INTRODUCTION

Many studies have indicated that economic development results from an increase in energy consumption.\textsuperscript{1–3} However, overuse of energy, especially from fossil fuels, releases a lot of carbon dioxide, a greenhouse gas, causing further environmental pollution and climate change. In other words, to accelerate economic growth, economies risk growth of gross domestic product (GDP) at the cost of increased CO\textsubscript{2} emissions.\textsuperscript{1,5} Reducing CO\textsubscript{2} emissions will also affect GDP growth, so it is necessary to investigate the balance in this trade-off.

In order to have sustainable development, economies have to keep a certain degree of energy consumption; therefore, a growing body of research has focused on improving energy efficiency. Energy efficiency reflects whether energy has been used efficiently.\textsuperscript{6–8} The methods to estimate energy efficiency can be roughly divided into two groups: cross-sectional and dynamic models. Dynamic models are more recent and have received more attention from researchers.\textsuperscript{9–11} This is primarily due to the fact that economic growth is a dynamic process and thus requires the dynamic analysis of energy efficiency. Dynamic analysis can avoid the potential bias that cross-sectional analysis may introduce due to the first moment of cross-sectional data.\textsuperscript{12–14}

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efficiency are generally classified as parametric and non-parametric.\textsuperscript{9} Parametric methods such as stochastic frontier analysis (SFA) estimate a production (cost) function, and deviations in the function form affect the results of such models. In contrast, it is not necessary to estimate the production (cost) function when using nonparametric methods, such as data envelopment analysis (DEA). Relative to SFA, DEA is more popular for investigating energy efficiency because it can easily consider undesirable outputs.\textsuperscript{10,11}

The DEA analytical framework uses mathematical programming models to compute the distance between each decision-making unit (DMU) and the best practice frontier constructed by the DMUs, based upon which the DMU efficiency scores can be calculated. With its methodological advancements, DEA has also received increasing attention in energy and environmental studies,\textsuperscript{12–18} in which energy efficiency measurement has been identified as an important application.\textsuperscript{17} Earlier studies dealing with this topic include Boyd and Pang\textsuperscript{19} and Ramanathan.\textsuperscript{20} Later, Hu and Wang developed a total-factor energy efficiency index and applied it to evaluate China’s regional energy efficiency. Wei et al\textsuperscript{21} conducted an empirical analysis of energy efficiency in the iron and steel sector in China by using the Malmquist index. Honma and Hu employed the total-factor energy efficiency model to evaluate regional energy efficiency in Japan. Zhang et al\textsuperscript{22} used DEA window analysis to investigate dynamic trends in the total-factor energy efficiency of a sample of developing economies. In addition to evaluating regional energy efficiency, Mukherjee\textsuperscript{25,26} employed DEA to assess manufacturing energy use efficiency in the United States and India.

A common feature of the above studies is that they evaluated energy efficiency ignoring undesirable outputs. However, fossil fuel–based energy use will inevitably produce undesirable outputs, such as CO\textsubscript{2} emissions.\textsuperscript{27} Zhou and Ang\textsuperscript{28} first developed several DEA models for evaluating energy efficiency based on environmental DEA technologies by incorporating undesirable outputs. Since then, more and more studies have focused on analyzing energy efficiency with both desirable and undesirable outputs. The more attention in energy efficiency is about the relationship in energy usage, economic growth, and environmental pollution, such as Wang and Feng.\textsuperscript{29} Some scholars, such as Sueyoshi and Goto,\textsuperscript{4} Dogan and Tugec,\textsuperscript{30} and Asayesh and Raad,\textsuperscript{31} use region or industries to evaluate energy efficiency. For instance, Mandal\textsuperscript{32} applied DEA to estimate the energy efficiency of the Indian cement industry, and indicated that biased energy efficiency scores resulted from neglecting undesirable outputs. Shi et al\textsuperscript{6} extended the DEA model by treating undesirable outputs as inputs to evaluate industrial energy efficiency in China. Yeh et al\textsuperscript{33} compared the total-factor energy efficiency between China and Taiwan by using DEA with undesirable outputs based on data translation. Some studies regard the CO\textsubscript{2}, SO\textsubscript{2}, etc. as the undesirable output to estimate its impact on energy efficiency.\textsuperscript{5,34–36} Also, some studies apply the directional distance function introduced by Chung et al\textsuperscript{37} to explore the impact of undesirable output on energy efficiency, such as Färe et al,\textsuperscript{18} Aparicio et al.\textsuperscript{38}

However, as dynamic DEA model introduced by Färe and Grosskopf,\textsuperscript{39} more studies have been widely applied and extended this dynamic DEA model in many fields.\textsuperscript{40–46} Sengupta\textsuperscript{47} proposed the dynamic DEA model to analyze risk and output fluctuation on the dynamic production frontier by using the adjustment cost method, including the shadow value of quasi-fixed input and its optimal path in the analysis of linear programming. Färe et al\textsuperscript{18} introduced several kinds of intertemporal variables into realistic multi-output production processes across periods. Dynamic DEA has been widely applied and extended in many fields.\textsuperscript{40–46} Tone and Tsutsui\textsuperscript{48} applied the slack-based model to measure overall efficiency and period efficiency considering carryovers as the link between two periods. Jafarian-Moghaddam and Ghoseiri\textsuperscript{39} developed a fuzzy dynamic multi-objective DEA model to assess the performance of railways. Soleimani-damaneh\textsuperscript{50} provided a new technique to gain an algorithm with computational advantages, using dynamic DEA models to estimate returns to scale. Sueyoshi and Sekianti\textsuperscript{42} dealt with dynamic DEA to assess the environmental performance of US coal-fired power plants during 1995-2007 and found that it is necessary for the United States to extend the scope of the Clean Air Act (CAA) to control the amount of CO\textsubscript{2} emissions.

Although there are many papers and a lot of research focusing on energy and environmental efficiencies such as CO\textsubscript{2} emissions and hazardous wastes,\textsuperscript{16,17,51–55} one limitation of these papers and research is that they evaluated undesirable output (e.g., CO\textsubscript{2}) efficiency within cross-sectional data and not over time, or only consider the dynamic efficiency analysis and ignore the slacks. Furthermore, according to International Energy Agency,\textsuperscript{56} energy demand is increasingly going to be exploited due to the growth in population and income. It is expected that in 2035, the world’s population will be 8.7 billion, GDP will increase more than 100%, and CO\textsubscript{2} emissions produced by energy will increase to 34.8 billion tons.\textsuperscript{57} Ravallion et al\textsuperscript{58} indicate that CO\textsubscript{2} emissions are affected by income distribution, because high-income economies tend to consume more fossil fuels than low-income economies. Therefore, in the case of the distribution of income in different economies, CO\textsubscript{2} emissions derived from energy consumption are different. Furthermore, based on Table 1, from 2010 to 2014, the CO\textsubscript{2} emissions share of high-income economies (including China) was 82.75%, 82.12%, 81.64%, 81.39%, and 80.94% (according to standard income levels from the World Bank in 2016; USD 12 235 per person per year). The reason we include China is that it will be very important in world economic development in the future. Therefore, it is a significant and important issue to investigate energy consumption in high-income economies.

Therefore, this study applies the dynamic slack-based measure DEA model by combining the SBM model and dynamic DEA model to explore energy efficiency of the research object by year and overall energy efficiency by using high-income economies (including China) from 2010
to 2014, and compares the results between static SBM and DSBM models. Moreover, this research follows Seiford and Zhu\textsuperscript{49} to promote CO\textsubscript{2} as an undesirable output and considers real GDP as a variable of carryover in the dynamic models\textsuperscript{48} to give some suggestions for energy policies. The method in the literature for processing efficiency generates overestimated scores when the dynamic essence is ignored. This shows a dynamic analysis whenever data are available. The data can be decomposed into efficiency variance elements, and the variance can be solved. We find that there exists a difference in the results depending on whether GDP is considered as the carryover variable. European economies are more efficient in energy consumption than others, and Asian economies are the most inefficient.

The following study, organized in Section 2, shows the dynamic DEA model. Section 3 presents the results and a discussion of the results. Section 4 offers conclusions and policy implications.

### 2 | METHODS

DEA is a means of measuring the relative efficiency of a set of decision-making units (DMUs) that apply multiple inputs to produce multiple outputs for a given time period. There are some methods for measuring efficiency deviations over time, for example, window analysis and the Malmquist index.\textsuperscript{60} Window analysis was proposed by Klopp,\textsuperscript{61} while the Malmquist index was established by Färe et al.\textsuperscript{62} Even if these models can take into account the time change effect, they usually ignore carryover activities between 2 consecutive terms and only focus on separate time periods independently, training local optimization in a single period. In the real business world, long-term planning and investment is a subject of great distress for business growth. The dynamic DEA model proposed by Färe and Grosskopf\textsuperscript{39} is the first innovative contribution for such a purpose. They introduced the dynamic aspects of production into the conventional DEA model when multiple outputs are involved. They formulated several intertemporal models, which became the origin for many later studies on dynamic DEA. Later, Chen,\textsuperscript{63} Nemoto and Goto,\textsuperscript{64} and Chang et al\textsuperscript{65} developed dynamic DEA, and Tone and Tsutsui\textsuperscript{48} assimilated SBM into dynamic DEA.

The causing model is nonoriented and it can process inputs and outputs individually. This means that the model is proper for nonuniformly distributed inputs and outputs and different weights can be assigned to the inputs and outputs depending on their degree of position. Tone and Tsutsui divided carryovers into 4 types to analyze the foundation of dynamic DEA models: (a) desirable (good), (b) undesirable (bad), (c) discretionary (free), and (d) nondiscretionary (fixed). The DEA model variables can be divided into 3 categories: input, output, and nonoriented. SBM can be used to identify the optimum solution.

Additionally, according to the characteristics of carryovers, we classify real GDP into desirable carryovers resembling profit carried forward to the next term. The main idea of this study is that governments in all economies must consider reducing CO\textsubscript{2} emissions in the process of economic growth. Therefore, GDP performance in this period will have an influence on the efficiency of the next period. We used dynamic SBM models, which can evaluate the overall efficiency of DMUs for whole terms as well as term efficiencies. For these cases, a single period optimization model does not fit for performance evaluation. To cope with a long-term point of view, the dynamic DEA model incorporates carryover activities into the model and supports measurement of period-specific efficiency based on long-term optimization during the whole period. The calculations of the system and period efficiencies under dynamic conditions are demonstrated. One important finding is that the method for calculating system efficiency in the literature produces overestimated scores when the dynamic nature is discounted. This makes it necessary to conduct a dynamic analysis whenever data are available.\textsuperscript{66}

Hence, another main consideration for the study is to choose a dynamic model for calculation. This study utilized the model established based on the expectations of Tone and Tsutsui,\textsuperscript{48} which included T periods and n DMUs, each of which has different inputs, outputs, and carryovers in period \( t \) and period \( t \) links to the next period, \( t + 1 \). The particulars of the model in Figure 1 are as follows:

Following is the nonoriented model:

\[
E_0^* = \min \frac{1}{T} \sum_{t=1}^{T} W_t^1 \left[ 1 - \frac{1}{m + n_{bad}} \left( \sum_{s=1}^{m} \frac{w_{it}^s}{x_{it}^s} + \sum_{s=1}^{n_{bad}} \frac{x_{it}^{s_{bad}}}{w_{it}^{s_{bad}}} \right) \right]
\]

\[
E_0^* = \min \frac{1}{T} \sum_{t=1}^{T} W_t^1 \left[ 1 + \frac{1}{s + n_{good}} \left( \sum_{s=1}^{s_i} \frac{w_{it}^s}{x_{it}^s} + \sum_{s=1}^{n_{good}} \frac{x_{it}^{s_{good}}}{w_{it}^{s_{good}}} \right) \right]
\]

\[\text{(1)}\]
\[ \sum_{j=1}^{n} z_{ij}^x \lambda_j^x = \sum_{j=1}^{n} z_{ij}^y \lambda_j^y + (\forall i; t = 1, \ldots, T - 1) \] (2)

Equation (2) shows the connection equation of \( t \) and \( t + 1 \):

\[ x_{itot} = \sum_{j=1}^{n} x_{ij}^x \lambda_j^x + s^-_i (i = 1, \ldots, m; t = 1, \ldots, T) \]

\[ x_{ifix} = \sum_{j=1}^{n} x_{ij}^f \lambda_j^f (i = 1, \ldots, F; t = 1, \ldots, T) \]

\[ y_{itot} = \sum_{j=1}^{n} y_{ij}^y \lambda_j^y - s^+_i (i = 1, \ldots, s; t = 1, \ldots, T) \]

\[ y_{ifix} = \sum_{j=1}^{n} y_{ij}^f \lambda_j^f (i = 1, \ldots, p; t = 1, \ldots, T) \]

\[ z_{itot}^{good} = \sum_{j=1}^{n} z_{ij}^{good} \lambda_j^x - s^-_i (i = 1, \ldots, ngood; t = 1, \ldots, T) \]

\[ z_{itot}^{bad} = \sum_{j=1}^{n} z_{ij}^{bad} \lambda_j^x + s^+_i (i = 1, \ldots, nbad; t = 1, \ldots, T) \]

\[ z_{itot}^{free} = \sum_{j=1}^{n} z_{ij}^{free} \lambda_j^x + s^+_i (i = 1, \ldots, nfree; t = 1, \ldots, T) \]

\[ z_{itot}^{fix} = \sum_{j=1}^{n} z_{ij}^{fix} \lambda_j^x (i = 1, \ldots, nfix; t = 1, \ldots, T) \]

\[ \sum_{j=1}^{n} \lambda_j^x = 1 (t = 1, \ldots, T) \]

\[ \lambda_j^x \geq 0, s^-_i \geq 0, s^+_i \geq 0, s^{good}_i \geq 0, s^{bad}_i \geq 0 \text{ and } s^{free}_i \text{ free} (\forall i, t). \] (3)

Here is the most efficient solution:

\[ E_{tot} = \frac{1 - \frac{1}{m+n+bad} \left( \sum_{j=1}^{m} \frac{w_j^x}{x_{ij}^x} \lambda_j^x + \sum_{j=1}^{n+bad} \frac{s^{bad}_j}{x_{ij}^x} \lambda_j^x \right)}{1 + \frac{1}{s+good} \left( \sum_{j=1}^{s} \frac{w_j^y}{y_{ij}^y} \lambda_j^y + \sum_{j=1}^{ngood} \frac{s^{good}_j}{y_{ij}^y} \lambda_j^y \right)} (i = 1, \ldots, T) \] (4)

### 3 | RESULTS

The research sample covers 48 high-income economies during 2010-2014 according to United Nations (UN) data, World Bank data, the BP Statistical Review of World Energy, the Taiwan Bureau of Energy and Ministry of Economic Affairs, and the Taiwan Directorate-General of Budget, Accounting, and Statistics, Executive Yuan, in 2017 (Table 2). We used three input variables, fossil fuel energy consumption, real capital stock, and labor force; one output variable, CO2 emission; and one carryover variable, real GDP.

Table 3 presents descriptive statistics of the input, output, and carryover variables’ data results as follows: (A) fossil fuel energy consumption: The average energy consumption from 2010 to 2014 was 5173.855 per kg. Iceland had the highest energy consumption at 18 562.667 per kg in 2014, and Uruguay had the lowest at 1211.183 per kg in 2010. (B) Real capital stock: From 2010 to 2014, the average was USD 11 856 237.27. South Korea had the highest real capital stock in 2014 at USD 430 685 500, while Malta had the lowest at USD 1164.17 in 2012. (C) Labor force: The labor force average was 28 282 937 people during 2010-2014. China had the largest labor force at 796 905 370 persons in 2014, and Malta had the lowest at 173 272 persons in 2010. (D) CO2 emission: This study adopted Seiford and Zhu’s 59 DEA undesirable model to evaluate every region’s fossil fuel CO2 emissions from 2010 to 2014. In this period, fossil fuel CO2 emissions increased, on average, by 474 146.140 Ktons carbon each year. China was the highest at 10 291 926.878 Ktons in 2014, and Iceland was the lowest at 1 175 782.13. The United States had the highest GDP at USD 17 393 103 in 2014, and Malta had the lowest at USD 8741.06 in 2010.

#### 3.1 | Comparison of Static SBM and DSBM Research Results

The overall average efficiency value generated by the static SBM was 0.7241 (Table 4), and the differences among the continents indicate that the European high-income economies have the best energy efficiency, with an average value of 0.7759, the Asian economies have worse energy efficiency,
with an average value of 0.6336, the American economies’ average efficiency value was 0.7199, and the Oceania economies’ value was 0.7139. The overall efficiency value estimated by DSBM is 0.6869 (Table 5), and when the economies are divided by four continents, the average efficiency values of Oceania, Asia, Europe, and America are 0.8106, 0.6007, 0.7191, and 0.7308, respectively. Therefore, the overall efficiency of the evaluation results under the dynamic SBM model is lower than that of the static SBM model, showing that the empirical results of the dynamic model will not produce overall efficiency overestimation, which also conforms to the view of objectivity of Tone and Tsutsui 48’s model evaluation.

From 2010 to 2014, the economies that were efficient (efficiency value of 1) as estimated by the nonorientation DSBM model of VRS were China, United Kingdom, Italy, Luxembourg, Malta, the Netherlands, Norway, Uruguay, the United States, and Switzerland. The empirical results of taking GDP as a crossover variable show that the efficiency values of the Netherlands and Italy will not produce overall efficiency overestimation, which also conforms to the view of objectivity of Tone and Tsutsui 48’s model evaluation.

3.2 | Slack Variable Analysis of High-Income Economies (Including China)

This study employs the dynamic nonorientation SBM model of VRS to analyze various input and output adjustment ranges of high-income economies (including China) from 2010 to 2014 through target values that are regarded as the reference for economies to achieve energy and environmental efficiency corresponding to their benchmark in the frontier. The results are sorted as follows.

3.2.1 | Annual adjustment of energy consumption input of high-income economies (Including China) from 2010 to 2014

As shown in Table 6, from 2010 to 2014, the inputs in energy consumption of high-income economies (including China) should have been reduced by 20.68% on average, and these economies (Switzerland, Italy, United Kingdom, Hong Kong, Japan, Luxembourg, Malta, the Netherlands, Norway, Uruguay, the United States, and China) had no energy...
**TABLE 4**  Static SBM average energy efficiency value

| Economies          | 2010 | 2011 | 2012 | 2013 | 2014 | Mean | Means by Continents |
|--------------------|------|------|------|------|------|------|---------------------|
| The United States  | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Uruguay            | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Canada             | 0.6460 | 0.6441 | 0.6722 | 0.6496 | 0.5791 | 0.6382 |                   |
| Trinidad and Tobago| 0.2497 | 0.258 | 0.2458 | 0.2348 | 0.2182 | 0.2413 | 0.7199             |
| Iceland            | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The French         | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The British        | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Norwegian      | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Malta              | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Irish          | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Swiss          | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Luxembourg         | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Italian        | 1    | 1    | 1    | 1    | 0.9716 | 0.9943 |                   |
| Germany            | 0.8246 | 0.8474 | 1    | 1    | 0.9047 | 0.9706 |                   |
| The Greek          | 0.8246 | 0.8474 | 1    | 1    | 0.9047 | 0.9706 |                   |
| The Netherlands    | 1    | 1    | 0.8247 | 0.8566 | 0.8155 | 0.8994 |                   |
| Belgium            | 0.8509 | 0.8386 | 0.8148 | 0.8168 | 0.7874 | 0.8217 |                   |
| Austria            | 0.8532 | 0.8327 | 0.7982 | 0.7998 | 0.7855 | 0.8139 |                   |
| Spain              | 0.8224 | 0.7832 | 0.7551 | 0.7875 | 0.7465 | 0.7789 |                   |
| Portugal           | 0.742 | 0.7599 | 0.7959 | 0.795 | 0.7782 | 0.7742 |                   |
| Finland            | 0.7309 | 0.7207 | 0.7509 | 0.7707 | 0.7604 | 0.7467 |                   |
| Lithuania          | 0.7145 | 0.6711 | 0.708 | 0.7217 | 0.7088 | 0.7048 |                   |
| Latvia             | 0.7248 | 0.6334 | 0.6483 | 0.6583 | 0.6585 | 0.6647 |                   |
| Slovenia           | 0.6419 | 0.6404 | 0.6646 | 0.6556 | 0.6414 | 0.6488 |                   |
| The Danish         | 0.6313 | 0.6077 | 0.6191 | 0.6107 | 0.6236 | 0.6185 |                   |
| Slovakia           | 0.5629 | 0.5578 | 0.5922 | 0.5852 | 0.5743 | 0.5745 |                   |
| Estonia            | 0.5906 | 0.5081 | 0.4878 | 0.4741 | 0.4921 | 0.5105 |                   |
| The Swedish        | 0.4975 | 0.4845 | 0.4877 | 0.5018 | 0.4844 | 0.4912 |                   |
| Poland             | 0.4307 | 0.4197 | 0.4131 | 0.423 | 0.4021 | 0.4177 |                   |
| Hungary            | 0.3008 | 0.2845 | 0.2865 | 0.3068 | 0.2888 | 0.2935 |                   |
| The Czech Republic | 0.312 | 0.2972 | 0.2865 | 0.2878 | 0.2751 | 0.2917 | 0.7759             |
| Australia          | 0.6773 | 0.7578 | 1    | 1    | 0.7227 | 0.8316 |                   |
| New Zealand        | 0.5767 | 0.5914 | 0.61 | 0.6086 | 0.5863 | 0.5946 | 0.7131             |
| China              | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Kuwait             | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Cyprus             | 0.7984 | 0.8415 | 1    | 1    | 1    | 0.9280 |                   |
| Japan              | 1    | 1    | 1    | 1    | 0.5473 | 0.9095 |                   |
| Brunei             | 0.5715 | 0.5637 | 1    | 1    | 1    | 0.8270 |                   |
| Singapore          | 1    | 0.6047 | 0.6024 | 0.5753 | 0.5708 | 0.6706 |                   |

*(Continues)*
consumption adjustment requirements because their value was 0. Furthermore, 14 economies required more than annual average adjustments (the United Arab Emirates, Bahrain, Canada, Estonia, Finland, South Korea, Kuwait, New Zealand, Oman, Qatar, Saudi Arabia, Sweden, Trinidad and Tobago, and Taiwan). In 2010, 32 economies needed to adjust their inputs in energy consumption. The maximum adjustment range was a reduction of 77.77% for Qatar, and the minimum was 0.06% for France. In 2011, 31 economies, including Canada, needed to adjust their inputs in energy consumption. The maximum adjustment range was a reduction of 85.45% for Qatar, and the minimum was 0.03% for France. In 2012, 28 economies, including Canada, needed to adjust their inputs of energy consumption. The maximum adjustment range was a reduction of 86.69% for Qatar, and the minimum was 0.04% for Greece. In 2013, 28 economies, including Canada, needed to adjust their energy inputs. The maximum adjustment range was a reduction of 87.56% for Qatar, and the minimum was 0.08% for France. In 2014, 28 economies, including Canada, needed to adjust their energy inputs. The maximum adjustment range was a reduction of 87.88% for Qatar, and the minimum was 0.04% for France. The maximum adjustment range of energy consumption input was a reduction of 87.88% for Qatar in 2014, and the minimum was 0.03% for France in 2011. Based on the average energy consumption input range, the average adjustment range of energy consumption input was 23.59% in 2011 and 19.60% in 2012.

### 3.2.2 Annual adjustment in inputs of capital storage in high-income economies (Including China) from 2010 to 2014

As shown in Table 7, the capital investments in high-income economies (including China) should have been reduced by 28.32% on average from 2010 to 2014. Furthermore, 13 economies (Switzerland, Germany, United Kingdom, Ireland, Italy, Kuwait, Luxembourg, Malta, the Netherlands, Norway, Uruguay, the United States, and China) were without requirements in adjustment capital investment. However, 16 economies required more than average annual adjustments (the United Arab Emirates, Canada, the Czech Republic, Denmark, Estonia, Hong Kong, Hungary, Israel, South Korea, Poland, Qatar, Saudi Arabia, Slovakia, Sweden, Trinidad and Tobago, and Taiwan). In 2010, the capital input needed to be adjusted by 30 economies, including Canada, with the maximum adjustment range of 99.92% in South Korea and the minimum of 0.12% in Japan. In 2011, the capital input needed to be adjusted for 31 economies, including Canada, with the maximum adjustment range of 99.92% for South Korea and the minimum of 0.15% for Finland. In 2012, the capital stock input needed to be adjusted by 29 economies, including Canada, with the maximum adjustment range of 99.91% for South Korea and the minimum of 0.01% for France. In 2013, the capital input needed to be adjusted by 29 economies, including Canada, with the maximum adjustment range of 99.92% for South Korea and the minimum of 0.03% for France. In 2014, the capital stock input needed to be adjusted by 30 economies, including Canada, with the maximum adjustment range of 99.91% for South Korea and the minimum of 0.02% for France. The adjustment range of capital input was 99.92% higher than that of 2010 and 2011 in South Korea, while the adjustment range of minimum capital input was 0.01% in France in 2011. According to the average adjusted value each year, the average adjusted value of capital input was 29.39% in 2011 and 27.65% in 2010.

| Economies                 | 2010  | 2011  | 2012  | 2013  | 2014  | Mean  | Means by Continents |
|---------------------------|-------|-------|-------|-------|-------|-------|---------------------|
| Hong Kong                 | 0.6404| 0.5991| 0.6531| 0.6148| 0.6112| 0.6237|
| Oman                      | 0.7115| 0.5987| 0.5723| 0.5523| 0.6187| 0.6107|
| Israel                    | 0.5544| 0.5391| 0.5293| 0.5557| 0.5615| 0.5480|
| Bahrain                   | 0.5811| 0.5461| 0.5288| 0.5162| 0.52  | 0.5384|
| Taiwan                    | 0.4648| 0.4602| 0.4814| 0.4759| 0.4642| 0.4693|
| Qatar                     | 0.3754| 0.3856| 0.4134| 0.3954| 0.3828| 0.3905|
| Saudi Arabia              | 0.3412| 0.3747| 0.381 | 0.3694| 0.3443| 0.3621|
| The Arab United Nations   | 0.3331| 0.3393| 0.3557| 0.3513| 0.3426| 0.3444|
| South Korea               | 0.2738| 0.2826| 0.2787| 0.2821| 0.2898| 0.2814| 0.6336          |
| Mean                      | 0.7297| 0.7140| 0.7334| 0.734 | 0.7096| 0.7241|

The higher value of efficiency level shows the more efficient, while the 1 value means the DMU is most efficient.
TABLE 5  Average energy efficiency of DSBM

| Economies          | 2010 | 2011 | 2012 | 2013 | 2014 | Mean | Means by Continents |
|--------------------|------|------|------|------|------|------|---------------------|
| The United States  | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Uruguay            | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Canada             | 0.6672 | 0.6548 | 0.6723 | 0.661 | 0.6341 | 0.6579 |                     |
| Trinidad and Tobago| 0.2643 | 0.2632 | 0.2698 | 0.2656 | 0.2632 | 0.2652 | 0.7308              |
| Iceland            | 0.6712 | 0.6714 | 1    | 1    | 1    | 0.8685 |                     |
| The French         | 0.9998 | 0.9999 | 0.9998 | 0.9996 | 0.9997 | 0.9998 |                     |
| The British        | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Norwegian      | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Malta              | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Irish          | 0.845 | 0.8248 | 0.8281 | 0.8356 | 0.8665 | 0.84  |                     |
| The Swiss          | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Luxembourg         | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| The Italian        | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Germany            | 0.9991 | 0.9999 | 0.9999 | 0.9999 | 1    | 0.9998 |                     |
| The Greek          | 0.7637 | 0.6979 | 0.6484 | 0.659  | 0.6342 | 0.6806 |                     |
| The Netherlands    | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Belgium            | 0.8509 | 0.8934 | 0.8606 | 0.8546 | 0.8381 | 0.8595 |                     |
| Austria            | 0.9067 | 0.8757 | 0.8645 | 0.861  | 0.8603 | 0.8736 |                     |
| Spain              | 0.8393 | 0.8117 | 0.837  | 0.8291 | 0.7951 | 0.8224 |                     |
| Portugal           | 0.6835 | 0.6455 | 0.6397 | 0.6433 | 0.6342 | 0.6492 |                     |
| Finland            | 0.7006 | 0.7997 | 0.7707 | 0.7442 | 0.6927 | 0.7416 |                     |
| Lithuania          | 0.3682 | 0.3487 | 0.3607 | 0.3735 | 0.3737 | 0.3650 |                     |
| Latvia             | 0.3789 | 0.4204 | 0.4181 | 0.4074 | 0.4079 | 0.4065 |                     |
| Slovenia           | 0.4877 | 0.4541 | 0.4376 | 0.4388 | 0.4538 | 0.4544 |                     |
| The Danish         | 0.6493 | 0.6345 | 0.6437 | 0.6364 | 0.6486 | 0.6425 |                     |
| Slovakia           | 0.3967 | 0.3715 | 0.3774 | 0.3847 | 0.3919 | 0.3844 |                     |
| Estonia            | 0.3064 | 0.3059 | 0.3083 | 0.3195 | 0.3443 | 0.3169 |                     |
| The Swedish        | 0.5007 | 0.4917 | 0.4937 | 0.5043 | 0.4908 | 0.4962 |                     |
| Poland             | 0.4391 | 0.4297 | 0.4224 | 0.4299 | 0.4109 | 0.4264 |                     |
| Hungary            | 0.3085 | 0.2888 | 0.2865 | 0.3065 | 0.2888 | 0.2958 |                     |
| The Czech Republic | 0.3120 | 0.2972 | 0.2865 | 0.2878 | 0.2751 | 0.2917 | 0.7191              |
| Australia          | 0.7287 | 0.7578 | 0.9999 | 1    | 0.9999 | 0.8973 | 0.8106              |
| New Zealand        | 0.7385 | 0.7269 | 0.7424 | 0.7196 | 0.6926 | 0.7240 |                     |
| China              | 1    | 1    | 1    | 1    | 1    | 1    |                     |
| Kuwait             | 0.5156 | 0.5422 | 0.5633 | 0.5579 | 0.5323 | 0.5423 |                     |
| Cyprus             | 0.815 | 0.8433 | 1    | 1    | 0.9513 | 0.9219 |                     |
| Japan              | 0.9996 | 1    | 1    | 1    | 0.9936 | 0.9986 |                     |
| Brunei             | 0.707 | 0.7642 | 1    | 1    | 1    | 0.8942 |                     |
| Singapore          | 0.9286 | 0.6958 | 0.7203 | 0.6366 | 0.6206 | 0.7204 |                     |

(Continues)
### Table 5 (Continued)

| Economies               | 2010  | 2011  | 2012  | 2013  | 2014  | Mean  | Means by Continents |
|-------------------------|-------|-------|-------|-------|-------|-------|---------------------|
| Hong Kong               | 0.6482| 0.6043| 0.6541| 0.6435| 0.6379| 0.6376|                     |
| Oman                    | 0.3869| 0.3504| 0.3693| 0.3607| 0.3501| 0.3635|                     |
| Israel                  | 0.6094| 0.5803| 0.5657| 0.5913| 0.5967| 0.5887|                     |
| Bahrain                 | 0.3135| 0.305 | 0.3233| 0.3233| 0.3236| 0.3177|                     |
| Taiwan                  | 0.4685| 0.4548| 0.4673| 0.4425| 0.4322| 0.4531|                     |
| Qatar                   | 0.5423| 0.5331| 0.5553| 0.5531| 0.5414| 0.5450|                     |
| Saudi Arabia            | 0.3728| 0.3873| 0.381 | 0.3824| 0.3502| 0.3747|                     |
| The Arab United Nations | 0.3613| 0.368 | 0.3769| 0.3728| 0.3636| 0.3685|                     |
| South Korea             | 0.2786| 0.2848| 0.2818| 0.284 | 0.2898| 0.2838| 0.6007             |
| Mean                    | 0.6824| 0.6746| 0.6964| 0.6939| 0.6871| 0.6869|                     |

The higher value of efficiency level shows the more efficient, while the 1 value means the DMU is most efficient.

### Table 6

The adjustment range of energy consumption input from 2010 to 2014

| Economies               | 2010  | 2011  | 2012  | 2013  | 2014  | Mean  | Means by Continents |
|-------------------------|-------|-------|-------|-------|-------|-------|---------------------|
| The United States       | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Uruguay                 | −62.95| −62.49| −58.06| −60.76| −61.07| −61.07|                     |
| Canada                  | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Trinidad and Tobago     | −56.22| −56.63| −53.23| −53.41| −53.93| −54.68| −28.94             |
| Austria                 | −21.62| −26.1 | −25.64| −26.87| −26.08| −25.26|                     |
| Belgium                 | 0     | −31.78| −39.25| −40.78| −39.71| −30.3 |                     |
| Swiss                   | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| The Czech Republic      | −21.01| −21.38| −20.99| −17.18| −21.84| −20.48|                     |
| Germany                 | −0.12 | 0     | 0     | 0     | 0     | −0.024|                     |
| Danish                  | −21.87| −17.76| −12.65| −15.86| −13.15| −16.26|                     |
| Spain                   | 0     | −4.4 | −8.12 | −7.42 | −7.91 | −5.57 |                     |
| Estonia                 | −28.67| −35.44| −31.3 | −33.34| −29.26| −31.6 |                     |
| Finland                 | −62.21| −56.11| −63.25| −59.62| −63.1 | −60.86|                     |
| The French              | −0.06 | −0.03 | −0.05 | −0.08 | −0.04 | −0.052|                     |
| The United Kingdom      | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Greek                   | −18.87| 0     | −0.04 | 0     | 0     | −3.78 |                     |
| Hungary                 | −11.66| 0     | 0     | 0     | 0     | −2.33 |                     |
| The Irish               | −17.39| −11.75| −9.65 | −12.58| −9.66 | −12.21|                     |
| Iceland                 | −50.36| −50.09| 0     | 0     | 0     | −20.09|                     |
| The Italian             | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Lithuania               | 0     | −3.7 | −2.56 | −5.64 | −9.75 | −4.33 |                     |
| Luxembourg              | 0     | 0     | 0     | 0     | 0     | 0     |                     |

(Continues)
3.2.3 Annual adjustment of labor input in high-income economies (Including China) from 2010 to 2014

As shown in Table 8, the labor inputs in high-income economies (including China) should have been reduced by 9.67% on average from 2010 to 2014. Furthermore, 18 economies (Australia, Belgium, Bahrain, Canada, Switzerland, France, United Kingdom, Iceland, Italy, Luxembourg, Malta, the Netherlands, Norway, Uruguay, Slovenia, Trinidad and Tobago, the United States, and China) are located under the frontier and did not need to adjust their labor inputs. However, the United Arab Emirates, the Czech Republic, Spain, Israel, South Korea, New Zealand, Saudi Arabia, Sweden, and Taiwan had greater adjustment in labor inputs than the average. In 2010, 25 economies needed to adjust labor inputs, and the adjustment range should have been reduced by 54.72% for the United Arab Emirates and 0.01% for Japan. In 2011, 25 economies needed to adjust their labor inputs. The maximum adjustment range was 56.09% for the United Arab Emirates, and the minimum was 0.43% for Slovakia. In 2012, 23 economies needed to adjust their labor inputs. The maximum adjustment range was 56.53% for the United Arab Emirates, and the minimum was

| Economies                | 2010 | 2011 | 2012 | 2013 | 2014 | Mean | Means by Continents |
|-------------------------|------|------|------|------|------|------|---------------------|
| Latvia                  | 0    | 0    | 0    | −6.08| −8.68| −2.95|                     |
| Malta                   | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| The Netherlands,        | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Norway                  | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Poland                  | −10.52| −4.74| −0.7 | −10.07| −7.41| −6.69|                     |
| Portugal                | −16.19| 0    | 0    | 0    | 0    | −3.24|                     |
| Slovakia                | −16.17| −16.52| −11.56| −11.34| −6.82| −12.48|                     |
| Slovenia                | −28.41| −27.99| −19.03| −18.32| −19.93| −22.74|                     |
| The Swedish             | −42.19| −42.84| −42.53| −40.35| −42.34| −42.05| −11.97               |
| Australia               | −39.22| −41.59| 0    | 0    | 0    | −16.16|                     |
| New Zealand             | −30.85| −35.48| −37.83| −39.68| −43.48| −37.46| −26.81               |
| The Arab United Nations | −62.93| −63.92| −64.62| −65.83| −66.13| −64.69|                     |
| Bahrain                 | −27.96| −31.86| −28.24| −33.23| −37.46| −31.75|                     |
| Brunei                  | −62.32| −68.7 | 0    | 0    | 0    | −26.2 |                     |
| Cyprus                  | −6.54 | −2.35| 0    | 0    | 0    | −1.78 |                     |
| Hong Kong               | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Israel                  | −14.97| −15.61| −16.2 | −14.45| −14.97| −15.24|                     |
| Japan                   | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| South Korea             | −66.78| −66.41| −65.8 | −65.9 | −65.7 | −66.12|                     |
| Kuwait                  | −54.77| −59.69| −60.89| −54.08| −68.77| −59.64|                     |
| Oman                    | −27.76| −50.98| −41.48| −62.45| −62.75| −49.08|                     |
| Qatar                   | −77.77| −85.45| −86.69| −87.56| −87.88| −85.07|                     |
| Saudi Arabia            | −50.24| −48.91| −53.26| −48.26| −55.63| −51.26|                     |
| Singapore               | −11.12| −50.96| −46.42| −40.6 | −45.17| −38.85|                     |
| Taiwan                  | −48.52| −40.78| −40.36| −42.27| −44.17| −43.22|                     |
| China                   | 0    | 0    | 0    | 0    | 0    | −35.53|                     |
| Mean                    | −22.26| −23.59| −19.6 | −20.29| −21.1 | −20.68|                     |

These values of results are shown as percentage, namely, their units are %
### Table 7: The adjustment range of capital items from 2010 to 2014

| Economies                      | 2010  | 2011  | 2012  | 2013  | 2014  | Mean  | Means by Continents |
|--------------------------------|-------|-------|-------|-------|-------|-------|---------------------|
| The United States              | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Uruguay                        | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Canada                         | −30.72| −37.14| −38.34| −37.23| −35.04| −35.69|                     |
| Trinidad and Tobago            | −79.56| −78.18| −84.99| −85.1 | −88.06| −83.18| −29.72              |
| Austria                        | −5.03 | −11.17| −11.13| −13.7 | −8.25 | −9.86 |                     |
| Belgium                        | 0     | 0     | −1.41 | −2.42 | −2.81 | −1.33 |                     |
| Swiss                          | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| The Czech Republic             | −86.42| −85.05| −86.03| −86.67| −87.22| −86.28|                     |
| Germany                        | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Danish                         | −70.01| −68.59| −72.01| −75   | −74.98| −72.12|                     |
| Spain                          | −26.5 | −28.81| −10.38| −11.06| −12.26| −17.8 |                     |
| Estonia                        | −36.45| −58.3 | −67.58| −62.83| −62.16| −57.46|                     |
| Finland                        | −24.2 | −0.15 | −11.32| −12.73| −4.41 | −10.56|                     |
| The French                     | 0     | 0     | −0.01 | −0.03 | −0.02 | −0.01 |                     |
| The United Kingdom             | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Greek                          | −18.18| −4.92 | 0     | 0     | 0     | −4.62 |                     |
| Hungary                        | −97.43| −97.24| −96.88| −96.97| −97.36| −97.18|                     |
| The Irish                      | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Iceland                        | −48.23| −48.48| 0     | 0     | 0     | −19.34|                     |
| The Italian                    | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Lithuania                      | −11.1 | −21.83| −13.08| −14.72| −4.59 | −13.06|                     |
| Luxembourg                     | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Latvia                         | 0     | 0     | −28.73| −28.99| −26.64| −16.87|                     |
| Malta                          | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| The Netherlands                | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Norway                         | 0     | 0     | 0     | 0     | 0     | 0     |                     |
| Poland                         | −40.44| −54.11| −51.05| −38.19| −45.37| −45.83|                     |
| Portugal                       | −31.21| −25.14| −15.77| −5.53 | −9.26 | −17.38|                     |
| Slovakia                       | −39.08| −42.85| −35.95| −29.61| −33.5 | −36.2 |                     |
| Slovenia                       | −30.44| −31.99| −24.82| −21.73| −24.59| −26.71|                     |
| The Swedish                    | −83.97| −83.38| −84.24| −85.87| −86.13| −84.72| −22.86              |
| Australia                      | −30.06| −29.64| 0     | 0     | 0     | −11.94|                     |
| New Zealand                    | 0     | −5    | −10.15| −16.98| −18.26| −10.08| −11.01              |
| The Arab United Nations        | −65.33| −61.58| −64.3 | −65.28| −69.69| −65.24|                     |
| Bahrain                        | −15.1 | −20.41| −29.19| −32.02| −34.1 | −26.16|                     |
| Brunei                         | −32.87| −52.53| 0     | 0     | 0     | −17.08|                     |
| Cyprus                         | −19.69| −10.14| 0     | 0     | 0     | −5.97 |                     |
| Hong Kong                      | −72.89| −71.21| −70.04| −83.96| −85.76| −76.77|                     |
| Israel                         | −51.54| −53.72| −60.15| −63.01| −62.68| −58.22|                     |

(Continues)
TABLE 7 (Continued)

| Economies    | 2010   | 2011   | 2012   | 2013   | 2014   | Mean    | Means by Continents |
|--------------|--------|--------|--------|--------|--------|---------|---------------------|
| Japan        | −0.12  | 0      | 0      | 0      | −1.41  | −0.31   |                     |
| South Korea  | −99.92 | −99.92 | −99.91 | −99.91 | −99.91 | −99.91  |                     |
| Kuwait       | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Oman         | 0      | −49.47 | −61.55 | −60.67 | −47.88 | −43.91  |                     |
| Qatar        | −56.68 | −60.66 | −78.55 | −66.9  | −71.34 | −66.83  |                     |
| Saudi Arabia | −74.24 | −73.74 | −76.81 | −78.95 | −79.42 | −76.63  |                     |
| Singapore    | −1.18  | −2.79  | −9.74  | −51.48 | −47.24 | −22.49  |                     |
| Taiwan       | −48.68 | −42.57 | −40.72 | −38.81 | −36.12 | −41.38  |                     |
| China        | 0      | 0      | 0      | 0      | 0      | 0       | −40.06             |
| Mean         | −27.65 | −29.39 | −27.81 | −28.47 | −28.26 | −28.32  |                     |

These values of results are shown as percentage, namely, their units are %

TABLE 8 The adjustment range of labors from 2010 to 2014

| Economies          | 2010   | 2011   | 2012   | 2013   | 2014   | Mean    | Means by Continents |
|--------------------|--------|--------|--------|--------|--------|---------|---------------------|
| The United States  | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Uruguay            | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Canada             | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Trinidad and Tobago| 0      | 0      | 0      | 0      | 0      | 0       | 0                   |
| Austria            | −0.54  | 0      | −2.92  | −1.12  | −0.43  | −1      |                     |
| Belgium            | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Swiss              | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| The Czech Republic | −13.99 | −12.47 | −11.91 | −11.53 | −9.89  | −11.96  |                     |
| Germany            | −0.14  | 0      | 0      | 0      | 0      | −0.028  |                     |
| Danish             | −13.08 | −11.68 | −9.99  | −8.13  | −6.86  | −9.95   |                     |
| Spain              | −21.71 | −19.19 | −24.48 | −26.08 | −23.37 | −22.97  |                     |
| Estonia            | −3.7   | −3.31  | 0      | 0      | 0      | −1.4    |                     |
| Finland            | −25.2  | −3.62  | 0      | −16.89 | −26.88 | −14.52  |                     |
| The French         | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| The United Kingdom | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Greece             | −9.38  | −19.74 | −16.66 | 0      | −1.4   | −9.44   |                     |
| Hungary            | −9.74  | −18.69 | −10.87 | 0      | −12.4  | −10.34  |                     |
| The Irish          | −5.32  | −2.94  | −1.03  | 0      | 0      | −1.86   |                     |
| Iceland            | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| The Italian        | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Lithuania          | 0      | −7.71  | −4.16  | −2.63  | −1.83  | −3.27   |                     |
| Luxembourg         | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| Latvia             | −11.03 | 0      | −10    | −19.7  | −17.54 | −11.65  |                     |
| Malta              | 0      | 0      | 0      | 0      | 0      | 0       |                     |
| The Netherlands    | 0      | 0      | 0      | 0      | 0      | 0       |                     |

(Continues)
1.03% for Ireland. In 2013, labor input needed to be adjusted in 20 economies, with the maximum adjustment range of 56.25% for the United Arab Emirates and the minimum of 1.12% for Austria. In 2014, 23 economies needed to adjust their labor inputs. The maximum adjustment range was a reduction of 55.37% for Saudi Arabia and 0.43% for Austria. The maximum adjustment range of labor input was 56.53% for the United Arab Emirates in 2012, and the minimum adjustment range was 0.01% for Japan in 2010. Based on the average adjustment range each year, the maximum value of the average adjustment range of labor input was 10.74% in 2011 and the minimum was 9.11% in 2013.

### 3.2.4 Adjustment range of carbon dioxide output from 2010 to 2014

As shown in Table 9, CO₂ emissions in high-income economies (including China) should have been reduced by 0.41% on average from 2010 to 2014. Fourteen economies (Switzerland, France, United Kingdom, Iceland, Italy, Japan, Luxembourg, Malta, the Netherlands, Norway, Portugal, Uruguay, the United States, and China) should not have adjusted the demand in carbon dioxide emissions. Carbon dioxide emissions adjustment each year are less than the average value in 36 economies, including China, and CO₂ emissions are greater than the average value in 10 economies (the United Arab Emirates, Canada, the Czech Republic, Israel, South Korea, Kuwait, Poland, Qatar, Saudi Arabia, and Taiwan). In 2010, 23 economies needed to adjust their carbon dioxide emissions reduction, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia. In 2011, 34 economies needed to adjust their carbon dioxide emissions reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. In 2012, 25 economies, including Sweden, needed to reduce carbon dioxide emissions, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia. In 2011, 34 economies needed to adjust their carbon dioxide emission reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. In 2012, 25 economies, including Sweden, needed to reduce carbon dioxide emissions, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia. In 2011, 34 economies needed to adjust their carbon dioxide emission reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. 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In 2011, 34 economies needed to adjust their carbon dioxide emission reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. In 2012, 25 economies, including Sweden, needed to reduce carbon dioxide emissions, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia. In 2011, 34 economies needed to adjust their carbon dioxide emission reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. In 2012, 25 economies, including Sweden, needed to reduce carbon dioxide emissions, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia. In 2011, 34 economies needed to adjust their carbon dioxide emission reduction, with a maximum adjustment range of 4.76% for Saudi Arabia and minimum of 0.01% for Germany. 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In 2012, 25 economies, including Sweden, needed to reduce carbon dioxide emissions, with a maximum adjustment range of 5.51% for Saudi Arabia and minimum of 0.03% for Slovenia.
| Economies                   | 2010 | 2011 | 2012 | 2013 | 2014 | Mean | Means by Continents |
|----------------------------|------|------|------|------|------|------|---------------------|
| The United States          | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Uruguay                    | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Canada                     | 2.75 | 2.71 | 1.91 | 1.82 | 2.21 | 2.28 |                     |
| Trinidad and Tobago        | 0.35 | 0.33 | 0.29 | 0.28 | 0.39 | 0.33 | 0.65               |
| Austria                    | 0    | 0.03 | 0    | 0    | 0    | 0.01 |                     |
| Belgium                    | 0    | 0.15 | 0.29 | 0.31 | 0.32 | 0.21 |                     |
| Swiss                      | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| The Czech Republic         | 0.84 | 0.73 | 0.64 | 0.58 | 0.61 | 0.68 |                     |
| Germany                    | 0    | 0.01 | 0.01 | 0.01 | 0    | 0.01 |                     |
| Danish                     | 0.28 | 0.2  | 0.15 | 0.16 | 0.13 | 0.18 |                     |
| Spain                      | 0    | 0.06 | 0.14 | 0    | 0.12 | 0.06 |                     |
| Estonia                    | 0.04 | 0.08 | 0.05 | 0.06 | 0.17 | 0.08 |                     |
| Finland                    | 0.51 | 0.17 | 0.14 | 0.21 | 0.32 | 0.27 |                     |
| The French                 | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| The United Kingdom         | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Greek                      | 0    | 0.35 | 0.31 | 0    | 0    | 0    | 0.132               |
| Hungary,                   | 0    | 0.22 | 0    | 0    | 0    | 0    | 0.044               |
| The Irish                  | 0.25 | 0.19 | 0.18 | 0.16 | 0.19 | 0.194 |                  |
| Iceland                    | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| The Italian                | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Lithuania                  | 0    | 0.02 | 0    | 0    | 0.01 | 0.01 |                     |
| Luxembourg                 | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Latvia                     | 0    | 0.13 | 0    | 0    | 0    | 0    | 0.03               |
| Malta                      | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| The Netherlands,           | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Norway                     | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Poland                     | 0.55 | 0.76 | 0.44 | 0.61 | 0.55 | 0.58 |                     |
| Portugal                   | 0    | 0    | 0    | 0    | 0    | 0    |                     |
| Slovakia                   | 0.15 | 0.13 | 0.1  | 0.08 | 0.12 | 0.12 |                     |
| Slovenia                   | 0.03 | 0.04 | 0.01 | 0    | 0.09 | 0.03 |                     |
| The Swedish                | 0.22 | 0.21 | 0.15 | 0.11 | 0.13 | 0.16 | 0.1               |
| Australia                  | 1.23 | 1.25 | 0.01 | 0    | 0.01 | 0.5  |                     |
| New Zealand                | 0    | 0.02 | 0.05 | 0.05 | 0.07 | 0.04 | 0.27               |
| The Arab United Nations    | 1.6  | 1.5  | 1.57 | 1.46 | 1.85 | 1.6  |                     |
| Bahrain                    | 0.11 | 0.12 | 0.09 | 0.12 | 0.24 | 0.14 |                     |
| Brunei                     | 0.05 | 0.07 | 0    | 0    | 0    | 0.02 |                     |
| Cyprus                     | 0.05 | 0.04 | 0    | 0    | 0.02 | 0.02 |                     |

(Continues)
economies needed to reduce carbon dioxide emissions, with the maximum of 5.6% for Saudi Arabia, and a minimum of 0.01% in Lithuania and Australia. The largest CO₂ reduction adjustment was 5.6% in Saudi Arabia in 2014, and the smallest was 0.01% in Germany in 2011; Australia, Germany, and Slovenia in 2012; Germany in 2013; and Lithuania and Australia in 2014. According to the average adjustment range each year, the maximum value of carbon dioxide emission reduction adjustment range was 0.48% in 2011 and the minimum was 0.36% in 2013.

3.2.5 Adjustment range and improvement of crossover variable GDP

Besides the original characteristics of the data envelopment analysis method, the dynamic DEA method adds the concept of linking to the period of existence (carryover) in order to fully analyze the impact of cross-year time variables when evaluating overall efficiency. It also provides the adjustment rate during existence, which can be used as a reference for each DMU to achieve relative efficiency. The period of existence selected by this research is GDP, which is the economic basis for economies to be connected to the next year across the period. The original value of GDP, the target value of efficiency boundary, and the adjustment ratio of the carryover period of high-income economies (including China) from 2010 to 2014 are summarized as follows.

The overall average GDP of the 48 high-income economies (including China) from 2010 to 2014 was 73.62, among which the adjustment ranges in 2011 and 2012 were larger than average. Among the economies requiring adjustment, Trinidad and Tobago reached 422.92% in 2014, and France reached 0.01% in 2012. Among them, 25 economies needed to adjust their GDP in 2013, and the average adjusted value was 72.48%.

A total of 10 economies (Switzerland, Germany, United Kingdom, Italy, Luxembourg, the Netherlands, Norway, Uruguay, the United States, and China) did not need to adjust their GDP from 2010 to 2014. The remaining economies would have had to increase their GDP to achieve efficiency improvement, as shown in Table 10.

3.2.6 Slack variable analysis in high-income economies (Including China) divided by four continents

As shown in Table 11, the reduction in energy consumption in Asia is the largest at −35.53%, while that in Europe is the smallest at −11.97%. The reduction of capital stock in Asia is the largest at −40.06%, while that in Oceania is the smallest at −11.01%. The largest reduction in labor force is −20.67% in Asia, with no adjustment required in the Americas. In terms of CO₂ emission reduction, the maximum is 0.91% in Asia and the minimum is 0.10% in Europe. GDP is forecast to increase by 105.02% in the Americas (an average of 416.32% in Trinidad and Tobago) and by 5.73% in Oceania.

4 CONCLUSION AND POLICY IMPLICATIONS

This study used mainly DSBM and applied DEA-Solver Professional 9.0 software to investigate the energy and environment efficiency of high-income economies (including China) from 2010 to 2014. As sustainable economic development is increasing the demand for energy, in order to promote sustainable development on the Earth, governments will need to use social and environmental resources...
TABLE 10  The adjustment range of GDP in the period of 2010–2014

| Economies                  | 2010   | 2011   | 2012   | 2013   | 2014   | Mean   | Means by Continents |
|----------------------------|--------|--------|--------|--------|--------|--------|---------------------|
| The United States          | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Uruguay                    | 3.42   | 1.29   | 0      | 1.92   | 12.16  | 3.76   |                     |
| Canada                     | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Trinidad and Tobago        | 414.47 | 416.04 | 409.53 | 418.64 | 422.92 | 416.32 | 105.02              |
| Austria                    | 0.58   | 0      | 0.74   | 0      | 5.53   | 1.37   |                     |
| Belgium                    | 0      | 0      | 0.61   | 0      | 4.47   | 1.02   |                     |
| Swiss                      | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| The Czech Republic         | 180.77 | 205.47 | 220.72 | 227.06 | 238.15 | 214.43 |                     |
| Germany                    | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Danish                     | 0      | 12.01  | 12.51  | 10.4   | 10.58  | 9.1    |                     |
| Spain                      | 0      | 3.3    | 4.6    | 5.42   | 14.94  | 5.65   |                     |
| Estonia                    | 382.28 | 369.34 | 381.05 | 356.3  | 324.12 | 362.62 |                     |
| Finnish                    | 1.77   | 0      | 0      | 0      | 1.8    | 0.71   |                     |
| The French                 | 0      | 0      | 0.01   | 0      | 0.02   | 0.01   |                     |
| The United Kingdom         | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Greek                      | 37.21  | 67.38  | 91     | 103.48 | 113.86 | 82.59  |                     |
| Hungary                    | 191.51 | 224.62 | 247.32 | 241.61 | 239.11 | 228.83 |                     |
| The Irish                  | 18.52  | 30.4   | 32.73  | 29.15  | 23.2   | 26.8   |                     |
| Iceland                    | 0.06   | 0      | 0      | 0      | 0      | 0.01   |                     |
| The Italian                | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Lithuania                  | 343.25 | 351.75 | 342.05 | 320.72 | 314.46 | 334.45 |                     |
| Luxembourg                 | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Latvia                     | 308.41 | 275.65 | 262.4  | 248.72 | 247.46 | 268.53 |                     |
| Malta                      | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| The Netherlands, Poland    | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Norway                     | 0      | 0      | 0      | 0      | 0      | 0      |                     |
| Portugal                   | 177.54 | 170.12 | 189.31 | 183.72 | 200.58 | 184.25 |                     |
| Portugal                   | 70.8   | 92.27  | 107.44 | 107.81 | 114.06 | 98.48  |                     |
| Slovak                    | 273.78 | 307.77 | 309.42 | 300.13 | 298.65 | 297.95 |                     |
| Slovenia                   | 171.21 | 199.3  | 228.01 | 227.91 | 211.35 | 207.56 | 86.17               |
| The Swedish                | 0.15   | 4.03   | 3.32   | 0      | 3.51   | 2.2    |                     |
| Australia                  | 9.84   | 0      | 0      | 0      | 0      | 1.97   |                     |
| New Zealand                | 22.37  | 15.73  | 3.89   | 1.84   | 3.58   | 9.48   | 5.73                |
| The Arab United Nations    | 14.33  | 13.02  | 1.08   | 0      | 0      | 5.69   |                     |
| Bahrain                    | 378.47 | 385.99 | 360.22 | 349.91 | 340.58 | 363.03 |                     |
| Brunei                     | 21.75  | 0      | 0      | 0      | 0      | 4.35   |                     |
| Cyprus                     | 0      | 0      | 0      | 0      | 6.93   | 1.39   |                     |

(Continues)
more effectively to achieve the maximum output with the least input.

Based on the comprehensive analysis of the DEA model, the empirical results can be summarized as follows: (a) 12 economies (the United States, China, Uruguay, Luxembourg, Switzerland, Norway, Malta, Kuwait, Iceland, Ireland, Swiss, and United Kingdom) have an efficiency value of 1 in the past five years, implying their energy is used most efficiently in these high-income economies. (b) The results from DSBM show that 10 economies (the United States, China, Uruguay, Norway, Switzerland, United Kingdom, Italy, Luxembourg, Malta, and the Netherlands) achieved an energy efficiency value of 1 in 2010-2014, which means these economies efficiently use their resources. The average efficiency between 2010 and 2014 has an increasing trend. (c) It is found that the European average efficiency value is best, the Asian average efficiency value is the worst, the American average efficiency value is 0.7199, and the Oceanian average efficiency value is 0.7139. 4) We also find 9 economies (Switzerland, Luxembourg, Malta, the Netherlands, Norway, Uruguay, the United States, and China) do not need to adjust their inputs including energy consumption, capital, and labors. And 8 economies (Switzerland, Italy, Luxembourg, the Netherlands, Norway, Uruguay, the United States, and China) perform most efficient in using the energy consumption, capital, and labors to produce the GDP and undesirable output CO₂.

Therefore, first, it can be conducted that China, the United Kingdom, Italy, Luxembourg, Malta, the Netherlands, Norway, Uruguay, the United States, and Switzerland, all of which have efficient energy use, can continue to control emission reduction in accordance with the original energy use planning policy. Second, there are 10 economies (the United Arab Emirates, Canada, the Czech Republic, Israel, South Korea, Kuwait, Poland, Qatar, Saudi Arabia, and Taiwan) should decrease waste in their resources, and also need to strengthen the management of carbon dioxide emission reduction and management policies; formulate various industrial initiatives such as carbon dioxide emissions cap regulations; levy pollution taxes on the lock industry, metal manufacturing, mining, and other chemical industries; widen promotion of energy saving to households to encourage investing in energy-saving equipment; emphasize energy efficiency to reduce emissions; and generally reduce sources of pollution emission to effectively implement policies to reduce carbon dioxide pollution. Third, 14 high-income economies (the United Arab Emirates,
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3. Kahsai MS, Nondo C, Schaeffer PV, Gebremedhin TG. Income and Tobago, and Taiwan) should strengthen efforts to reduce energy consumption and encourage development of the energy industry to improve energy efficiency, then lock in an effective energy development mode and promote continuing to reduce energy consumption and improve the ratio of energy use, to achieve the purpose of reducing energy consumption, while reducing carbon dioxide emissions at the same time.

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