THE IMPACT OF THE ENERGY TRANSITION ON CHINA'S ECONOMY UNDER THE CARBON PEAKING AND CARBON NEUTRALITY GOALS
A Simulation Analysis Based on the CGE Model

by

Yachen LU[a,b,c], Jiaquan DAI[b,c], Lining WANG[b,c*], Yu LIU[d], and Chunfang WU[b,c]

[a] School of Economics and Management, China University of Petroleum, Beijing, China
[b] CNPC Economics and Technology Research Institute, Beijing, China
[c] Key Laboratory of Oil and Gas Market Simulation and Price Forecast, China National Petroleum Corporation, Beijing, China
[d] Institutes of Science and Development, Chinese Academy of Sciences, Beijing, China

Original scientific paper
https://doi.org/10.2298/TSCI2205043L

With the acceleration of the global response to climate change, China announced to the world in 2020 the goals of carbon peaking by 2030 and carbon neutrality by 2060, which reflects its firm determination implement Intended Nationally Determined Contributions. Energy transition is the key to achieving the carbon peaking and carbon neutrality goals. It is of great theoretical and practical significance to study the impact of low carbon energy transition on China's macro-economy under the carbon peaking and carbon neutrality goals. Based on three carbon neutrality scenarios, this paper uses the dynamic computable general equilibrium model to simulate and estimate the impact of different energy transition pathways on China's macro-economy. The results show that under the carbon peaking and carbon neutrality target, accelerating energy transition will have a certain negative impact on China's economic growth, and different energy transition pathways have different impacts on the macro-economy. The sustainable transformation scenario that promotes energy transformation through the carbon tax policy to adjust carbon emission intensity and the renewable energy incentive policy to reduce costs has the least negative impact on the macro-economy, promoting employment growth, and optimizing industrial structure to a certain extent in the process of energy transformation. In conclusion, relevant policy recommendations are put forward for the achievement of the carbon peaking and carbon neutrality goals, and the promotion of high quality economic development.

Key words: *carbon peaking, carbon neutrality, energy transition, CGE model, macro-economy*

Introduction

On September 22, 2020, President Xi Jinping announced for the first time in his speech at the General Debate of the 75th Session of the United Nations General Assembly that China will scale-up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060. This is China's first long-term climate goal following its commitment to peak CO_2 emissions by 2030 under the Paris Agreement in 2015, showing China's sense of responsibility for the international community. In October 2021, the central government of China

* Corresponding author, e-mail: wanglining87@cnpc.com.cn

issued two guidelines, namely the *Opinions on Full, Accurate and Comprehensive Implementation of New Development Philosophy to Achieve Peak Emissions and Carbon Neutrality* and the *Action Plan for Carbon Dioxide Peaking Before 2030*, which improved the top-level design for achieving carbon peaking and carbon neutrality in China and manifested the country's firm determination implement its Intended Nationally Determined Contributions. At the 6th Plenary Session of the 19th CPC Central Committee, President Xi emphasized that peaking CO_2 emissions and achieving carbon neutrality would bring about a broad and profound economic and social systemic change, and should be incorporated into the overall plan for ecological conservation and development, once again highlighting the strategic position and great significance of carbon peaking and carbon neutrality.

China has not yet completed its industrialization, and its total primary energy consumption ranks first in the world. In 2020, fossil fuels consumption (including coal, oil and natural gas) accounted for 84.4% of the country's total primary energy consumption, higher than the global average of 83.1% and energy-related CO_2 emissions were responsible for more than 80% of its total emissions [1, 2]. In order to achieve its carbon neutrality goal, China needs to slash CO_2 emissions by accelerating its low carbon energy transition, which would induce all-round impacts on its economy and society. Progress has been made in the study of energy transition under carbon peaking and carbon neutrality in China [3-5]. Some of the studies have simulated pathways toward carbon peaking and carbon neutrality under different scenarios with energy system modelling. By comparing four carbon neutrality scenarios with the China TIMES model, Zhang and Chen [6] found that early peak attainment requires extensive utilization of renewables over the next decade and an accelerated phasing-out of coal after 2025. He *et al.* [7] developed six long-term development scenarios according to the the temperature goal set out in the Paris Agreement, and conducted an evaluation on pathways to carbon emissions and energy transformation, and requirements in technology, policy and investment for each scenario. They concluded that technological pathways towards carbon neutrality would rely heavily on both conventional and breakthrough emission reduction technologies. Yu *et al.* [8] proposed a pathway toward achieving medium- and long-term emission reduction goals with a self-developed national energy techno-economic model in a bottom-up approach. The Institute of Climate Change and Sustainable Development, Tsinghua University [9] focused on explaining road maps toward low carbon transition for end-use sectors and the power sectors, and believed that China's 2060 carbon neutrality target is consistent with the goal to limit the global temperature rise to 1.5 °C. Some studies analyzed macroeconomic impacts of peak emissions in China [10, 11]. Lu and Chen [12] assumed four carbon peaking scenarios, quantitatively analyzed the impacts of enhanced carbon peaking commitments on China's macro-economy using the dynamic computable general equilibrium (TE-CGE) model. The study shows that the earlier emissions peak, the higher the required carbon tax is, and the more macroeconomic variables, for example GDP falls, the more the share of the tertiary sector gains. Zhu and Ling [13] evaluated the impacts of different carbon peaking scenarios on China's industrial structure based on dynamic CGE modelling. They found that emission reduction policies could generate the following benefits: promoting industrial optimization; enabling low carbon industrial sectors such as agriculture, light industry and service sectors to acquire more share in the total output; cutting the share of energy-intensive industrial sectors such as the non-metallic mineral processing and metal processing sectors. Reducing the proportion of high carbon energy output, including coal and oil and raising the proportion of low carbon energy output like natural gas and renewables. Duan and Wang [14] made a comparative analysis of long-term impacts on China from the strategic adjustment of the upper limit for global warming from 2-1.5 °C from the perspectives of emission pathway, energy structure adjustment and economic impact based on

an integrated energy-economy-environment system model for China. The study revealed that the economic loss under 1.5 °C would be 8% higher than that under the 2 °C, while average losses under the same goals could be minimized as much as 69.3% with negative emission technologies.

After reviewing literature, we found that most studies focused on analyzing factors impacting the achievement of carbon peaking and carbon neutrality goals and very few touched upon economic and social impacts of the accelerated energy transition under the carbon peaking and carbon neutrality goals. Though based on the CGE model, some studies failed to incorporate the then latest input and output statistics; most studies analyzed impacts on China's macro-economy and industrial structure under different carbon peaking scenarios, without considering the carbon neutrality target in a holistic manner. To overcome these limitations, this paper uses the CGE model for China, jointly developed by the Institutes of Science and Development, Chinese Academy of Sciences and the Centre for Policy Studies, Victoria University, Australia, to analyze the macroeconomic impact of the energy transition on China under the carbon peaking and carbon neutrality goals.

Model methodology and scenario setting

Model methodology

The CGE model, widely used in economic policy evaluation, can simulate complex economic interactions, estimate how macroeconomic indicators, including GDP, prices, import and export, react to changes in macroeconomic policies and trace the change in variables such as output and prices of sectors. This paper uses input-output tables from 149 sectors of China in 2017 as the underlying database to develop a dynamic CGE model, aligned with the country's current economic situation. The model involves 159 sectors (the electricity sector and its outputs are split into coal-fired generation, gas-fired generation, nuclear power, hydro power, wind power, solar power, geothermal energy, and transmission and distribution sectors; the oil and gas sector and outputs are split into crude-oil, pipe-line gas, liquefied natural gas), six categories of economic players (manufacturing, investment, residents, government, offshore, and inventory), three input factors (labor, capital, and land), and nine categories of distribution inputs (wholesale and retail, rail, road, waterway, and air transportation, pipe-line transportation, transportation services, storage, and insurance). According to the Walrasian equilibrium, the CGE model should include three modules – production, demand, and equilibrium.

Production module

The production module describes an input decision and an output allocation of each production sector, which determines the optimal input and output based on the cost minimization rule, and allocates the output to the domestic market or to export into foreign markets based on the profit maximization rule. The production function of the model generally features a multi-layer nested structure, with the top nest being a Leontief production function involving intermediate inputs, value-added inputs and other inputs. Intermediate inputs are represented by a CES function with both domestic or imported products. Value-added inputs are defined by a CES function with combined inputs of labor, land, capital and energy with an elasticity of substitution of 1.12. The elasticity of substitution between capital and energy inputs is 0.5 [14-17].

The module deploys a multi-layer nested production function describe substitution relationships between different energy products in each input of the energy sector. Fossil energy consists of a combination of coal, oil, and natural gas. Their substitution relationships are depicted by a CES function, with an elasticity of substitution of 0.5. Coal includes raw coal and coking products, with their relationship depicted by a CES function and an elasticity of substi-

tution of 0.5. Oil covers crude-oil and petroleum products, and the elasticity of substitution is set at 0.5. Natural gas contains natural gas and gas products, with its elasticity of substitution setting at 0.5 [14-17]. A Leontief production function is applied to portray the substitution relationship between electricity generation and transmission and distribution in the electricity sector. The electricity generation sector covers the basic power supply sector and the variable power sector. The former consists of fossil fuel generation, *i.e.*, coal-fired generation, gas-fired generation, hydro power, and nuclear power, while the latter involves wind power, solar power, and biothermal energy. A CES function is used to portray the incomplete substitution relationship between the two sectors, with the elasticity of substitution setting at three. The substitution relationships between thermal power, nuclear power, and hydro power are also depicted with a CES function and the elasticity of substitution is five, as is the case with wind power, solar power, and biothermal energy.

Demand module

The final demand for goods consists of household consumption, government consumption, exports, investment, and inventories. The total household consumption expenditure is a function of the national income, and the consumption choice is made to reflect maximized utility, *i.e.* a maximized utility function subject to its budget constraint. The household consumption is described by a merged CES function involving both domestic and imported products, and the household expenditure elasticity against different goods is 1.2 [15]. The demand for exports of goods is a downward sloping curve, mainly influenced by export prices, and the price elasticity of export demand is 4 [17]. In terms of investment demand, sectors select based on the cost minimization rule the optimal portfolio of investments, which is also a merged CES function involving both domestic and imported products, with an Armington elasticity between different domestic products and imports at 2.9 [18]. Government consumption and inventories are assumed to be exogenous variables.

Carbon emission module

The model introduces CO_2 emissions from fossil fuel combustion and industrial manufacturing processes. The CO_2 emission factors from IPCC AR5 (2014) are used and fossil energy emissions for 2017-2020 are calibrated against the *World and China Energy Outlook* (2021) to calculate carbon emissions from fossil fuel combustion. In the paper, CO_2 emissions from industrial manufacturing processes are represented by those from cement manufacturing processes due to limited data availability and the fact that the latter account for more than 70% of the former. A CES function is applied to portray the emission reduction behavior of the cement industry as a partial substitution relationship between emissions and manufacturing inputs, with the elasticity of substitution setting at 0.11.

Equilibrium module

A general equilibrium module must satisfy three conditions – market clearance, zero profit, and income balance. The market clearance condition reflects the fact that supply of production factors equals demand of goods. The zero-profit condition requires that the ex-works price of a product is equal to its marginal cost and its market price equals its marginal cost-plus taxes and logistic cost. The income balance condition includes the balance of investment and savings, the balance of government income and the balance of international payments.

Scenario setting

This paper uses a CGE model to evaluate impacts on China's economy and society of different energy transition pathways toward carbon peaking and carbon neutrality. The scenario settings include a baseline scenario and three carbon neutrality scenarios, tab. 1. Specifically, by introducing external shocks, three different carbon neutrality scenarios and policy differences under those scenarios are portrayed in the CGE model. External shocks, including but not limited to carbon market regulation, renewable energy incentives, and high consumption output control, are deployed to promote a green and low carbon energy transition and ensure the achievement of the carbon neutrality target on schedule. This paper argues that the differences between the carbon neutrality policy scenarios and the baseline scenario are manifested mainly through two aspects:

– under the carbon neutrality scenarios, the energy efficiency levels will decline more rapidly after 2040, and will be only 69% of the baseline scenario in 2060 and
– the carbon price rises at an initially slow, then fast pace, and will stand at $200/ton in 2060.

The differences between the three carbon neutrality scenarios can be boiled down into four aspects: first, under carbon neutrality Scenario 1, the only external shocks are energy efficiency and carbon taxes, second, under carbon neutrality Scenarios 2 and 3, the cost of renewables will start to drop significantly in 2040 due to the accelerated technological progress spurred by incentive policies for renewables, and will be equivalent to 85% and 53% of the baseline scenario in 2060, respectively, third, the energy transition will make the end-use sector see a steady rise in the electrification level, which will rise to 55%, 64%, and 78% under the three carbon neutrality scenarios, from 50%, the level of the baseline scenario, and fourth, industrial restructuring, *i.e.*, controlling output of chemical and steel sectors, is a must for accelerating the energy transition under carbon neutrality Scenario 3, fig. 1, tab. 2.

Table 1. The CGE model scenario setting

Scenarios		Parameter assumption
Baseline scenario		Not affected by the carbon peaking and carbon neutrality goals, not confined by any energy or climate policies, and energy transition and technological progress at the current pace
Carbon neutrality scenarios	Scenario 1	Energy efficiency levels fall faster, carbon taxes play a regulatory role in the market
	Scenario 2	Energy efficiency levels fall faster, carbon taxes play a regulatory role in the market, and incentive policies for renewables produce remarkable results
	Scenario 3	Energy efficiency levels fall faster, carbon taxes play a regulatory role in the market, incentive policies for renewables produce remarkable results, and the output of energy-intensive industries is tightly controlled

The baseline scenario and the three carbon neutrality scenarios exhibit different energy consumption structures and emission pathways under the influence of the policy shocks. Table 3 reveals structures of primary energy consumption at the point of carbon peaking and carbon neutrality, and fig. 2 shows emission pathways under the four scenarios. Under the baseline scenario, carbon emissions will peak around 2025 at about 10.89 billionns. In 2060, coal, oil, natural gas, and non-fossil energy will account for 17.7%, 13.9%, 15.3%, and 53.1%,

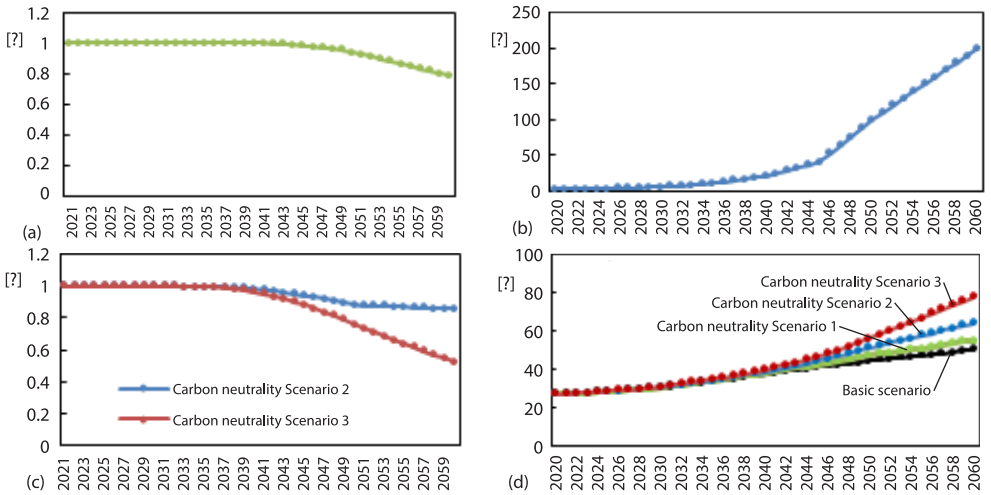

Figure 1. Policy shock trends based on the CGE model; (a) energy efficiency, (b) carbon taxshock, (c) renewables cost, and (d) electrification

Table 2. Policy shock effects based on the CGE model

Scenarios		External shock effects (comparing data in 2060)			
		Energy efficiency	Carbon price	Renewables cost	Electrification
Baseline scenario		1	0	1	41%
Carbon neutrality scenarios	Scenario 1	69%	200	1	55%
	Scenario 2	69%	200	85%	64%
	Scenario 3	69%	200	53%	78%

Table 3. Primary energy consumption structures based on the CGE model

	Baseline scenario		Carbon neutrality Scenario 1		Carbon neutrality Scenario 2		Carbon neutrality Scenario 3	
	2030	2060	2030	2060	2030	2060	2030	2060
Coal	45.0%	17.7%	44.4%	7.2%	44.3%	5.0%	43.8%	3.0%
Oil	18.7%	13.9%	18.8%	7.2%	18.8%	5.6%	18.9%	4.1%
Gas	12.9%	15.3%	12.9%	12.4%	12.9%	9.4%	12.9%	8.1%
Non-fossil energy	23.4%	53.1%	23.9%	73.2%	24.0%	80.0%	24.4%	84.8%

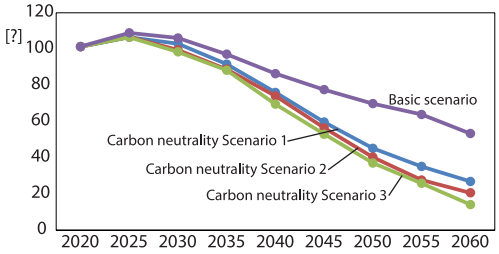

Figure 2. Emission pathways under different scenarios based on the CGE model (excl. carbon sinks and CCUS)*

* The carbon emission pathways in the CGE model do not consider the effects of carbon sinks and carbon capture, utilization and storage (CCUS). Such effects, when considered, would allow the achievement of net zero emissions under any of the three scenarios in 2060.

respectively, and carbon emissions (without considering carbon sinks and carbon capture, utilization and storage (CCUS), sic passim, will drop to 5.34 billionns. Under these three carbon neutrality scenarios, emissions will peak around 2025 at about 10.65 billionns. In 2060, the shares of coal, oil, natural gas, and non-fossil energy will account for 7.2%, 7.2%, 12.4%, and 73.2% of the total energy demand, with emissions declining to 2.69 billionns under carbon neutrality Scenario 1, and 5.0%, 5.6%, 9.4%, and 80.0%, with emissions down to 2.07 billionns under carbon neutrality Scenario 2, and 3.0%, 4.1%, 8.1% and 84.8%, with emissions reduced to 1.42 billionns under carbon neutrality Scenario 3.

Result analysis

Impact on micro-economy

Different pathways of China's low carbon energy transition will induce different impacts on economic growth. The macroeconomic impacts of different carbon neutrality scenarios are revealed by comparing with the baseline scenario. Figure 3 shows impacts on GDP under the three carbon neutrality scenarios compared with the baseline scenario, and fig. 4 indicates impacts on capital.

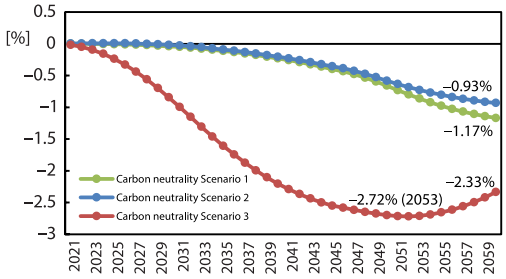

Figure 3. Impacts of policy shocks on GDP under three carbon neutrality scenarios

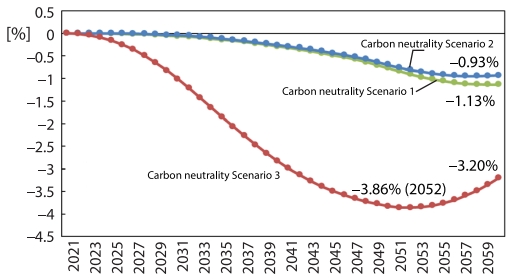

Figure 4. Impacts of policy shocks on capital under three carbon neutrality scenarios

As can be seen from figs. 3 and 4, both GDP and capital demand decline under the three carbon neutrality scenarios. Compared with the baseline scenario, the cumulative GDP decline in the three scenarios will be 0.04%, 0.02%, and 0.84%, respectively in 2030, and 1.17%, 0.93%, and 2.33%, respectively in 2060. The cumulative capital decline in the three scenarios will be 0.05%, 0.03%, and 0.82%, respectively in 2030, and 1.13%, 0.93%, and 3.20%, respectively in 2060. Overall, the cumulative changes in GDP and capital are small under Carbon Neutrality Scenarios 1 and 2 (more obvious in Scenario 2). The main reasons for larger changes in Scenario 3 are: Carbon Neutrality Scenario 1 is mainly affected by the carbon tax policy (the CO_2 emissions are taxed and the tax revenue is subsidized to the residents in the form of consumption tax reducing), with carbon price as the transmission medium in achieving the carbon peaking and carbon neutrality goals on macro-economy and Under Carbon Neutrality Scenario 1, there are two mechanisms for the energy transition impact GDP and capital:

– Affected by the carbon tax, the cost of fossil energy industries such as coal mining and coal-fired power is rising. The increase in capital prices will lead to a decrease in capital demand in these capital-intensive industries, which in turn will cause the decrease in GDP.
– In the construction industry, a high energy consuming industry, the price increase of fossil energy pushes up the prices of the main investment goods, driving up the real estate price, reducing the demand, slashing the output of capital-intensive industries, and leading to further declining capital demand.

Compared with carbon neutrality Scenario 1, Scenario 2 is additionally impacted by the technological progress in renewable energy, resulting in a small increase in GDP and capital stock, and the transmission mechanism is:

– *Scale effect*. As the proportion of renewable energy continues to increase, the capital demand rises in renewable energy and decreases in fossil energy. In the long run, the decrease in the cost of renewable energy brings about an increase in capital demand that is greater than the decrease in capital demand for fossil energy. The total capital stock increases, and the GDP grows slightly.
– *Substitution effect*. Due to the increased cost of fossil energy, the road transportation and urban transportation sectors are more likely to replace energy with capital. The demand for capital is further increased.

Compared with carbon neutrality Scenarios 1 and 2, Scenario 3 requires intensive adjustment of the industrial structure to reduce carbon emissions, that is, to control the total output level of these industries by raising the tax of high energy consuming sectors such as steel and chemicals, resulting in more intense fluctuations in GDP and capital.

Under the carbon peaking and carbon neutrality goals, the impact of the energy transformation pathways of Scenarios 1 and 2 is relatively mild on the macro economy before carbon peaking and basically negligible, however, the impact is very severe in Scenario 3.

Impact on employment

Different pathways of China's low carbon energy transition will also have different impacts on employment. Figure 5 presents impacts of different carbon neutrality scenarios on employment, comparing these scenarios with the baseline scenario.

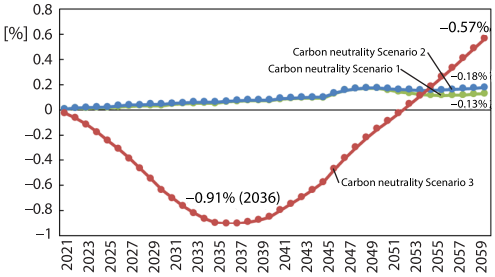

Figure 5. Impacts of policy shocks on employment under three carbon neutrality scenarios

As can be seen from fig. 5, employment increases in all three scenarios, but with different trends. Compared with the baseline scenario, the employment in 2030 will cumulatively increase by 0.03%, and0.04%, and decrease by 0.64%, respectively in the three scenarios. In 2060, the GDP will cumulatively increase by 0.13%, 0.17%, and 0.57%, respectively. Overall, the cumulative change in employment under Scenarios 1 and 2 is small and has been on an upward trend; in Scenario 3, employment experiences a rapid decline followed by a substantial increase, and finally turns negative to positive. The main reasons for the great fluctuation in Scenario 3 are: under Scenario 1, energy transformation impacts residents' employment via two mechanisms:

– *Scale effect*. Carbon tax is subsidized to residents through consumption tax, which increases residents' income and consumption demand, thus further increases the demand for labor-intensive industries such as education, health, and residential services. Scale effect drives labor demand to rise, resulting in increase in employment.
– *Substitution effect*. With lower labor price compared with energy price, labor-intensive industries have an increasing demand for labor and decreasing demand for energy, which in turn boosts employment.

Compared with carbon neutrality Scenario 1, the policy shock in Scenario 2 involves the impact of technological progress in renewable energy, resulting in a slight increase in the employment, via the pass-through effects:

– *Scale effect*. Along with the rise in GDP, household consumption increases, stimulating the output expansion of labor-intensive industries such as the service industry and agriculture, and then the labor demand.
– *Substitution effect*. With lower labor price compared with energy price, labor-intensive industries have an increasing demand for labor and decreasing demand for energy, which in turn boosts employment.
– *Substitution effect.* For labor-intensive sectors with high energy consumption such as road transportation, with energy prices rising, labor prices gain advantage, and get to substitute energy, resulting in an increase in labor demand.

In carbon neutrality Scenario 3, in the short term, output control in the steel and chemical industries will directly slash labor demand, resulting in a significant downward trend in employment; however, in the long run labor will gain a comparative advantage by reducing wages and begin to return to the equilibrium level, stimulating labor demand and boosting employment.

To sum up, under the carbon peaking and carbon neutrality goals, the energy transformation of Scenarios 1 and 2 has slightly pushed up employment while the one in Scenario 3 has severely impacted employment.

Impact on industrial structure

The changes in industrial structure are different under different carbon neutrality scenarios, which can be seen from the trends of industrial structure adjustments under the four scenarios in tab. 4. Compared to the baseline scenario, in the three carbon neutrality scenarios, the proportion of the primary industry decreases slightly, the proportion of the secondary industry decreases, and the proportion of the tertiary industry increases. Compared with the three carbon neutral scenarios, in carbon neutrality Scenarios 1 and 2, by the means of carbon market adjustment and renewable energy incentives can promote energy transition and optimization of industrial structure. In the long run, the proportion of the secondary industry and tertiary industry will remain previous 20% and 70%, respectively. In carbon neutral Scenario 3, output control of energy-intensive industries is added to accelerate energy transformation, and the industrial structure is adjusted faster. Under this scenario, the secondary industry accounts for less than 20% while the tertiary industry accounts for nearly 75%. The development of the manufacturing industry is limited, which is not conducive to the long-term stable development of the economy.

Table 4. Trend of industrial structure adjustment under different scenarios

	Baseline scenario		Carbon neutrality Scenario 1		Carbon neutrality Scenario 2		Carbon neutrality Scenario 3	
	2030	2060	2030	2060	2030	2060	2030	2060
Proportion of primary industry	7.2%	7.0%	7.2%	6.9%	7.2%	6.9%	7.2%	6.9%
Proportion of secondary industry	33.8%	21.6%	33.7%	21.0%	33.7%	21.0%	33.3%	18.6%
Proportion of tertiary industry	59.0%	71.4%	59.1%	72.1%	59.1%	72.1%	59.5%	74.5%

Impact on industry output

The low carbon energy transition restricts the investment in fossil energy in corporate activities, thereby affecting investment and output in different industries. Under different policy scenarios, the pathways to the low carbon energy transition are different, and the positions of various sectors in the industrial chain are different, so the impact of achieving the carbon peaking and carbon neutrality goals on industry output is also different.

Impact on energy industry output

The low carbon energy transition has a greater impact on the fossil energy sector, the main source of carbon emissions, resulting in a decline in the output of the fossil energy sector. Within the energy industry, the replacement of clean energy with non-clean fossil energy also has a great impact on the structure of energy, figs. 6 and 7.

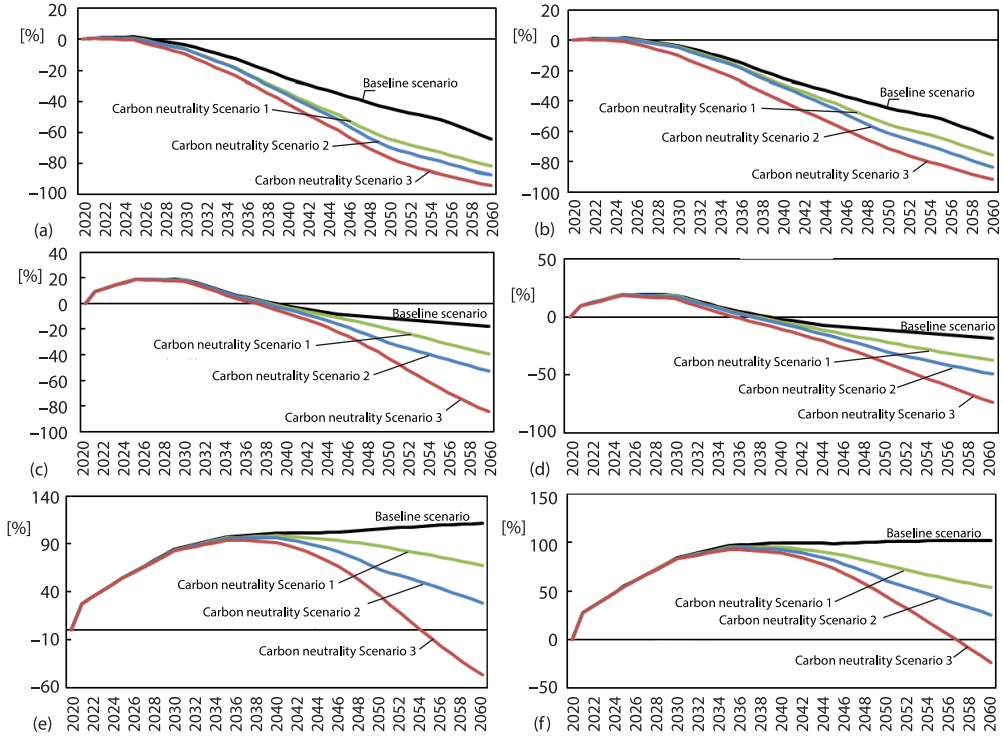

Figure 6. Impact of policy shocks on the fossil energy sector under different scenarios (compared with 2020); (a) coal, (b) coking, (c) crude oil, (d) refining, (e) natural gas, and (f) natural gas supply

As can be seen from fig. 6, in both the baseline scenario and the carbon neutrality scenario, the change trend of the output of coal mining and coking sectors is basically the same, with output declining gradually over time. The cumulative output decline in 2060 under carbon neutrality Scenario 2 is more than 80%, and the figure is more than 90% in Scenario 3. The trend of output change in crude-oil extraction and refining sectors is basically the same. Under the carbon neutrality scenarios, the output declines more significantly and rapidly, especially under carbon neutrality Scenario 3, the cumulative decline in 2060 will be more than 70%. The trend of the output change in natural gas extraction and supply industries is also basically the

same, but it is quite different from that of the coal and oil sectors. The output still maintains a positive growth trend under the baseline scenario, and Scenario 1 and 2, however, a downtrend shows under carbon neutrality Scenario 3.

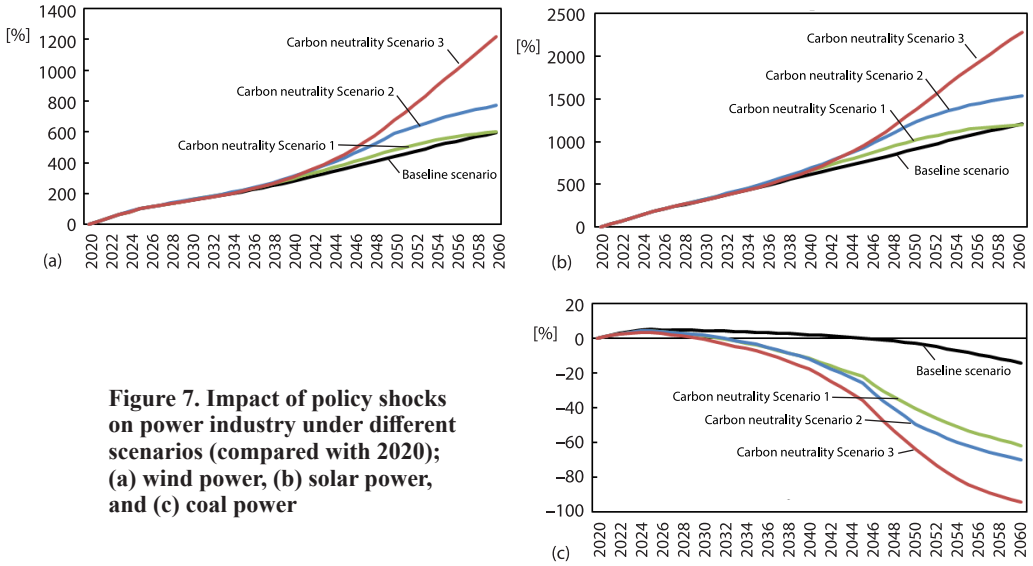

Figure 7. Impact of policy shocks on power industry under different scenarios (compared with 2020); (a) wind power, (b) solar power, and (c) coal power

It can be seen from fig. 7 that the non-fossil fuel power generation gradually increases over time, and the growth rate of different scenarios begins to differ after 2040. The greater the enforcement of low carbon energy transformation is, the faster the non-fossil fuel power generation will grow, especially in Scenario 3, the wind power generation will increase by more than 1,200% compared with 2020, and more than 2,200% in solar power generation. Under the three carbon neutrality scenarios, coal-fired power generation still maintains a positive growth before carbon peaking compared with 2020, and then begins to decline continuously, with a cumulative decline of more than 60% by 2060.

In general, with the intensification of emission reduction, carbon emission reduction policies can drive up the cost of enterprises. However, the energy industry is affected not only in production, but in downstream demand. The decline in the demand of downstream sectors triggers the slump in the output of the energy industry, especially the carbon-intensive energy sectors.

Impact on output of high energy consuming industries

In the process of low carbon energy transition, the carbon tax policy regulates energy prices, prompting enterprises in various sectors to adjust energy inputs, which in turn affects the output of non-energy sectors, especially energy-intensive industries, fig. 8.

As can be seen from fig. 8, the sharp decline in the output of fossil energy imposes negative impact over output of related industries, especially the mining auxiliary and pipe-line transportation sectors. Under carbon neutrality Scenario 2, the output of mining auxiliary and pipe-line transportation sectors will drop by 28.6% and 26.2%, respectively compared with the baseline scenario by 2060, and the output of basic chemical raw materials sector, synthetic materials sector and pesticide sector will decrease by 4.4%, 3.0%, and 2.1%, respectively. Under carbon neutrality Scenario 3, industries closely related to fossil energy, as well as steel industry and other regulated industries and their upstream and downstream sectors will be impacted

more, and their output will decline more sharply. By 2060, compared with the baseline scenario, the output of mining auxiliary, basic chemical raw materials and pipe-line transportation sectors will decline by 50%, 45%, and 34%, respectively, and the output of the steel industry will decline by 27%. On the whole, the carbon peaking and carbon neutrality goals have a greater negative impact on energy auxiliary, chemical industry and its downstream products-related industries.

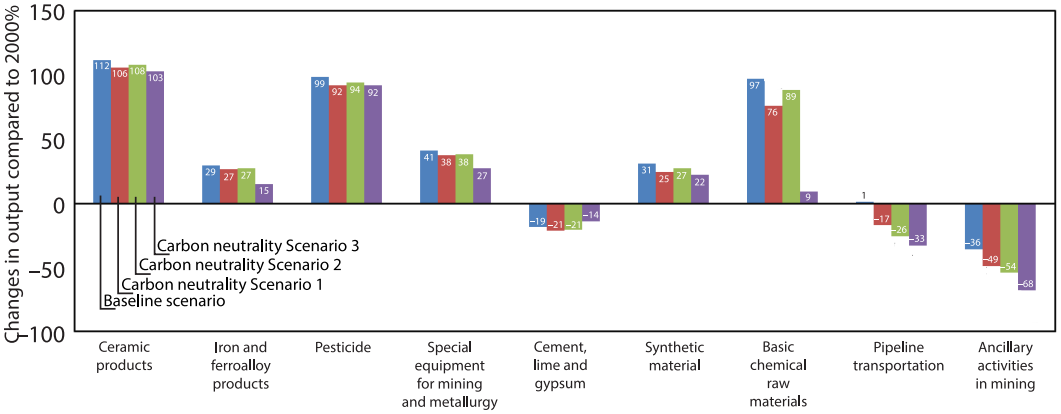

Figure 8. Negative impacts of policy shocks on non-energy industries under different scenarios

Robustness check

In the CGE model, the fluctuation of the results of each variable in all the three scenarios is less than 0.0001% for 10% of fluctuation of substitution elasticity between energy sources and the substitution elasticity between labor, land, capital and energy, respectively, which shows that the accuracy of the value of the elasticity of substitution has little effect on the results of this model.

Conclusion and suggestions

This paper adopts the dynamic CGE model to analyze the impact of the low carbon energy transition pathways on China's economy, employment and industry output under the carbon peaking and carbon neutrality goals. Therefore, the following conclusions can be drawn.

- Under the carbon peaking and carbon neutrality goals, accelerating the energy transition will have negative impact on China's economic growth to some extent. The choice of energy transformation pathways decides the size of the economic cost, as different energy transition pathways have different impacts on the macro economy.
- The energy transition pathway that only relies on the adjustment of carbon tax policies and the development of carbon emission reduction technologies to achieve carbon neutrality (Carbon Neutrality Scenario 1) has a relatively mild impact on the economy, and promote the employment and optimization of the industrial structure to some extent. The sustainable transition scenario (carbon neutrality Scenario 2) that promotes energy transition by regulating carbon emissions through carbon tax policies and reducing costs through renewable energy incentive policies has the least negative impact on the macro economy, promotes employment growth in the process of energy transformation, and optimizes the industrial structure to a certain extent. Rigid control over the development of industries such as cement and steel (carbon neutrality Scenario 3) promotes the proportion of the primary, secondary

and tertiary industries, however, it imposes huge negative impact on the economic growth. It will cause *industrial hollowing-out*, and will impact employment, which is not conducive to the stable development of the economy.

In the process of energy transformation for achieving the carbon peaking and carbon neutrality goals, the economic cost must be considered. The following policy recommendations are put forward to maintain stable economic growth and energy transition.

Relevant departments need to formulate a detailed roadmap and timetable for both the short-term and long-term goals. In the process of achieving the carbon peaking and carbon neutrality goals, a short-term excessively rigid target will certainly help to promote emission reduction, but it is also easy to induce problems such as economic downturn, increasing unemployment, and even stagflation. Carbon neutrality is a comprehensive social governance project which requires medium and long-term mechanisms. A rush for quick results is harmful. We should consider more efficient methods with lower social costs, and be cautious about measures with strong supply shocks, such as production restrictions and shutdowns, especially at present, when China's economic development is facing the triple pressure of demand contraction, supply shock, and weakening expectations. For example, in industries with high pollution and high environmental risks, incremental reforms should be carried out to drive stock adjustment. We should promote the replacement of carbon-intensive production capacity by increasing investment in low carbon and zero-carbon production and strictly control investment in new high carbon production. In addition, the carbon peaking target should be set within a certain range, to accelerate the implementation of the emission plan for major energy consumption and high carbon emission industries, which cannot only avoid too rigid supply constraints, but also ensure the fulfillment of the carbon peaking target, beneficial to supply elasticity and the balance between economic growth and low carbon transition.

Overall consideration should be given to efficiency and fairness so as to promote co-ordinated regional development. Achieving the carbon peaking and carbon neutrality goals means accelerating the adjustment of the energy structure and gradually achieving the substitution of clean energy for fossil energy. In the process of energy transformation, some carbon-intensive economic activities, technologies and even industries will be replaced. Traditional energy, especially coal and thermal power will be impacted severely. The output of relevant infrastructure, manufacturing and service sectors will decline, while the output of renewable energy and its related sectors will rise. In the next few decades, Shaanxi, Shanxi, Inner Mongolia and other northwestern regions that are heavily dependent on fossil energy for their economic activities will experience a painful period of green transformation. The contribution of carbon-intensive industries to the regional economic growth will continue to decrease, and workers there will face risks of unemployment. Therefore, it is necessary to provide appropriate financial incentives and subsidies, accelerate the construction of infrastructure for renewable energy, and provide alternative employment opportunities in production.

Overall consideration should also be taken to both safety and efficiency to ensure the steady transition from fossil energy to renewable energy. Clean, low carbon, and renewable energy from a wide range of sources has obvious advantages over the fossil energy. However, it still faces challenges in applications, especially in maintaining the stability of power supply, due to the constraints of technical capabilities and power infrastructure. This problem of renewable energy was highlighted in the recent global energy crisis, as insufficient energy supply will lead to a decline in the operating rate of enterprises thus affecting the steady development of the economy. In addition, under the guidance of policies, the investment in fossil energy industries such as the coal and oil industry will decrease, resulting in a decline in fossil energy

supply and an increase in fossil energy prices, which will affect the cost-effectiveness of fossil energy dependent industries, which is not conducive to economic development. Therefore, to actively and steadily promote the optimization of the energy structure, we should adhere to bottom-line and problem-oriented thinking, improve weak links and promote the transformation. By improving the storage and transportation capacity of fossil energy, and strengthening the construction of power emergency peak-shaving capacity, energy supply security can be guaranteed. The replacement of fossil energy by renewable energy anyway shall be advanced in an orderly manner while making sound judgment of energy supply and demand, and securing safe and stable supply of energy.

References

[1] ***, CNPC Economics and Technology Research Institute. World and China Energy Outlook 2060, 2021
[2] ***, bp. bp's Statistical Review of World Energy 2021[EB/OL]. 2021-07-08. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, 2021
[3] Liu, X., *et al*., Research on the High-Quality Development Path of China's Energy Industry under the Target of Carbon Neutrality, Journal of Beijing Institute of Tecnology (Social Sciences Edition), *23* (2021), 03, pp. 1-8
[4] Liu, J, *et al.*, Comparison of Sectoral Low-Carbon Transition Pathways in China under the Nationally Determined Contribution and 2° C Targets, *Renewable and Sustainable Energy Reviews*, *149* (2021), 111336
[5] Xiao, M., *et al*., Scenario Analysis of Energy System Transition-a Case Study of Two Coastal Metropolitan Regions, Eastern China, *Energy Strategy Reviews*, *26* (2019), 100423
[6] Zhang, S., Chen, W., China's Energy Transition Pathway in a Carbon Neutral Vision, *Engineering*, *14* (2021), 7, pp. 64-76
[7] He, J., *et al*., Towards Carbon Neutrality: A Study on China's Long-Term Low-Carbon Transition Pathways and Strategies, *Environmental Science and Ecotechnology*, *9* (2021), 100134
[8] Yu, B., *et al*., Research on China's CO_2 Emission Pathway under Carbon Neutral Target, *Journal of Beijing Institute of Tecnology (Social Sciences Edition)*, *23* (2021), 02, pp. 17-24
[9] ***, Project Comprehensive Report Preparation team of Institute of Climate Change and Sustainable Development, Tsinghua University. China's Long-Term Low-Carbon Development Strategies and Pathways: Comprehensive Report, China Population, *Resources and Environment*, *30* (2020), 11, pp. 1-25
[10] Zhui, J., *et al*., Impact of Carbon Emission Constraint on China's Economy: Based on Dynamic CGE Model, *Technology Economics*, *37* (2018), 11, pp. 102-109
[11] Wang, Y., *et al*., The Impact of Peak Carbon Emission on China's Economy under Different Scenarios: Based on CGE Model, *Resources Science*, *39* (2017), 10, pp. 1896-1908
[12] Lu, C., Chen, W., A General Equilibrium Analysis of the Economic Impacts for China Reaching the Peak Before 2030, *Environmental Economics Research*, *6* (2021), 01, pp. 10-30 + 200
[13] Zhu, P., Ling ,W., Study on the Impact of Different Peak Carbon Emission Scenarios on Industrial Structure: An Analysis Based on Dynamic CGE Model, *The Theory and Practice of Finance and Economics*, *41* (2020), 5, pp. 110-118
[14] Duan, H., Wang, S., China's Challenge: Strategic Adjustment of Global Temperature Control Target from 2 ℃ to 1.5 ℃, *Management World*, *35* (2019), 10, pp. 50-63
[15] He, J., *et al*., *A CGE Model of Carbon Tax and Carbon Dioxide Reduction*, *10* (2002), Jan., pp. 39-47
[16] Willenbockel, D., Structural Effects of a Real Exchange Rate Revaluation in China: A CGE Assessment [EB/OL], (2006-12-25), https://mpra. ub. uni- muenchen. de/920/1/MPRA-paper-920. pdf, 2006
[17] Yu, L., HE, Y., The Elasticity of Energy Substitution and Restructuring of China's Economy, *China Industrial Economics*, *04* (2013), pp. 30-42
[18] Zha, D., *et al*., Research of Energy and Non-energy Substitution for Industrial Sector: Based on Muti-Elasticity Method, *Management Review*, 28 (2016), 06, pp. 180-191

Paper submitted: June 14, 2022
Paper revised: July 13, 2022
Paper accepted: August 5, 2022

© 2022 Society of Thermal Engineers of Serbia
Published by the Vinča Institute of Nuclear Sciences, Belgrade, Serbia.
This is an open access article distributed under the CC BY-NC-ND 4.0 terms and conditions