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An Application of Scenario Input–Output Analysis

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The Economic and Environmental Impacts of Power Supply Configuration Change in China: An Application of Scenario Input–Output Analysis

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Abstract

With China's rapid economic development, the country has become the largest energy consumer with the largest amount of CO_2 emissions in the world. China has declared that CO_2 emissions per gross domestic product (GDP) will be reduced by 60%–65% compared with that in 2005 and the total CO_2 emissions will peak by 2030. To achieve these targets, it is crucial for China to break away from its conventional coal-based energy structure and change the power source from thermal power to low-carbon energy to achieve the CO_2 reduction targets. Structural change in power sources, however, may have negative economic and social consequences, especially on coal and coal-related industries. Therefore, it will be necessary to clarify the impact of a change in the power supply configuration on the economy as well as the impact of reducing CO_2 emissions.

This paper estimates an input–output table of renewable-energy power generation sectors to implement a scenario input–output analysis for China that estimates the difference in environmental, economic, and social effects by different power supply configurations. The estimated results show that the replacement of thermal power generation by wind power or solar power will greatly reduce CO_2 emissions and the macroeconomic and social impacts will be marginal. However, there may be large negative economic and social impacts on the coal and coal-related industries such as mining, coal products, and transportation. Therefore, it is also necessary to mitigate the impacts on coal-related industries along with the promotion of the power source shift.

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Keywords

Scenario input-output analysis, Renewable energy, Power supply configuration, CO_2 emissions, China

List of abbreviations

CCEF	California's Clean Energy Future
CEC	China Electricity Council
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
NBSC	National Bureau of Statistics of China
NDC	Nationally Determined Contributions
RCOT	Rectangular Choice of Technology
WIOD	World Input-Output Database

The Economic and Environmental Impacts of Power Supply Configuration Change in China: An Application of Scenario Input–Output Analysis

1. Introduction

China's energy consumption has increased rapidly in the last decade, and China has become the largest energy consumer and CO_2 emitter in the world. Saving energy and reducing emissions are becoming urgent issues in China. As a matter of fact, China has declared that CO_2 emissions per GDP will be reduced by 60%–65% (compared with that in 2005) and the total carbon emissions will peak by 2030 [1] as stated in the Nationally Determined Contributions in the Paris Agreement in 2015. Moreover, at the United Nations' 2020 General Assembly, China's President Xi Jinping made the ambitious pledge that China will be a carbon-neutral country before 2060.[2] China's economy is highly dependent on fossil energy, especially on coal. To achieve these targets, China needs to reform its energy structure and reduce coal consumption. Coal-fired power generation provides approximately 70% of China's total power generation, and the power generation sector accounts for nearly 50% of China's total CO_2 emissions.[3]

Although renewable power generation is now rapidly spreading throughout China, some issues deserve discussion. For example, it is not clear how large the negative and positive economic effects will be, given the replacement of coal-fired power generation with renewable energies. Moreover, it is not clear how much CO_2 emissions can be reduced when coal-fired power generation is replaced by renewable energies, nor is it clear how much the labor force will be affected by the introduction of renewable energies. This paper applies scenario input–output analysis to these challenges in China to determine the economic, environmental, and social effects by shifting power sources from coal to renewable energy.

2. Methodology

2.1 Scenario Input–Output Analysis

Input–output analysis is a convenient economic tool to determine the overall effect of demand shift or structural change on production, energy consumption, or CO_2 emissions. It is important to note that input–output analysis assumes that one kind of commodity is produced by one kind of activity. However, electricity is produced by such plural activities

1 See National Development and Reform Committee of China (2015).

2 See UN News dated September 22, 2020 <https://news.un.org/en/story/2020/09/1073052>

3 See China Statistical Yearbook 2019 <http://www.stats.gov.cn/tjsj/ndsj/2019/indexch.htm> and World Input-Output Database: Environmental Accounts – CHN_CO2 <http://www.wiod.org/database/eas13>.

as thermal power, hydropower, nuclear power, wind power, and solar power. Changing the activity share in the power generation structure will produce different economic, environmental, and social effects even if the final energy demand remains the same.

Several methods have been developed to tackle this objective. Yoshioka and Suga (1997) proposed a methodology that rearranged a rectangular input–output table where one product is produced by plural activities into one square so that the Leontief inverse matrix may be defined. Duchin and Levine (2011, 2012) developed a model of Rectangular Choice of Technology (RCOT) with factor constraints that apply linear programming to input–output analysis. The RCOT model allows several input structures in a sector to analyze the economic and environmental effects of technology selection. Fujikawa (2011) applied the RCOT method of Yoshioka and Suga (1997) to analyze thermal and nuclear power substitutability and named this method “scenario input–output analysis.” Wang (2016) applied scenario input–output analysis to estimate economic and environmental effects when the power source shifts from thermal power to renewable-energy power. This analysis used a newly developed input–output table by the Institute for Economic Analysis of Next-Generation Science and Technology, Waseda University. This paper will apply scenario input–output analysis to estimate how economic, environmental, and social effects differ by changing the power source in China following these previous studies.

The standard input–output table has the comparable industry and commodity names in its rows and columns, respectively. In other words, traditional input–output analysis is based on the standard input–output tables that assume that one commodity is produced by one industry and one industry produces one commodity. Because the input (or technical) structure of each industry is expressed by the corresponding column, one industry name is assumed to be synonymous with “activity.” This assumption, however, does not necessarily hold true for all industries in the real economy. The power industry is one of the typical examples where electricity (a commodity in the power industry) is produced by various kinds of activities such as thermal power, window power, solar power, hydropower, and nuclear power. On the other hand, there is only one electricity row on the input side because all activities produce the same good: electricity. However, there are plural activities (columns) in the electricity industry. The scenario input–output analysis is a method used to combine plural activities into one by giving exogenously the share of the output of each activity.

Figure 1 illustrates an input–output table where power generation activities are composed of five types of energy such as nuclear power, thermal power, hydropower, solar power, and wind power.

Figure 1 Input–output table with multiple activities in power generation

		Other Intermediate Input	Power Generation					Final Demand	Domestic Product
		$j = 1, \ldots, n$	Nuclear Power	Thermal Power	Hydropower	Solar Power	Wind Power		
Other Intermediate input	$i = 1, \ldots, n$	$\mathbf{X}^{11}$	$\mathbf{x}_1^{12}$	$\mathbf{x}_2^{12}$	$\mathbf{x}_3^{12}$	$\mathbf{x}_4^{12}$	$\mathbf{x}_5^{12}$	$\mathbf{f}^1$	$\mathbf{x}^1$
Power Generation		$\mathbf{x}^{21}$	x_1^{22}	x_2^{22}	x_3^{22}	x_4^{22}	x_5^{22}	f^2	x^2
Value Added		$\mathbf{v}^1$	v_1^2	v_2^2	v_3^2	v_4^2	v_5^2		
Domestic Product		$\mathbf{x}^{1\prime}$	z_1	z_2	z_3	z_4	z_5		

Source: compiled by the authors.

The power generation sector is assumed to be composed of five activities: nuclear power, thermal power, hydropower, solar power, and wind power in this paper. Changing the shares of the activity mix in the electricity industry will bring different economic and environmental effects even if the level of the final demand is unchanged.

2.2 Estimating Power Generation Activities

In the model equation, the power sector is expressed by a superscript number 2, and the other sectors are indicated with a superscript number 1. The other sectors are collectively referred to as the “normal sector.” The power sector is subdivided into five activities. The activity subdivision of the power sector is based on the studies by Fujikawa (2011) and Wang (2016).

The production function of the normal sector is expressed in equation 1:

$$x_j^1 = min\left[x_{ij}^{11}/a_{ij}^{11}, x_j^{21}/a_j^{21}\right] \quad (i,j = 1,\cdots,n), \tag{1}$$

where

x_j^1: Output of the normal sector

x_{ij}^{11}: Input from the i^{th} industry (normal sector) to the j^{th} industry (normal sector)

x_j^{21} : Input from the power sector to the j^{th} industry (normal sector)

a_{ij}^{11} : Input coefficient from the i^{th} industry (normal sector) to j^{th} industry (normal sector)

a_j^{21} : Input coefficient from the power sector to the j^{th} industry (normal sector).

The production function of the power sector is expressed in equation 2:

$$z_k = min[x_{ik}^{12}/a_{ik}^{12}, x_k^{22}/a_k^{22}] \quad (i,j = 1,\cdots,n, k = 1,\cdots,5), \tag{2}$$

where

z_k : Output of each activity in the power sector

x_{ik}^{12} : Input from the i^{th} industry (normal sector) to the k^{th} activity (power sector)

x_k^{22} : Input from the power sector to the k^{th} activity (power sector)

a_{ik}^{12} : Input coefficient from the i^{th} industry (normal sector) to the k^{th} activity (power sector)

a_k^{22} : Input coefficient from the power sector to the k^{th} activity (power sector).

The demand–supply equilibrium for the normal and power sectors can be expressed in simultaneous equations 3 and 4:

$$\mathbf{A}^{11}\,\mathbf{x}^{1} + \mathbf{A}^{12}\,\mathbf{z} + \mathbf{f}^{1} = \mathbf{x}^{1}, \tag{3}$$

$$\mathbf{a}^{21}\,\mathbf{x}^{1} + \mathbf{a}^{22}\,\mathbf{z} + f^{2} = x^{2}, \tag{4}$$

where

$\mathbf{A}^{11}$: Input coefficient matrix from the normal sector to normal sector, $\mathbf{A}^{11} = \left[a_{ij}^{11}\right]$ ($n \times n$)

$\mathbf{A}^{12}$: Input coefficient matrix from the normal sector to power sector, $\mathbf{A}^{12} = [a_{ik}^{12}]$ ($n \times 5$)

$\mathbf{a}^{21}$: Input coefficient vector from the power sector to normal sector, $\mathbf{a}^{21} = \left[a_j^{21}\right]$ ($1 \times n$)

$\mathbf{a}^{22}$: Input coefficient vector from the power sector to power sector, $\mathbf{a}^{22} = [a_k^{22}]$ (1×5)

$\mathbf{f}^{1}$: Final demand ($n \times 1$) vector for the normal sector

f^{2} : Final demand for the power sector, which is a scalar

$\mathbf{x}^{1}$: Output ($n \times 1$) vector for the normal sector

x^{2} : Output of the power sector, which is a scalar

$\boldsymbol{z}$: Output (5×1) vector of each activity in the power sector.

The final demands $\mathbf{f}^{1}$ and f^{2} are exogenous variables that are given from outside the equation system. The number of unknown endogenous variables in the above simultaneous equations is $n + 6$; n in $\mathbf{x}^{1}$, 1 in x^{2}, and 5 in $\boldsymbol{z}$, and the number of equations is no more than $n + 1$. Since the number of equations is less than the unknown endogenous variables, we cannot solve the above simultaneous equation as it is. Therefore, we need to add certain assumptions or “scenarios” to solve the equations.

2.3 Setting Assumptions

We set the following two assumptions to solve the equations.

Assumption 1: All of the electricity produced through the five different energy sources is supplied and consumed.

$$z_1 + z_2 + z_3 + z_4 + z_5 = x^2, \quad (5)$$

where $z_1, z_2, z_3, z_4,$ and z_5 stand for the nuclear power output, thermal power output, hydropower output, solar power output, and wind power output, respectively.

Assumption 2: The power supply configuration is given by exogenous parameters.

$$\begin{cases} z_1 = \alpha_1 x^2 \\ z_2 = \alpha_2 x^2 \\ z_3 = \alpha_3 x^2 \\ z_4 = \alpha_4 x^2 \\ z_5 = (1 - \alpha_1 - \alpha_2 - \alpha_3 - \alpha_4) x^2 \end{cases}, \quad (6)$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4,$ and α_5 stand for the shares of the nuclear power output, thermal power output, hydropower output, solar power output, and wind power output, respectively.

The above two assumptions are summarized in the following matrix equation, which we call the "scenario equation."

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ 1 - \alpha_1 - \alpha_2 - \alpha_3 - \alpha_4 \end{bmatrix} x^2,$$

$$\boldsymbol{z} - \mathbf{c}x^{\mathbf{2}} = \mathbf{0}, \quad (7)$$

where $\boldsymbol{z} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{bmatrix}$ $\mathbf{c} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ 1 - \alpha_1 - \alpha_2 - \alpha_3 - \alpha_4 \end{bmatrix}$.

Because the number of equations increases by 5 because of these assumptions, the total number of unknown variables matches the total number of equations. We can then solve simultaneous equations 3 and 4.

2.4 Estimating the Economic, Environmental, and Social Impacts

Equation 7 can be modified into equation 7'.

$$\mathbf{z} = \mathbf{c}x^{\mathbf{2}}. \quad (7')$$

Substitution of equation 7' into equations 3 and 4 gives equations 8 and 9.

$$\mathbf{A^{11}}\,\mathbf{x^1} + \mathbf{A^{12}}\mathbf{c}x^{\mathbf{2}} + \mathbf{f^1} = \mathbf{x^1}, \quad (8)$$

$$\mathbf{a^{21}}\,\mathbf{x^1} + \mathbf{a^{22}}\,\mathbf{c}x^{\mathbf{2}} + f^{\mathbf{2}} = x^{\mathbf{2}}. \quad (9)$$

Then, we get equation 10.

$$\begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12}\mathbf{c} \\ \mathbf{a}^{21} & \mathbf{a}^{22}\mathbf{c} \end{bmatrix} \begin{bmatrix} \mathbf{x}^1 \\ x^2 \end{bmatrix} + \begin{bmatrix} \mathbf{f}^1 \\ f^2 \end{bmatrix} = \begin{bmatrix} \mathbf{x}^1 \\ x^2 \end{bmatrix}. \tag{10}$$

Finally, we obtain equilibrium output equation 11. It is important that the input coefficient vector of the power sector is defined as a weighted average of those of five activities in the power sector.

$$\begin{bmatrix} \mathbf{x}^1 \\ x^2 \end{bmatrix} = \left[\boldsymbol{I} - \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12}\mathbf{c} \\ \mathbf{a}^{21} & \mathbf{a}^{22}\mathbf{c} \end{bmatrix} \right]^{-1} \begin{bmatrix} \mathbf{f}^1 \\ f^2 \end{bmatrix}. \tag{11}$$

We can calculate the outputs of $\mathbf{x}^1$ and x^2 when the final demands $\mathbf{f}^1$ and f^2 are given. The Leontief inverse matrix depends on the scenario or the share of the activities in the power sector.

The total CO_2 emissions (**emi**) can be calculated using the CO_2 emission coefficients $\mathbf{e}_x$ and $\mathbf{e}_z$ for the normal and power sectors, respectively, as shown in equation 12.

$$\mathbf{emi} = [\mathbf{e}_x \quad \mathbf{e}_z] \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{z} \end{bmatrix}. \tag{12}$$

The total required labor force (**eng**) can be estimated using labor coefficients $\mathbf{l}_x$and $\mathbf{l}_z$, which are defined as labor input per unit output of the corresponding sector, as shown in equation 13.

$$\mathbf{eng} = [\mathbf{l}_x \quad \mathbf{l}_z] \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{z} \end{bmatrix}. \tag{13}$$

2.5 Data Sources and Estimating Coefficients

(1) Input–output tables

We used the “2012 Input–output Table of China” issued by the National Bureau of Statistics of China (NBSC) for our data. However, the power sector in the input–output table of China is not divided by power generation activity. We estimated an input–output table where the power generation sector is divided into nuclear, thermal, hydro, and renewable energy based on “The Input–Output Table for Analysis of the Next-Generation Energy System” issued by the Research Institute for Next-Generation Science and Economics of Waseda University in Japan.[4] We borrowed the input coefficients from the Waseda University table, where we assumed that the input coefficients of the power generation sector are similar between Japan and China.

4 See the website of <http://www.f.waseda.jp/washizu/table.html> (in Japanese).

(2) Energy consumption and CO_2 emissions[5]

We used the following three-step method when we estimated CO_2 emission intensity by industry.

(i) Step 1: Nominal value of fossil energy input by industry

We calculated the nominal consumption value of three fossil energies such as coal, oil, and natural gas using the "2012 Input–Output Table of China" issued by NBSC.

(ii) Step 2: Calorie-based fossil energy input by industry

We got calorie-based total fossil energy consumption from the "2013 China Energy Statistical Yearbook" issued by NBSC. We calculated the calorie-based fossil energy input by industry by multiplying the calorie-based total fossil energy consumption and nominal consumption share of each industry, which is obtained in Step 1.

(iii) Step 3: CO2 emissions by industry

We obtained CO_2 emission coefficients from the "2006 IPCC Guidelines for National Greenhouse Gas Inventories" issued by the Intergovernmental Panel on Climate Change (IPCC)as is shown in Table 1.[6] We calculated CO_2 emissions by industry as a product of CO_2 emission coefficients and calorie-based fossil energy consumption by industry, which was obtained in Step 2.

Table 1 CO_2 emission factors by fuel type

Fuel type	Carbon content (kg-C/TJ)	Effective CO_2 emissions (kg-CO2/TJ)
Coal	25.8	94.6
Oil	20.0	73.3
Natural Gas	15.3	56.1

Source: prepared by authors based on IPCC (2006).

(3) Required labor

Labor data are based on "Socio Economic Accounts 2016" issued by the World Input–Output Database (WIOD).[7] The WIOD labor data are often used in calculating labor coefficients by industry, but the sector classification in manufacturing is too approximate to apply to our analysis. We therefore used the share of labor data issued in the *China Economic Census Yearbook 2013*, where we retrieved more detailed statistics. Moreover,

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5 Energy consumption or CO_2 emissions in the construction stage of power plants are outside of the scope of this study since this study focuses on the operation stage of power generation.

6 As to the details, see Volume 2 Energy P23–24. Table 1.4, <https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html >.

7 See Timmer et al. (2015).

we used the labor coefficients for power generation activities in the “Renewable Energy-Focused Input–Output Table” developed by Hienuki et al. (2015).

3. Results and Discussion

3.1 Setting the Scenario for Analysis

China has set a goal of achieving carbon neutrality by 2060. China’s nonfossil fuel power generation will need to increase more than 90% by 2050 to achieve that goal according to Professor He Jiankun, Chief of the Academic Committee of the Institute of Climate Change and Sustainable Development, Tsinghua University.[8] Although significant growth in renewable-energy generation is needed, this study focuses on wind and solar power generation. We excluded hydroelectric power generation as well as nuclear power because both take a long time from planning to operation and their shares are fixed in the current situation. The power supply share in China as of 2012 is as follows: 79% thermal power, 2% nuclear power, 17% hydropower, and 2% new energy of wind and solar power. Therefore, we fixed approximately 20% for nuclear and hydropower, and we distributed the remaining 80% to thermal, wind, and solar power. Then, we implemented the following two simulations: (1) wind power generation replaces thermal power generation, and (2) solar power generation replaces thermal power generation. Finally, we calculated the production, employment, and CO_2 emission effects in each power supply configuration scenario.

3.2 Impacts by Choice Wind or Solar Power

Table 2 shows the results when wind power generation replaces thermal power generation in 20% increments. The first row shows the share of wind power generation substituted for thermal power generation, and the substitution share increases from left to right every 20%. Because the ratio between hydropower and nuclear power is fixed, the alternative ratio for wind power can be up to 80%. The second row shows the changes in total production, the third row shows CO_2 emissions, and the fourth row shows the number of employees. If the value for the cell is positive, the estimated value is higher than the current status, whereas if the number is negative, the estimated value is lower than the current status.

8 ICCSD is a research institute that conducts research in collaboration with the Chinese government to formulate policies for China's climate change countermeasures and the realization of sustainable development goals. See “Launch of the Outcome of the Research on China’s Long-Term Low-Carbon Development Strategy and Pathway,” in the press conference for China’s Long-Term Low-Carbon Development Strategy and Pathway. <*https://mp.weixin.qq.com/s/4-EJfwl6F3a94Yu4O96_Jw*>.

Table 2 Change of output, CO_2, and employment by increase in wind power generation

Wind power share	20%	40%	60%	80%
Change of total output	−0.42%	−0.82%	−1.17%	−1.48%
Change in CO_2 emissions	−9.9%	−19.5%	−28.0%	−35.4%
Change of employment	−0.10%	−0.19%	−0.27%	−0.34%

Source: prepared by authors.

First, CO_2 emissions will decrease significantly as the replacement by wind power increases. If the substitution rate is 80%, CO_2 emissions will decrease by 35.4%. On the other hand, the total production and number of employees will also decrease when the substitution rate increases, but the negative effect is marginal. If the substitution rate becomes 80%, the total production will decrease by 1.48%, and the number of employees will decrease by 0.34%. In short, the replacement of thermal power generation by wind power generation can greatly contribute to the reduction of CO_2 emission, but the reduction of the total production amount and number of employees will be marginal.

Table 3 Change of output, CO_2, and labor by increase of solar power

Solar power share	20%	40%	60%	80%
Change of total output	0.6%	1.2%	1.6%	2.0%
Change in CO_2 emissions	−13.4%	−17.7%	−25.3%	−32.0%
Change of labor	0.6%	1.0%	1.4%	1.8%

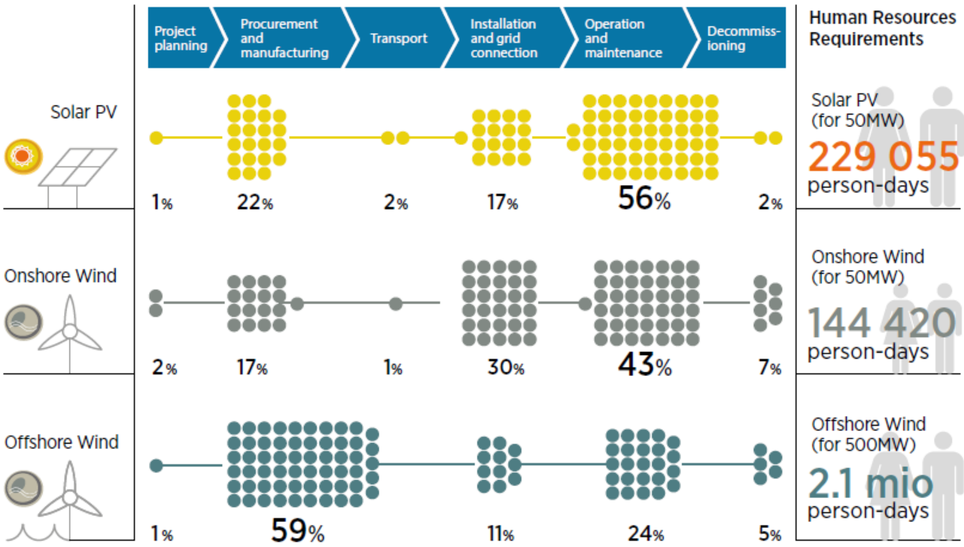
Source: prepared by authors.

Table 3 shows the results where solar power generation replaces thermal power generation in 20% increments. The CO_2 emissions will greatly decrease when the substitution rate by solar power increases as we have observed in the case of wind power generation. If the replacement rate is 80%, the rate of CO_2 decrease will be 32%, which is slightly lower than the case of wind power generation. On the other hand, unlike the results of the case of wind power generation, the total production and number of employees increase when the substitution rate increases. If the substitution rate is 80%, the total production will increase by 2%, and the number of employees will increase by 1.8%. In other words, the substitution of thermal power generation with solar power generation can contribute to a reduction of CO_2 emissions. At the same time, there will be an increase in total output and the number of employees.

3.3 Economic and Social Impact Differences between Wind and Solar Power

This section examines the reasons why wind power and solar power generation have different economic and employment effects. California's Clean Energy Future (CCEF) (2012) compared the job creation effects of renewable energy with that of conventional power generation technology. According to the study, in general, the job creation effect of renewable energy is larger than that of thermal power generation, but wind power generation is an exception. Its job creation effect is smaller than that of thermal power generation. According to the International Renewable Energy Agency (IRENA) 2020 report,[9] the number of jobs required for the operation and maintenance of solar power generation is higher than that needed for wind power generation as shown in Figure 2.[10]

Figure 2: Employment along several important renewable value chains



Source: International Renewable Energy Agency (IRENA) (2020), p 63.

Table 3 shows the installed capacity and annual power generation of renewable energy in China. When comparing wind and solar power plants with the same capacity in China, the annual power generation of a wind power plant is much higher than that of a solar power plant. The annual power generation of a wind power plant with 1 kW capacity is around 2,000 kWh, whereas that of a solar power plant is no more than 1,200–1,400 kWh according to China Electricity Council. In other words, it is necessary to install solar power plants with at least 1.5 times capacity compared with wind power plants to generate the same amount of power. It is possible that the replacement of thermal power by solar power

9The International Renewable Energy Agency (IRENA) is an intergovernmental organization to advance knowledge and promote the adoption and sustainable use of renewable energy. Founded in 2009, it was the first international organization to focus exclusively on renewable energy. Headquarters is located at Abu Dhabi, United Arab Emirates.

10Similar results have been reported in the following studies: Wei et al. (2010), Shirley and Kammen (2012), Moriizumi et al. (2017), and He et al. (2019).

is more expensive than the replacement by wind power and that solar power replacement has larger economic impacts than wind power.

3.4 Negative Impacts on the Thermal Power and Related-Industry Sectors

The analysis shows that the replacement of thermal power generation by wind power generation has a negative impact on the thermal power generation-related industries. He et al. (2019) pointed out that an increased share of renewable energy inhibits such traditional energy industries as mining and coal products and it can promote renewable-energy industry development. Tables 4 and 5 summarize the impacts of wind power generation on the output and number of employees of the thermal power generation industry and related industries in replacing thermal power generation.

As shown in Table 4, not only the output of thermal power generation but also the output of related industries will be significantly reduced by wind power generation substitution. In particular, coal/petroleum/natural gas mining, coal/petroleum products, the gas supply, waste treatment, and transportation—which are related to the fuel supply or treatment of thermal power generation—will be greatly affected.

Table 4 Installed capacity and power generation in renewable energy in China in 2018

	Installed capacity (GW)	Power generation (TWh)
Solar Photovoltaic power	175	178
Wind power	184	366

Source: National Energy Administration of China (2019).

Table 5 Output reduction of thermal power-related industries by wind power replacement

Wind power share	20%	40%	60%	80%
Coal, Petroleum, and Natural Gas	−6.67%	−13.16%	−18.82%	−23.80%
Coke, Refined Petroleum	−2.70%	−5.33%	−7.62%	−9.64%
Waste treatment	−1.80%	−3.56%	−5.08%	−6.43%
Gas Supply	−1.41%	−2.79%	−3.99%	−5.05%
Other Nonmetallic Mineral	−1.28%	−2.51%	−3.59%	−4.54%
Transport	−0.48%	−0.95%	−1.36%	−1.72%

Source: prepared by authors.

Replacement with wind power generation will significantly reduce the number of employees in the thermal power generation industry and related industries. If 80% of thermal power is replaced by wind power, the number of employees in the thermal power generation industry will decrease by more than 3 million, and the number of employees in the related industries of fuel production, refining, and transportation will decrease by more than 2 million. The number of unemployed workers in coal mining is expected to be particularly large. Many workers in this industry are unskilled, and re-employment after unemployment is relatively difficult. When China introduces wind power generation on a large scale, the Chinese government will need to consider how to absorb the unemployed workforce.

Table 6 Employment reduction in thermal power-related industries replaced by wind power,

Unit: 1,000 Person

Wind power share	20%	40%	60%	80%
Thermal Power	−899	−1,776	−2,540	−3,211
Coal, Petroleum, and Natural Gas	−461	−910	−1,301	−1,645
Transport	−113	−223	−319	−403
Coke, Refined Petroleum	−28	−55	−80	−101
Nonmetallic Mineral	−21	−42	−60	−76
Gas Supply	−4	−9	−13	−17

Source: prepared by authors.

4. Concluding Remarks

This paper focuses on China’s power industry from the perspective of power supply configuration. The power industry is composed of multiple power generation activities such as nuclear power, hydropower, thermal power, wind power, and solar power. It was therefore difficult to handle the power industry through the traditional framework of input–output analysis. However, scenario input–output analysis makes it possible to analyze the difference in the economic, environmental, and social effects caused by the different power supply configurations. Scenario input–output analysis gives shares of multiple power generation activities in the power sector as parameters that integrate multiple activities into one column in a square input–output table.

It was confirmed that the replacement of thermal power generation with renewable energy (wind power and solar power) might greatly contribute to the reduction of CO_2 emissions in China. If all thermal power generation is replaced by renewable energy, China’s CO_2 emissions can be reduced by more than 30%. On the other hand, a decrease in thermal power generation leads to a decrease in production and employment in related industries such as coal mining, coal refining, and transportation, and the macro impacts on production and employees are marginal. In the case of 80% replacement by wind power scenario, China’s total output is reduced by 1.48%, and the total number of employees is reduced by 0.34%.

The economic and social effects are not the same when the results of solar power and wind power generation are compared. In the case of 80% replacement by solar power scenario, China’s total output increases by 2%, and the number of employees increases by 1.8%. The reason for this positive macro impact is that the solar power generation equipment is composed of many parts that require time and labor for maintenance and repair. The effect of job creation by solar power generation is greater than the effect by wind power generation. Moreover, although wind power generation has a negative effect on the macro economy, its relative scale is extremely small compared to its CO_2 reduction effect. The results show the possibility of simultaneous realization of economic growth and reduction of CO_2 emissions by substituting renewable-energy power generation for thermal power generation.

The negative impacts on coal-related industries are inevitable when thermal power generation is replaced by renewable-energy generation. The negative impacts are especially serious in coal mining and for coal products. When China promotes renewable-energy power generation, adjustment policies will be required to mitigate the impacts of reduced production in these industries.

References

California's Clean Energy Future (CCEF) (2012), “Preliminary Estimates of Job Creation”. <http://www.bioin.or.kr/fileDown.do?seq=16187>

Duchin, F., and Levine, S. H. (2011), “Sectors may use multiple technologies simultaneously: The rectangular choice-of-technology model with binding factor constraints,” *Economic Systems Research*, 23(3), 281-302. <https://doi.org/10.1080/09535314.2011.571238>

Duchin, F., and Levine, S. H. (2012), “The rectangular sector-by-technology model: not every economy produces every product and some products may rely on several technologies simultaneously,” *Journal of Economic Structures*, 1(1), 1-11. <https://doi.org/10.1186/2193-2409-1-3>

Fujikawa, K. (2011), “Input output model to evaluate environmental policies,” in Ban K. (ed.), *Model development for comprehensive analysis on Japanese environmental policies and economy* (Final report of Policy Research of Environmental Economics, 2009-2011), 225-267, Ministry of the Environment, Japan. (in Japanese) <http://www.env.go.jp/policy/keizai_portal/F_research/f-01-03.pdf>

He, L., Yang, X., Zhong, Z., and Zhu, J. (2019), “On employment effect of renewable energy investment in China: From the overall and industrial perspective,” *Journal of Central South University (Social Science)*, 25(3), 84-95. <http://www.zndxsk.com.cn/upfile/soft/2019/03_skb/10-p84-19sk03.pdf>

Hienuki, S., Kudoh, Y., and Hondo, H., (2015), “Life cycle employment effect of geothermal power generation using an extended input-output model: The Case of Japan,” *Journal of Cleaner Production*, 93, 203-212.

Institute for Economic Analysis of Next-generation Science and Technology, *Input-output table for analysis of next-generation energy system*. <http://www.f.waseda.jp/washizu/table.html> (in Japanese)

Intergovernmental Panel on Climate Change (IPCC) (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. <https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>

International Renewable Energy Agency (IRENA), *Post-COVID recovery: An agenda for resilience, development and equality.* <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Post-COVID_Recovery_2020.pdf>

Moriizumi, Y., Hondo, H., and Nakano, S. (2017), “Renewable energy and employment potential: a comparative analysis based on an input-output model,” *Journal of the Japan Institute of Energy*, 96(1), 16-27. DOI: https://doi.org/10.3775/jie.96.16

National Bureau of Statistics of China (NBSC) (2015), *Input output table in China 2012*, China Statistics Press. (in Chinese)

National Bureau of Statistics of China (NBSC) (2013), *China Energy Statistical Yearbook 2013*, China Statistics Press. (in Chinese)

National Bureau of Statistics of China (NBSC) (2014), *The 3rd China Economic Census*, China Statistics Press (in Chinese)

National Development and Reform Committee of China (2015) *Enhanced Actions on Climate Change: China’s Intended Nationally Determined Contributions*. <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China%20First/China's%20First%20NDC%20Submission.pdf>

National Energy Administration of China (2019), *Renewable energy power development monitoring and evaluation report 2018*.

<http://zfxxgk.nea.gov.cn/auto87/201906/t20190610_3673.htm>

Ryaboshlyk, V. (2006), "A dynamic input – output model with explicit new and old technologies: an application to the UK," *Economic Systems Research*, 18(2), 183-203. <https://doi.org/10.1080/09535310600653040>

Shirley, R., and Kammen, D. (2012), "Estimating the Potential Impact of Renewable Energy," Renewable and Appropriate Energy Laboratory (RAEL) <https://rael.berkeley.edu/wp-content/uploads/2016/03/RAEL-Green-Jobs-Report_-Shirley-and-Kammen_May2012.pdf>

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), "An Illustrated User Guide to the World Input-Output Database: The Case of Global Automotive Production," *Review of International Economics*, 23, 575-605. <https://onlinelibrary.wiley.com/doi/abs/10.1111/roie.12178>

Wang, J. (2016), "Economic and environmental effects of power generation by renewable energies in China: an application of scenario input output analysis," *Input Output Analysis-innovation and I-O technique* (Pan-Pacific Association for Input Output Studies), 24(1), 35-48. (in Japanese)

Wei, M., Shana, P., and Daniel, K. (2010), "Putting Renewables and Energy Efficiency to Work: How Many Jobs can the Clean Energy Industry Generate in the US," *Energy Policy*, 38, 919-931. < https://doi.org/10.1016/j.enpol.2009.10.044>

Yoshioka, K., and Suga, M. (1997), "Application of input output approach in environmental analysis: A study of scenario Leontief inverse," in Ueta, K., et at. *An Econometric Approach to Environmental Problems, The Economic Analysis*, 154, 87-132, Economic Research Institute, Economic Planning Agency. (in Japanese)