, the World Economic Outlook points out that COVID-19's negative impact on the economy will continue (IMF, 2020b).

The implementation of various non-pharmaceutical health interventions has also caused the COVID-19 pandemic to have a huge

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impact on the environment and climate. As regards environment, with strict non-pharmaceutical health intervention measures adopted, China positively reduced energy-related carbon emissions in the first quarter compared with the same period last year. From the perspective of sector, transport ranked the first for reducing energy-related carbon emission, which decreasing by 61.9% (Wang and Wang, 2020). And Wang and Su found that strict epidemic prevention measures had a positive impact on China's environment from multiple perspectives (Wang and Su, 2020). Berman and Ebisu compared the data during the outbreak with historical data in the United States and found that nitrogen dioxide has been reduced by 25.5% and PM2.5 has also declined (Berman and Ebisu, 2020). Malliet et al. used the Computable General Equilibrium model to evaluate the economic and environmental impact of the lockdown measures and found that France will reduce carbon emissions by 6.6% in 2020 (Malliet et al., 2020). Adams analyzed hourly air pollution observations in Ontario in 2020 and the previous five years found that after the declaration of the State of Emergency (SOE), both nitrogen dioxide and nitrogen oxides demonstrated a reduction, and fine particles remained unchanged compared with historical concentrations (Adams, 2020). Rugani and Caro found that Italy's CF from March to April of 2020 decreased by 20% compared to the same period in the past by calculating the carbon footprint (CF) indicator for Italy from March to April 2020 and compared it with the same period from 2015 to 2019 (Rugani and Caro, 2020). Corinne Le Quéré et al. found that the daily global carbon dioxide emissions in April decreased by 17% (-11 to -25% for $\pm 1\sigma$), compared with the same period in 2019. During the epidemic, the reduction in economic activities is an important reason for the decline in carbon emissions and the improvement of the environment (Le Quéré et al., 2020). With regard to energy, Birol pointed out that the renewable energy industry is suffering losses due to supply chain delays, stock market taxes, and other issues (Birol, 2020). Gillingham et al. reported that due to the impact of the epidemic, the consumption of aviation fuel and gasoline in the United States has decreased by 50% and 30% respectively in the short term, and the electricity demand has decreased by less than 10%. At the same time, carbon dioxide emissions have decreased by 15%, and local air pollutants have also declined (Gillingham et al., 2020). Santiago et al. found that from March 14 to April 30, Spain's electricity consumption decreased by 13.49% compared with the average value of the previous five years (Santiago et al., 2021). However, when analyzing 3E changes, previous studies more focused on individual countries or global. In international trade, imports and exports between countries can also affect the carbon emissions and energy consumption of other countries (Ahmad and Wyckoff, 2003). Hence, this article analyzes the impact of national internal and external 3E from the perspective of international trade.

Data from the World Bank show that in 2018, the United States' imports of goods and trade were 3.15 trillion dollars, and exports were 2.498 trillion dollars in international trade, making it the world's largest trade importer and the second-largest trade exporter (IMF, 2020a). It is also a major carbon emitter. According to the statistical review of world energy 2020 released by BP, the carbon emission of the United States in 2019 is 4964.7 million tons, which is the second-largest carbon emitter in the world, and the per capita carbon emission is the highest among all countries in the world (BP, 2020). In the epidemic, as of September 16, the cumulative number of infections has exceeded 6.49 million in the United States. Therefore, the impact of the epidemic in the United States on domestic and foreign countries will continue. Based on the above analysis, this paper uses the input-output table to build a national carbon emissions trading network, in which we evaluate the changes in the carbon emission density of various countries from 2000 to 2014, and the degree of internal and external impacts on carbon emissions in various countries during the epidemic, particularly the impact of the US epidemic on the carbon emissions of countries around the world, namely spillover effect. It provides a new perspective for measuring the impact of international carbon emissions.

2. Literature review

With the deepening of globalization, economic ties among countries have been strengthened. Therefore, when a country's economy is impacted, the impact on the world economy or individual economy is increasing, the spillover effect is increasing. At present, the commonly used model to assess the spillover effects of economy, environment, and energy is the global vector autoregressive (GVAR) model. GVAR model is developed by Pesaran et al. based on VAR (Dong et al., 2019b; Dufour and Renault, 1998; Potjagailo, 2017). Based on GVAR, Kempa and Khan analyzed the two-way spillover effects of public debt and economic growth in the euro area using data from 11 major euro area countries from the first quarter of 1991 to the fourth quarter of 2014 (Kempa and Khan, 2017). Bettendorf constructed GVAR model of nine EU countries, Japan, Britain, and the United States, and found that spillover effects of general risk are much stronger than those of bailouts (Bettendorf, 2019). Hoxha used the GVAR model to assess how the financial shocks of the 15 EU countries are transmitted to the European transition countries. The results indicated that the spillover effects of negative shocks and financial pressures from EU-15 to European transition countries are always negative, and the magnitude of these effects varies greatly in different regions (Hoxha, 2018). Sznajderska and Kapuściński analyzed the spillover effect of China's negative output shock on different economies by comparing GVAR model with the Bayesian GVAR model. The results demonstrated that the spillover effect is stronger for the economies with smaller exchange rate elasticity and higher share of manufacturing industry in the total value-added and the economies with larger scale (Sznajderska and Kapuściński, 2020). Yang utilized the GVAR model to evaluate the technological innovation efficiency of nine high-tech industries in China from 1997 to 2016 and analyze the spillover effect of technological innovation efficiency of China's high-tech industries (Yang Youcai, 2020). Smith et al. used GVAR model to analyze the impact of the epidemic on global carbon dioxide consumption and fossil energy consumption from 2020 Q1 to 2021Q4 (Smith et al., 2020). Generally, GVAR is suitable for simulating the high-dimensional system under the global economic framework and analyzing the economic transmission and linkage in the global economic system, but it is rarely used in energy and carbon emissions. GVAR requires high data.

The network connects connected actors and is a collection of actors and their relationships. Network analysis depicts the characteristics of the relationship between actors and actors and the characteristics of actors in the network by analyzing the structural attributes of nodes and edges in the network, which is usually used in sociology and management. (Scott, 1988). Smith and Whited applied social network analysis to international trade, analyzed the characteristics of the international trade network, and measured the world structure, which attracted the attention of scholars (Smith and White, 1992). Kali and Reyes combined international trade with a network approach to construct a new global trade network map and got indicators of how well connected a country is into the global trading system (Reyes, 2005). Chen et al. combined complex network analysis with input-output analysis to analyze the characteristics of energy flows in international trade (Chen et al., 2018). Using input-output data, Contreras combined input-output with network analysis to identify key sectors of an economy (Contreras, 2020). López et al. combine structural path analysis (SPA) with complex network analysis to assess the export embodied carbon emissions of other countries in the world caused by China's imports from different sectors or industry clusters (López et al., 2020). Through these studies considered input-output data, they just wondered whether there is a relationship between actors, instead of fully using input-output data. However, compared with GVAR model, the steps of network analysis are relatively simple, and the data requirements are not high. Therefore, the contribution of this paper is: firstly, this paper constructs a sector-based international carbon emission matrix, sector-based international energy matrix. Secondly, by using network analysis, nine indexes are

constructed, namely, internal economic closeness, external economic closeness, internal and external economic activity index, internal carbon emission density, external carbon emission density, internal and external carbon emission activity index, internal energy consumption density, external energy consumption density, the internal and external energy activity index, and analyzed the impact of the epidemic on 3E. Finally, we measure and analyze the impact of 3E between the United States and other countries.

3. Methodology and data

3.1. Construction of a sector-based international 3E matrix

As shown in Fig. 1, in the input-output table provided by the world input-output database (WIOD), the first quadrant is the intermediate input-use matrix (in the blue line frame), which shows the consumption and distribution relationship of products among sectors in the world. The intermediate input matrix can be expressed as equation (1). In order to estimate the impact of international carbon emissions, this paper combines the total carbon emissions with the input-output table to construct an international carbon emissions matrix. First, divide the total output of each country's sector by the total carbon emissions to obtain the carbon emission intensity f . Then, multiply the corresponding elements between the intermediate input-use matrix and the carbon emission intensity to obtain the international carbon emission matrix CA. As showing in Equation (2):

$$A = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nn} \end{bmatrix} \quad (1)$$

$$CA = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nn} \end{bmatrix} \cdot \begin{bmatrix} f_1^c & f_1^c & \dots & f_1^c \\ f_2^c & f_2^c & \dots & f_2^c \\ \dots & \dots & \dots & \dots \\ f_n^c & f_n^c & \dots & f_n^c \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \dots & \dots & \dots & \dots \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix} \quad (2)$$

Among them, x_{ij} represents the intermediate products exported by sector i to sector j , f_i^c represents the carbon emission intensity of sector i , and c_{ij} represents the carbon emissions caused by the intermediate products exported by sector i to sector j . The International Carbon Emission Matrix shows the carbon emission flow relationships between sectors and sectors on a global scale, and these flows constitute a macroscopic carbon emission flow network. In network analysis, each sector represents the node of the network, and the import and export relationship between sectors is the carbon emission flow relationship, which is the arc in the network, and it is worthwhile.

Similarly, we can get the international energy consumption matrix

EA:

$$EA = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nn} \end{bmatrix} \cdot \begin{bmatrix} f_1^e & f_1^e & \dots & f_1^e \\ f_2^e & f_2^e & \dots & f_2^e \\ \dots & \dots & \dots & \dots \\ f_n^e & f_n^e & \dots & f_n^e \end{bmatrix} = \begin{bmatrix} e_{11} & e_{12} & \dots & e_{1n} \\ e_{21} & e_{22} & \dots & e_{2n} \\ \dots & \dots & \dots & \dots \\ e_{n1} & e_{n2} & \dots & e_{nn} \end{bmatrix} \quad (3)$$

Where, f_i^e is the energy intensity of sector i , e_{ij} is the energy consumption caused by the export of intermediate products from sector i to sector j . The international energy consumption matrix shows the embodied energy flow relationship between sectors in the world, which constitutes the macro energy flow network. Similarly, in network analysis, each department represents the node of the network, and the import and export relationship between departments, that is, the energy flow relationship, is the arc of the network, and it has value and direction.

3.2. Network analysis method based on international 3E matrix

Nomenclature.

ρ_i^x The internal economic closeness of country i , the higher the ρ_i^x , the greater the degree of mutual influence of economic between national sectors.

ρ_{ij}^x The external economic closeness of i country to j country, the greater the ρ_{ij}^x , the higher the effect of j on i .

$IEXI_i$ The internal and external economic activity index of country i , and the larger the $IEXI_i$ is, the greater the impact of the interaction within the country's sectors on economic activity

ρ_i^c The internal carbon emission density of country i , the higher the ρ_i^c the greater the degree of mutual influence of carbon emissions between national sectors.

ρ_{ij}^c The external carbon emission density of i country to j country, the greater the ρ_{ij}^c , the higher the effect of j on i .

$IECI_i$ The internal and external carbon emission impact index of country i , and the larger the $IECI_i$ is, the greater the impact of the interaction within the country's sectors on carbon emissions

ρ_i^e The internal energy consumption density of country i , the higher the ρ_i^e , the greater the degree of mutual influence of energy consumption between national sectors.

ρ_{ij}^e The external energy consumption density of i country to j country, the greater the ρ_{ij}^e , the higher the effect of j on i .

$IEEI_i$ The internal and external energy activity index of country i , and the larger the $IEEI_i$ is, the greater the impact of the interaction within the country's sectors on energy

Since the international 3E matrix includes the influence of various

		Intermediate products				Final demand	Total output
		Sector 1	Sector 2	...	Sector n		
Intermediate products	Sector 1	x_{11}	x_{12}	...	x_{1n}	y_1	x_1
	Sector 2	x_{21}	x_{22}	...	x_{2n}	y_2	x_2

	Sector n	x_{n1}	x_{n2}	...	x_{nn}	y_n	x_n
Value added		z_1	z_2	...	z_n		
Total output		x_1	x_2	...	x_n		

Fig. 1. Diagram of the input-output table of WIOD.

national departments, we apply the network analysis method to construct nine indicators to analyze the influence of 3E between international sectors, namely internal economic closeness, external economic closeness, internal and external economic activity index, the internal carbon emission density, the external carbon emission density, and the internal and external carbon emission impact index, internal energy consumption density, external energy consumption density, internal and external energy activity index.

This study mainly uses the concept of density in network analysis. Density refers to the ratio of the number of arcs to the number of arcs that may exist, as shown in Equation (4):

$$\rho = \frac{N}{S(S-1)/2} \quad (4)$$

Where ρ represents the density of the network, N is the number of arcs in the network, that is, the number of economic (carbon emission, energy) relationships between departments, and S is the number of nodes in the network, that is, the total number of sectors. Since the 3E relationship of the national carbon emission matrix is directional and numerical, this paper uses Wasserman et al. (Wasserman and Faust, 1994) and Liu et al. (Liu et al., 2020) for reference, and defines the network density with direction and numerical as:

$$\rho = \frac{\sum n_{ij}}{S(S-1)} \quad (5)$$

In this study, the international carbon emission matrix includes multiple countries and regions. Hence, in order to explore the relationship among carbon emissions among countries, we learn from the concepts of sub-graph and sub-density. In this paper, the set of sectors in each country is a subset of all sectors in the international carbon emission matrix, and the carbon emission relationship of each country's sector is a sub-graph of the international carbon emission network. From the sub-graph, the sub-density can be obtained. The sub-density reflects the degree of influence of carbon emissions among the internal sectors of a country. This paper defines it as the internal carbon emission density, as shown in Equation (6).

$$\rho_i^c = \frac{\sum c_i}{s_i(s_i-1)} \quad (6)$$

Among them, ρ_i^c is the internal carbon emission density, $\sum c_i$ is the amount of carbon emissions transferred between the internal sectors of country i , and s_i is the actual sector of the country. Internal carbon emission density reflects the degree of carbon emission transferred through economic activities among all sectors of a country. The higher the internal carbon emission density, the greater the degree of mutual influence of carbon emissions between national sectors.

Similarly, internal economic closeness can be defined ρ_i^x , internal energy consumption density ρ_i^e , as shown in equation (7) and equation (8):

$$\rho_i^x = \frac{\sum x_i}{s_i(s_i-1)} \quad (7)$$

$$\rho_i^e = \frac{\sum e_i}{s_i(s_i-1)} \quad (8)$$

In the international carbon emission matrix, the carbon emission relationship of all sectors of a country includes not only the internal carbon emission flow relationship but also the carbon emission relationship between the country and other countries. On this basis, this paper defines the external carbon emission density, as shown in Equation (5):

$$\rho_{ij}^c = \frac{\sum c_{ij}}{s_i s_j} \quad (9)$$

Among them, ρ_{ij}^c is the carbon emission density between i country and

j country, that is, the external carbon emission density of i country to j country. $\sum c_{ij}$ is the carbon emissions caused by country i 's export to country j , and s_i and s_j are the number of sectors in country i and country j , respectively. The external carbon emission density ρ_{ij}^c reflects the degree of influence of the sector of country j on the carbon emissions of country i . The greater the ρ_{ij}^c , the higher the effect of j on i .

Similarly, we can define the external economic closeness ρ_{ij}^x , external energy consumption density ρ_{ij}^e , as shown in equation (10) and equation (11) respectively:

$$\rho_{ij}^x = \frac{\sum x_{ij}}{s_i s_j} \quad (10)$$

$$\rho_{ij}^e = \frac{\sum e_{ij}}{s_i s_j} \quad (11)$$

Besides, in order to measure the relative size of internal and external carbon emission density, we define the internal and external carbon emission impact index (IECI_{*i*}), as shown in Equation (12):

$$IECI_i = \frac{\sum c_i - \sum_{j=1}^n c_{ij}}{\sum_{j=1}^n c_{ij}}, (i \neq j) \quad (12)$$

It can be seen from Eqn 12 that the larger the internal and external carbon emission impact index is, the greater the impact of the interaction within the country's sectors on carbon emissions; on the contrary, the smaller the internal and external carbon emission impact index, the greater the impact of interaction between external sectors and the country on carbon emissions.

Similarly, we can define the internal and external economic activity index (IEEI_{*i*}) and internal and external energy activity index (IEEI_{*i*}).

$$IEEI_i = \frac{\sum x_i - \sum_{j=1}^n x_{ij}}{\sum x_i}, (i \neq j) \quad (13)$$

$$IEEI_i = \frac{\sum e_i - \sum_{j=1}^n e_{ij}}{\sum e_i}, (i \neq j) \quad (14)$$

3.3. Data sources

The input-output table in this research comes from the 2016 version of the input-output table released by WIOD (<http://www.wiod.org/home>), and the carbon emission data use the environmental account released by WIOD. The input-output table provided by WIOD includes the economic output, intermediate input, and added value of 43 countries or economies (28 European countries plus 15 major economies). Carbon emission data includes 56 sectors of 43 countries. The rest countries are represented by ROW. These 43 economies include not only major developed countries, such as the United States, Japan, Germany, etc. but also emerging countries, such as China, India, Russia, etc. In terms of economic output and carbon emissions, the sum of these countries occupies a dominant position. Besides, the input-output table provided by WIOD is a non-competitive input-output table, which separates intermediate products from final demand. It meets the requirements of this network analysis method. In the actual analysis, the data of EU countries are integrated for research. See Appendix A1 for country and country code. As for the number of sectors in each economy, in the input-output table, if a country has neither output nor input in a sector, then we think that the country has no sector, that is, no actor. As a result, the 56 sectors, excluding those without output and consumption, are the number of sectors in the country.

4. Results and analysis

4.1. The effect of national internal economy, carbon emission, and energy

From Equations (6)–(8), we can get the internal economic closeness,

internal carbon emission density, and internal energy consumption density of each country, as shown in Table 1, Table 2, and Table 3 respectively. From 2000 to 2014, the internal economic closeness of all countries increased, that is, the economic interaction between internal departments of all countries changed closely. Considering the internal carbon emission density, in 2000–2014, the internal carbon emission density of China, Russia, India, South Korea, Brazil and other countries increased. In particular, China and India increased significantly, revealing that while China and India are developing economically, the carbon emission links among the internal sectors of the country are gradually becoming closer and the carbon emissions are increasing, and the internal departments of China and India have a great influence on carbon emissions. The internal carbon emission density of the United States, the European Union, Japan, and the United Kingdom has decreased. It can be found that most of the increase in internal carbon emission density is in developing countries, and most of the decrease is in developed economies. On the one hand, this phenomenon can be attributed to the development of low-carbon technologies in developed countries. On the other hand, from an industrial perspective, developed economies have transferred some industries with greater carbon emission intensity to developing countries through industrial transfer which reduces its internal carbon emission density. Moreover, emerging countries are bound to face the contradiction between environment and economy in the process of rapid development. However, due to the limitation of technology and capital, emerging countries often lead to rapid growth of carbon emissions to promote economic development at the expense of environment. Similar to the internal carbon emission density, the internal energy consumption density of China, Russia, India, South Korea, Brazil and other countries increased, among which China and India increased significantly. The internal energy consumption density of the United States, the European Union, Japan, the United Kingdom and other economies has decreased. On the one hand, the energy efficiency of the United States, Britain, Japan and other economies is higher than that of China, India, Mexico and other economies (Zhang et al., 2018). On the other hand, Lan and Malik et al. (Lan et al., 2016) point that as the per capita GDP increases, so does the geographical separation between the ‘production’ of energy and the ‘consumption’ of energy. According to the results of Meng and Hu et al. (Meng et al., 2020), most of the developing countries are producers, whose production- and final production-based energy consumptions are higher than their consumption-based ones. In contrast, the developed countries are consumers, whose consumption-based energy consumptions are higher. In addition, albeit the internal carbon emission density and internal energy consumption density of the United States has decreased, it is always in the top five.

Table 1
Internal economic closeness.

2000			2014		
Country code	ρ_i^x	Ranking	Country code	ρ_i^x	Ranking
USA	2557.77	1	CHN	9237.69	1
EMU	1983.48	2	EMU	4304.66	2
JPN	1482.64	3	USA	4095.66	3
CHN	871.03	4	RUS	1420.63	4
GBR	438.18	5	JPN	1398.21	5
BRA	222.15	6	IND	832.17	6
CAN	197.59	7	GBR	830.37	7
IND	190.10	8	BRA	750.48	8
KOR	189.07	9	KOR	578.06	9
RUS	168.49	10	AUS	480.45	10
AUS	148.06	11	CAN	477.47	11
TUR	125.96	12	IDN	315.79	12
MEX	125.28	13	TUR	282.75	13
CHE	83.15	14	MEX	234.96	14
IDN	62.91	15	CHE	219.85	15
NOR	32.93	16	NOR	97.78	16

Table 2
The internal carbon emission density.

2000			2014		
Country code	ρ_i^c	Ranking	Country code	ρ_i^c	Ranking
CHN	1289.61	1	CHN	4077.63	1
USA	936.72	2	RUS	1012.24	2
RUS	874.11	3	IND	771.30	3
EMU	615.09	4	USA	691.00	4
IND	349.34	5	EMU	503.77	5
JPN	292.04	6	JPN	284.18	6
KOR	114.61	7	KOR	154.60	7
GBR	91.17	8	BRA	139.28	8
BRA	90.94	9	IDN	121.63	9
AUS	86.23	10	AUS	95.38	10
CAN	75.63	11	TUR	87.24	11
IDN	68.95	12	CAN	80.25	12
MEX	67.54	13	MEX	74.71	13
TUR	61.37	14	GBR	73.64	14
CHE	4.89	15	CHE	4.86	15
NOR	4.79	16	NOR	4.63	16

Table 3
Internal energy consumption density.

2000			2014		
Country code	ρ_i^e	Ranking	Country code	ρ_i^e	Ranking
USA	24947.60	1	CHN	65907.23	1
RUS	22423.87	2	RUS	30320.73	2
CHN	20758.82	3	USA	20430.49	3
EMU	18108.17	4	EMU	16632.50	4
JPN	8870.73	5	IND	12902.49	5
IND	6741.70	6	JPN	6871.56	6
KOR	3371.52	7	BRA	4759.11	7
BRA	3343.79	8	KOR	4432.86	8
CAN	2656.98	9	CAN	3216.87	9
GBR	2133.92	10	IDN	2508.79	10
MEX	1925.88	11	MEX	2157.34	11
AUS	1626.66	12	AUS	1752.63	12
IDN	1478.66	13	GBR	1738.36	13
TUR	1408.43	14	TUR	1719.19	14
NOR	216.45	15	NOR	260.86	15
CHE	212.74	16	CHE	250.87	16

4.2. Spillover effects of US economic activity, carbon emissions, and energy consumption

To explore the impact of the reduction of internal economic closeness, internal carbon emission density and internal energy consumption density in the United States on other countries, we will further analyze

Table 4
The external economic closeness of the United States to other countries.

2000			2014		
Country code	ρ_{ij}^x	Ranking	Country code	ρ_{ij}^x	Ranking
CAN	45.19	1	CAN	88.27	2
EMU	34.90	4	EMU	72.80	5
JPN	18.35	8	CHN	50.38	9
MEX	17.21	9	MEX	45.31	13
GBR	10.34	14	JPN	21.83	24
KOR	6.48	22	GBR	19.30	25
CHN	5.71	26	KOR	15.31	32
BRA	3.16	43	IND	8.88	55
RUS	2.22	56	BRA	8.65	57
IND	1.96	61	RUS	6.99	63
CHE	1.79	66	CHE	6.19	65
NOR	1.77	69	IDN	2.81	101
AUS	1.53	73	TUR	2.62	108
IDN	1.30	82	AUS	1.92	126
TUR	1.09	86	NOR	1.72	134

the relationship and changes of external 3E density between the United States and other countries. Tables 4–6 show the external economic closeness, external carbon emission density, and external energy consumption density of other countries in the United States.

The external economic closeness of the United States to other countries measures the impact of the United States on the economy of other countries by importing intermediate products from other countries. The US's external carbon emission density to other countries measures the extent of the US's impact on other countries' carbon emissions through imported intermediate products. The external energy consumption density of the United States to other countries measures the impact of the United States on the energy consumption of other countries by importing intermediate products. Thanks to globalization, the economic closeness of the United States to other countries is rising, which shows that the United States comes from the increase of intermediate input of other countries and has an increasing impact on intermediate products of other countries. In the external carbon emission density of the United States to other countries, the external carbon emission density to Canada, China, Mexico, Brazil, India and other countries has increased, revealing that the trade between the US and these countries is expanding, and the impact of the United States on its export embodied carbon emissions is greater. For China, the United States has the greatest impact on China's carbon emissions through trade structure of intermediate products at home "and" export market shares of final products at home ". At the sector level, the impact of the United States on China's carbon emissions is mainly concentrated in a few sectors, such as textiles products, machinery, etc (Zhao et al., 2016). For India, Wang and Liu pointed out that the major receiver of India's export embodied renewable energy is developed countries, such as the European Union and the United States. Secondly, the import and export of intermediate products is the main driving factor of embodied renewable energy consumption, and most of them are embodied in the manufacturing industry (Wang and Liu, 2021).

The research of some scholars(Dong et al., 2019a; Wang and Jiang, 2020; Wang et al., 2020; Yan et al., 2020; Zhao et al., 2016; Zhong et al., 2018; Zhu et al., 2018) suggested that carbon transfer through trade was mainly concentrated in the carbon-intensive industrial sectors in the European Union, the United States and other countries in trade, such as mineral, chemicals, metals, oil, transport, and other manufacturing. Economies gathered at the two ends of these global value chains are found to have lower or even negative net carbon outflows, the global emissions in trade primarily have flown from developing to developed countries and regions. So, the US and the EU have high absolute net CO2 imports. Developing countries such as China, India and Brazil have more and more carbon emissions from their exports, including carbon dioxide and virtual water, which are caused by the import of imported goods(Liu et al., 2017). Meanwhile, the US's external carbon emission density to

Table 5
The external carbon emission density of the United States to other countries.

2000			2014		
Country code	ρ_{ij}^c	Ranking	Country code	ρ_{ij}^c	Ranking
CAN	24.79	2	CAN	28.87	2
EMU	13.49	3	CHN	10.00	5
RUS	13.24	4	MEX	8.62	8
MEX	5.27	18	EMU	7.65	12
CHN	5.14	19	RUS	6.17	17
BRA	3.45	26	BRA	3.98	28
GBR	3.14	27	IND	3.36	34
JPN	2.80	30	JPN	2.26	48
KOR	2.19	37	GBR	2.13	52
IND	1.67	45	KOR	2.05	53
IDN	0.97	62	TUR	1.16	73
AUS	0.93	65	IDN	0.70	99
TUR	0.60	82	AUS	0.37	120
NOR	0.49	89	NOR	0.29	139
CHE	0.13	154	CHE	0.09	182

Table 6
The external energy density of the United States to other countries.

2000			2014		
Country code	ρ_{ij}^e	Ranking	Country code	ρ_{ij}^e	Ranking
CAN	992.24	2	CAN	972.42	2
EMU	432.83	4	EMU	387.51	7
RUS	353.68	6	RUS	333.37	8
GBR	132.83	21	MEX	181.79	13
MEX	115.60	23	IND	160.00	17
CHN	107.89	25	CHN	156.80	20
BRA	98.71	26	KOR	112.83	31
KOR	96.08	28	GBR	108.84	33
JPN	94.11	29	BRA	108.26	34
IDN	44.56	47	JPN	79.49	47
IND	35.00	56	NOR	24.24	89
NOR	32.78	57	TUR	20.91	95
AUS	19.99	70	IDN	15.52	107
TUR	12.39	91	AUS	7.56	134
CHE	5.18	129	CHE	6.83	139

Table 7
Economic closeness of other countries to the United States.

2000			2014		
Country code	ρ_{ij}^x	Ranking	Country code	ρ_{ij}^x	Ranking
EMU	40.06	2	EMU	93.819	1
CAN	33.67	6	CAN	66.931	6
MEX	26.38	7	MEX	46.710	11
JPN	12.99	13	CHN	25.707	21
GBR	9.88	15	JPN	14.737	33
KOR	6.62	20	GBR	14.442	34
BRA	3.15	44	BRA	11.305	43
AUS	2.80	49	KOR	10.361	47
CHN	2.68	51	AUS	5.254	72
IND	1.60	71	IND	4.840	77
CHE	1.44	75	CHE	3.262	97
IDN	0.79	100	TUR	2.330	116
RUS	0.78	102	RUS	1.848	128
TUR	0.58	116	IDN	1.793	129
NOR	0.48	126	NOR	1.496	141

Table 8
The external carbon emission density of other countries to the United States.

2000			2014		
Country code	ρ_{ij}^c	Ranking	Country code	ρ_{ij}^c	Ranking
EMU	10.06	5	EMU	9.99	6
CAN	8.58	8	CAN	9.25	7
MEX	7.09	12	CHN	8.23	10
JPN	6.32	13	MEX	7.06	13
GBR	3.10	29	JPN	2.84	38
KOR	1.59	46	BRA	2.63	42
BRA	1.51	48	GBR	2.37	47
AUS	1.26	54	KOR	1.28	67
CHN	0.96	64	IND	1.16	74
CHE	0.70	76	AUS	0.86	92
IND	0.43	96	CHE	0.64	104
IDN	0.38	103	TUR	0.35	123
TUR	0.22	127	IDN	0.28	141
RUS	0.18	137	RUS	0.20	154
NOR	0.11	164	NOR	0.16	160

the EU, the United Kingdom, Japan and other countries has decreased, which reveals that the US's external carbon emissions are shifting from countries such as the EU to Canada, China and other countries. Hence, the US epidemic has a great influence on China, India, Brazil and other countries. The external carbon emission density of the United States to Canada, China, Mexico, the European Union, and Russia has always been relatively high, and it is in the top 30 of 240 external carbon

Table 9
External energy consumption intensity of other countries to the United States.

2000			2014		
Country code	ρ_{ij}^e	Ranking	Country code	ρ_{ij}^e	Ranking
EMU	314.54	7	CAN	454.07	3
MEX	306.71	8	MEX	450.79	4
CAN	291.97	9	EMU	442.44	5
JPN	157.77	16	CHN	177.27	14
GBR	78.65	31	BRA	177.18	15
BRA	62.16	37	JPN	96.83	38
KOR	56.17	42	GBR	83.42	42
AUS	43.00	48	KOR	52.81	59
CHN	31.85	59	IND	33.81	78
CHE	16.48	76	TUR	27.07	82
IDN	11.90	93	AUS	26.13	84
IND	11.64	95	CHE	16.58	104
TUR	6.87	117	NOR	10.81	123
RUS	5.39	128	IDN	8.56	131
NOR	5.17	130	RUS	7.13	135

emission densities, revealing that the US epidemic has a greater impact on the carbon emissions of these countries.

Among the external energy consumption density of the United States to other countries, the external energy consumption density of the United States to Canada, the European Union, Russia, the United Kingdom and other economies decreased, while that to Mexico, India, China, South Korea and other countries increased. Chen and Wu indicated that a region with federal energy resources expanded from local environment may grab a consistent quantity of the usefulness of energy resources from other foreign regions(Chen and Wu, 2017). Our results show that the U.S. embodied energy demand for other countries is gradually shifting from Canada, the European Union, Russia to India, China, South Korea and other countries. In addition, the carbon emission density of the United States to Canada and Iceland increased, while the energy density decreased. The carbon emission density of the United States to South Korea and Switzerland decreased, while the energy density increased. To sum up, the external carbon emission 3E density of the United States to Canada, China, Mexico, the European Union and Russia is always higher, and it is in the top 30 of the 240 external carbon emission density. At the same time, the United States wants to let the manufacturing industry return and get rid of the dependence on other countries in some manufacturing industries. Therefore, the US epidemic has a great impact on China, India, Brazil, Canada and other countries.

The external economic closeness of other countries to the United States measures the impact of other countries on the U.S. economy through the import of American intermediate products. The external carbon emissions density of other countries to the United States measures the extent to which other countries' imports affect US carbon emissions. The external energy consumption density of other countries to the United States measures the impact of importing intermediate products on the energy consumption of the United States. During the study period, the economic closeness of other countries to the United States has increased, but the European Union, Canada and Mexico are always at the forefront, and China's economic closeness to the United States has increased significantly. For carbon emission density, during 2000–2014, the external carbon emissions density from Canada, China, Brazil, and India to the United States increased, that is, the degree of impact on the US carbon emissions increased. Among them, China's growth rate is obvious, combine with the US's external carbon emission density to China, which reveals that the trade ties between China and the US have been significantly strengthened during 2000–2014. The external carbon emissions density of the European Union, Mexico, Japan, the United Kingdom, South Korea and other countries to the United States has reduced. In particular, Japan has significantly reduced. Combining with the US's external carbon emission density to other countries, the US's mutual influence on carbon emissions among developed countries is gradually decreasing, while the influence of

developing countries on the US is increasing. From a trade perspective, in the process of globalization, the trade ties between the United States and other countries have gradually strengthened. Regard to industrial, this may be due to the gradual transfer of some industries in the United States, and the manufacture of intermediate products from developed countries to developing countries. The intermediate products made in developing countries are relatively cheaper, so the products used in the United States are gradually inclined to be imported from developing countries. For energy density, Japan, South Korea, Australia and Indonesia have lower energy density than the United States, while other countries have higher carbon emission density than the United States. Similar to carbon emissions, energy consumption is also implied in the import and export of intermediate products. The factors influencing the embodied energy include the scale of import and export, energy efficiency, import and export structure, and so on(Lam et al., 2019). Jiang et al. (2020) pointed out that in the process of economic globalization, developing countries mainly export products to developed countries, which consumes a lot of energy and causes environmental pollution. International joint efforts contribute to reducing environmental pollution in developing countries and achieving the global goal of saving energy and reducing emissions. In short, the European Union, Canada, China, and Mexico have a greater impact on the 3E of the United States, ranking at the forefront of the 240 external economic closeness, external carbon emissions density and external energy consumption density. Hence, when they are hit by the epidemic, they have a greater impact on the US.

4.3. Internal and external impact index

Fig. 2 shows the internal and external economic activity index of each country in 2000 and 2014 (the index of NOR was 0.36 and 0.43 in 2000 and 2014 respectively). Fig. 3 shows the internal and external carbon emission impact index of each country in 2000 and 2014 (the NOR index was -0.99 and -0.63 in 2000 and 2014, respectively). Fig. 4 shows the internal and external energy activity index of each country in 2000 and 2014 (the index of NOR in 2000 and 2014 was -0.33 and -0.35 respectively). The internal and external economic activity index reflects the leading factors of economic growth of each economy, the internal and external carbon emissions impact index reflects the dominant factors of carbon emissions in various countries or regions. The internal and external energy activity index reflects the leading factors of energy consumption in each country or region. During the study period,

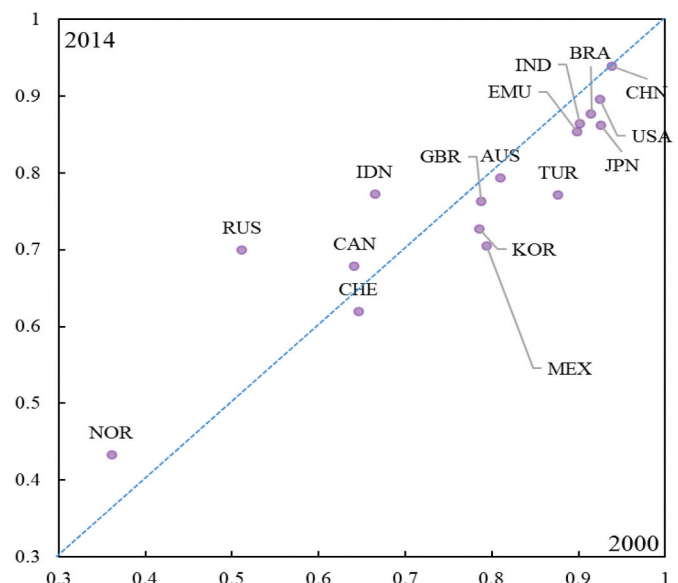


Fig. 2. The internal and external economic activity index of each country.

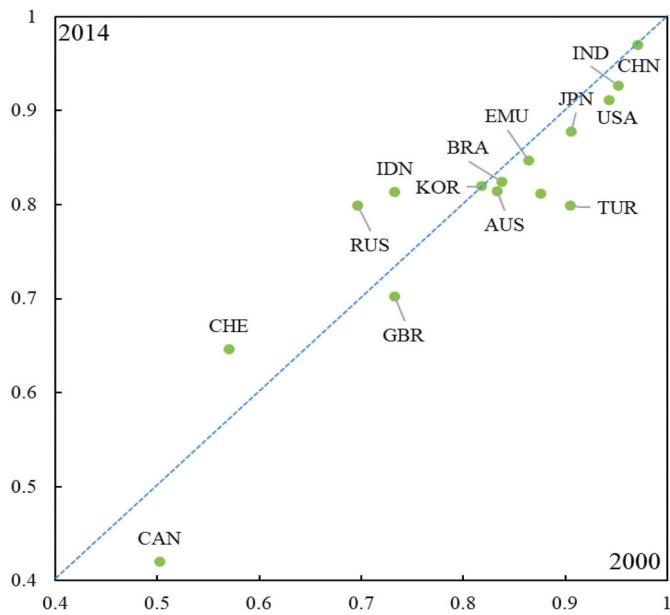


Fig. 3. The internal and external carbon emission impact index of each country.

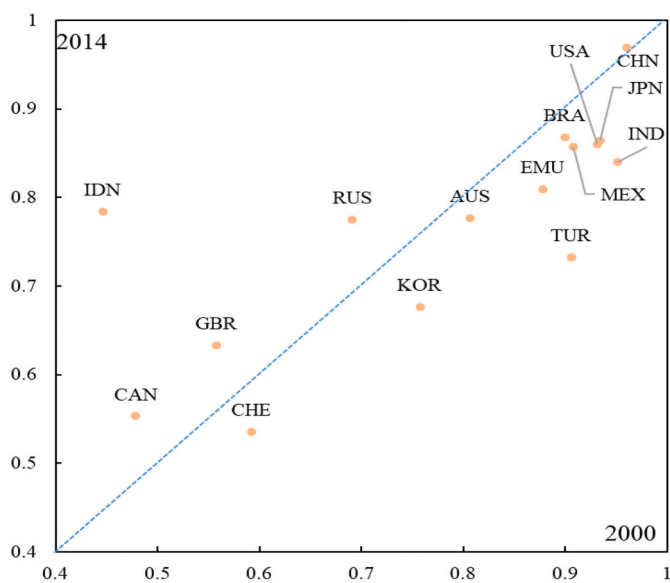


Fig. 4. The internal and external energy activity index of each country.

the internal and external economic activity index of most countries decreased, such as Australia, Brazil, the United States, Japan, the United Kingdom, Turkey and so on. This shows that the proportion of intermediate products exports of these countries increased, and the external economy increased its impact. Canada, Indonesia, Norway, Russia's internal and external economic activity index rose, indicating that the proportion of exports of these countries decreased and the internal economic impact increased. Among them, Canada, Chile, Russia, Turkey, Norway's internal and external economic activity index are all below 0.8, which is affected by external factors. Moreover, China has not changed significantly. As illustrated in Fig. 3, during 2000–2014, the internal and external carbon emission indexes of most countries decreased, such as the United States, China, Japan, etc., which indicates that most countries are more affected by external influences. Simultaneously, as for CHE, CAN, and NOR, their internal and external carbon emission impact index is relatively small, indicating that they are more

affected by other countries. Especially for CAN, CAN is greatly affected by other countries, especially the United States. Hence, in the epidemic, the United States may have the greatest impact on CAN's carbon emissions. As for the internal and external energy activity index, the domestic and foreign energy activity index of Canada, Britain, Indonesia and Russia increased, while that of China changed little. The internal and external energy activity index of other economies decreased. It is worth noting that Norway's internal and external energy impact index is always negative, indicating that its energy consumption is greatly affected by the external economy. In addition, Canada, Chile, the United Kingdom, South Korea's internal and external energy activity index is less than 0.7, which is greatly affected by external factors.

5. Conclusion

This paper constructs the sector-based international carbon emission matrix, sector-based international energy matrix, and uses network analysis to analyze the impact of the epidemic on 3E of each country through internal economic closeness, external economic closeness, internal and external economic activity index, internal carbon emission density, external carbon emission density, internal and external carbon emission impact index, internal energy consumption density, external energy consumption density, and internal and external energy activity index, and measures the influence of 3E between the United States and other countries.

The internal carbon emissions density and internal energy consumption density in the United States has declined, and most developed economies also exhibit this characteristic, while the internal carbon emissions density and internal energy consumption density in developing countries has increased. The decline in the internal carbon emission density and internal energy consumption density of the United States and most developed economies depend on its carbon emission reduction policies, R&D intensity and efficiency (Wang and Wang, 2019). From a global perspective, it may also be related to the outsourcing of some industries to other countries. The increase of internal carbon emission density and internal energy consumption density in developing countries may be due to their emphasis on economic development and less on related research and development of carbon emission reduction technology. In this epidemic, China, the United States, Russia, the European Union, and India's internal carbon emissions and internal energy consumption were greatly affected by the epidemic.

The impact of the United States on economic, carbon emissions and energy in developing countries has become greater. With the deepening of economic globalization, the economic interaction between the United States and other countries is increasing. At the same time, the relationship between countries through the supply chain is becoming closer and closer, which also leads to the emergence of industrial transfer. These transfers often occur between developed and developing countries. From the perspective of the US's external carbon emission density to other countries, China, Russia, Brazil, and India are more affected by the United States. Among other countries' external carbon emissions to the United States, China, Mexico, and Brazil have an increased impact on the United States' carbon emissions. Trade links with these countries have increased. Although the impact of other countries on the external carbon emissions of the United States increases, it is less than the impact of the United States on its external carbon emissions. Judging from the external energy density of the United States to other countries, Mexico, China, India and South Korea are more affected by the United States, but the influence of Mexico on the United States is greater than that of the United States on Mexico. Besides Mexico, there is the European Union, Japan, Turkey, Australia and Chile.

Affected by the epidemic, the economic output, carbon emissions and energy consumption of the United States will see a substantial decline. And affected by the United States, the embodied carbon emissions and embodied energy of exports of other countries will also drop

significantly, and the developing countries will be significantly affected. In terms of internal carbon emission density and internal energy consumption density, the United States is at the forefront, and the United States is more affected by the epidemic. At the same time, in the internal and external carbon emissions impact index, the United States has a higher value, with internal carbon emissions playing a leading role. In addition, since the United States affected the most by the epidemic, the US carbon emission and energy consumption will suffer more lasting from the epidemic. EIA predicts that after the US carbon emissions are reduced by 2.9% in 2019, energy-related carbon emissions will be reduced by 11.5% and energy consumption will be reduced by 7.8%. in 2020(EIA, 2020). In terms of external carbon emissions, the United States has the highest impact index on other countries, such as Canada, China, Mexico, etc., and most of them are developing countries. Therefore, the embodied carbon in exports of these countries will drop significantly. Among the external energy sources, the impact index of the United States on Canada, the European Union, Mexico, Russia, India,

and China is in the forefront, and the embodied energy exports of these countries will also face a sharp decline.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
the name of the country corresponding to the country code

Country Name	Country Code
Australia	AUS
Brazil	BRA
Canada	CAN
Switzerland	CHE
China	CHN
European Union	EU
The United Kingdom	GBR
Indonesia	IDN
India	IND
Japan	JPN
South Korea	KOR
Mexico	MEX
Norway	NOR
Russia	RUS
Turkey	TUR
the United States	USA

Author contribution

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Supervision, Writing- Reviewing and Editing. Xinyu Han: Methodology, Software, Data curation, Investigation Writing – original draft, Writing- Reviewing and Editing.

References

- Adams, M.D., 2020. Air pollution in Ontario, Canada during the COVID-19 state of emergency. *Sci. Total Environ.* 742, 140516.
- Ahmad, N., Wyckoff, A., 2003. Carbon Dioxide Emissions Embodied in International Trade of Goods.
- Altig, D., et al., 2020. Economic uncertainty before and during the COVID-19 pandemic. *J. Publ. Econ.*, 104274
- Berman, J.D., Ebisu, K., 2020. Changes in US air pollution during the COVID-19 pandemic. *Sci. Total Environ.* 739, 139864.
- Bettendorf, T., 2019. Spillover effects of credit default risk in the euro area and the effects on the Euro: a GVAR approach. *Int. J. Finance Econ.* 24, 296–312.
- Biorol, F., 2020. Put clean energy at the heart of stimulus plans to counter the coronavirus crisis. *International Energy Agency* 14.
- BP, 2020. *Statistical Review of World Energy*. BP, London.
- Chen, B., et al., 2018. Global energy flows embodied in international trade: a combination of environmentally extended input–output analysis and complex network analysis. *Appl. Energy* 210, 98–107.
- Chen, G.Q., Wu, X.F., 2017. Energy overview for globalized world economy: source, supply chain and sink. *Renew. Sustain. Energy Rev.* 69, 735–749.
- Contreras, M.G.A., 2020. Detecting diffusion properties of sectors in the mexican economy, 2012. *Invest. Economica* 79, 110–136.
- Dong, F., et al., 2019a. Drivers of the decoupling indicator between the economic growth and energy-related CO₂ in China: a revisit from the perspectives of decomposition and spatiotemporal heterogeneity. *Sci. Total Environ.* 685, 631–658.
- Dong, F., et al., 2019b. Examining the synergistic effect of CO₂ emissions on PM_{2.5} emissions reduction: evidence from China. *J. Clean. Prod.* 223, 759–771.
- Dufour, J.-M., Renault, E., 1998. Short run and long run causality in time series: theory. *Econometrica* 1099–1125.
- EIA, 2020. *Short-term energy outlook*. https://www.eia.gov/outlooks/steo/report/Energy_Information_Administration.
- Fernandes, N., 2020. Economic Effects of Coronavirus Outbreak (COVID-19) on the World Economy. Available at SSRN 3557504.
- Flaxman, S., et al., 2020. Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. *Nature* 584, 257–261.
- Gillingham, K.T., et al., 2020. The short-run and long-run effects of covid-19 on energy and the environment. *Joule* 4, 1337–1341.
- Hoxha, A., 2018. Explaining the impact of the global financial crisis on European transition countries: a GVAR approach. *Focus on European Economic Integration* 81–97.
- IMF, 2020a. *Balance of Payments Statistical Yearbook*. International Monetary Fund, Washington D.C.
- IMF, 2020b. *World Economic Outlook*. International Monetary Fund, Washington D.C.
- Jiang, L., et al., 2020. Energy use embodied in international trade of 39 countries: spatial transfer patterns and driving factors. *Energy* 195, 116988.

- Kempa, B., Khan, N.S., 2017. Spillover effects of debt and growth in the euro area: evidence from a GVAR model. *Int. Rev. Econ. Finance* 49, 102–111.
- Lai, S., et al., 2020. Effect of Non-pharmaceutical Interventions for Containing the COVID-19 Outbreak in China. medRxiv.
- Lam, K.L., et al., 2019. Energy intensity and embodied energy flow in Australia: an input-output analysis. *J. Clean. Prod.* 226, 357–368.
- Lan, J., et al., 2016. A structural decomposition analysis of global energy footprints. *Appl. Energy* 163, 436–451.
- Le Quéré, C., et al., 2020. Temporary reduction in daily global CO₂ emissions during the COVID-19 forced confinement. *Nat. Clim. Change* 10, 647–653.
- Liu Shijin, H.Y.a.W.D., 2020. An Impact Path Analysis of COVID-19 Outbreak in China and Policy Response. *Management World*.
- Liu, X., et al., 2017. Virtual carbon and water flows embodied in international trade: a review on consumption-based analysis. *J. Clean. Prod.* 146, 20–28.
- Liu, X., et al., 2020. Differential Impact of Non-pharmaceutical Public Health Interventions on COVID-19 Epidemics in the United States.
- López, L.A., et al., 2020. Mapping China's flows of emissions in the world's carbon footprint: a network approach of production layers. *Energy Econ.* 87, 104739.
- Malliet, P., et al., 2020. Assessing short-term and long-term economic and environmental effects of the COVID-19 crisis in France. *Environ. Resour. Econ.* 1–17.
- Meng, J., et al., 2020. The unequal contribution to global energy consumption along the supply chain. *J. Environ. Manag.* 268, 110701.
- Potjagailo, G., 2017. Spillover effects from Euro area monetary policy across Europe: a factor-augmented VAR approach. *J. Int. Money Finance* 72, 127–147.
- Reyes, R.K.a.J., 2005. Financial Contagion on the International Trade Network. *Economic Inquiry*.
- Rugani, B., Caro, D., 2020. Impact of COVID-19 outbreak measures of lockdown on the Italian Carbon Footprint. *Sci. Total Environ.* 737, 139806.
- Santiago, I., et al., 2021. Electricity demand during pandemic times: the case of the COVID-19 in Spain. *Energy Pol.* 148, 111964.
- Scott, J., 1988. Social network analysis. *Sociology* 22, 109–127.
- Smith, D.A., White, D.R., 1992. Structure and dynamics of the global economy: network analysis of international trade 1965–1980*. *Soc. Forces* 70, 857–893.
- Smith, L.V., et al., 2020. Assessing the Impact of COVID-19 on Global Fossil Fuel Consumption and CO₂ Emissions. ISER DP.
- Sznajderska, A., Kapuściński, M., 2020. Macroeconomic spillover effects of the Chinese economy. *Rev. Int. Econ.* 28, 992–1019.
- Wang, Q., Jiang, R., 2020. Is carbon emission growth decoupled from economic growth in emerging countries? New insights from labor and investment effects. *J. Clean. Prod.* 248, 119188.
- Wang, Q., Liu, Y., 2021. India's renewable energy: new insights from multi-regional input output and structural decomposition analysis. *J. Clean. Prod.* 283, 124230.
- Wang, Q., et al., 2020. China's coal consumption in a globalizing world: insights from multi-regional input-output and structural decomposition analysis. *Sci. Total Environ.* 711, 134790.
- Wang, Q., Su, M., 2020. A preliminary assessment of the impact of COVID-19 on environment—A case study of China. *Sci. Total Environ.*, 138915.
- Wang, Q., Wang, S., 2019. Decoupling economic growth from carbon emissions growth in the United States: the role of research and development. *J. Clean. Prod.* 234, 702–713.
- Wang, Q., Wang, S., 2020. Preventing carbon emission retaliatory rebound post-COVID-19 requires expanding free trade and improving energy efficiency. *Appl. Energy* 746, 141158.
- Wasserman, S., Faust, K., 1994. *Social Network Analysis: Methods and Applications*. Cambridge university press.
- WHO, 2020. **Coronavirus disease (COVID-2019) situation reports**. <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports> World Health Organization.
- Yan, Y., et al., 2020. Carbon endowment and trade-embodied carbon emissions in global value chains: evidence from China. *Appl. Energy* 277, 115592.
- Yang Youcai, G.L., Shi, Qianzi, 2020. Spillover effects of technological innovation efficiency among high-tech industries in China—based on GVAR model. *Manag. Rev.* 32, 138–149.
- Zhang, Y.-J., et al., 2018. Energy efficiency, carbon emission performance, and technology gaps: evidence from CDM project investment. *Energy Pol.* 115, 119–130.
- Zhao, Y., et al., 2016. Driving factors of carbon emissions embodied in China-US trade: a structural decomposition analysis. *J. Clean. Prod.* 131, 678–689.
- Zhong, Z., et al., 2018. Transnational transfer of carbon emissions embodied in trade: characteristics and determinants from a spatial perspective. *Energy* 147, 858–875.
- Zhu, Y., et al., 2018. Exploring the characteristics of CO₂ emissions embodied in international trade and the fair share of responsibility. *Ecol. Econ.* 146, 574–587.