The continuous growth of energy consumption, particularly from fossil fuels, has promoted economic development, but has also caused excessive greenhouse gas emissions.¹ Fossil fuels account for approximately 95% CO₂ emissions.² 

According to the Intergovernmental Panel on Climate Change reports, CO₂ emissions have increased by 2.0 ppm per year since 2001, and if this current rate continues, the earth’s temperature might rise by more than 1.5°C from 2030 to 2052.³ Therefore, European Union (EU) try to optimize the energy consumption structure and improving the energy efficiency.
in order to reduce greenhouse gas emissions. Forests can play a significant role in this aspect by carbon sequestration because they can offset greenhouse gas emissions.\(^4\)

The concept of Europe sustainable forest management in the theme of forest protection pan-European ministerial meeting to be formally defined in 1993: Namely, we should manage and use the forest land in an appropriate manner and degree. Maintaining biodiversity, forest productivity, regeneration, vitality, from the regional, national, and global level to keep the forest to meet current and future related ecological, economic, and social functions, and no other ecosystem damage.\(^5–7\) The parties to the convention held by Conference of the Parties have met annually from 1995 to assess progress in dealing with the climate change and energy consumption. These conferences also paid more attention to the size of the forestry area.\(^8\) In 2015, the Paris Agreement planned to limit the global temperature to 1.5\(^{\circ}\)C above pre-industrial levels, further highlighting the importance of forestry areas in absorbing greenhouse gases.

To achieve sustainable development, the EU countries attempt to reduce energy consumption while maintaining steady economic growth. The EU countries’ environment has been well protected by the environmental law. As early as 1990, EU countries began increasing their forestry areas.\(^9\) Since 1990, forests have grown in all regions of Europe, and Europe is the only region in the world with a sustained net increase in forest area over the past 20 years. Europe has seen a net increase in forest area of 5.1 million hectares since 2005 and 16.69 million hectares since 1990. In Europe, the volume of trees in 2010 reached 96.252 billion cubic meters, of which 21.75 billion cubic meters were produced in the 27 EU countries. As shown in Figure 1, the average forestry area increased yearly from 2009 to 2016. The Paris Agreement incorporated the stipulations for reducing deforestation and preventing forest degradation. Plants can absorb carbon dioxide, emit oxygen through photosynthesis during their growth, and store carbon dioxide in the atmosphere in vegetation and soil. Therefore, the increase in forest areas can enhance carbon storage in certain regions and improve energy efficiency. This study evaluates the impact of forestry areas on the annual and overall energy efficiency of 28 EU countries.

To create the maximum output with the least input, the data envelopment analysis (DEA), a linear programming model first introduced by Charnes et al.\(^10\) is mainly used as a measurement for evaluating the relative efficiencies of decision-making units (DMUs) with different inputs and outputs over a certain period. It is further applied in the environmental and energy efficiency.\(^11–18\) Most previous studies devised traditional DEA models to calculate the energy efficiency in different areas. For example, Ramanathan\(^19\) adopted the DEA method to study the linkage among GDP growth, energy consumption, and \(\text{CO}_2\) emissions simultaneously. The DEA analytical framework is used to find the energy-saving target for APEC economies without reducing their maximum potential gross domestic productions (GDPs) from 1991 to 2000.\(^20\) Additionally, some scholars utilize the nonradial DEA approach and the Malmquist index to measure macroeconomic performance and environmental efficiency.\(^21,22\) However, the above studies do not consider the impact of carry-over variables that change over time, and this could lead to bias and inefficiency if we assume static optimization; therefore, long-term quasi-fixed input might not be allocated effectively or might not reach the optimal level.\(^23\) In addition, when we try to analyze overall efficiency by combining some periods with intertemporal effects, we need to consider the dynamic interrelationship of consecutive periods.\(^24\)

Several scholars made great contributions to the formation and rapid development of the dynamic DEA model. Sengupta\(^25\) developed a dynamic DEA model and introduced the adjustment cost method. This approach can analyze the fluctuations of the output and risk on the dynamic production frontier while including the shadow value of quasi-fixed inputs and their optimal paths into an analytic linear programming problem. Färe and Grosskopf\(^26\) proposed a dynamic DEA model, which can formulate different intertemporal input and output variables into a realistic multi-output production process across consecutive periods. Subsequently, various types of research utilized the dynamic DEA model to measure the panel data efficiency.\(^27–34\) Dritsaki and Dritsaki\(^35\) studied the causal relationship between energy consumption, economic growth, and \(\text{CO}_2\) emissions based on a dynamic DEA approach. Ton and Tsutsui\(^36\) use carry-over variables as the linkage to construct a slacks-based measure that can assess

![Figure 1](image-url) 

**Figure 1** The average forestry area of EU countries from 2009 to 2015.
period efficiency and overall efficiency separately. Tihana then collected quarterly data from the Zagreb Stock Exchange from April 2009 to June 2012 and analyzed the relative efficiency of stocks using a dynamic slacks-based model.

In previous studies, labor force, capital stock, and energy consumption were used as input variables, and CO$_2$ as output variable. In terms of the characteristics of carry-overs, we use the real GDP as the desirable carry-over in this paper, so that the corresponding profits carry GDP forward to the next period. As we mentioned above, all governments of European countries need to reduce the carbon dioxide emissions while pursuing economic growth. The performance of real GDP in one term will exert an influence on energy efficiency in the next term. In addition, most of the studies mentioned above focus on short-term efficiency of DMUs. Scholars such as Klopp and Färe et al. even though these models include the efficiency of time change, the carry-over function between two consecutive time periods is often excluded because the models mainly concentrate on a single term and achieve the goal of optimization in a single period. To achieve stability, governments and corporations usually make long-term plans for economic and business growth. Färe and Grosskopf first showed several intertemporal models and laid a solid foundation for the subsequent development of dynamic DEA measures, then they applied the dynamic conditions of production in the traditional DEA model. Since then, Kao, Cheng et al. and Tone and Tsutsui assimilated an SBM into a dynamic DEA.

The above model is nonoriented: It can handle inputs and outputs separately. Nonuniform distributed input and output variables can be processed by the SBM measure, and the weight of each variable is based on its degree of importance in this model. There are four different types of carry-over activities: (a) desirable (good), (b) undesirable (bad), (c) discretionary (free), and (d) nondiscretionary (fixed), which are the foundation of evaluation in the dynamic DEA model. To find optimal solutions using the SBM model, variables in the DEA model can be divided into three categories: input, output, and nonoriented factors.

Considering the feature of carry-over variables, we view real GDP as a desirable carry-over, which is similar to the profit of GDP carried forward to the next period. This study mainly focuses on the key point that governments in the EU countries must consider when reducing CO$_2$ emissions and increasing forestry areas for a sustainable and stable economic growth. Because GDP results in one period can have an impact on the energy efficiency in the next period, we use a nonoriented SBM dynamic DEA model to assess the period and overall efficiency of DMUs.

The methodology of this research is derived from the extant literature. For instance, there are $j$ DMUs $(j = 1, \ldots, n)$ in period $t (t = 1, \ldots, T)$; each DMU has multiple inputs and multiple outputs over period $t$; there is also a carry-over (link) in period $t$, which is used as a linkage to the next period $t + 1$. Figure 2 shows the process of analysis in this study. The model of this research sets up $n$ DMUs $(j = 1, \ldots, N)$ over period $t$, and each DMU has three inputs and two outputs in each period. Real GDP, which belongs to a good link, is viewed as the carry-over from period $t$ to period $t + 1$.

The nonoriented model is as follows:

\[
\rho_0^* = \min \left\{ \frac{1}{T} + \sum_{t=1}^{T} W_t \left[ 1 + \frac{1}{s_{i_{\text{good}}}} \left( \sum_{m=1}^{m_{\text{good}}} \frac{w_{i_{\text{good}}}^s z_{i_{\text{good}}}^s}{s_{i_{\text{good}}}} + \sum_{m=1}^{m_{\text{nbad}}} \frac{w_{i_{\text{bad}}}^s z_{i_{\text{bad}}}^s}{s_{i_{\text{bad}}}} \right) \right] \right\}
\]

\[
\sum_{j=1}^{n} z_{q_t j}^s A_t^s = \sum_{j=1}^{n} z_{q_t j}^s A_t^s + 1 \quad (\forall i; t = 1, \ldots, T - 1)
\]
Equation (2) expresses the relationship between period $t$ and period $t + 1$:

$$x_{it} = \sum_{j=1}^{n} x_{ij} \lambda_j^t + s^-_it \quad (i = 1, \ldots, m; t = 1, \ldots, T)$$

$$y_{it} = \sum_{j=1}^{n} y_{ij} \lambda_j^t - s^+_it \quad (i = 1, \ldots, s; t = 1, \ldots, T)$$

$$x_{good}^{it} = \sum_{j=1}^{n} x_{good}^{ij} \lambda_j^t - s^{good}_it \quad (i = 1, \ldots, n; t = 1, \ldots, T)$$

where $n$ DMUs $(j = 1, \ldots, n)$ are set over period $t$ $(t = 1, \ldots, T)$. $\lambda_j^t$ is a nondiscretionary (fixed) input variable.

The most efficient solution is shown in Equation (4):

$$\rho_{it} = \frac{1 - \frac{1}{m} \left( \sum_{i=1}^{m} \frac{w^-_i s^-_{iit}}{x_{iit}} \right)}{1 + \frac{1}{s + ngood} \left( \sum_{i=1}^{s} \frac{w^+_i s^+_{iit}}{y_{iit}} + \sum_{i=1}^{ngood} \frac{s^{good}_{iit}}{y_{iit}} \right)} \quad (i = 1, \ldots, T)$$

where $m$ inputs $(i = 1, \ldots, m)$ of the DMUs in the process. $P$ represents nondiscretionary (fixed) inputs. $S$, multiple outputs $(i = 1, \ldots, s)$; $Z$, four types of links (carry-over), such as good, bad, free, and fixed, and $w$ is the weight of the input and output variables, depending on their degree of importance.

3 | RESULTS

In this section, we first introduce the data sources and variables. Thereafter, we analyze the empirical results and provide the predicted adjustment range of each variable.
| Variable (unit)                      | Ave  | Max  | Min  | St. dev |
|-------------------------------------|------|------|------|---------|
| Capital stock (million dollars)     | 123962 | 792030 | 1656 | 183782 |
| Labor force (thousand people)       | 8759.88 | 43294.64 | 172.24 | 11201.46 |
| Total energy consumption (thousand metric tons) | 2446 | 23088 | 24 | 4134 |
| CO₂ emissions (thousand metric tons) | 689976 | 942783 | 1420 | 190494 |
| Forestry area (square kilometers)   | 57194 | 281020 | 4 | 71759 |
| Real GDP (million dollars)          | 6121913 | 3890607 | 8528 | 942377 |

**TABLE 2** Descriptive statistics

**TABLE 3** Energy efficiency value of 28 countries without forestry area for 2009-2016

| Countries          | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Overall efficiency | Rank |
|--------------------|------|------|------|------|------|------|------|------|-------------------|------|
| United Kingdom     | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1                 | 1    |
| Sweden             | 0.9991 | 0.9996 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9996 | 0.9997 | 7    |
| Spain              | 0.7693 | 0.8250 | 0.9073 | 0.8701 | 0.8321 | 0.8630 | 0.7559 | 0.7067 | 0.8147 | 13   |
| Slovenia           | 0.6247 | 1    | 0.7126 | 0.8324 | 0.8257 | 0.7855 | 0.6626 | 0.7024 | 0.7680 | 15   |
| Slovak           | 0.3856 | 0.3786 | 0.3751 | 0.4313 | 0.4243 | 0.4274 | 0.3943 | 0.4336 | 0.4063 | 26   |
| Romania           | 0.3839 | 0.4042 | 0.3713 | 0.3941 | 0.4059 | 0.4202 | 0.4732 | 0.4575 | 0.4136 | 25   |
| Portugal          | 0.5081 | 0.5725 | 0.6815 | 0.9988 | 0.9972 | 0.9896 | 0.7051 | 0.7546 | 0.7751 | 14   |
| Poland            | 0.3102 | 0.2986 | 0.2953 | 0.3192 | 0.3404 | 0.3323 | 0.3289 | 0.3243 | 0.3185 | 28   |
| The Netherlands   | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9974 | 0.9348 | 10   |
| Malta             | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1                 | 1    |
| Luxembourg        | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1                 | 1    |
| Lithuania         | 1    | 0.5714 | 0.4668 | 0.4631 | 0.4268 | 0.4428 | 0.4175 | 0.5527 | 0.5420 | 21   |
| Latvia            | 0.4544 | 1    | 0.9999 | 0.4547 | 0.4420 | 0.4503 | 0.4827 | 0.5968 | 0.6089 | 19   |
| Italy             | 0.9999 | 0.9999 | 0.9999 | 1    | 1    | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 5    |
| Ireland           | 0.7307 | 1    | 1    | 0.7914 | 0.8065 | 0.7973 | 1    | 0.9999 | 0.8903 | 11   |
| Hungary           | 0.5251 | 0.5185 | 0.5278 | 0.6038 | 0.4848 | 0.4505 | 0.4428 | 0.4958 | 0.5060 | 22   |
| Greece            | 0.6127 | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0.9501 | 9    |
| Germany           | 0.9843 | 0.9837 | 0.9834 | 0.9843 | 0.9818 | 0.9828 | 0.9710 | 0.9669 | 0.9797 | 8    |
| France            | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 5    |
| Finland           | 0.6921 | 0.6650 | 0.6582 | 0.6643 | 0.6832 | 0.6942 | 0.6466 | 0.6534 | 0.6696 | 17   |
| Estonia           | 0.5423 | 0.6243 | 0.5152 | 0.5393 | 0.5376 | 0.4990 | 0.6414 | 0.5969 | 0.5626 | 20   |
| Denmark           | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1                 | 1    |
| Czech             | 0.3934 | 0.4119 | 0.4251 | 0.4090 | 0.4294 | 0.4251 | 0.4013 | 0.4265 | 0.4153 | 24   |
| Cyprus            | 0.5380 | 0.6546 | 0.6801 | 1    | 1    | 1    | 1    | 1    | 0.8588 | 12   |
| Croatia           | 0.3742 | 0.5775 | 0.5381 | 0.5067 | 0.5493 | 0.5501 | 0.4613 | 0.4711 | 0.5034 | 23   |
| Bulgaria          | 0.2484 | 0.3231 | 0.3675 | 0.3437 | 0.3633 | 0.3507 | 0.3387 | 0.3633 | 0.3374 | 27   |
| Belgium           | 0.9988 | 0.7286 | 0.7640 | 0.7242 | 0.7161 | 0.6917 | 0.6509 | 0.6829 | 0.7436 | 16   |
| Austria           | 0.6538 | 0.6548 | 0.6474 | 0.6341 | 0.6340 | 0.6387 | 0.6243 | 0.6458 | 0.6416 | 18   |
| Average           | 0.7046 | 0.7568 | 0.7470 | 0.7487 | 0.7457 | 0.7425 | 0.7185 | 0.7362 | 0.7371 | 0.7377 |
in Malta in 2011. Second, for the output variables, the average CO₂ emissions are 689,976 thousand tons. The highest amount of CO₂ emissions is in Germany, at 942,783 thousand tons in 2015, and the lowest amount of CO₂ emission is in Malta at 142,0 thousand tons in 2016. The average forestry area is 57,194 square kilometers. The maximum value is in Sweden at 281,020 square kilometers in 2009, and the minimum value is in Malta at nearly 4 square kilometers. The average GDP decreased by 3.56% from 2009 to 2016, which is a total average of 6,121,913, and Germany had the highest GDP at 3,890,607 million dollars in 2014, with Malta having the lowest GDP at 852,8 million dollars in 2009.

The results show a large gap in economic development and social scale among the countries. Compared with other EU countries, Germany has a faster economic development and a larger job market. The values of capital stock, labor force, and GDP in Germany are the highest, but CO₂ emissions remain high. Therefore, the German government should adjust its policies to control CO₂ emissions. Malta is the smallest state in the EU with the lowest value of variables.

### 3.2 Empirical results

In this section, we adopt a nonoriented dynamic SBM model to analyze the overall energy efficiency and the impact of forestry area on energy efficiency. Moreover, we also suggest improvements in each country based on the results of the adjustment range.

| Countries     | Term efficiency | Overall efficiency | Rank |
|---------------|-----------------|--------------------|------|
|               | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  |       |       |
| United Kingdom| 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |
| Sweden        | 0.9999| 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |
| Spain         | 0.7642| 0.999 | 0.9999| 1     | 1     | 0.9999| 0.9999| 0.9962| 0.9681| 13    |
| Slovenia      | 0.6980| 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0.9573| 14    |
| Slovakia      | 0.2824| 0.2719| 0.2812| 0.3509| 0.3040| 0.2942| 0.3426| 0.3805| 0.3131| 24    |
| Romania       | 0.4242| 0.5222| 0.4395| 0.4756| 0.4702| 0.4820| 0.6808| 0.6816| 0.5083| 19    |
| Portugal      | 0.2616| 0.2595| 0.9653| 0.9995| 0.9979| 0.9959| 0.6416| 0.7736| 0.6148| 17    |
| Poland        | 0.2488| 0.9994| 0.664  | 0.2721| 0.2958| 0.2795| 0.2871| 0.2976| 0.2750| 25    |
| The Netherlands| 0.9979| 1     | 0.9983| 0.9994| 0.9978| 0.9990| 0.0721| 0.0519| 0.2190| 27    |
| Malta         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Luxembourg    | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Lithuania     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0.5598| 0.6232| 0.6692| 0.8431| 16    |
| Latvia        | 1     | 0.9999| 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Italy         | 0.9999| 0.9986| 0.9999| 1     | 1     | 1     | 1     | 0.9999| 0.9999| 0.9999| 10    |
| Ireland       | 0.2064| 0.3705| 1     | 0.2249| 0.4052| 0.9984| 1     | 0.9999| 0.5011| 20    |
| Hungary       | 0.3543| 1     | 0.4467| 0.5625| 0.3178| 0.2757| 0.3588| 0.4489| 0.3784| 22    |
| Greece        | 0.3714| 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0.8503| 15    |
| Germany       | 0.9895| 0.9891| 0.9889| 0.9895| 0.9878| 0.9885| 0.9816| 0.9786| 0.9867| 12    |
| France        | 0.9999| 0.9999| 0.9999| 0.9999| 0.9999| 0.9999| 0.9999|       |       | 10    |
| Finland       | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Estonia       | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Denmark       | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Czech         | 0.1932| 0.2267| 0.2361| 0.2143| 0.2186| 0.2165| 0.2870| 0.3001| 0.2341| 26    |
| Cyprus        | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |       |
| Croatia       | 0.3753| 0.4610| 0.5574| 0.5892| 0.5372| 0.5524| 0.6242| 0.6333| 0.5258| 18    |
| Bulgaria      | 0.3590| 0.4323| 0.5090| 0.4450| 0.4477| 0.4383| 0.5193| 0.5193| 0.4577| 21    |
| Belgium       | 0.9966| 0.2127| 0.1536| 0.0681| 0.0706| 0.0615| 0.0627| 0.0643| 0.0906| 28    |
| Austria       | 0.3546| 0.5708| 0.3183| 0.2876| 0.2921| 0.2883| 0.3019| 0.3140| 0.3224| 23    |
| Average       | 0.7099| 0.7724| 0.7914| 0.7671| 0.7622| 0.7654| 0.7422| 0.7539| 0.7159| 0.7581|
3.2.1 | Energy efficiency analysis

The Paris Agreement explicitly emphasizes the role of forests in absorbing greenhouse gases or increasing carbon stocks. Most previous studies have, however, evaluated the energy efficiency without considering the forestry area; hence, their empirical results may lack objectivity and the energy efficiency of each EU country may be underestimated or overestimated. We first adopt dynamic SBM nonoriented model to assess the countries’ energy efficiency value by DEA-Solver software without using forestry area as the output variable.

Table 3 displays term and overall efficiencies without forestry area as the output variable for 2009-2016. The average overall efficiency is 0.7377. From the efficiency of each year, the average energy efficiency is stable between 7.00 and 7.60; nonetheless, the energy consumption and energy efficiency can still be reduced and improved significantly, respectively. The overall efficiency values of the United Kingdom, Malta, Luxembourg, and Denmark are 1; they fall on the efficient frontier. The overall efficiency values of Sweden, Italy, and France are approximately 1, indicating that these countries have done an excellent job in the period of focus. There are 12 countries that perform well: Their energy values are higher than 0.7, but lower than 1. Slovenia is among them; it performed well in 2010, 2012, and 2013 at 1, 0.8324, and 0.8257, respectively. The country's overall efficiency value is 1, but it was below 0.7 in 2009 and 2015, indicating possible unstable factors in 2009 and 2015. Portugal has done badly in 2009, with an energy efficiency value of only 0.5081. Since then, its value has increased gradually until 2014, although the values of 2015 and 2016 are close to 0.7, which means that the Portuguese government had taken effective measures in improving energy efficiency. The remaining 12 countries did not perform well in terms of the overall efficiency value, which are all below 0.7. In particular, Slovakia, Romania, Poland, and Bulgaria did the worst job among the rest of the 12 countries, with overall efficiency values below 0.5. This means that there was no significant improvement in 8 years for these four countries. Therefore, they have large room to adjust their policies and take measures to improve energy efficiency in the future.

Using forestry area as the output variable in the evaluation, Table 4 shows the estimated results of the adjusted energy efficiency with the average overall efficiency value of 0.7581. The energy efficiency value without the forestry area in the analysis is relatively smaller: This signifies a lack of objectivity and possible underestimation. However, countries such as the United Kingdom, Sweden, Malta, Denmark, Italy, France, and Luxembourg—with an energy efficiency value of 1—show that the forestry area has no impact on their original values. The original energy efficiency values of four countries, including Latvia, Finland, Estonia, and Cyprus, are all much less than 1, but their values become 1 after adding the forestry area to the output, implying there has been a marked increase in energy efficiency. After including the forestry area, several countries such as Slovakia, Portugal, Poland, the Netherlands Ireland, Hungary, Greece, the Czech Republic, Belgium, and Austria changed from high to low energy efficiency. The energy efficiency value of Belgium, one of the most underestimated countries, fell by 680.35% during from 2009 to 2016. There are also 10 countries (Spain, Slovenia, Lithuania, Latvia, Germany, Finland, Estonia, Cyprus, Croatia, and Bulgaria) whose average energy efficiency values change from high to low efficiency. Estonia is the most underestimated country because its average overall efficiency value had risen by 43.80%. In terms of energy efficiency measured by the included forestry area, the countries with an efficiency value of 1 (best energy efficiency) in each year from 2009 to 2016 include Cyprus, Denmark, Estonia, Finland, Latvia, Luxembourg, Malta, and the United Kingdom. Additionally, Belgium, the Czech Republic, and Poland are in the bottom five for energy efficiency, making them the least energy-efficient countries.

In sum, when the results in Tables 3 and 4 are compared, the average of total energy efficiency without forestry area is 0.738 and that with forestry area is 0.758, highlighting the assessment of energy efficiency without forestry area is lack of objectivity. Among the 28 European countries, only four countries’ energy efficiency value is 1, such as the United Kingdom, Malta, Luxembourg, and Denmark, and even the forestry area does not have influence on them. France’s rank remains unchanged in these two different results. The countries that changed from high energy efficiency to low energy efficiency are as follows: Austria, Belgium, Czech, Greece, Hungary, Ireland, the Netherlands, Poland, Portugal, Slovakia, wherein the average energy efficiency value of Austria falls from 0.6416 to 0.3224 after considering the forestry area into the output variables. The value of Belgium falls from 0.8903 to 0.5011, the value of Ireland falls from 0.8903 to 0.5011, and the value of the Netherlands falls from 0.9348 to 0.2190; these four countries have the huge shift from high energy efficiency to low energy efficiency.

There are twelve countries that change from low energy efficiency to high energy efficiency, such as Bulgaria, Croatia, Cyprus, Estonia, Finland, Germany, Latvia, Lithuania, Romania, Slovenia, Spain, and Sweden, wherein Cyprus, Estonia, Finland, Latvia, and Sweden have significant increase after taking the forestry area into account, and their energy efficiency rise from 0.8588, 0.5626, 0.6698 and 0.6089 all to 1, respectively.
### 3.2.2 Adjustment range analysis

Table 5 lists the predicted adjustment range average for the input and output variables. The adjustment range presents the difference of prediction on the efficient frontier, explained by input and output variables. The input or output should be added if the adjustment range is greater than 0, reduced if less than 0, and constant if equal to 0.

As indicated by Table 5, the overall average of the capital stock should be reduced by 1.79%. However, the United Kingdom, Sweden, the Netherlands, Malta, Luxembourg, Latvia, Italy, Germany, France, Finland, Estonia, Denmark, and Cyprus do not need to adjust their capital stock. Slovakia, Romania, and Czech have average adjustment ranges of the capital stock that are at the bottom three of the 28 countries. Hence, Slovak, Romania, and Czech should reduce capital stock by 4.20%, 11.34%, and 14.36%, respectively. For the labor force, the overall average adjustment range should be reduced by 18.13%. However, the United Kingdom, Sweden, the Netherlands, Malta, Luxembourg, Latvia, Italy, Germany, France, Finland, Estonia, Denmark, and Cyprus need no change. The countries whose adjustment ratios need to be greater than the average adjustment range each year are Slovakia, Romania, Poland, Hungary, Czech, Croatia, and Bulgaria; their adjustment ranges are −56.84%, −78.32%, −70.11%, −57.51%, −54.04%, and −75.06%, respectively. All countries need to reduce the total energy consumption by 15.3%. The adjustment range of 0 indicates that no adjustment is needed. In addition, the adjustment ranges of Slovak, Poland, Bulgaria, and Austria are −53.41%, −92.07%, −77.64, and −43.00, respectively, implying that they can improve energy efficiency.

#### Table 5 The average adjustment range of input variables and output variables

| Adjustment range | Capital stock | Labor force | Total energy consumption | CO₂ emissions | Forestry area |
|------------------|---------------|-------------|--------------------------|---------------|---------------|
| United Kingdom   | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Sweden           | 0.00          | 0.00        | 0.00                     | 0.01          | 0.00          |
| Spain            | −2.84         | −2.99       | −0.97                    | 0.02          | 2.86          |
| Slovenia         | −1.71         | −5.65       | 0.00                     | 0.10          | 5.58          |
| Slovakia         | −4.20         | −56.84      | −53.41                   | 1.63          | 290.35        |
| Romania          | −11.34        | −78.32      | −5.34                    | 6.75          | 92.19         |
| Portugal         | −0.07         | −21.92      | −10.51                   | 0.05          | 134.78        |
| Poland           | −1.31         | −70.11      | −92.07                   | 50.58         | 145.34        |
| The Netherlands  | 0.00          | 0.00        | −8.95                    | 2.33          | 1025.81       |
| Malta            | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Luxembourg       | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Lithuania        | 0.00          | −11.34      | −18.71                   | 0.11          | 19.84         |
| Latvia           | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Italy            | 0.00          | 0.00        | 0.00                     | 0.01          | 0.01          |
| Ireland          | −0.36         | −0.01       | −15.51                   | 0.01          | 266.86        |
| Hungary          | −1.34         | −65.64      | −3.73                    | 2.57          | 302.41        |
| Greece           | 0.00          | −2.54       | −4.48                    | 0.59          | 43.97         |
| Germany          | 0.00          | 0.00        | 0.00                     | 4.06          | 0.00          |
| France           | 0.00          | 0.00        | 0.00                     | 0.02          | 0.01          |
| Finland          | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Estonia          | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Denmark          | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Czech            | −14.36        | −57.51      | −24.12                   | 9.61          | 557.96        |
| Cyprus           | 0.00          | 0.00        | 0.00                     | 0.00          | 0.00          |
| Croatia          | −2.64         | −54.04      | −36.79                   | 0.51          | 90.72         |
| Bulgaria         | −3.13         | −75.06      | −77.64                   | 4.46          | 8.22          |
| Belgium          | −3.39         | −0.77       | −33.23                   | 5.18          | 2592.80       |
| Austria          | −3.41         | −4.91       | −43.00                   | 1.69          | 467.18        |
| Average          | −1.79         | −18.13      | −15.30                   | 3.22          | 215.96        |

*Note: Unit (%).*
consumption significantly. For CO₂ emissions, the adjustment ranges of the United Kingdom, Malta, Luxembourg, Latvia, Finland, Estonia, Denmark, and Cyprus are all 0: no need to reduce CO₂ emissions. The rest of the 19 countries have a tiny room for improvement, except Poland, whose adjustment range can reach about 51%, indicating that CO₂ emissions should be reduced significantly. The overall average forestry area should increase by 215.96% from 2009 to 2016. Ten countries with a value of 0 do not need adjustments, while the remaining need major adjustments in the forestry area. In particular, the average adjustment ranges of Belgium, the Netherlands, and Czech Republic are even as high as 2592.80%, 1025.81%, and 557.96%, respectively, implying that they have to strengthen environmental protection and increase the area covered by varieties of green vegetation.

Using forestry area as the output, we found that the top 3 energy inefficient countries are Belgium, the Netherlands, and Czech Republic. By contrast, forestry area has the greatest impact on energy efficiency; therefore, increasing the forestry area can increase energy efficiency. In addition, adjusting the labor force allocation, reducing energy consumption, and controlling CO₂ emissions can improve energy efficiency.

Based on the dynamic DEA model, we use GDP as the carry-over to determine the relationship between input and output variables. We then present the adjustment range of carry-over in Table 6. The overall average adjustment range of carry-over is 0.67, implying that the countries will need only a slight increase of 0.67% in GDP. More than half of these countries did not need GDP adjustments because the value of average adjustment range was 0. With

| Adjustment range | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Average |
|------------------|------|------|------|------|------|------|------|------|---------|
| United Kingdom   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Sweden           | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Spain            | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Slovenia         | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Slovakia         | 2.03 | 0    | 0.62 | 1.16 | 0.87 | 0    | 0    | 0.21 | 0.61    |
| Romania          | 5.2  | 7.98 | 7.78 | 8.68 | 2.57 | 0    | 3.12 | 0    | 4.42    |
| Portugal         | 0    | 0    | 0.02 | 0.02 | 0    | 0    | 2.31 | 0    | 0.29    |
| Poland           | 0.47 | 0    | 0    | 0.62 | 0    | 0    | 2.07 | 0    | 0.40    |
| The Netherlands  | 0    | 0    | 0    | 0    | 0    | 0    | 6.44 | 0    | 0.81    |
| Malta            | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Luxembourg       | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Lithuania        | 0    | 0    | 0    | 0    | 0    | 0    | 1.85 | 0    | 0.23    |
| Latvia           | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Italy            | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Ireland          | -0.03| 0    | 0    | 1.13 | 0    | 0    | 0    | 0    | 0.14    |
| Hungary          | 1.18 | 0    | 0    | 3.78 | 2.26 | 0    | 0.34 | 0    | 0.95    |
| Greece           | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Germany          | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| France           | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Finland          | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Estonia          | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Denmark          | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Czech Republic   | 2.12 | 0    | 0.51 | 3.66 | 8    | 9.96 | 4.35 | 2.54 | 3.89    |
| Cyprus           | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |
| Croatia          | 0    | 0.42 | 1.41 | 2.05 | 1.86 | 2.62 | 3.12 | 0.86 | 1.54    |
| Bulgaria         | 3.6  | 4.86 | 0    | 0.34 | 2.34 | 3    | 4.12 | 0    | 2.28    |
| Belgium          | 0    | 0    | 0.3  | 1.48 | 2.63 | 0    | 0.86 | 0.48 | 0.72    |
| Austria          | 0    | 1.76 | 2.99 | 3.98 | 5.03 | 1.81 | 1.65 | 1.99 | 2.40    |
| Average          | 0.52 | 0.54 | 0.49 | 0.96 | 0.91 | 0.62 | 1.08 | 0.22 | 0.67    |
the exception of Romania and the Czech Republic, the remaining 11 countries have adjustment ranges very close to 0, meaning no significant GDP adjustments are needed. Romania has the highest adjustment range, with an average value of 4.42% in the given period. The adjustment ranges were higher than the overall average during 2010-2012, while the values in each year were 7.98, 7.78, and 8.68, respectively. The Czech Republic reached 8% and 9.96% in 2013 and 2014, respectively, with values that are higher than the overall average. Compared with other input and output variables, the GDP has a small effect on energy efficiency.

4 | DISCUSSION

Previous studies on energy efficiency have not considered the impact of forestry areas until the 2015 Paris Agreement further highlighted the importance of forestry areas in absorbing greenhouse gases and reducing CO₂ emissions. These areas should be considered when measuring the objectivity of the assessment process and accurately determining energy efficiency. We therefore listed forestry area as one of the output variables. As a result, the energy efficiency value in each year increases slightly.

The overall capital stock and energy consumption declined, and the overall labor force and forestry area increased, whereas the overall GDP declined continuously. In 2009, the overall CO₂ emissions declined, whereas the actual CO₂ emissions rose by 3.41% in 2016. In addition, the energy efficiency reached the average level only from 2010 to 2014. Consequently, the overall energy consumption decreased, while CO₂ emissions did not decline. According to the estimated results above, only four countries have a consistent energy efficiency score of 1 before and after taking the forestry area into account. For the United Kingdom, Malta, Luxembourg, and Denmark, they do not have to make many adjustments. These four countries should maintain the current level of management of forestry area and carbon dioxide emissions and increased the stability of economic development. For the countries that change from high energy efficiency to low energy efficiency after considering the forestry area, such as Austria, Belgium, Czech, Greece, Hungary, Ireland, the Netherlands, Poland, Portugal, and Slovakia, indicating that there had been no significant increase in the forestry area in these ten countries, these countries need to make appropriate adjustments to their environmental protection strategies and managements, and effectively increase the forestry area gradually. On the other hand, for the countries that change from low energy efficiency to high energy efficiency, such as Bulgaria, Croatia, Cyprus, Estonia, Finland, Germany, Latvia, Lithuania, Romania, Slovenia, Spain, and Sweden, it indicates that these countries did have better performance of forest protection and management during the sample period. As a whole, carbon dioxide emissions had increased considerably from 2009 to 2016, the European countries therefore should further strengthen the limitation and control on carbon dioxide emissions, and continue to enhance the use of renewable energy. In addition, all the 28 European countries should improve economic exchanges between countries in order to promote the future development of their own economy.

This study also shows the difficulty of achieving the goal of the Paris Agreement. For instance, Germany has the biggest economy, but remains the largest emitter of CO₂. Thus, although its CO₂ is declining slightly, it is more likely to fall short of the Paris Agreement’s targets, the same problem other countries face.

5 | CONCLUSION

To effectively reduce CO₂ emissions and reduce the average temperature to 1.5°C, the 2015 Paris Agreement has emphasized the significance of maintaining and increasing forestry areas. Therefore, this study explores the impact of forestry area on energy efficiency in 28 EU countries. We used DEA-Solver software to assess energy efficiency using a nonoriented dynamic SBM model. Capital stock, labor force, and total energy consumption are the input variables; CO₂ emissions and forestry area are output variables; and GDP is a carry-over variable.

Our results show that an inclusion of forestry area triggered a small increase in annual and overall energy efficiency. However, energy efficiency reached the average level only from 2010 to 2014. Although the overall energy consumption gradually decreased, CO₂ emissions remained problematic. The GDP has also declined; thus, energy efficiency remains a challenge in EU countries.

CO₂ emissions are projected to be reduced by 30% until 2030, which is the target of the Paris Agreement. However, as our study suggests, it will be difficult for the 28 EU countries to reach this target if additional measures are not taken. The EU should take further measures to increase forestry area, adjust labor force, and change energy consumption from fossil energy to renewable energy to reduce CO₂ emissions. In addition, we suggest a longer duration for future research to observe the trend of all variables and include additional inputs and outputs from other databases. Time series analysis can be used in further studies.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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