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Assessing Multiple Pathways for Achieving China's National Emissions Reduction Target

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Abstract: In order to achieve China's target of carbon intensity emissions reduction in 2030, there is a need to identify a scientific pathway and feasible strategies. In this study, we used stochastic frontier analysis method of energy efficiency, incorporating energy structure, economic structure, human capital, capital stock and potential energy efficiency to identify an efficient pathway for achieving emissions reduction target. We set up 96 scenarios including single factor scenarios and multi-factors combination scenarios for the simulation. The effects of each scenario on achieving the carbon intensity reduction target are then evaluated. It is found that: (1) Potential energy efficiency has the greatest contribution to the carbon intensity emissions reduction target; (2) they are unlikely to reach the 2030 carbon intensity reduction target of 60% by only optimizing a single factor; (3) in order to achieve the 2030 target, several aspects have to be adjusted: the fossil fuel ratio must be lower than 80%, and its average growth rate must be decreased by 2.2%; the service sector ratio in GDP must be higher than 58.3%, while the growth rate of non-service sectors must be lowered by 2.4%; and both human capital and capital stock must achieve and maintain a stable growth rate and a 1% increase annually in energy efficiency. Finally, the specific recommendations of this research were discussed, including constantly improved energy efficiency; the upgrading of China's industrial structure must be accelerated; emissions reduction must be done at the root of energy sources; multi-level input mechanisms in overall levels of education and training to cultivate the human capital stock must be established; investment in emerging equipment and accelerate the closure of backward production capacity to accumulate capital stock.

Keywords: carbon intensity reduction target; pathways design for emissions reduction; emissions reduction assessment; stochastic frontier analysis

1. Introduction

Rapid industrialization has brought increased wealth for society and subsequently improved people's living standards. Furthermore, the growing industrialization has also led to the increase of urbanization. Meanwhile, the demand for energy is growing considerably. However, the current energy structure in China is dominated by fossil fuels. Therefore, the increasing demand for energy will bring a tremendous increase in carbon dioxide emissions [1,2]. According to the Intergovernmental Panel on Climate Change (IPCC), global climate change in the past 50 years is largely attributed to the fact that greenhouse gas emissions are growing [3–5]. Following the report from the International Energy Agency (IEA), China had surpassed the USA by 2007 and had become the world's largest carbon emitter. China was responsible for 19.12% of global carbon emissions in 2016 [6]. At the United

Nations Climate Change Conference in 2015, China submitted its Intended Nationally Determined Contribution (INDC) report, in which it states that it will reduce its carbon intensity (CO_2 emissions per unit GDP) by 60–65% in 2030 compared to the level in 2005 [7]. The realization of this target can accelerate China's transformation to a green, low-carbon economy and serve as an important foundation and model in achieving the global target of 2 °C temperature increase [8]. Although some progress has been achieved (i.e., the energy intensity decreased 33.8% from 2005 to 2014), China's carbon intensity is still at a high level. The energy consumption structure still needs to be optimized [9]. In order to achieve its target on emissions reduction in 2030, there is a need for identifying a scientific pathway and feasible strategies, especially before China achieves the early peaking of its carbon emissions [10–12].

The imbalance in economy development between regions appears in all economies, as differentiated growth always results in early-developing and late-developing regions [13]. The imbalances are visible not only in economic growth, but also in other facets like sectorial structures and models of energy consumption [14,15]. In order to achieve the target of emission reduction, policies must fit into the reality of local socioeconomic development. López-Peña et al. [16] found the effect of improving energy efficiency on emissions reduction is more effective and less costly than developing new energy sources in the short to middle run. Chang et al. [17] found that the optimization of the energy demand structure was an effective way for emissions reduction based on an empirical study for Taiwan 1984 to 2004, which includes data from three sectors with the highest carbon emissions: high-speed transportation sector, petrochemical raw materials, and steel. Tian et al. [18] further found that not only should the energy be optimized but also the energy demand structure should be optimized for meeting the target of emissions reduction, as seen from an example in Beijing. Elliott et al. [19] analyzed the relationship between urban energy intensity and transnational corporations shown in a data sample drawn from prefecture-level cities in China from 2005 to 2008, found a significant negative correlation between inflow of foreign direct investments (FDI) and urban energy intensity, which is also affected by the cities' geographical locations. Peters et al. [20] found that optimizing a country's trade model could be used to achieve emissions reduction targets. Zhang et al. [12] found most environment-related scientific innovations had positive effects on emissions reduction from their empirical study in 2000–2013. Yang et al. [21] developed transcendental logarithmic functions of production and growth to study China's energy structure and its evolution, and discovered that human capital investments, capital stock investments, and progressing fossil fuel technologies were helpful towards achieving a win-win scenario of both growth and emissions reduction. Al-Mulali et al., Sheng and Guo [22,23] found that urbanization, to a certain extent, could effectively improve the energy efficiency and thereby reduce carbon emissions.

Among their studies, researchers postulated many strategies and methods to realize reduction targets, including better energy efficiency or demand structure, more FDI, newer trade models, more environment-related innovations, and higher urbanization rates. Despite differences, certain common themes can be gleamed. For example, upgrades to the economic structure can impact emissions through affecting domestic consumption and technological progress, while investments into capital stock and human capital are major factors for economic growth [24]. Urbanization can lead to reduced energy use and emissions by improving human capital use, energy consumption structure, and energy efficiency [25,26]. It is also widely recognized that innovative activities are inseparable from human capital and capital stock, which include environment-related innovations [27,28]. At the same time, practical results from OECD countries have shown that technological improvements and optimization of the energy structure and economic structure are crucial to achieving reduction goals [29–31]. Based on existing research, we encapsulate the elements of reduction policies into five main factors: energy structure, economic structure, human capital, capital stock, and potential energy efficiency, and consider all reduction policies and measures to be the optimization of one or more factors [32–36].

In existing studies, investigators have discussed various pathways for increasing energy efficiency, such as optimizing its energy demand structure, attracting FDI, improving its trade model, encouraging environment-related innovations, and furthering urbanization etc. [18–23]. On the one hand, the previous researches' conclusions of carbon intensity emissions reduction give us a theoretical guidance to consider the factors achieving emissions reduction goals, on the other hand, none of the factors affecting the achievement of emissions reduction targets is independent. For example, the improvement of energy may not be independent, it works with others factors, like economic structure, human capital, capital stock, and potential energy efficiency. System analysis method is the key to formulating the scientific emissions reduction pathway. China is the largest developing country and also the largest emissions contributor; therefore, it plays an important role in world development and mitigation. At the same time, the energy structure, economic structure, human capital, capital stock, and potential energy efficiency in China are very different from that in other countries. However, there is a lack of systematic analysis on assessing multiple pathways for carbon emissions reduction. Throughout the existing studies, we have found that research on emissions reduction pathways was either based on the theoretical exploration of single factor scenarios or multi-situation simulations in other countries. How to design and assess its transition pathways to emissions reduction has caught attention from both researchers and policymakers. Any reduction policies should be rooted in the socioeconomics of a region, and reduction measures proven effective elsewhere may not be compatible with the Chinese reality.

In this paper, we set out to build upon previous work, and aim to address the following questions: (1) Can the goal of emissions reduction be achieved through a single-factor pathway? (2) If single-factor pathways cannot meet the targets, how should we develop a multi-factor pathway? (3) How feasible it is for each multiple pathway to achieve the emissions reduction target?

The remainder of this paper is organized as follows. Section 2 will describe the research methodology, data and the parameters used for the scenario development. The parameters include energy structure, economic structure, human capital, capital stock, and potential energy efficiency; Section 3 presents the results of the study. Section 4 concludes the study and the managerial implications are also discussed.

2. Methodology, Data and Parameter Design for the Scenario Development

This section provides a basic description of the model and the source of the data. Further, we describe the parameters for setting up the scenarios in the analysis.

2.1. The Model

Energy efficiency plays an important role in energy saving and emissions reduction, and it is also closely related to industrial development, energy security, environmental protection and social welfare [37,38]. Among the previous studies, Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) were the models mainly used to measure efficiency [39–41]. Although the DEA method is convenient in evaluating energy efficiency, its production frontier is fixed (i.e., any stochastic disturbance is considered as efficient factors), and thus the result may easily be influenced by extreme values [42]. As a result, the SFA method was recommended by the majority of scholars to evaluate energy efficiency. For example, Lin and Long [41] used the SFA model to analyze energy efficiency of China's chemical industry; Chen et al. [42] used Bayesian stochastic frontier analysis for measuring efficiency of fossil-fuel electricity generation companies in China. Meanwhile, the SFA will be the key method for evaluating energy efficiency in this paper.

The SFA model of energy intensity by Stern and Jotzo was used for the analysis [43]. This model investigates how energy intensity can be changed by several parameters among 84 countries. In this study, we specify this model in one country, i.e., China. The model has the following form:

$$\begin{aligned} \ln \tfrac{E_i}{Y_i} = \quad & -\alpha_0 - \alpha_K \ln \tfrac{K_i}{Y_i} - \alpha_H \ln \tfrac{H_i}{Y_i} - \alpha_W W_i - \sum_{j=2}^{5} \beta_j e_{ji} + \sum_{k=2}^{4} \gamma_k y_{ki} + \ln u_i + \ln v_i \\ & \ln u_i \sim N^+(\Gamma z_i, \sigma_u^2), \ln v_i \sim N^+(0, \sigma_v^2) \end{aligned} \tag{1}$$

where E_i is the mean energy consumption of the country i; Y_i is average Gross Domestic Product (GDP) of the country i; K_i is average capital stock of the country i; H_i is average human capital of the country i; W_i is average winter temperature of the country i; y_{ki} is the ratio of agriculture, mining, manufacturing, or service sector in its GDP of the country i; e_{ki} is the ratio of coal, oil, natural gas, bioenergy, and primary electricity in its total energy consumption of the country i; v_i is the normally distributed random error term; u_i is potential un-efficiency term, which follows a truncated distribution with a non-negative expectation. The potential energy efficiency is also affected by a series of additional factors denoted by z_i, including total factor productivity, ratio of capital stock to land area (representing environmental damage potential in the absence of mitigating technologies), trade rate of market exchange rate to purchasing power parity, openness (ratio of export/import to GDP), corruption, energy reserve, origin of legislations, etc.

The coefficients α_K, α_H and α_W are respectively the coefficients of capital stock, human capital, and winter temperature; e_j is the ratio of coal, natural gas, primary energy, or bioenergy in energy consumption; β_j is the coefficient of energy source; y_k represents the ratio of agriculture, mining and utilities, manufacturing, or service sector in GDP; γ_k is the coefficient of sector; $\ln \nu_t$ is the measurement error. The predicted energy intensity takes the following form:

$$\hat{p}_t(\ln \frac{E}{Y}) = -\alpha_0 - \alpha_K \ln \frac{K_t}{Y_t} - \alpha_H \ln \frac{H_t}{Y_t} - \alpha_W W_t - \sum_{j=2}^{5} \beta_j e_{ji} + \sum_{k=2}^{4} \gamma_k y_{ki} + \ln v \tag{2}$$

$\ln \mu$ can be calculated by Equation (3)

$$\ln u_t = \ln \frac{E}{Y} - \hat{p}_t(\ln \frac{E}{Y}) \tag{3}$$

The potential energy efficiency in the period t is calculated by beta convergence.

The predictive value of carbon emissions in 2030 is given by the following equations.

$$\hat{p}_t(\frac{C}{Y}) = Exp[\hat{p}_t(\ln \frac{E}{Y})] \times (\frac{C}{E})_t \tag{4}$$

$$(\frac{C}{E})_t = \pi_{coal} \times e_{coal} + \pi_{oil} \times e_{oil} + \pi_{gas} \times e_{gas} \tag{5}$$

where the carbon emission coefficient is 3.693 for coal; 2.884 for oil; 2.055 for natural gas, with data from the IPCC 5th Assessment Reports [44].

In Equation (4), $\hat{p}_t(\ln \frac{E}{Y})$ has already been obtained from Equation (3), while $\hat{p}_t(\frac{C}{Y})$ refers to the carbon emission per unit energy in period t, and Equation (5) shows its solution. To ensure accuracy, we use 2013 as the base period to revise $\hat{p}_t(\ln \frac{E}{Y})$ in the period t by the following:

$$\hat{\hat{p}}_t(\frac{C}{Y}) = \hat{p}_t(\frac{C}{Y}) \times (\frac{C}{Y})_{2013} / \hat{p}_{2013}(\frac{C}{Y}) \tag{6}$$

where $(\frac{C}{Y})_{2013}$ is calculated as the ratio of the real carbon emissions to GDP of 2013, with data from EIA [45].

2.2. The Data

The required data and their various sources are presented in Table 1.

Table 1. Data source.

Data	Source
Energy structure	All energy data is from the IEA database [46]. Data was collected on the use of oil, natural gas, coal and peat, primary electricity and biomass.
Economic structure	These variables of economic structure are from World Development Indicators [47].
Capital stock	The real investment series in the Penn World Table, version 9.0 [48].
Carbon emission	Data for CO_2 emissions from fossil fuel combustion are from the International Energy Agency, IEA [46].
Temperature	The average winter temperature only, temperature data gridded by country as derived by Mitchell et al. [49].
Human capital	Data for number of workers from Penn World Table, version 9.0. [48]; Data of average number of years in education as derived by Barro and Lee [50].

It can be noted that the national GDP is used for analyzing the economic structure. In this study, we define that the national GDP is a sum of outputs from the agriculture sector, mining & utilities sector, manufacturing sector and services sector. We collected data for the agriculture sector, manufacturing sector and service sector from World Development Indicators. Afterwards, we computed the output for mining & utilities sector. The unit for GDP is in millions of USD. Using the perpetual inventory equation to measure the Capital stock measure, a detailed process follows Stern and Jotzo [43]. We used the average winter temperature as the temperature data, given a default value of -5.8 °C each year. The human capital is computed by Equations (7) and (8). According to Caselli and Jones' suggestions [51,52], we assume $\theta = 0.07$, *workers* denoting the number of workers, and s denoting their average number of years in education. The former comes from Penn World Table, version 9.0, and the latter from Barro and Lee's database [50]. The human capital factor is calculated by the following:

$$Human\ capital\ h = Exp(\theta s) \tag{7}$$

$$Total\ human\ capital\ H = Total\ workers\ \times\ h \tag{8}$$

2.3. Parameter Design and the Scenario Development

China has submitted their emissions reduction contribution plans to the United Nations Framework Convention on Climate Change, yet the feasibilities of the Chinese targets are not fully known. As China is the largest contributor of carbon emission, the realization of its target is important for the world. In this study, we calculate China's carbon intensity reduction from the five dimensions of energy structure, economic structure, human capital, capital stock, and potential energy efficiency. The CPS, NPS, and 450S scenarios are used for energy structure; the LEC and HEC scenarios for economic structure; the Kruger and HC14 scenarios for human capital; the EIU and HCS scenarios for capital stock; and the β-USA, U4, U5, and U6 scenarios for potential energy efficiency.

2.3.1. Energy Structure

IEA had modeled energy consumption structure in China under the settings of current policies, new policies, and average atmospheric CO_2 at 450 ppm, denoted as CPS, NPS, and 450S [32], presented in Table 2.

Table 2. Scenario settings.

Energy Structure	Coal	Oil	Gas	Electricly	Biomass
CPS	57.66%	17.73%	8.78%	10.40%	5.43%
NPS	53.99%	17.80%	9.74%	12.39%	6.08%
450S	45.51%	16.88%	10.74%	18.55%	8.32%

Data source: CPS, NPS, 450S from IEA: "World Energy Outlook 2014"; 70PP and 73PP from the IEA [32].

It appears that changes to energy structure alone can make a significant contribution. Table 3 shows how the growth rates of various energy indicators will change following energy structure adjustments (without other changes).

Table 3. Changes of energy index growth rate under various energy scenarios.

Energy Indexes	2009–2014	2014–2030		
		CPS	NPS	450S
Total Energy	4.84%	3.20%	3.20%	3.20%
Fossil	4.19%	2.86%	2.66%	1.96%
Non-fossil	10.99%	5.40%	6.42%	8.94%
Coal	3.02%	2.37%	1.95%	0.87%
Oil	6.09%	3.32%	3.35%	3.00%
Gas	15.59%	6.02%	6.72%	7.37%

It can be seen that under these three scenarios, the most prominent changes happen to the growth rates of fossil fuel. A more aggressive energy structure change can lead to a lower growth rate. Under these three scenarios, China needs to reduce the growth rate for coal consumption from current 3.02% to a rate between 0.87% and 2.37%. Besides, the growth rate for oil and natural gas consumption should also be reduced to half of the current level.

2.3.2. Economic Structure

We base our low economy scenario (LEC) on the predictive results of the CGEDRC model by Hu et al. [53,54], and our high economy scenario (HEC) on the LEC and HEC scenarios provided by Li and Lou [55], presented in Table 4.

Table 4. Economic structure Scenario settings.

Economy Structure	Agriculture	Mining & Utilities	Manufacturing	Services
LEC	3.20%	13.62%	31.78%	51.40%
HEC	3.10%	11.58%	27.02%	58.30%

Data source: LEC reference Li Shantong, He Jianwu CGEDRC Model Prediction Results: LEC reference to Li Ping and other CN3ET-DCGE model prediction results. Among them, secondary is allocated to mining & utilities and manufacturing according to the proportion of about 3:7, which refer to the 2014 economic structure.

Under the two scenarios, the growth rates of economic indicators in China are listed as Table 4 shows. Huenemann [56] pointed out that the growth rate of China's economy has been slowing down in recently years. As can be seen in Table 5, under the LEC scenario the growth rate of each economic structure component continues to decrease, with the largest drop taking place in agriculture (from the current 6.36 to −0.62%), while the changes to the second sector are smaller, and the service sector drops from 9.67 to 6.53%. Under the HEC scenario, the non-service sector shows a remarkable drop from the present 6.62 to 4.24%, while the service sector's growth rate has a slightly less steep drop compared to LEC. Since carbon emissions largely originate from non-service sectors, the more impactful economic scenario has a stronger reduction result.

Table 5. Growth of economic indicators under various economic scenarios.

Economy Indexes	2009–2014	LEC	HEC
		2014–2030	**2014–2030**
Total Economy	8.02%	6.05%	6.05%
Agriculture	6.36%	−0.62%	5.07%
Mining & Utilities	6.51%	6.18%	3.84%
Manufacture	6.75%	6.49%	4.15%
Service	9.67%	6.53%	7.61%
No-service	6.62%	5.59%	4.24%

2.3.3. Human Capital

Human capital is described by the number of workers and their years of education, which can also partially reflect technological changes. We incorporate predictions on human capital by Bailliu et al. [57], and use Equation (9) below to determine the status of human capital in China by 2030, which will be denoted by the Kruger scenario. This is compared to the HC14 scenario, under which human capital continues to grow at the same rate as 2014 (0.74%). Kruger serves as the more realistic scenario, while HC14 (maintaining the 2014 growth level) simulates the ideal scenario. Kruger assumes an annual human capital growth rate of 1%, and HC14 assumes the 2014 rate of 1.47% can be maintained, just as Figure 1 shows. It can be seen that the HC14 scenario grows faster and more aggressively than Kruger, while the latter predicts steadier growth.

$$Human\ capital = Exp(\theta s) \times N \quad (9)$$

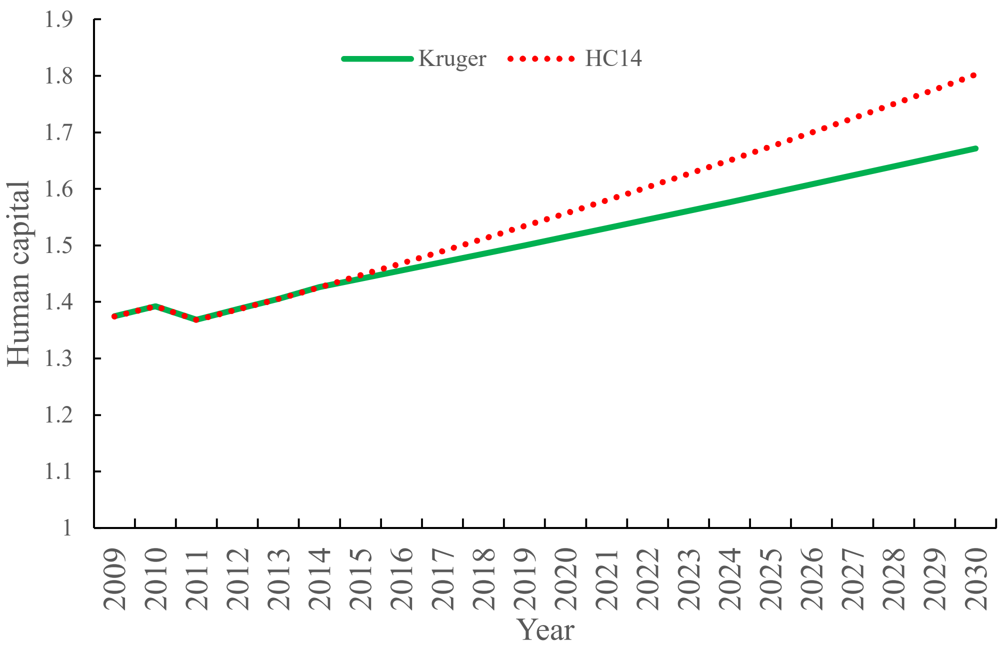

Figure 1. Forecast of human capital. Sources: Data on workers are from Penn World Table, version 9.0 [48]. Average schooling of the population over the age of 15 from Barro and Lee's (2001) database [50].

In Equation (1), N is the number of workers, S is the average years of education, the parameter θ is assumed to be 0.07. According to Kruger, the number of workers will be reduced by 7% in 2030 compared to 2010, and the average years of education will have increased by 11.9 years.

2.3.4. Capital Stock

Variations of investments are included under the capital stock dimension. Investment changes have strong effects on both energy consumption and total productivity. We incorporate the EIU database's predictions on capital stock in China, designated in the EIU scenario, and compare it with the assumption that capital stock has a growth rate based on 2014, except dropping one percent every 3 years, denoted in the HCS scenario.

It can be seen that from 2009 to 2014, the growth of capital stock is relatively stable in China. Assuming the 2014 growth can be maintained, the following predictions can be made. The EIU scenario is less steep and more likely to be achieved, while the HCS scenario is simpler and more aggressive, just as Figure 2 shows. China experienced a capital stock growth rate of 12.47% during 2009–2014, while the EIU scenario forecasts an annual growth of 7.07% in the 2014–2030 period, which is steady enough to appear true to the present Chinese economy. The HCS scenario assumes the growth rate is lowered by one percent every 3 years starting from 2014's 10.63%.

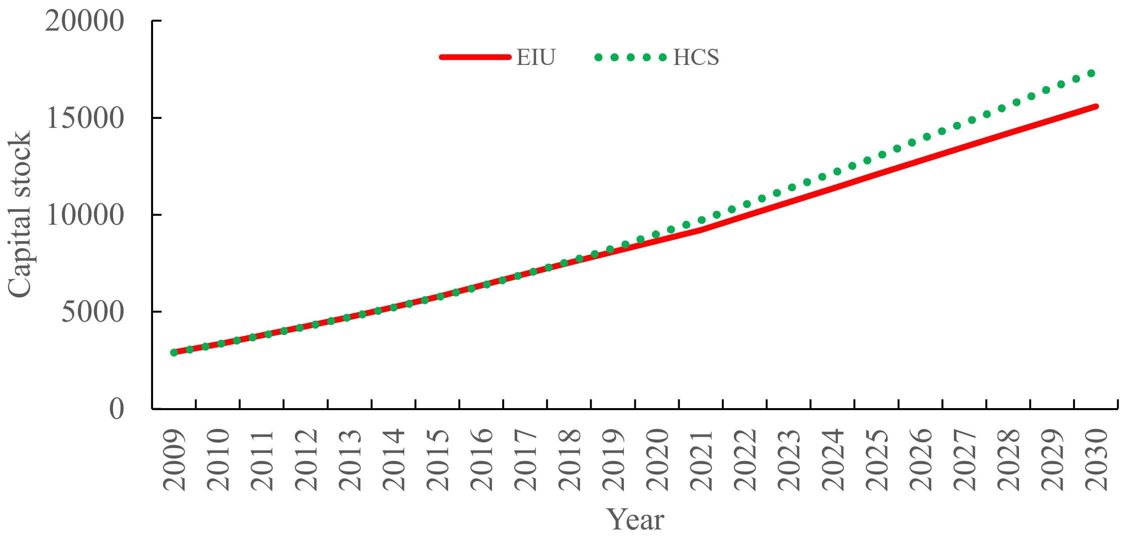

Figure 2. Forecast of capital stock.

2.3.5. Potential Energy Efficiency

We define potential energy efficiency as the logarithm of the ratio of predicted energy intensity to real energy intensity (*lnu*, see equations in above sections). This prediction is founded on the presumption that China's potential energy efficiency can be described by a beta-convergence towards that of the USA. This is the β-USA scenario.

Following Stern [58], we assume $\ln \hat{\mu}_{it}$ conforms to the beta-convergence equation below

$$\Delta(\ln \widetilde{u}_{CNt} - \ln \widetilde{u}_{USAt}) = -\beta_i(\ln \widetilde{u}_{CNt-1} - \ln \widetilde{u}_{USAt-1}) + \varepsilon_{it} \quad (10)$$

The following illustrates β-USA, in which China's potential energy efficiency converges towards the USA, the largest economy and technological leader in the world. In this study, u is negatively correlated to the speed of technological progress. We have found China to have a u change rate of -4% in the 2009–2014 period. The U4 scenario assumes this rate is maintained. The U5 and U6 scenarios respectively assume change rates that are even steeper by 1% and 2%, presented in Figure 3.

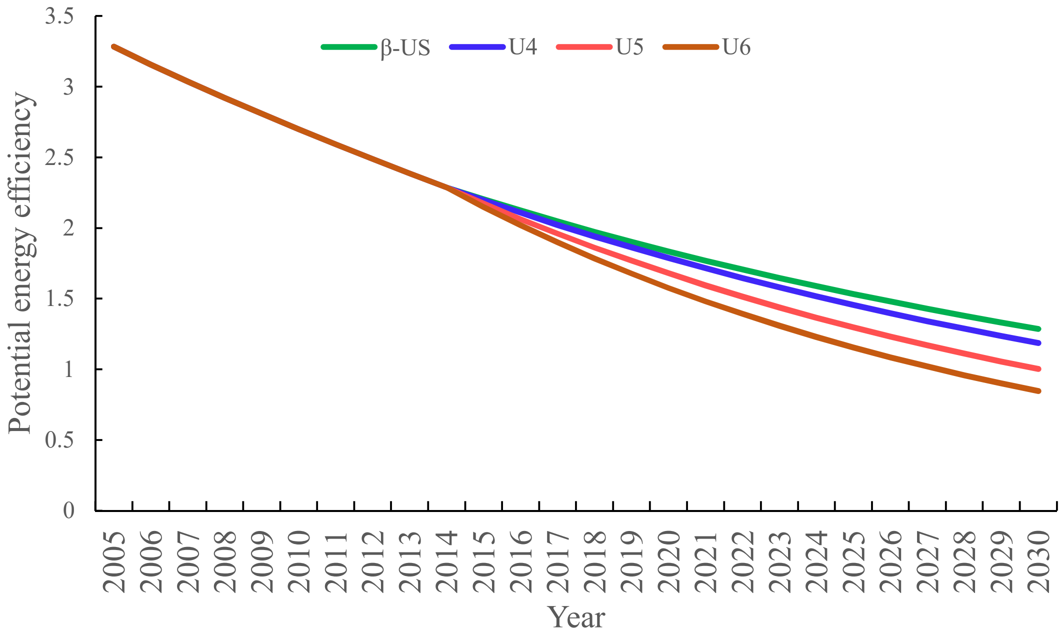

Figure 3. Forecast of potential energy efficiency.

To better illustrate growth rates, we choose $1/u$ as the growth rate indicator for energy efficiency, presented in Table 6. It represents the ratio of GDP produced by unit energy consumption in China to the world, and it having a higher growth rate means faster progress in energy efficiency. From 2009 to 2014, China experienced a potential energy efficiency growth rate of 4.19%, which is similar to the result of beta-convergence. However, under the U5 and U6 scenario, the $1/u$ value must be higher by an additional 1.1–2.2 percent.

Table 6. The change of energy efficiency index under each situation.

	2009–2014	2014–2030			
1/u	4.19%	β-US	U4	U5	U6
		3.66%	4.19%	5.29%	6.41%

From the five dimensions laid out above, we obtain $3 \times 2 \times 2 \times 2 \times 4 = 96$ policy combinations to forecast how well China performs in hitting its 2030 targets. We found that the results only 24 of the 96 scenarios are close to China's carbon intensity reduction targets. Thus, the table only shows the 24 combination scenarios and 4 basic scenario combinations, the total combination scenarios are 28.

3. Results

Based on parameter design and the scenario development in Section 2.3, we can predict the carbon intensity reduction effects of China under the BAU scenario, single factor adjustment scenarios, and multi-factors combination scenarios, by 2030. Comparing the effects of emission reduction under different scenarios, the design of scientific emission reduction pathways will be given.

3.1. The BAU (Business As Usual) Combination

First, we assume that China does not take any measure to change its energy structure, meaning that no new policy on energy structure will be made. Its energy structure is assumed CPS, economic structure is assumed LEC, human capital is assumed Kruger, and capital stock is assumed EIU, all of which continue with the normal economic trajectory with external economic impacts not accounted for. Its potential energy efficiency is assumed to follow the β-USA scenario.

Under BAU, by 2030, China's carbon intensity will be lowered by 32.43% compared to 2005, remarkably less than the 60–65% target in the INDC report. The results in each dimension can be seen below.

3.2. Combinations with Single-Factor Adjustments

The BAU combination only leads to a 32.43% reduction, which means an additional 27.57% contribution is needed to reach the 60% in 2030 target. With BAU as a baseline, we can first analyze how single-factor adjustments contribute to reduction, see Table 7 for details.

Table 7. Analysis of contribution degree under various situations.

Scenario	Contribution
NPS	2.31%
450S	8.40%
HEC	5.98%
HC14	2.93%
HCS	2.12%
U4	5.30%
U5	14.91%
U6	23.11%

With only energy structure adjustments, imposing the NPS and 450S conditions, respectively, carbon intensity is reduced further by 2.31% and 8.4%. That is to say, at most a reduction of 8.4% is achievable by changing energy structure alone.

If we only adjust economic structure, the HEC condition can further decrease carbon intensity by 5.98%, which is considerable.

By only taking human capital into consideration, by imposing the HC14 condition, the combination has a total reduction of 35.36%, meaning HC14 only contributes 2.93%. The effect of human capital seems limited.

Only from the adjustment of capital stock, the combination has a total reduction of 34.55%. The capital stock contribution is only 2.12%.

Considering the adjustments of potential energy efficiency only by imposing the U4, U5 and U6 conditions, respective reductions of 37.72%, 47.33% and 55.54% can be achieved. The contribution is 5.3% from U4, 14.91% from U5, and 23.11% from U6. The target is still unachievable, but potential energy efficiency obviously can make the greatest contribution.

In summary, the potential energy efficiency condition U6 has the highest contribution at 23.11%; the capital stock condition HCS has the lowest at 2.12%. It can be seen that the target cannot be achieved by policy adjustments to any single one of the five factors.

3.3. Multi-Factor Adjustments

Having shown any single factor cannot help reach the goal alone, the 28 combinations are then analyzed and categorized as Table 8 presents.

Table 8. Combinations with single-factor adjustments.

Scenario Combinations	Energy Structure	Economy Structure	Human Capital	Capital Stock	Energy Efficiency	Reduced Intensity	Contribution
Baseline energy structure + steady economic structure + baseline efficiency							
1	CPS	LEC	Kruger	EIU	β-USA	32.43%	0
2	CPS	LEC	HC14	EIU	β-USA	35.36%	2.93%
3	CPS	LEC	Kruger	HCS	β-USA	34.55%	2.12%
4	CPS	LEC	HC14	HCS	β-USA	37.39%	4.96%
Steady energy structure + steady economic structure + very aggressive efficiency							
5	NPS	LEC	Kruger	EIU	U6	57.06%	24.63%
6	NPS	LEC	HC14	EIU	U6	58.92%	26.50%
7	NPS	LEC	Kruger	HCS	U6	58.41%	25.98%
8	NPS	LEC	HC14	HCS	U6	60.21%	27.79%
Steady energy structure + steady economic structure + very aggressive efficiency							
9	450S	LEC	Kruger	EIU	U6	61.06%	28.64%
10	450S	LEC	HC14	EIU	U6	62.75%	30.33%
11	450S	LEC	Kruger	HCS	U6	62.28%	29.86%
12	450S	LEC	HC14	HCS	U6	63.92%	31.50%
Aggressive energy structure + aggressive economic structure + aggressive efficiency							
13	450S	HEC	Kruger	EIU	U5	57.96%	25.54%
14	450S	HEC	HC14	EIU	U5	59.79%	27.36%
15	450S	HEC	Kruger	HCS	U5	59.28%	26.86%
16	450S	HEC	HC14	HCS	U5	61.05%	28.62%
Baseline energy structure + aggressive economic structure + very aggressive efficiency							
17	CPS	HEC	Kruger	EIU	U6	59.48%	27.05%
18	CPS	HEC	HC14	EIU	U6	61.24%	28.81%
19	CPS	HEC	Kruger	HCS	U6	60.75%	28.32%
20	CPS	HEC	HC14	HCS	U6	62.45%	30.03%
Steady energy structure + aggressive economic structure + very aggressive efficiency							
21	NPS	HEC	Kruger	EIU	U6	60.86%	28.44%
22	NPS	HEC	HC14	EIU	U6	62.56%	30.14%
23	NPS	HEC	Kruger	HCS	U6	62.09%	29.66%
24	NPS	HEC	HC14	HCS	U6	63.74%	31.31%
Aggressive energy structure + aggressive economic structure + very aggressive efficiency							
25	450S	HEC	Kruger	EIU	U6	64.51%	32.09%
26	450S	HEC	HC14	EIU	U6	66.05%	33.63%
27	450S	HEC	Kruger	HCS	U6	65.62%	33.20%
28	450S	HEC	HC14	HCS	U6	67.12%	34.69%

Notes: According to the scenarios setting method, it was found that only 24 of the 96 scenarios are close to China's carbon intensity reduction targets. Thus, the table only shows the 24 combination scenarios and 4 basic scenario combinations, the total combination scenarios are 28.

Under energy structure, CPS is considered the baseline scenario, NPS the steady scenario, and 450S the aggressive scenario. Under economic structure, HEC is considered the aggressive scenario, LEC the steady scenario. Under potential energy efficiency, β-USA is considered the baseline scenario, U4 the steady scenario, U5 the aggressive scenario, and U6 the very aggressive scenario. The baseline and target-achieving combinations are analyzed in the following sections, as Table 8 shows.

As Scenario combinations 1–4 shows, there are four policy combinations for baseline energy structure and efficiency with steady economic policies, achieving reductions between 32.43% and 37.39%. Combination 1 has the lowest contribution at 32.43%, which is the baseline one where the two remaining factors contribute zero. Combination 4 adds 4.96% to achieve a 37.39% reduction, i.e., given other conditions, the most aggressive human capital and capital stock policies have a total contribution of 4.96%.

As Scenario combinations 5–8 shows, with steady energy and economic structures, and very aggressive efficiency policies, the reduction is between 57.06% and 60.21%. Combination 8 achieves a reduction of 60.21%, which reaches the target. In this case, given other conditions, the combination of NPS, U6, HC14, HCS contributes 27.79%. To follow this path means China must make steady adjustments to energy structure and maintain an energy efficiency improvement rate 2% higher than the world.

As Scenario combinations 9–12 shows, by combining aggressive energy structure, steady economic structure, and very aggressive energy efficiency policies, China can reach carbon intensity reductions between 61.06% and 63.92%. Actually achieving these changes would be a great challenge to China's energy policies and efficiency-related technologies.

As Scenario combinations 13–15 shows, by carrying out aggressive policies in three dimensions, reductions between 57.96% and 61.05% can be achieved. Combination 16 hits the target by causing a 61.05% reduction, in which the conditions of 450S, U5, HC14 and HCS will contribute 28.62%. This path requires China to make aggressive changes to its energy structure and efficiency and general economic structure, raising the ratio of non-fossil energy sources, expanding the service sector further than the steady scenario, and realizing an efficiency improvement rate 1% ahead of the world.

As Scenario combinations 16–20 shows, with this set, reductions between 59.48% and 62.45% can be achieved. Here the combinations 18, 19 and 20 can realize the target. Given the conditions, HEC, U6, HC14 and HCS achieve a contribution of 30.03%. This path involves no change to energy structure, aggressive economic changes, improving energy efficiency at a rate 2% faster than the world, and potentially a faster increase of the service sector ratio.

As Scenario combinations 21–24 shows, this set leads to reductions between 60.86% and 63.74%. All four combinations hit the target, and NPS, HEC, U6, HC14, and HCS combination has a total contribution of 31.33%. Following this path means only making steady changes to energy structure, while aggressively changing the economic structure, and making even faster progress in efficiency. Compared to the previous one, this set has similar economic structure and efficiency requirements, yet ramps up the energy structure change, making it less optimal.

As Scenario combinations 25–28 shows, this set leads to reductions between 64.51% and 67.12%. All four combinations hit the target, and the 450S, HEC, U6, HC14, and HCS combination contributes 34.69%. Again, this requires even greater changes to the energy structure in addition to other aggressive policies, which is suboptimal.

4. Conclusions and Discussion

China is currently the world's largest energy consumer and contributor for global carbon emission. China has repeatedly stated its willingness to take the responsibility in fighting global climate change, and to also set up clear targets for emissions reduction. As China's industrialization is still progressing, carefully designed policies are essential to mitigate the economic impact of carbon control. We used multiple policy pathways to simulate the outcomes of emissions reduction. The five factors are energy structure, economic structure, human capital, capital stock, and potential energy efficiency.

By applying the stochastic frontier analysis of energy efficiency for the 96 scenarios of policy combinations, we can find the better pathways for achieving the emissions reduction target for China. The results of the stochastic frontier analysis shows that (1) it is unlikely to reach the 2030 intensity reduction target of 60% by only optimizing a single factor; potential energy efficiency U6, the most effective scenario, still only contributes 23.11%, while the lowest, capital stock HCS only contributes 2.12%; (2) the analysis of multiple-factor pathways show that effective scenarios usually require a very aggressive energy efficiency policy (meaning they have to have 2% higher energy efficiency than the global level), which can be a challenge for China in its middle and later stage of industrialization; (3) if China only adopts an aggressive energy efficiency policy, in order to achieve emission reduction targets, it requires that the proportion of fossil fuels be less than 80% in the energy structure, and the average growth rate of fossil fuels be reduced by about 2.2%; in terms of economic structure, the proportion of the service sectors should reach to 60.4% or more, and the average growth rate of non-sectors should be reduced by 2.4%; in terms of human capital, China is required to maintain at least the growth rate in 2014; the growth rate of the capital stock should follow the current economic development trend and be reduced moderately. Overall, the combination of factors is needed for China to achieve its target, and policy adjustments must be made in its energy structure, economic structure, human capital, capital stock, and efficiency.

4.1. Specific Recommendations

The results also have several specific recommendations for carbon reduction policy makers.

Firstly, energy efficiency must be constantly improved. From the results of the study, it can be seen that energy efficiency is the biggest contributor to emission reduction targets. Thus, policymakers should try to improve regional energy efficiency as much as possible, including relying on technology innovation and proper market-based mitigation mechanisms.

Secondly, the upgrading of China's industrial structure must be accelerated. Apparently, this goal cannot be achieved by expanding the service sector alone. Instead, policymakers must also encourage the second sector to transform from labor-intensive manufacturing to knowledge-intensive high technologies and equipment manufacturing, ensuring their quality increase at a pace appropriate for their scales.

Thirdly, emissions reduction must be done at the root of energy sources. Presently, China possesses rich coal deposits, is more export-reliant on oil and natural gas, and faces several bottlenecks in growing its renewable energy sources. Any energy policy must be founded on this resource basis and devised with long term considerations. In addition to transforming the energy structure, China has to ensure its energy security and must respond to climate changes. Therefore it is advisable to concentrate efforts on clean low-carbon energy, and develop both non-fossil sources as well as methods to utilize fossil energy more cleanly and efficiently.

Fourthly, to ease the carbon emissions constraints of further growth, it is necessary to increase investment in human capital so as to cultivate and accumulate the human capital stock of the low-carbon economy. The main methods include: increased investment in basic education; vocational education; technical training and raising the overall levels of education; clarifying responsibilities of governments, enterprises and individual; establishing multi-level input mechanisms; strengthening investment in knowledge and skills training for workers.

Finally, capital stock needs enough room to grow before they can support emissions reduction. China needs policies that ensure the sustained and steady growth of investment in domestic capital stock, including focus on the investment in the transformation and upgrading of traditional equipment, accelerating the speed of closure backward production capacity.

There are the same limitations in this article. First, in our study, the factors taken into consideration included energy structure, economic structure, human capital, capital stock, and energy efficiency; some others factor maybe neglected. For a broad analysis, some factors that may affect emissions reductions should also be included in the scenario setting, including urbanization rate, R&D investment, etc. Second, the scenario setting needs to be further updated. More recently, IEA released 2 Degree Scenarios (2DS) and Beyond 2 Degree Scenarios (B2DS) in the Energy Technology Perspectives reports. Future research should be based on the most recently available scenarios to further analysis. Third, the SFA model used in this study assumed that the random error term obeys normal distribution. In future, our study will be based on the hypothesis that the random error term obeys half-norm distribution and truncated normal distribution, respectively.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used Y L. conceived and designed the work; M.Y.W. conducted the analysis; Y.W.L. drafted the paper; S.X.Y. and M.Y.W. polished the manuscript; L.Y.Y. collected the data for analysis.

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