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Carbon dioxide emissions reduction efficiency and growth potential: case of China

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Abstract

Purpose – Understanding China's carbon dioxide (CO_2) emission status is crucial for getting Carbon Neutrality status. The purpose of the paper is to calculate two possible scenarios for CO_2 emission distribution and calculated input-output flows of CO_2 emissions for every 31 China provinces for 2012, 2015 and 2017 years.

Design/methodology/approach – In this study using the input and output (IO) table's data for the selected years, the authors found the volume of CO_2 emissions per one Yuan of revenue for the industry in 2012 and the coefficient of emission reduction compared to 2012.

Findings – Results show that in the industries with a huge volume of CO_2 emissions, such as "Mining and washing of coal", the authors cannot observe the reduction processes for years. Industries where emissions are being reduced are "Processing of petroleum, coking, nuclear fuel", "Production and distribution of electric power and heat power", "Agriculture, Forestry, Animal Husbandry and Fishery". For the "construction" industry the situation with emissions did not change.

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Originality/value – "Transport, storage, and postal services" and "Smelting and processing of metals" industries in China has the second place concerning emissions, but over the past period, emissions have been sufficiently reduced. "Construction" industry produces a lot of emissions, but this industry does not carry products characterized by large emissions from other industries. Authors can observe that Jiangsu produces a lot of CO_2 emissions, but they do not take products characterized by significant emissions from other provinces. Shandong produces a lot of emissions and consumes many of products characterized by large emissions from other provinces. However, Shandong showed a reduction in CO_2 emissions from 2012 to 2017.

Keywords China carbon neutrality 2060, Carbon neutrality strategies, Climate regulation, Low carbon dioxide emissions

Paper type Research paper

1. Introduction

1.1 Literature review

According to the United Nations (UN) Environment Program in 2008–2018, the volume of anthropogenic greenhouse gas emissions increased by 1.5% per year and reached 55 billion tons of carbon dioxide equivalent ($CO_2 - eq$) in 2018. China makes the most significant contribution to global anthropogenic greenhouse gas emissions (13.1 billion tons of $CO_2 - eq$., 24%), the United States (5.7 billion tons of $CO_2 - eq$., 10%), the European Union (4.1 billion tons of $CO_2 - eq$., 7%), India (3.4 billion tons of $CO_2 - eq$., 7%), the Russian Federation (1.6 billion tons of $CO_2 - eq$., 3%) and Japan (1, 2 billion tons of $CO_2 - eq$., 2%). The contribution of each of the other issuers does not exceed 2% of the global issue, but they total account for about 40% of the worldwide issue (UN, 2019).

Carbon neutrality refers to achieving net-zero CO_2 emissions. The balancing of the emissions of CO_2can perform with its removal or by eliminating emissions from society (the transition to the "post-carbon economy") (Porfiriev *et al.*, 2020). For 1990–2017, CO_2 emissions associated with energy consumption increased 1.6 times in the global economy. The main driver was the growth of world gross domestic product (GDP) by 2.1 times. The world population has grown by only 1.4 times, which means increase in average per capita CO_2 emissions against the background of an increase in average per capita energy consumption due to improved levels and quality of life. The main limiting factor for CO_2 emissions decreased in the energy intensity of world GDP by 35%. The carbon intensity of the consumed energy (which depends on the structure of the fuel and energy resources used) has not changed over the past almost 30 years, but it has increased by 0.4%. An important conclusion follows: in low economic growth rates and weak investment activity, a large-scale reduction of greenhouse gas (GHG) is unrealistic. Policy in this area cannot be separated from the general socio-economic development strategy and should be considered as its organic component, which is entirely consistent with the priorities of the UN sustainable development goals (SDG)'s and the Paris Agreement.

Currently, China is promoting supply-side reforms, high-quality economic development, structural adjustments and steady growth (Liu *et al.*, 2012, 2013, 2015). The potential capacity of the Chinese economy has provided ample room to meet external challenges and achieve high-quality development (Qi *et al.*, 2016; Hui, 2018; Roach, 2017). The Chinese government keeps the economy running within a specific range and believes the Chinese economy is resilient (Özyurt, 2010; Guan *et al.*, 2008).

The authors try to analyze Chinese Economy by using historical input-output data. Thus, input and output analysis (referred to as IOA) can comprehensively reflect the input-output relationship between various economic system areas and reveal the inner economic relations of mutual dependence and restriction between various. The function of input-output accounting is to reflect the direct and obvious economic links between various sectors in the production process, and reveal the indirect, hidden links between various sectors. Leontief began studying input-output technology and compiling input-output tables in 1931 (Leontief, 2008). In China, Chen Xikang and his students constructed the first experimental input-output table of the national economy for 1973 (Chen *et al.*, 2017). With the rapid spread of the input-output technique in China, it is necessary to now exchange experience and search for solutions to theory's problems and applications. After the 11th The Communist Party of China (CPC) central committee, China focused on economic construction, which created the conditions for the research and application of modern economic analysis methods including input-output techniques. Since then, input-output table preparation, input-output technology research and input-output table application has rapidly developed. In the 1960s, Romania's famous economist Nicholas Georgescu – Roegen (1906–1994), first introduced the concept of entropy from physics to economics. He published a book on the laws of entropy and the economic process, illustrating how the essential means of economic activity continued to increase entropy (Geordslugescu-Roegen, 1993). In 1997, professor Wang Hengjun of Xiaan university of Posts and Telecommunications in China also advocated applying the concepts of energy and entropy in physics into economics and put forward the concepts of economic energy, economic entropy, absolute economic entropy and relative economy. He believed that entropy caused economic crises, as an inevitable social and economic phenomenon (Wang, 2002). In the United States of America (USA), Yakovenko, the professor of physics at the University of Maryland, found that economic systems and thermal systems are analogous. That means that the monetary system at equilibrium obeys the Boltzmann distribution in a closed economy. Yakovenko used computer simulations to explain the inhomogeneity of the distribution of wealth, showing that the disparity between the rich and the poor is a natural phenomenon in the world (Motesharrei *et al.*, 2016; Yakovenko, 2010). From the point of view of physics, entropy is a disordered state of molecular motion. From a statistical physics point of view, entropy is the logarithm of all particle states. While from the perspective of information, entropy is a measurement method of information. Few researchers analyzed the development of the economy on the basis of input-output tables using information entropy. Various methods are used, some of which involve taking into account of multiple components – internal and external subsystems and monitoring the entropy of complex systems, as reflected in the works of Vladimir Bulygin, Gennadiy Averin, Vladimir Opritov and Alexander Banaru (Opritov, 1999; Averin and Zviagintseva, 2013). Nevertheless, there is a research gap in the case of input-output data analysis using information entropy. Evaluation of systems using entropy are 137 developing branches of analysis.

Over the past half century, China has launched tens of ecological projects nationwide, with the main purposes of protection and restoring of forests and grasslands, primarily to prevent flooding, desertification and soil erosion, and to improve biomass productivity (Vasiev *et al.*, 2020). Now, in the context of climate change mitigation, they are becoming probably the world's most extensive nature conservation program, in terms of scale and investment (Bryan *et al.*, 2018; Lu *et al.*, 2018). The primary question is can China be Carbon Neutrality 2060? As [1] Asit K. Biswas emphasized in China Daily, the latest studies indicate that benefits from an aggressive climate change-mitigation strategy will increase GDP by 2–3%, reduce demands for fossil fuels by 80% and cut carbon emissions by 75–80% by 2050. Such developments will improve China's global competitiveness, make its economy more resilient and boost its soft power. If these goals are achieved, China will become a leading decarbonization technology provider for the world. In the paper, the authors pursue comparing various scenarios concerning decreasing CO_2 emissions in China.

Therefore, this paper tasks to:

(1) Analyze the scenarios concerning achieving Carbon Neutrality Goals 2060;

(2) Recommend carbon neutrality strategy 2060.

The first chapter of the paper, is a theoretical background literature review concerning carbon neutrality research. The second part represents sample and data and methodological background, modeling formula. Third part is the presentation of results concerning economy modeling and industrial economy modeling.

2. Methods

2.1 Data

Ecological, social and energy data was used from China Year Statistical Books from 1991 to 2019. The authors used input-output tables 2012, 2015 and 2017 from Carbon emission accounts and dataset https://www.ceads.net/user/index.php?id=1087&lang=en. China's National Bureau of Statistics data compiles national level input-output tables in open sources, published every five years since 1992. The authors' model uses China's regional input and output table from historical point of view. Research has been done based on China's 31 provinces and 42 industrial sectors in 2012, 2015 and 2017. It was the difference in the industries classification between 2012, 2015 and 2017, "Other manufacturing" and "Comprehensive use of waste resources" compiled in 2017 in one item "Other manufacturing and waste resources" and "Scientific research and polytechnic services" divided into two parts: "Scientific research" and "Polytechnic services". According to the National Bureau of Statistics information, the 2019 table will be published in 2022. Therefore, the authors are modeling the China Economy for 2012, 2015 and 2017. This research contains Supplementary Data – see Supplementary Information file. Industrial sectors acronyms please see in Appendix.

2.2 Methodological base

The authors created a regression model linking emissions by industry, by province and considering the estimated annual reduction in emissions. The authors build a regression model based on two assumptions:

(1) The amount of CO_2 emissions per 1 Yuan of income in the industry for one year is a constant value for all provinces;

(2) The amount of CO_2 emissions per 1 Yuan is reduced according to the power law;

(3) Then the number of emissions for each province can be calculated using the formula:

$$CO_2^{province} = \sum_{industry} K_{industry} \times e^{u_{ind} \times (Year-2012)} \times D^{year}_{province,\, industry} \quad (1)$$

(4) $CO_2^{province}$ – the amount of CO_2 emissions in the province;

(5) K_{ind} – the volume of CO_2 emissions per one Yuan of revenue for the industry in 2012;

(6) u_{ind} – the coefficient of emission reduction compared to 2012;

(7) $D^{year}_{province,\, industry}$ – revenue by industry in the province in a given year (2012, 2015, 2017).

The authors also compare the entropy of financial flows and emissions. Complexity modeling of economic efficiency and growth potential is increasingly essential for countries and provinces. Evaluating the monetary flows, kinetic energy (efficiency) and potential capacity (resilience) provides crucial information for economic development (Yan *et al.*, 2020).

The process of the entire formula is based on the ecological network formula created by Ulanowicz etc. (Ulanowicz and Hannon, 1987, 1991, 2009, 2017; Fath *et al.*, 2019). The concept of information entropy is used to scale the sustainable development capacity H of a single system:

$$H = -K\sum_{i,j}\frac{T_{ij}}{T}\log\frac{T_{ij}}{T} \quad (2)$$

Where, T is the total flow in the system, T_{ij} represents the flow between node i and node j, and H represents the information entropy. K represents the adjustment coefficient:

$$X = K\sum_{i,j}\frac{T_{ij}}{T}\log\frac{T_{ij}T}{T_i T_j} \quad (3)$$

Where, T is the total flow in the system, T_{ij} represents the flow between node i and node j, $T_{i\cdot}$ represents the input flow, $T.j$ represents the output flow. X represents the common entropy and K represents the adjustment coefficient by the formula:

$$\Psi = -K\sum_{i,j}\frac{T_{ij}}{T}\log\frac{T_{ij}^2}{T_i T_j} \quad (4)$$

Where, T is the total flow in the system, T_{ij} represents the flow between node i and node j, $T_{i\cdot}$ represents the input flow, $T.j$ represents the output flow, Ψ represented condition entropy and K represents adjustment coefficient

According to the algorithm, the following conclusions can be drawn:

$$H = X + \Psi \quad (5)$$

The modeling of Public Inter-Provincial Input-Output Tables in China process is as follows:

(1) Calculate the X, Ψ of every China' Province (so the result is 31 X and 31 Ψ in 2012, 2015 and 2107 yy). Considering that totally 31 Provinces are separate subsystem the boundary of every province (It is a closed system of every Subsystem-Province).

(2) Calculate input efficiency and potential growth which means inputs play an essential role in the one Inters Province.

Authors summarize the fundamental analysis, made abstraction modeling logistics and CO_2 emissions tracking. In authors' calculations, the balance is not considered in Yuan, but in CO_2 emissions. The authors consider the entropy model analysis as the most effective one. Complexity modeling of economic efficiency and growth potential is increasingly essential for countries and provinces. Evaluating the monetary flows, energy driving (efficiency) and potential capacity (resilience) provides the crucial information for economy development.

Research shows a promising idea of the authors is that the balance is used as a basis for calculating the redistribution of emissions between provinces. The idea is that the region, by selling its products to another province, transfers responsibility for its emissions. Thus, we consider how emissions are redistributed. Thus, the authors used the level of decreasing of the CO_2 emission for every industry from the Institute of Climate Change and Sustainable Development, Tsinghua University (He, 2021).

3. Results

The authors found and used the IO tables data for the selected years. The optimization criterion is based on the mean squared error (see Figures 1 and 2).

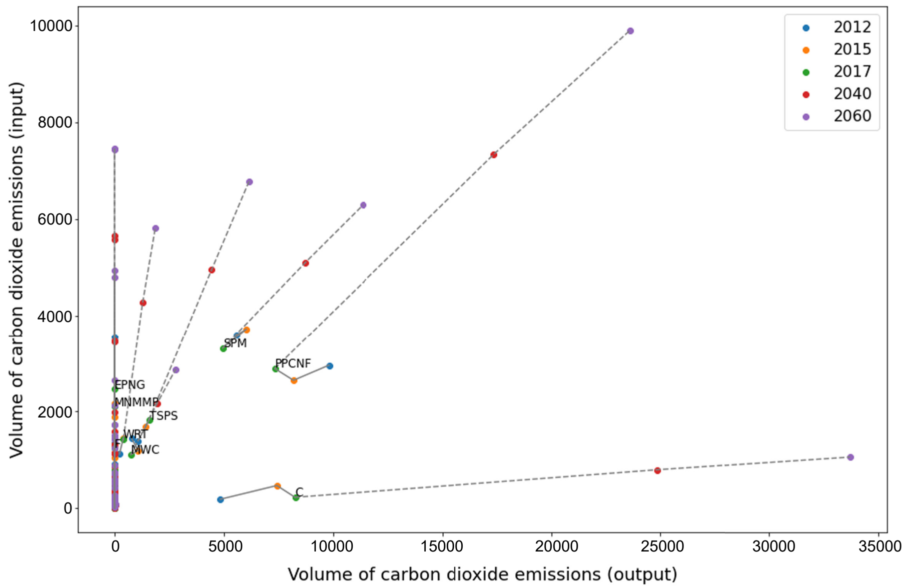

Figure 1.
China industry analysis, 2012–2060

In Figure 1 the lower right corner indicates the industries in 2012 that had a huge volume of CO_2 emissions, such as Mining and washing of coal (MWC), Wholesale and retail trades (WRT), and Transport, storage and postal services (TSPS) industries. However, we can't observe the reduction processes in emissions for years for these industries. In the lower right corner, the construction industry produces a lot of emissions, but this industry does not take products characterized by large emissions from other industrial sectors. The upper-left corner shows that Processing of petroleum, coking, processing of nuclear fuel (PPCNF) and Smelting and processing of metals (SPM) industries do not produce emissions themselves, but at the same time consume a lot of products characterized by significant emissions from other industries. PPCNF industry has a special point-on the $X - 0$ axis. But this industry consumes products from industries that produce maximum CO_2 emissions, and consumes a lot. Therefore, along the Y axis (input) it has a great value. That is, it does not produce CO_2 itself, but other industries are trying for it. The worst is the upper-right corner: Extraction of petroleum and natural gas (EPNG) industry produces a lot of emissions and consumes many products characterized by large emissions from other industries. The industries with the lowest level of CO_2 emissions are located in the lower left corner, in our case they are WRT and TSPS. The results shows that the CO_2 emissions would increase with the China economic growth nevertheless we used planning limits for decreasing emissions.

The authors calculated input-output flows of CO_2 emissions for every 31 China provinces.

In Figure 2 in the lower right corner, we can observe the provinces producing many CO_2 emissions. Still, they do not take products characterized by significant emissions from other provinces. In our case it is Jiangsu. As an economically developed province along the eastern coast of China, Jiangsu has the largest provincial power grid in the state grid system. Jiangsu has consistently ranked first in China in terms of power consumption and grid load. It has long faced challenges such as large traditional energy consumption, weak energy endowment conditions and high pressure to reduce carbon emissions. Statistics show that in 2020 in Jiangsu, the total amount of new energy power generation reached

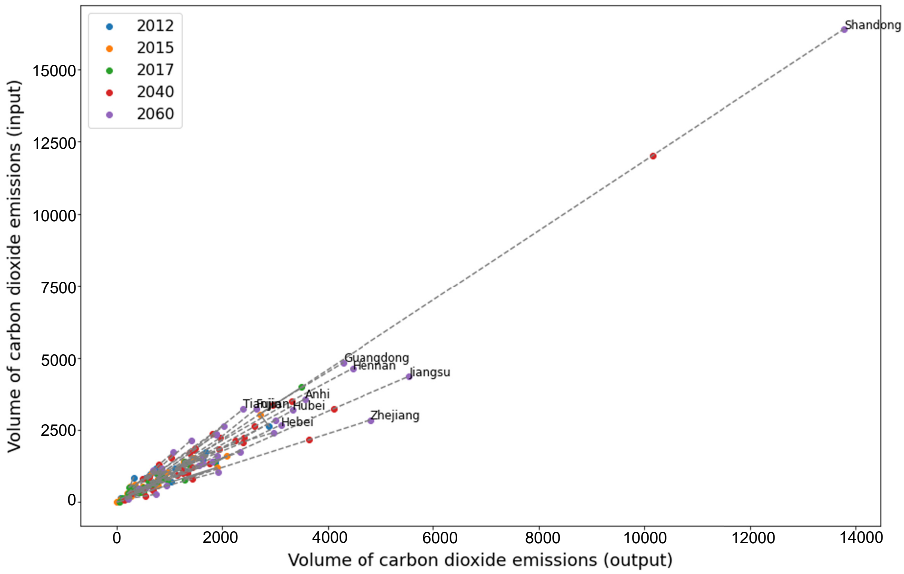

Figure 2.
Province analysis, 2012–2060

52.2 billion kWh, equivalent to reducing coal consumption in the province by about 15 million tons, reducing CO_2 emissions by about 48 million tons (Liang and Zhang, 2011; Tao *et al.*, 2020).

Shandong in the upper-right corner produces many emissions and consume many products characterized by large emissions from other provinces. However, Shandong showed a reduction in CO_2 emissions from 2012 to 2017 and rapid growth again between 2040 and 2060. At present, Shandong Province's energy structure is dominated by high-carbon fossil energy, accounts for about 88%, ranking first in the country. Shandong Province has a heavy industrial structure, with traditional industries accounting for about 70% of industry, heavy chemical industries accounting for about 70% of traditional industries, coal consumption accounting for more than 76% of primary energy consumption, energy consumption in 2019 reached 413.9 million tons of standard coal, accounting for 8.5% of the total national total, carbon emissions in 2017 was 806 million tons, accounting for 8.2% of the total national total, energy consumption and carbon emissions ranked first in the country (Wang *et al.*, 2014). The results showed that Shandong Province's ability of CO_2 reduction was being strengthened step by step. Systematically plan ecological environmental protection in Shandong Province during the 14th Five-Year Plan, integrate the response to climate change into the strategic planning system and promote carbon reduction and air pollution prevention and control from parallel to one. China will pay close attention to formulating a plan of action for the peak of CO_2 emissions in Shandong Province by 2030 and scientifically compile unique plans, action plans and guidance opinions on the synergistic efficiency of carbon reduction and the prevention and control of air pollution.

The authors performed an information entropy analysis using IO tables. Input in our case is consumed from other industries, output is produced and sent to other industries (see Figures 3–8).

Figure 3 shows that the maximum efficiency and potential capacity in production and distribution of CO_2 emissions to other industries is in the PPCNF and C industries. In this case the maximum efficiency is peak economic efficiency and potential capacity – is the potential

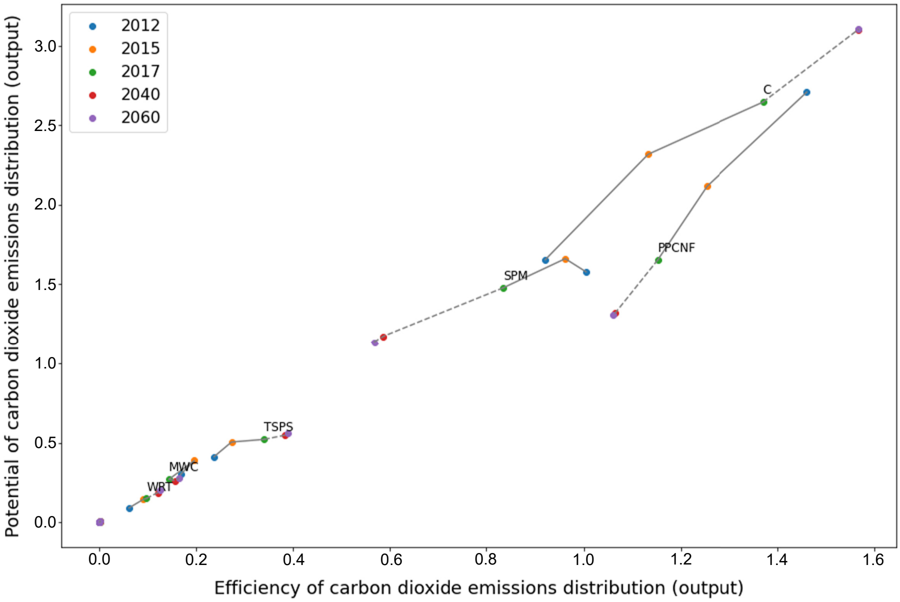

Figure 3.
Efficiency and potentials of CO_2 emissions distribution (output)

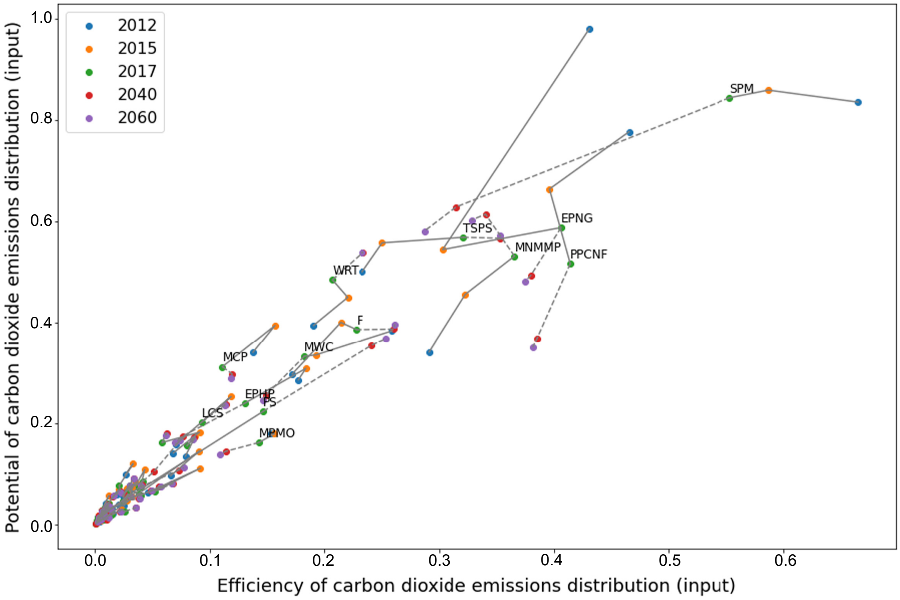

Figure 4.
Efficiency and potentials of CO_2 emissions distribution (input)

growth to development (resilience). We can see less efficiency and potentiality in the CO_2 distribution in the following industries: WRT, MWC, and TSPS. The results shows that PPCNF industry efficiency will decrease till 2060, while efficiency of the construction industry will seriously grow on.

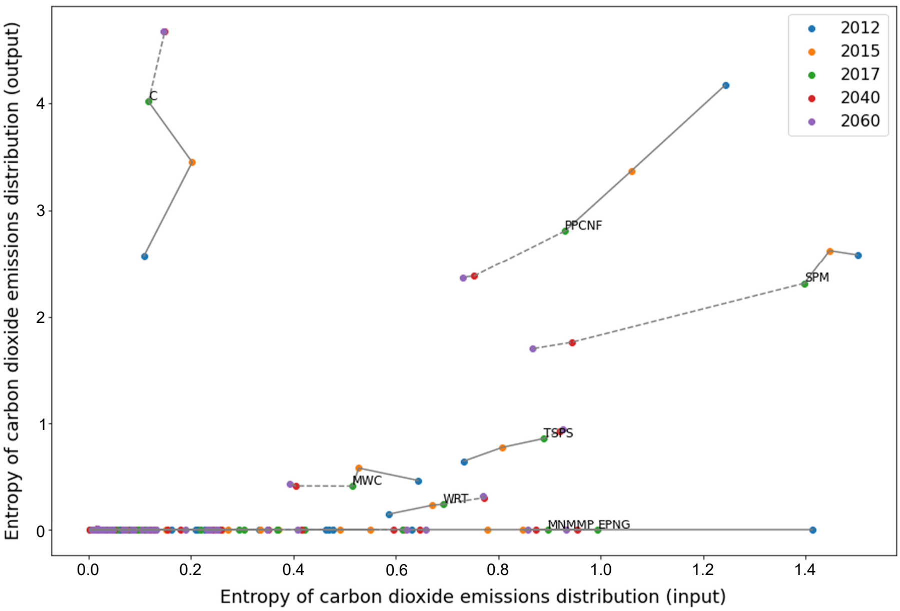

Figure 5.
Entropy of CO_2 emissions distribution (input)

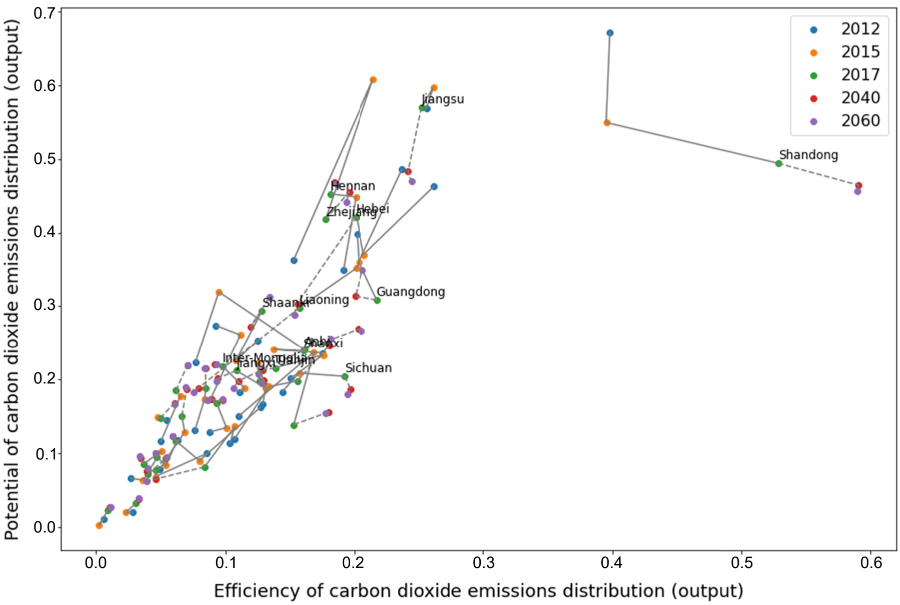

Figure 6.
Efficiency and potentials of CO_2 emissions distribution (output)

Figure 4 shows that the maximum efficiency and potentials in CO_2emission distribution in case of CO_2consumption from others are in the PPCNF, SPM, EPNG and TSPS industries. We also can see less efficiency and potentiality in the CO_2 distribution in the next industries:

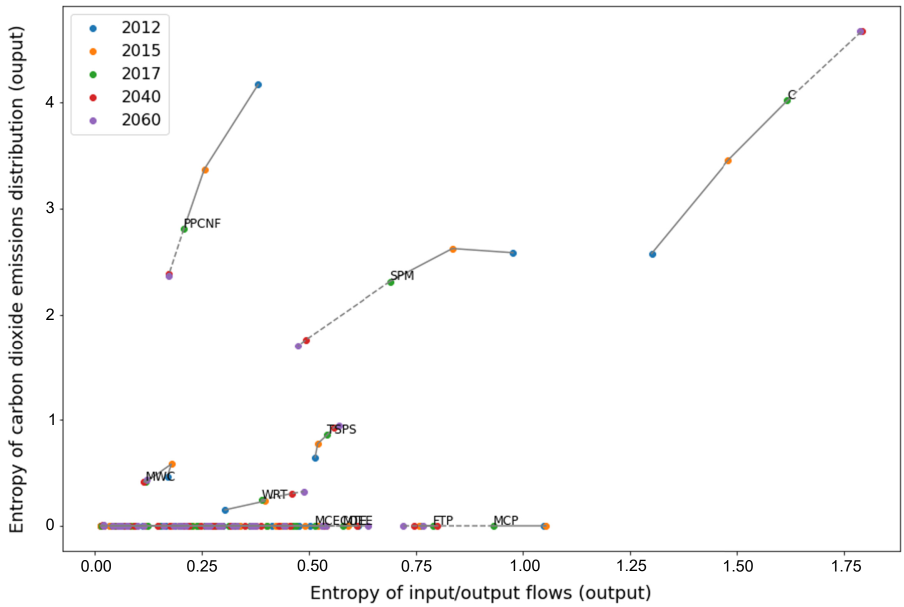

Figure 7.
Entropy of CO_2 emissions distribution (output-output)

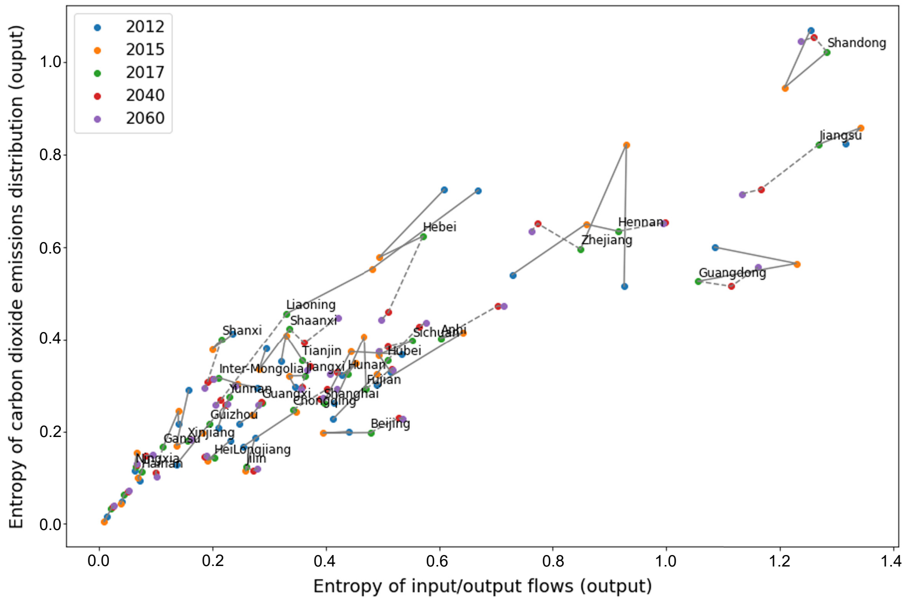

Figure 8.
Entropy analysis 2012, 2015, 2017 (output)

Production and distribution of electric power and heat power (EPHP), Mining and washing of coal (MWC), Manufacture of chemical products (MCP), Mining and processing of metal ores (MPMO) and Leasing and commercial services (LCS) industries.

Entropy means a measure of the complexity, randomness or uncertainty of the system: the less system elements are subordinate to any order, the higher the entropy (Yakovenko, 2010). Figure 5 shows that the maximum entropy in CO_2 emission distribution in case of CO_2 consumption from others is in the SPM and PPCNF industries. We can observe less entropy in the CO_2 distribution in the next industries: WRT, MWC and TSPS; exciting fact that construction industry generates a considerable amount of the CO_2 emissions. The products, and hence the responsibility for these generated emissions, are used in many industries. But at the same time, there are practically no products related to the generation of CO_2 in construction. PPCNF industry significantly do not generate CO_2, but at the same time actively use products from the industries that actively use CO_2 in the production. Fuel and Metal industries themselves generate and actively use products related to the CO_2 emission, thus, these industries are the most polluted.

Figure 6 shows that the maximum efficiency and potentials in CO_2 emission distribution in production and sending products to other provinces is Shandong. Jiangsu, Hebei, Zhejiang, Guandong and Henan have a high potential in CO_2 distribution. The less efficiency and potentiality in the CO_2 distribution we can see in the Anhui, Hebei and Inner Mongolia. Jiangsu, Hebei, Guandong and Henan also have a high level of potential in CO_2 distribution. All of these provinces, except for Henan, are located on the seashore. Henan region is located in the Huang he river region. High potential concerning CO_2 emissions reduction in these regions is associated with its binding in the surface layers of sea/river waters. Passive absorption of CO_2 by the ocean surface – this is a natural process that constantly occurs in the Earth's atmosphere. Waves mix the upper layers of water, and due to this, the ocean, like a sponge, absorbs excess CO_2 from the atmosphere, which is neutralized as it sinks into the bottom layers. However, if too much CO_2 gets into the ocean waters, it disrupts the acid-base balance of ocean waters: their acidity increases (that is, the pH value decreases). During this reaction, the CO_2 entering the ocean (including anthropogenic) passes into soluble bicarbonate ions HCO3 – and is thus neutralized (Sulpis *et al.*, 2018). For example, considering the differences between sectors, Jia Dong and co-authors in their research decoupling index between carbon emission and the economic development of Henan 12 industrial sectors shows a downward trend. In 2035, in Henan, four sectors will achieve carbon neutralization and the overall decoupling effect of carbon emissions will be obvious (Dong *et al.*, 2021). Guangdong province as the pioneer of the national economy in China, occupies an important position, hence, study of carbon emission of Guangdong province, is of great significance. So, the reduction of implied carbon emissions in construction and other similar industries mainly reduces intermediate inputs or increases replacement for high-energy consumption inputs. The development of green industry technologies gave the Guangdong opportunity to be the first in China concerning CO_2 reduction (Chen *et al.*, 2017).

Nevertheless, we observe the trend that Guandong was decreased in efficiency of the CO_2 emission distribution from 2012 to 2017 and stable upward trend in 2040–2060. On the other hand, Henan was increased in the efficiency of the CO_2 distribution from 2012 to 2017 and forecast from 2040 to 2060 also has downward trends.

It is exciting to compare the entropy of financial flows and CO_2 emissions flows.

Figure 7 shows that the maximum entropy in CO_2 emission output distribution is in "Construction" industry. The less entropy we can observe in WRT, MWC and TSPS. SPM industry moved to the more stable positions with the less entropy. PPCNF has the flows with CO_2 emissions extremely more than financial flows between industries.

For entropy analysis input distribution, please, see tables in Supplementary materials. Analysis shows that the maximum entropy in CO_2 emission input distribution is in the SPM industry, on the other hand, can observe less entropy in Mining and processing of metal ores (MPMO), Mining and washing of coal (MWC), Manufacture of electrical machinery and equipment (MEME), Manufacture of metal products (MMP), PTF and Other manufacturing and waste resources (OMWR). Moreover, entropy of the EPNG and PPCNF industries have downward trends. Thus, in these industries the entropy of the CO_2 carbon dioxide emissions distribution has downward trends and the entropy of the input flows.

Figure 8 shows that the maximum entropy in CO_2 emission output distribution is in Shandong, Jiangsu and Guandong. We can observe less entropy in Gansu, Guizhou, Jilin and Heilongjiang provinces. Upper-left corner of Figure 8 shows that the entropy of emissions is higher than the entropy of finance. The lower right corner shows the opposite result.

4. Conclusion

China increased ecological environmental protection by entering a new coordinated control of pollution reduction and carbon reduction, and coordinated control measures such as adjusting the energy and industrial structures. It can not only reduce carbon emissions, but also reduce air pollutant emissions from the root causes.14th Five-year Plan" China's ecological environmental protection work shouldered a heavy responsibility – to achieve carbon peak by 2030; to achieve carbon neutrality by 2060. 2021 is less than ten years away from attaining the carbon peaking target, and only 4.5 years away from completing the 14th Five-Year Plan. In the paper, from the perspective of provincial-level regions the spatial imbalance of efficiency and potential of economic development towards carbon neutrality 2060 was observed. The inequality in China's regional development has been prominent from the 2012, 2015 and 2017 input-output table. From the modeling results, authors rank China's provincial development in input-output efficiency growth.

The traditional perspective is to rank regional development only based on GDP growth. In contrast, here the authors advocate a new evaluation method from efficiency and potential growth perspectives based not on the monetary, but on the emissions methodology. Unbalanced emissions regional economic development has become problematic and a barrier to the national economy's sustainability goals. The critical point is to make clear that the idea of energy substitution and energy efficiency alone cannot achieve the global emission reduction goal. Achieving such a goal, requires socio-economic changes in population control and consumption reduction. Serious consideration should be given to reducing the material scale of economic growth. Current climate policy emphasizes the second half of the climate equation, arguing that technological innovation can manage increased CO_2 emissions. Thus, about 65% of CO_2 emissions come from economic activity and 35% from the intensity of CO_2 per unit of economic output.

The authors calculated input-output flows of CO_2 emissions for every 31 China provinces. Then, using the IO tables data for the selected years, the authors found K_{ind} and u_{ind}. As a result, the authors emphasize nine industries characterized by the highest CO_2 emissions (that generate more than 95% of CO_2 emissions): AFAHF, MWC, PPCNF, SPM, EPHP, PDG, C, WRT, TSPS. In industries with huge volume of CO_2 emissions, such as MWC, we can't observe the reduction processes in these emissions for years. In the following industries, emissions are being reduced, such as PPCNF, EPHP, AFAHF. TSPS and SPM industries in China have second place concerning emissions, but emissions were reduced enough for the past period. Construction industry produces many emissions, but this industry does not take products characterized by large emissions from other industrial sectors. The maximum efficiency and potentials in CO_2 emission distribution in production and sending to other industries is in the PPCNF and C industries. We can see less efficiency and potentiality in the CO_2 distribution in the following industries: WRT, MWC and TSPS. The results show that PPCNF industry' efficiency will decrease till 2060, while efficiency of the construction industry will seriously grow on. The maximum entropy in CO_2 emission distribution in the case of CO_2 consumption from others is in the SPM and PPCNF industries. We can see less entropy in the CO_2 distribution in the next industries: WRT, MWC and TSPS, exciting fact that C industry generates a significant amount of the CO_2 emissions. The products, and hence the responsibility for these generated emissions, are used in many industries. But at the same time, there are practically no products related to the generation of CO_2 in construction. PPCNF significantly do not generate CO_2, but at the same time actively use products from the industries that are actively used CO_2 in production. Fuel and Metal industries themselves generate and actively use products related to the CO_2 emission, thus, these industries are the most polluted.

Jiangsu produces a lot of CO_2 emissions still they do not take products characterized by significant emissions from other provinces. Shandong produces many emissions and consume many products characterized by large emissions from other provinces. However, Shandong showed a reduction in CO_2 emissions from 2012 to 2017 and rapid growth again between 2040 and 2060. At present, Shandong Province's energy structure is dominated by high-carbon fossil energy, which accounts for about 88%, ranking first in the country.

The maximum efficiency and potentials in CO_2 emission distribution concerning consumption from the other provinces shows Shandong province. Jiangsu, Hebei, Guandong and Henan also have a high level of potential in CO_2 distribution. Nevertheless, we observe the trend that Guandong was decreased in efficiency of the CO_2 emission distribution from 2012 to 2017 and stable upward trend in 2040–2060. On the other hand, Henan was increased in the efficiency of the CO_2 distribution from 2012 till 2017 and forecast from 2040 to 2060 also has downward trends. The maximum entropy in CO_2 emission output distribution is in construction industry. The less entropy we can observe in WRT, MWC and TSPS. SPM industry moved to the more stable positions with the less entropy. PPCNF has the flows with CO_2 emissions extremely more than financial flows between industries. The maximum entropy in CO_2 emission input distribution is in the SPM industry. On the other hand, the less entropy we can observe in MPMO, MWC, MEME, MMP and PTF, OMWR. Moreover, entropy of the EPNG and PPCNF have downward trends. EPNG industry produce a lot of emissions and consume a lot of products characterized by large emissions from other industries. Thus, in these industries the entropy of the CO_2 emissions distribution has downward trends and the entropy of the input flows. The maximum entropy in CO_2 emission input distribution is in Shandong, Jiangsu and Guandong. The less entropy we can observe in Gansu, Guizhou, Jilin, Heilongjiang provinces.

For achieving carbon neutrality, provinces need to:

(1) Accelerate the revision of local regulations and government regulations on ecological and environmental protection, incorporate carbon peaking and carbon neutrality into local regulations and government regulations such as the Regulations on Environmental Protection, the Regulations on the Prevention and Control of Air Pollution and the Regulations on the Promotion of Cleaner Production, promote the preparation of the Climate Regulations or the Regulations on Climate Change, etc., and make sufficient preparations for the enactment of the Regulations on the Promotion of Carbon Neutrality in Provinces.

(2) Accelerate the construction of the decomposition and implementation mechanism of pollution reduction and carbon reduction targets.

(3) Vigorously cultivating green and environmental protection industries, expanding the scale of green industries, developing energy-saving and environmental protection industries, clean production industries and clean energy industries and stimulating Shandong's new kinetic energy through innovation.

(4) Improve the road-based transport structure

(5) Promote the construction of green financial system in the forefront.

The research has several constraints, which also sustain exciting avenues for future analysis. First, the China Economy input-output sheets, restricting the generalizability of research findings and limit the study data to 2012, 2015 and 2017 year. For further research, Authors will continue use China Economy input-output table 2021 year when available. Besides, 2015, 2017 research data includes Tibet, 2012 – does not include such information. Also, we only analyze 30 sectors in 2007, as consolidation structure had changed in 2012. All these factors can complicate the research. However, it is possible to overcome. As a future research direction, authors see the development of the Chinese economy towards carbon neutrality 2060 on the basis of system balance methodology, space -time analysis and information theory.

Notes

1. By Asit K. Biswas/Cecilia Tortajada | China Daily | Updated: 2021–05–31 07:21
2. National Bureau of Statistics of China (stats.gov.cn) (date of access 07.02.2022)

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Further reading

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Appendix

Abbr	2017
AFAHF	Agriculture, Forestry, Animal Husbandry and Fishery
MWC	Mining and washing of coal
EPNG	Extraction of petroleum and natural gas
MPMO	Mining and processing of metal ores
NPNOO	Mining and processing of nonmetal and other ores
FTP	Food and tobacco processing
TI	Textile industry
MLFFFRP	Manufacture of leather, fur, feather and related products
PTF	Processing of timber and furniture
MPPACESA	Manufacture of paper, printing and articles for culture, education and sport activity
PPCNF	Processing of petroleum, coking, processing of nuclear fuel
MCP	Manufacture of chemical products
MNMMP	Manuf. of non -metallic mineral products
SPM	Smelting and processing of metals
MMP	Manufacture of metal products
MGPM	Manufacture of general-purpose machinery
MSPM	Manufacture of special purpose machinery
MTE	Manufacture of transport equipment
MEME	Manufacture of electrical machinery and equipment
MCECOEE	Manufacture of communication equipment, computers and other electronic equipment
MMI	Manufacture of measuring instruments
OMWR	Other manufacturing and waste resources
RMPME	Repair of metal products, machinery and equipment
EPHP	Production and distribution of electric power and heat power
PDG	Production and distribution of gas
PDTW	Production and distribution of tap water
C	Construction
WRT	Wholesale and retail trades
TSPS	Transport, storage and postal services
AC	Accommodation and catering
ITSITS	Information transfer, software and information technology services
FTP	Finance
RE	Real estate
LCS	Leasing and commercial services
SR	Scientific research
PS	Polytechnic services
AWEPF	Administration of water, environment and public facilities
RROS	Resident, repair and other services
E	Education
HCSW	Health care and social work
CSE	Culture, sports and entertainment
PASISO	Public administration, social insurance and social organizations

Source(s): China's National Bureau of Statistics [2]

Table A1.
List of acronyms

Supplementary material

The supplementary material for this article can be found online.

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