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# Link between Energy Efficiency and Sustainable Economic and Financial Development in OECD Countries

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**Abstract:** The growing risk of climate change caused by the emission of greenhouse gases poses new challenges to contemporary countries. The development of economies is usually related to increasing levels of greenhouse gas emissions. Therefore, the question arises whether it is possible to achieve sustainable economic and financial development and simultaneously reduce greenhouse gas emissions. This paper assumes it is possible if energy efficiency is increased. The aim of the paper is to show the link between energy efficiency and sustainable economic and financial development in Organisation for Economic Co-operation and Development (OECD) countries for the period 2000–2018 by using data envelopment analysis (DEA) and regression analysis. The results show a slight upward trend of total factor energy efficiency (TFEE) in OECD countries for the analysed period; however, there is a difference in TFEE levels. Developed OECD countries have higher TFEE levels than developing OECD countries. The links between total factor energy efficiency and sustainable economic and financial development reveal different impacts depending on the variables taken into consideration.

**Keywords:** energy efficiency; sustainable economic development; sustainable financial development; DEA; regression

## 1. Introduction

Energy consumption and greenhouse gas (GHG) emissions are rising along with increasing production. Energy consumption and demand are continually growing, and most of the energy is obtained from non-renewable resources. Energy is essential for an economy because it represents a production input in various industries and sectors, but also affects sustainable development. According to the Organisation for Economic Co-operation and Development (OECD) [1], the world economy will be much larger in 2050 than today and will increase energy consumption by 80%. Three-quarters of the rising energy demand is due to energy consumption in the industrial sector and buildings, mostly in fast-growing developing (emerging) countries [2]. The use of energy has different effects on economic activity, society and the environment, so there is a need for energy savings and energy efficiency. The emission of greenhouse gases (mainly carbon dioxide, $CO_2$) should be reduced in order to mitigate global warming and climate change. Therefore, higher energy consumption and pollution are issues that should be addressed through sustainable development and finance. Sustainable development is development that meets the needs of today's generation, but does not jeopardise the needs of future generations. In order to achieve this, Sustainable Development Goals (SDGs) have been established as a way to cover social, economic and environmental issues. Furthermore, sustainable finance contributes to sustainable development and supports the SDGs, integrating environmental, social and governance (ESG) criteria into investments in order to direct them towards sustainable economic activities.

Energy efficiency and the reduction of $CO_2$ emissions have been set as targets of sustainable development goals. One of the goals of sustainable development is dedicated to affordable and sustainable energy, and the target is to double the rate of global energy efficiency improvement by 2030. According to the OECD [3], energy efficiency is a tool for addressing several energy issues, such as energy security and economic, social and climate change issues. At the same time, energy efficiency increases competitiveness and improves consumer welfare. Various benefits are achieved by improving energy efficiency: it reduces primary energy consumption, energy demand, energy costs, environmental pollution and dependence on energy imports. On the other hand, it increases energy security, competitiveness and economic growth and creates jobs [4]. Due to these benefits, some researchers have investigated the link between energy efficiency and economic growth and development [5,6]. Energy efficiency influences energy consumption, thus affecting carbon emissions and climate change. Therefore, energy efficiency can be considered as a contributor to energy consumption and decreasing carbon emissions, mitigating climate change and obtaining economic development.

A well-established financial framework is necessary to support the achievement of sustainable development goals. Highly developed countries have more opportunities to obtain funds and offer innovative financing. Domestic and external (official development assistance and foreign direct investment) funds and flows as well as regulations are the prerequisites for financing the three pillars of sustainable development (social, economic and environmental). Sustainable finance contributes to sustainable development because it consists of environmental, social and governance criteria. Ziolo et al. [7] confirmed a positive link between sustainable finance and the three pillars of sustainable development. Public and private funding (blended finance, social impact investing and green finance) are mostly mobilised to fit sustainable development goals. Financial development ensures the development of financial markets by facilitating access to finance and encouraging foreign direct investment (FDI) inflow. It increases savings and investments, using them to achieve economic growth while increasing energy consumption [8]. However, financial development can reduce energy consumption through energy efficiency [9] if funds are invested in energy efficiency technologies. Investments in energy efficiency and other sustainable development goals are vast. Therefore, sustainable financial development should use government, private sector and other institutional funds and flows, especially sustainable finance and energy investments directed towards energy efficiency projects, in order to gain economic and environmental benefits and financial returns.

Based on all of these issues, this research focuses on energy efficiency and sustainable economic and financial development. Countries that aim to achieve sustainable development should establish energy efficiency and carbon emission reduction policies [10]. Thus far, studies have mostly focused on the relationship between energy consumption, economic growth and carbon emissions (a survey by Adewuyi and Awodumi [11]), energy consumption and financial development [12–14], or energy efficiency and economic development [15]. Some studies have focused on the energy intensity and financial development nexus [16], while others have investigated total factor energy efficiency (TFEE) with a desirable gross domestic product (GDP) variable and undesirable $CO_2$ [17]. However, there is still a lack of literature on the relationship between energy efficiency and sustainable economic and financial development. Therefore, the purpose of this study is to extend the literature on this issue by conducting research on the measurement of energy efficiency and analysing the relationship between energy efficiency and sustainable economic and financial development.

The world economy, including the OECD countries, has made efforts towards sustainable development. OECD countries have worked together and enacted policies for sustainable economic growth, higher standards of living, and financial stability and development. The OECD Action Plan on Sustainable Development Goals (SDGs) was developed to support the 2030 Agenda. The most recent OECD report [18] shows that, on average, OECD countries achieve some SDGs related to energy, cities, climate, education and sustainable production. Of course, there are imbalances between countries. One policy segment is energy, because energy consumption depends on economic activity, structure, efficient energy use [19] and population. Current energy policies should be based on decreasing energy consumption by applying efficient energy use, diversifying energy sources and increasing demand for clean energy [20]. Policies should be implemented in order to obtain the multiple benefits that energy efficiency provides. According to the International Energy Agency (IEA) [21], during the period 1990–2017, global economic growth doubled, total primary energy supply rose by about 60% and energy intensity decreased by 35%. However, in OECD countries, energy intensity and total primary energy supply decreased. Sustainable economic development, energy prices and energy policy could influence energy issues. According to BP [20], energy consumption in OECD countries in 2030 will increase by 6% and the carbon emission level will decrease by 10% compared to 2020. Furthermore, financial development and funds also play a role in obtaining sustainable economic development in OECD countries; private investment, green investment and finance should be promoted in order to achieve such development. According to OECD reports and data, it is evident that an economic–financial–environmental nexus exists in OECD countries and should be investigated.

The aim of this paper is to show the link between energy efficiency and sustainable economic and financial development in OECD countries for the period 2000–2018 by using data envelopment analysis (DEA) and regression analysis. The main research questions are as follows:

RQ1: What are the differences in energy efficiency between OECD countries?

RQ2: What is the trend of energy efficiency in OECD countries?

RQ3: What kind of relationship is there between energy efficiency and sustainable economic and financial development in OECD countries?

RQ4: Does this relationship remain the same for all of the analysed countries?

The research consisted of two stages. The first stage was to measure the energy efficiency of OECD countries for the observed period by using the DEA window method to investigate the trend of total factor energy efficiency (TFEE). The second stage applied Tobit regression to investigate the link between energy efficiency and sustainable economic and financial development and vice versa using linear regression. We used proxy variables to represent sustainable economic and financial development to analyse the relationship between them. The findings can help in establishing energy efficiency and economic policy in order to obtain sustainable economic growth, provide efficient use of energy and decrease carbon emissions.

The results show a slight upward trend of TFEE in OECD countries for the observed period, with differences in the level among countries. Developed OECD countries have higher TFEE than developing OECD countries. The links between total factor energy efficiency and sustainable economic and financial development reveal different influences of the observed indicators. The results of the study show that adjusted net savings (ANS) and industry value added (Industry) have a negative impact, while GDP per capita and renewable energy consumption increase the TFEE value. Urbanisation is not statistically significant for TFEE. Furthermore, the results show that the level of increased energy efficiency leads to decreased carbon emissions. On the other hand, regarding indicators for sustainable financial development, research and development (RD) and health expenditures (H) have a positive influence, financial institutions have a negative influence, and FDI has no statistical significance for changing TFEE. In the long run, TFEE has a positive influence on sustainable financial development, but its effect on achieving sustainable economic development is not complete.

The contributions of this research are as follows: (1) it extends the literature and research on the link between energy efficiency and sustainable development; (2) it measures total factor energy efficiency (TFEE) in OECD countries with desirable GDP output and undesirable $CO_2$ emission output; (3) it shows how total factor energy efficiency changes during the observed period with regard to $CO_2$ emissions; and (4) it investigates the link between total factor energy efficiency and sustainable economic and financial development in both directions.

The structure of the paper is as follows. After the introduction, Section 2 is devoted to the literature review, followed by the methodology and data section. Sections 4 and 5 present the results and discussion and the final section summarises the findings of the research.

## 2. Energy Efficiency, Sustainable Economic and Financial Development

Economic growth, efficient use of energy and pollution mitigation should be interrelated in order to achieve sustainable development. Economic growth, on the one hand, and energy efficiency, on the other, allow both a decrease in energy consumption and economic and financial progress. Therefore, energy efficiency draws the attention of global institutions and is incorporated into global, national and business strategies [22].

There are different assessments and levels of energy efficiency. Energy intensity and energy efficiency are the indicators used in macro-level energy and economic policy. Energy intensity is an indicator of sustainable development [23], calculated as energy per unit of GDP, and shows how well an economy converts energy into money output. It is the reciprocal of energy efficiency. High energy intensity indicates high prices, i.e., high cost of converting energy to GDP, while low energy intensity indicates low prices, i.e., low cost of converting energy to GDP [24]. Based on that, low energy intensity is a desirable goal in an economy. Energy intensity is a proxy for energy efficiency. Even so, it can happen that energy intensity does not necessarily reflect real energy efficiency [21]. Energy efficiency is the amount of output that can be produced with given energy input. Still, energy cannot be the only input for generating economic production; other inputs should also be used. A combination of three inputs, capital, labour and energy, is used to measure total factor energy efficiency (TFEE). The TFEE model is in the field of eco-efficiency assessment and was introduced in a study by Hu and Wang [25].

Furthermore, development envelope analysis (DEA) is usually employed as a model to measure TFEE at the macroeconomic level [26]. Surveys of applying DEA in energy efficiency assessment are given by Mardani et al. [27] and Yu and He [28]. These studies show that DEA is a good tool for analysing energy efficiency and that the results are different. This method is used for analysing energy efficiency on both the national and cross-national level [29–31]. In addition to what has been said, TFEE uses multiple inputs to generate GDP economic output [32–37], and due to global concern about environmental pollution, $CO_2$ emission has been taken into account as an undesirable output [37,38]. The main information about TFEE for the observed periods and countries, as well as the models used and findings, are given in Table A1 (in Appendix A).

Economic and financial development are multidimensional and coherent processes. Many variables are necessary to assess these processes, so one or several proxy variables are applied for their analysis. The usual proxy variable for economic development is GDP per capita, and for financial development it is domestic credit to the private sector by banks (FD) or market capitalisation. The variable used for sustainable development (economic sustainability) is adjusted net savings.

The impact of financial and economic development on energy efficiency results in mixed findings. Most studies have investigated the relationship between energy efficiency and economic development using energy intensity and economic growth as indicators. The U shape between these two indicators has also been explored. Lan-yue et al. [39] investigated the relationship between energy consumption, economic output and energy intensity in countries with different levels of development for the period 1996–2013. They found a linear relationship between the three variables. Furthermore, they found that changes in economic consumption are influenced by economic output and energy intensity, especially in developing countries. Deichmann et al. [40] explored the relationship between economic growth and energy intensity in 134 countries for the period 1990–2014. By applying a regression model, they found a threshold effect of income growth on energy intensity change. Mohmood and Ahmad [41] showed an inverse relationship between energy intensity and economic growth in European countries. Destais et al. [42] did not detect any linear relationship between income and energy demand (energy intensity) in 44 countries using a method based on panel smooth transition regression models. Lin and Abudu [43] analysed how the development stage influences energy intensity in sub-Saharan African countries. They found that low-income countries have both higher energy intensity and higher carbon emissions. Zhong [44] explored the relationship between energy intensity and economic development, applying two concepts: the supply and demand sides of energy consumption. The author detected that energy intensity is higher from the supply side than from the demand side due to structural decomposition, and that changes in sectors determine energy intensity. Pan et al. [45] examined the impact of industrialisation and trade openness on energy intensity. They confirmed that industrialisation has a positive effect on energy intensity, while trade openness has a direct negative effect on energy intensity. Ohene-Asare et al. [15] detected a bi-directional relationship between total factor energy efficiency and economic development in 46 African countries for the period 1980–2011. Pan et al. [46] explored the relationship between energy efficiency and economic development in European countries from 1990 to 2013. They determined that there was a U-shape between these two indicators. Yang and Li [47] analysed the impact of energy investments on total factor energy efficiency and sustainable development in China for the period 2003–2014. They found that Beijing and Shanghai had the highest level of energy efficiency due to investments, and other parts of China had low energy efficiency by investments. The long-term impact of energy efficiency and sustainability on the population has been revealed by investigating the most significant projects in hydropower energy [48,49].

Azhgaliyeva et al. [50] found that high GDP per capita and energy prices lead to declined energy intensity. Furthermore, they found that five energy efficiency policies lead to lower energy intensity: taxes, standards, grants, strategic planning and government direct investment. Shahbaz [51] explored the relationship between energy intensity, economic growth, financial development and $CO_2$ emission. The results showed that economic growth and energy intensity increase $CO_2$ emission, while financial development decreases it.

Canh et al. [16] analysed the nexus between financial development and energy intensity. Their findings revealed that financial development increases production energy intensity. However, the particular indicators of financial development they applied decrease energy intensity. Financial institutions and oil price shock indicators decrease energy production intensity, while the financial market indicator decreases energy consumption intensity. Chen, Huang and Zheng [52] found that financial development has limited impact on declining energy in OECD countries as a result of mature financial systems. Adom et al. [53] confirmed that financial development decreases energy intensity. Aydin and Onay [54] came up with three energy intensity threshold points; above those points, financial development influences $CO_2$ emissions. Pan et al. [55] pointed out that financial development, trade openness and technological innovation affect energy intensity. Foreign direct investment can be a proxy for financial development, because financial development attracts foreign capital and new technology that can affect energy intensity and environmental degradation [56]. For example, Hübler and Keller [57] found that foreign direct investment decreases energy intensity in developing countries. The same was confirmed by Jiang et al. [58], who analysed the impact of foreign direct investment on energy intensity in China's provinces.

Table A1 (in the Appendix A) presents the relationship between economic and financial development and energy efficiency and information about the applied models and findings for the observed period and countries.

We provided a short, relevant literature review based on the research of the relationship between energy efficiency (energy intensity) and economic and financial development. Energy efficiency supports the achievement of sustainable development goals (SDGs) related to energy (especially SDG7) and may be connected with sustainable economic and financial development. However, we did not find a particular paper dealing with the link between energy efficiency and sustainable economic and financial development. Furthermore, we evidenced a lack of research on the observed OECD countries. We analysed the link between energy efficiency and sustainable economic and financial development in OECD countries, since there is a research gap in this scope, and our study fills in this gap and presents an original and novel research approach.

## 3. Materials and Methods

Our research consisted of two stages. The first stage was devoted to measuring the total factor energy efficiency in OECD countries for the period 2000–2018 by using DEA window analysis [59,60]. We chose the DEA window model to capture the dynamics and performance trends, while simultaneously examining the stability of efficiency evaluations both across and within the specified windows. The second stage was devoted to examining the link between the energy efficiency index and both sustainable economic and financial development determinants by using panel-data Tobit [61] and linear regression models. For that propose, we used two datasets of independent variables considering the aspect of the analysis: sustainable economic and sustainable financial indicator datasets. Similar approaches that combine the DEA analysis with econometric methods have been used in different studies and areas [62–64].

### *3.1. DEA Window Analysis*

In order to discuss the first and second research questions (RQ1 and RQ2), which consider the differences and trends of energy efficiency between OECD countries, we employed data envelopment analysis (DEA) methodology. DEA is a non-parametric mathematical modelling technique introduced by Charnes, Cooper and Rhodes [65] to evaluate the relative efficiency of a set of comparable decision-making units (DMUs) capable of handling multiple inputs and outputs. The basic model measures static relative efficiency, assuming a constant return to scale.

In this paper, we employed a DEA window analysis [59] to measure the total energy efficiency of 37 OECD countries ($n = 37$), capturing the dynamics of change during the period 2000–2018 ($T = 19$). Taking into account different sizes and development levels of these countries, we used a variable return to scale assumption [66]. DEA window analysis emulates moving average principle, where each country is treated as a different DMU in each year ($t = 1, \ldots, T$). Therefore, a country's performance in a particular year is contrasted with its own performance and the performance of other countries in years covered by the observed window. The window moves for the one-year period from one analysis to the other, dropping the first year from the previous window and adding a new year. The process continues until the last window is reached. Asmild et al. [60] stressed that the analysis within one window assumes that there are no technical changes, and the width of the window ($0 < w < T$) is very important. They claimed that the results would be more credible with a narrower window. In our analysis, we compared the results assuming narrower ($w = 5$) and wider ($w = 10$) windows in order to check the effect of technology change on the efficiency evaluation [64]. The calculation of the total number of windows and DMUs was adopted from Cvetkoska and Savić [67]. The number of windows was calculated as $l = T - w + 1$ (15 for $w = 5$ and 10 for $w = 10$), while the number of DMUs in each window was calculated through the formula: $n \times w$ (185 or 370). The number of different DMUs was calculated as $n \times w \times l$ (2775 or 3700).

Let us assume that the performance set is dived into subsets of $m$ inputs and $r$ outputs for each of $n$ DMUs in each of $T$ periods. Therefore, we have the $n \times m \times T$ dimension input vector $X$ and $n \times r \times T$ dimension vector of output $Y$. The window denoted by $l_w$ starts at time $l$, $1 \le l \le T$ and finishes at time $\max(l + w, T)$ with window width $w$. The efficiency score $Z^t_{kl_w}$ of DMU$_k$ at time $t$ in window $l_w$ is estimated using the DEA model window (1)–(5) [60,63]:

$$\min Z^t_{kl_w} \tag{1}$$

s.t.

$$Y_{l_w}\lambda \ge Y^t_{kl_w} \tag{2}$$

$$Z^t_{kl_w} X^t_{kl_w} - X_{l_w}\lambda \ge 0 \tag{3}$$

$$\sum_{i=1}^{n \times w} \lambda_i = 1 \tag{4}$$

$$Z_{kl_w}^t \geq 0,\ \lambda_i \geq 0,\ i = 1, \ldots, n \times w \tag{5}$$

where $X_{l_w}$ and $Y_{l_w}$ represent $n \times m \times w$ vector of inputs and $n \times r \times w$ vector of outputs in window $l_w$. For our analysis, we allowed variable returns to scale (VRS) by constraint (4) [66]. It is likely that the size or development levels of the countries in the observed set will influence their efficiency [62]. The efficiency score $Z_{kl_w}^t \in [0,1]$ must lie between 0 and 1, where all DMUs with a value equal to 1 are considered as efficient, lying in the frontier which envelops all inefficient DMUs ($Z_{kl_w}^t < 1,\ k = 1, \ldots, n;\ t = l, \ldots, l + w$). Finally, each $\mathrm{DMU}_k{}^t$ is simultaneously estimated in different windows by different values of efficiency score $Z_{kl_w}^t$. Accordingly, we used the mean total energy efficiency score (Equation (6)) in the next stage:

$$\overline{Z}_{kt} = \sum_{l=t-1}^{t+w-1} Z_{kl_w}^t / w,\ k = 1, \ldots, n,\ \ t = 1, \ldots, T \tag{6}$$

### *3.2. Panel Data Regression Models*

In the second stage, regression models were used to provide answers to the third and fourth research questions (RQ3 and RQ4) and reveal whether there is a relationship between energy efficiency and sustainable economic and financial development in OECD countries and whether this relationship remains the same for all analysed countries.

Regression is commonly used to reveal the effect of exogenous factors on relative efficiency [68–70]. Hoff [71] compared second-stage approaches and concluded that Tobit and even ordinary least squares (OLS) regression are usually sufficient methods for modelling DEA scores. The two-limit Tobit regression model is used to deal with limited dependent variables based on the panel dataset [64]. In our study, the censored dependent variable mean efficiency score $\overline{Z}_{kt} \in [0,1]$ was calculated by the DEA window analysis at the first stage. The Tobit regression model for panel data [61,72,73] is given by Equations (7) and (8):

$$Z_{kt} = \alpha + g_{kt}\beta + v_k + \varepsilon_{kt} \tag{7}$$

$$\overline{Z}_{kt} = \left\{ \begin{array}{c} 0,\ \ Z_{kt} \in [-\infty, 0) \\ \alpha + g_{kt}\beta + v_k + \varepsilon_{kt},\ \ Z_{kt} \in [0,1] \\ 1,\ \ Z_{kt} \in (1, \infty] \end{array} \right\} \tag{8}$$

where $Z_{kt}$ is an unobserved variable ($k = 1, \ldots, n,\ \ t = 1, \ldots, T$) and $Z_{kt}$ is a constant; $v_k$ indicates the fixed effect and $\varepsilon_{kt}$ indicates interference, and both of these are half-normal distributed independent of each other. The explanatory (independent) variables denoted by $g_{kt}$ and $\beta$ are coefficients showing the possibility of variation of total energy efficiency scores by varying those explanatory variables. In our analysis, we used two sets of explanatory variables related to sustainable economic and financial development.

We also used multiple panel-data linear regression [74] to check how TFEE means affect the dynamics of proxy variables for sustainable economic and financial development proxies. One linear regression model follows Equation (7), but it uses these proxies as dependent variables and TFEE as one of the independent variables.

### *3.3. Data and Variable Selection*

As already mentioned, in the first stage of research, we measured the total factor energy efficiency using DEA window analysis. Energy efficiency was measured based on the following selected indicators. Three indicators were used as input variables: gross capital formation (constant 2010 USD) as capital, labour force total as labour and primary energy consumption (in exajoules) as energy.

Two indicators were used as output variables: GDP (constant 2010 US$) as GDP desirable output and carbon dioxide emissions in million tonnes of carbon dioxide as $CO_2$ emission the undesirable output (Table 1). The chosen variables were mostly selected as input and output variables in previous studies on TFEE measurement, because gross capital formation (constant 2010 US$) covers capital stock, labour force total represents supply of labour in production, primary energy consumption measures the total energy demand of an economy, GDP measures the value of final production and $CO_2$ emission is the result of production and affects climate change. Capital, labour and GDP were obtained from the World Development Indicators database, while energy consumption and $CO_2$ emissions were obtained from the BP Statistical Review of World Energy.

**Table 1.** Details on indicators for total factor energy efficiency (TFEE).

| Abbreviation | Variable Name | Unit of Measurement | Source |
|---|---|---|---|
| K | Capital | Gross capital formation (constant 2010 US$) | World Development Indicators |
| L | Labour | Labour force, total | World Development Indicators |
| E | Energy consumption | Primary energy consumption (in Exajoules) | BP Statistical Review of World Energy |
| GDP | Gross domestic product | GDP (Constant 2010 US$) | World Development Indicators |
| $CO_2$ | $CO_2$ emissions | Carbon Dioxide Emissions in Million tonnes of carbon dioxide | BP Statistical Review of World Energy |

Source: Authors' presentation.

The total factor energy efficiency evaluation assumes gas (e.g., $CO_2$) emission as a by-product associated with economic output such as GDP [75,76]. In this case, GDP is so-called normal output and needs to be increased, while $CO_2$ emission is undesirable output and should be reduced. On the other hand, the DEA model is usually either input oriented, by minimising inputs, or output oriented, by maximising outputs. There are several possible solutions for treating undesirable outputs that need to be minimised in DEA [77]: ignore them, treat them as inputs, transform the data or transform the model from linear to nonlinear form. We chose to transform the $CO_2$ emission data through Equation (9), introduced by Ali and Seiford [78], being the most appropriate. The idea is to treat $CO_2$ emission as an output of the process and avoid ignoring it or using a negative in the dataset:

$$(Y) \;=\; -Y + d, \quad d > \max|Y| \tag{9}$$

In the second stage, we use two panel-data Tobit and linear regression models to investigate the links between efficiency scores obtained in the first stage and sustainable economic and financial development. For that purpose, we used proxies for sustainable economic development variables: adjusted net savings, including particulate emission damage (% of GNI), which is usually a proxy for sustainable development; GDP per capita (constant 2010 USD$), often a proxy for economic development; industry (including construction); value added (% of GDP); urban population (% of total population); and renewable energy consumption (in exajoules). These indicators represent the three pillars of sustainable development, with a focus on sustainable economic development. We also used several variables as proxies for sustainable financial development: domestic credit to the private sector by banks (% of GDP), usually a proxy for financial development; financial markets index; financial institutions index; research and development expenditure (% of GDP); current health expenditure (% of GDP); and foreign direct investment, net inflows (% of GDP). Those indicators were chosen because they represent the funding of sustainable development. Research and development expenditure (% of GDP) and current health expenditure (% of GDP) were chosen due to their role in the public financing industry, innovation, infrastructure and health, which cover some of the sustainable development goals. Adjusted net savings, GPD per capita, industry value added, urbanisation, domestic credit to the private sector by banks, RD expenditure, health expenditure and foreign direct investment were obtained from the World Development Indicators database. Renewable energy consumption was obtained from the BP Statistical Review of World Energy, and financial markets and financial institutions from the International Monetary Fund (IMF) database. The details on variables of sustainable economic and financial development are given in Table 2.

**Table 2.** Details of variables for sustainable economic and financial development.

| | | | |
|---|---|---|---|
| **Sustainable Economic Development Variables** | | | |
| ANS | Adjusted net savings * | Adjusted net savings, including particulate emission damage (% of GNI) | World Development Indicators |
| GDP pc | GDP per capita | GDP per capita (constant 2010 US$) | World Development Indicators |
| Industry | Industry value added | Industry (including construction), value added (% of GDP) | World Development Indicators |
| Urban | Urbanisation | Urban population (% of total population), | World Development Indicators |
| Renew E | Renewable energy | Renewable energy Consumption (Exajoules) | BP Statistical Review of World Energy |
| **Sustainable financial development variables** | | | |
| FD | Domestic credit to private sector by banks | Domestic credit to private sector by banks (% of GDP) | World Development Indicators |
| FM | Financial markets | Financial Markets Index | IMF database |
| FI | Financial institutions | Financial Institutions Index | IMF database |
| RD | Research and development expenditure | Research and development expenditure (% of GDP) | World Development Indicators |
| H | Health expenditure | Current health expenditure (% of GDP) | World Development Indicators |
| FDI | Foreign direct investment | Foreign direct investment, net inflows (% of GDP) | World Development Indicators |

* Adjusted net savings is a relatively new measure of economic sustainability: https://www.tutor2u.net/economics/reference/sustainable-development-adjusted-net-saving (accessed: 5.10.2020). Source: authors' presentation.

## 4. Results

In this section, the total factor energy efficiency (TFEE) score and dynamics for 37 OECD countries for the time period 2000–2018 are assessed, and the relationships between those scores and sustainable economic and financial development variables are evaluated. Descriptive statistics of all data are given in Table 3. There were 703 observations in total (37 countries for 19 periods). The big difference between minimum and maximum values shows variability in the level of development as well as $CO_2$ emission, incentives for RD, health and the ability to attract foreign direct investment. For example, the standard deviation for GDP, capital and energy consumption is more than two times bigger than the mean values, and similarly for $CO_2$ emission and renewable energy consumption. This variability is mainly caused not by differences between years in the observed period, but by differences between countries. Group descriptive analysis usually exhibits significantly greater values for between-country than within-country deviation due to slight upward trends of mean values.

**Table 3.** Descriptive statistics of data.

| Abbreviation | Variable Name | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **TFEE Indicators** | | | | | |
| K (in 000000) | Capital | 269,259.781 | 551,929.864 | 1902.592 | 38,778,517.216 |
| L (in 000000) | Labour | 16.723 | 27.740 | 0.169 | 165.483 |
| E | Energy consumption | 6.309 | 15.324 | 0.115 | 96.996 |
| GDP (in 000000) | Gross domestic product | 1,216,475.716 | 2,592,751.302 | 10,535.472 | 10,535.472 |
| $CO_2$ | $CO_2$ emissions | 350.690 | 894.055 | 2.509 | 5884.151 |
| **Sustainable economic development variables** | | | | | |
| ANS | Adjusted net savings | 9.806 | 6.261 | –11.279 | 38.591 |
| GDP pc | GDP per capita | 36,186.253 | 22,195.159 | 4862.876 | 111,968.350 |
| Industry | Industry value added | 25.312 | 5.441 | 10.527 | 41.107 |
| Urban | Urbanisation | 76.469 | 11.095 | 50.754 | 98.001 |
| Renew E | Renewable energy | 0.193 | 0.531 | 0.000 | 5.504 |
| **Sustainable financial development variables** | | | | | |
| FD | Domestic credit to private sector by banks | 87.066 | 42.849 | 0.187 | 308.792 |
| FM | Financial markets | 0.537 | 0.257 | 0.019 | 1.000 |
| FI | Financial institutions | 0.685 | 0.179 | 0.203 | 1.000 |
| RD | RD expenditure | 1.751 | 1.032 | 0.129 | 4.953 |
| H | Health expenditure | 8.249 | 2.142 | 3.988 | 17.197 |
| FDI | Foreign direct investment | 5.111 | 10.326 | −58.322 | 86.589 |

Source: Authors' presentation.

The only exception is foreign direct investment within-country deviation (1.7), which is greater than between-country deviation (1.1). This is due to a massive variation of FDI means over the observed period. For better insight, the overall annual FDI means trend line is presented in comparison to the trend of normalised annual GDP means, labelled as GDP (norm), in Figure 1.

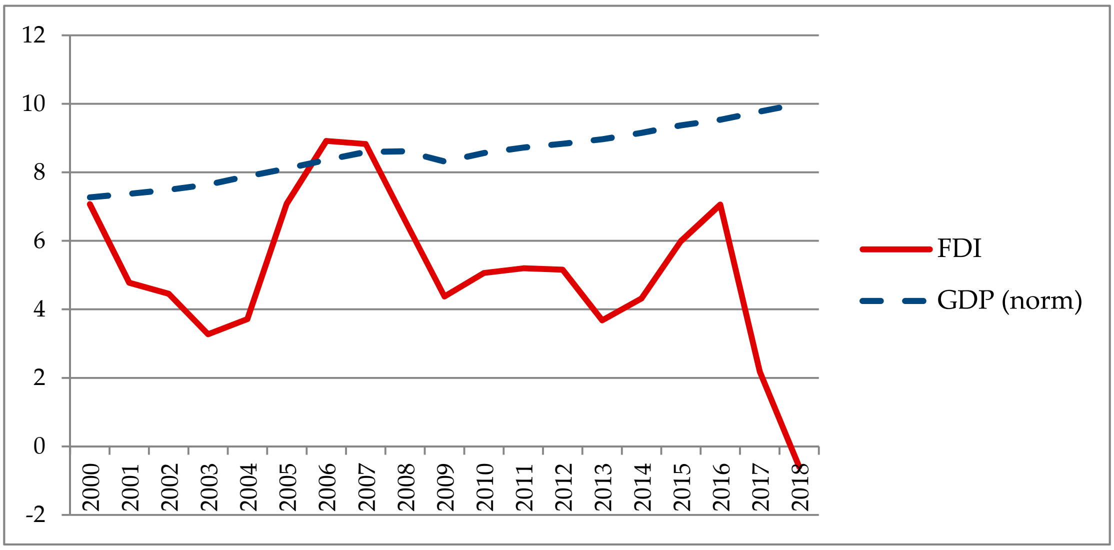


**Figure 1.** Variability of GDP and foreign direct investment means. Source: authors' presentation.

### *4.1. Total Factor Energy Efficiency*

In the first stage of the analysis, focusing on evaluating the total factor energy efficiency and its changes over 2000–2018, we used DEA window analysis (models 1–5) as performed by Cooper et al. [79].

In order to answer research questions RQ1 and RQ2, we selected two window sizes to investigate the dynamic of efficiency in different time spans, under the assumption that the effects of technological changes are gradual. The level and speed of adopting new technologies are not the same for all 37 OECD countries under observation. Therefore, we compared the TFEE of the selected countries for a 5-year (w = 5) and 10-year (w = 10) window in order to check the consistency in efficiency changes throughout the observed period. In both cases, overall efficiency showed upward and downward trends, creating similar curve shapes (Figure 2). A more significant difference in average efficiency is evident at the beginning of the observed period, prior to the world economic crisis from 2000 to 2009. However, from 2010 to 2018, the difference in average overall efficiency was only about 0.02.

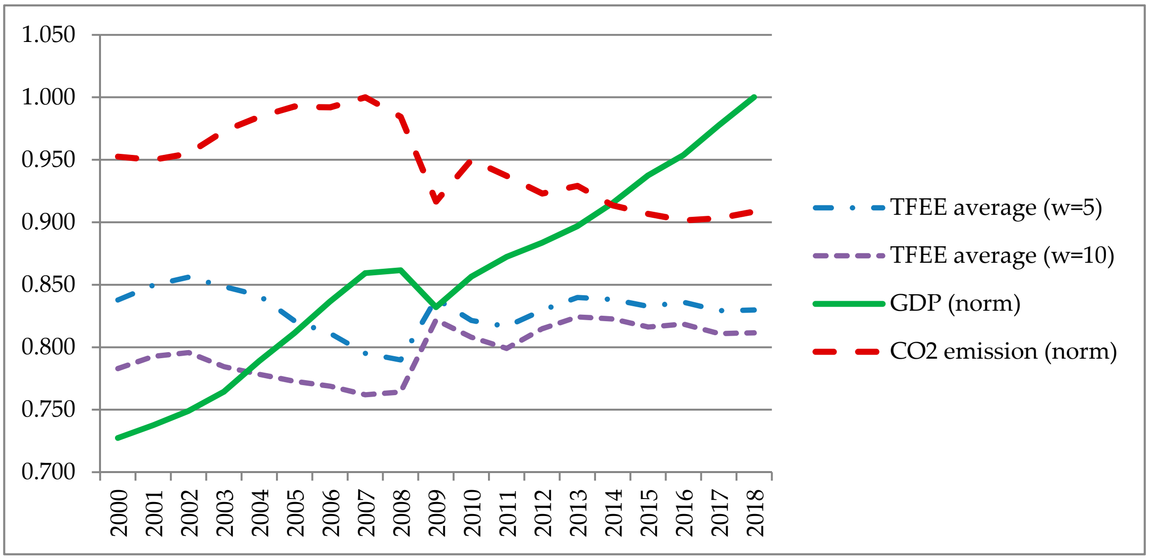


**Figure 2.** TFEE, GDP and $CO_2$ emission trends. Source: authors' presentation.

We can also compare the shape of output curves with efficiency curves. The strong increasing GDP trend (except from 2008 to 2009) is more effective in the 10-year window, since the efficiency evaluation assumes that the same technology will be retained over a more extended period. On the other hand, the undesirable output of $CO_2$ emission deteriorates efficiency, which means that the hill in the curve should cause a valley in the efficiency curve. Obviously, if we compare the shape of the efficiency curves with the $CO_2$ emission curve as observed in a mirror, we can see that that they are almost the same. The conclusion is that $CO_2$ emission has a substantial correlation with TFEE in both cases.

Table 4 provides an overview of the performance for the 5-year and 10-year windows, while the average efficiencies for both windows are shown in Tables 5 and 6. Unsurprisingly, the overall average efficiency is higher for the 5-year window (0.830) in comparison to the 10-year window (0.797) [64]. Contrary to this, the average annual changes of TFEE are smaller for the narrower window, −0.04%, in comparison to 0.07% for the larger window (Table 4, columns 4 and 7). The average TFEE values vary between 0.516 and 0.998 in the 5-year window and 0.487 and 0.991 in the 10-year window.

**Table 4.** Analytics of TFEE.

| | Five-Year Window ($w$ = 5) | | | Ten-Year Window ($w$ = 10) | | | |
|---|---|---|---|---|---|---|---|
| **Country** | **Average Overall TFEE by Country** | **Rank** | **Average Annual Growth** | **Average Overall TFEE by Country** | **Rank** | **Average Annual Growth** | **Rank Difference ($w$ = 5 vs. $w$ = 10)** |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Australia | 0.886 | 15 | −0.02% | 0.862 | 15 | 0.12% | 0 |
| Austria | 0.805 | 22 | 0.22% | 0.782 | 21 | 0.28% | 1 |
| Belgium | 0.841 | 20 | 0.12% | 0.817 | 17 | 0.18% | 3 |
| Canada | 0.842 | 19 | 0.05% | 0.813 | 18 | 0.24% | 1 |
| Chile | 0.742 | 27 | −1.21% | 0.689 | 27 | −0.97% | 0 |
| Colombia | 0.771 | 25 | −1.21% | 0.743 | 25 | −1.35% | 0 |
| Czech Republic | 0.559 | 36 | −0.21% | 0.514 | 36 | −0.02% | 0 |
| Denmark | 0.976 | 10 | 0.00% | 0.948 | 10 | 0.15% | 0 |
| Estonia | 0.698 | 31 | −0.91% | 0.664 | 29 | −0.77% | 2 |
| Finland | 0.800 | 23 | 0.29% | 0.774 | 23 | 0.39% | 0 |
| France | 0.993 | 4 | 0.13% | 0.975 | 4 | 0.20% | 0 |
| Germany | 0.962 | 11 | 0.21% | 0.939 | 11 | 0.32% | 0 |
| Greece | 0.845 | 18 | 0.46% | 0.807 | 19 | 0.80% | −1 |
| Hungary | 0.636 | 34 | 0.20% | 0.590 | 34 | 0.35% | 0 |
| Iceland | 0.977 | 9 | −0.12% | 0.976 | 3 | −0.12% | 6 |
| Ireland | 0.889 | 14 | 0.34% | 0.866 | 14 | 0.50% | 0 |
| Israel | 0.826 | 21 | 0.19% | 0.780 | 22 | 0.43% | −1 |
| Italy | 0.984 | 8 | −0.06% | 0.969 | 6 | −0.10% | 2 |
| Japan | 0.988 | 5 | 0.20% | 0.971 | 5 | 0.33% | 0 |
| Korea | 0.516 | 37 | 0.17% | 0.487 | 37 | 0.42% | 0 |
| Latvia | 0.915 | 12 | −0.08% | 0.885 | 13 | −0.24% | −1 |
| Lithuania | 0.874 | 16 | −0.67% | 0.787 | 20 | −0.90% | −4 |
| Luxembourg | 0.998 | 1 | −0.01% | 0.986 | 2 | −0.07% | −1 |
| Mexico | 0.716 | 30 | −0.07% | 0.643 | 32 | 0.11% | −2 |
| Netherlands | 0.909 | 13 | 0.21% | 0.885 | 12 | 0.26% | 1 |
| New Zealand | 0.736 | 28 | −0.69% | 0.685 | 28 | −0.39% | 0 |
| Norway | 0.995 | 2 | −0.02% | 0.991 | 1 | 0.17% | 1 |
| Poland | 0.724 | 29 | −0.09% | 0.653 | 30 | −0.01% | −1 |
| Portugal | 0.790 | 24 | 0.47% | 0.757 | 24 | 0.66% | 0 |
| Slovakia | 0.585 | 35 | 0.01% | 0.544 | 35 | 0.08% | 0 |
| Slovenia | 0.689 | 32 | 0.55% | 0.648 | 31 | 0.37% | 1 |
| Spain | 0.760 | 26 | 0.02% | 0.738 | 26 | 0.23% | 0 |
| Sweden | 0.860 | 17 | 0.13% | 0.828 | 16 | 0.25% | 1 |
| Switzerland | 0.984 | 7 | 0.04% | 0.964 | 8 | 0.25% | −1 |
| Turkey | 0.644 | 33 | −0.42% | 0.607 | 33 | −0.10% | 0 |
| United Kingdom | 0.988 | 6 | 0.00% | 0.963 | 9 | 0.43% | −3 |
| US | 0.994 | 3 | 0.20% | 0.969 | 7 | 0.36% | −4 |
| Average | 0.830 | | −0.04% | 0.797 | | 0.07% | |
| Min | 0.516 | | −1.21% | 0.487 | | −1.35% | |
| Max | 0.998 | | 0.55% | 0.991 | | 0.80% | |

**Table 5.** Total factor energy efficiency means for 5-year window ($w$ = 5).

| Average by Term | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia | 0.890 | 0.943 | 0.934 | 0.904 | 0.888 | 0.875 | 0.862 | 0.863 | 0.868 | 0.867 | 0.865 | 0.864 | 0.881 | 0.882 | 0.883 | 0.882 | 0.895 | 0.896 | 0.896 |
| Austria | 0.765 | 0.774 | 0.804 | 0.783 | 0.805 | 0.806 | 0.819 | 0.810 | 0.816 | 0.817 | 0.827 | 0.811 | 0.816 | 0.817 | 0.821 | 0.812 | 0.805 | 0.799 | 0.798 |
| Belgium | 0.819 | 0.851 | 0.899 | 0.905 | 0.865 | 0.831 | 0.836 | 0.823 | 0.824 | 0.845 | 0.849 | 0.825 | 0.836 | 0.856 | 0.841 | 0.828 | 0.814 | 0.824 | 0.809 |
| Canada | 0.833 | 0.852 | 0.860 | 0.843 | 0.831 | 0.810 | 0.808 | 0.837 | 0.826 | 0.843 | 0.818 | 0.817 | 0.816 | 0.816 | 0.833 | 0.869 | 0.903 | 0.889 | 0.902 |
| Chile | 0.972 | 0.947 | 0.968 | 1.000 | 1.000 | 0.835 | 0.763 | 0.748 | 0.613 | 0.751 | 0.626 | 0.576 | 0.563 | 0.582 | 0.631 | 0.628 | 0.636 | 0.641 | 0.624 |
| Colombia | 1.000 | 0.995 | 0.987 | 0.955 | 0.956 | 0.914 | 0.809 | 0.747 | 0.687 | 0.720 | 0.694 | 0.657 | 0.652 | 0.651 | 0.621 | 0.641 | 0.641 | 0.656 | 0.661 |
| Czech Republic | 0.599 | 0.582 | 0.582 | 0.606 | 0.592 | 0.585 | 0.554 | 0.500 | 0.492 | 0.538 | 0.531 | 0.534 | 0.544 | 0.561 | 0.553 | 0.541 | 0.569 | 0.581 | 0.575 |
| Denmark | 0.976 | 0.989 | 1.000 | 1.000 | 0.995 | 0.989 | 0.932 | 0.926 | 0.941 | 0.996 | 1.000 | 0.998 | 1.000 | 0.986 | 0.982 | 0.983 | 0.956 | 0.956 | 0.931 |
| Estonia | 0.870 | 0.806 | 0.711 | 0.648 | 0.662 | 0.679 | 0.639 | 0.599 | 0.694 | 0.854 | 0.732 | 0.686 | 0.661 | 0.653 | 0.664 | 0.716 | 0.700 | 0.651 | 0.639 |
| Finland | 0.744 | 0.765 | 0.791 | 0.791 | 0.791 | 0.768 | 0.797 | 0.789 | 0.803 | 0.831 | 0.818 | 0.792 | 0.806 | 0.827 | 0.833 | 0.837 | 0.814 | 0.813 | 0.791 |
| France | 0.969 | 0.986 | 1.000 | 1.000 | 0.993 | 0.989 | 0.996 | 0.999 | 0.995 | 0.993 | 0.991 | 0.992 | 0.993 | 0.991 | 1.000 | 0.995 | 0.996 | 0.996 | 1.000 |
| Germany | 0.921 | 0.939 | 0.963 | 0.948 | 0.969 | 0.970 | 0.952 | 0.956 | 0.955 | 0.947 | 0.946 | 0.965 | 0.987 | 0.964 | 0.973 | 0.978 | 0.976 | 0.979 | 0.983 |
| Greece | 0.759 | 0.765 | 0.782 | 0.722 | 0.756 | 0.802 | 0.711 | 0.683 | 0.709 | 0.812 | 0.846 | 0.909 | 0.966 | 0.976 | 0.965 | 1.000 | 0.989 | 0.949 | 0.961 |
| Hungary | 0.598 | 0.645 | 0.647 | 0.665 | 0.609 | 0.628 | 0.622 | 0.623 | 0.593 | 0.679 | 0.641 | 0.645 | 0.657 | 0.654 | 0.632 | 0.634 | 0.654 | 0.637 | 0.614 |
| Iceland | 1.000 | 1.000 | 1.000 | 0.997 | 1.000 | 0.800 | 0.989 | 0.989 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 0.994 | 0.976 | 0.957 | 0.948 | 0.952 | 0.959 |
| Ireland | 0.825 | 0.837 | 0.850 | 0.836 | 0.858 | 0.809 | 0.797 | 0.818 | 0.827 | 0.887 | 0.992 | 0.993 | 0.894 | 0.952 | 0.885 | 0.938 | 0.929 | 0.974 | 1.000 |
| Israel | 0.791 | 0.807 | 0.871 | 0.929 | 0.939 | 0.892 | 0.856 | 0.824 | 0.805 | 0.832 | 0.812 | 0.775 | 0.768 | 0.814 | 0.816 | 0.815 | 0.788 | 0.783 | 0.786 |
| Italy | 0.995 | 1.000 | 1.000 | 0.981 | 0.977 | 0.988 | 0.990 | 0.998 | 0.990 | 0.988 | 0.980 | 0.987 | 0.993 | 0.998 | 0.992 | 0.987 | 0.960 | 0.946 | 0.938 |
| Japan | 0.951 | 0.965 | 0.969 | 0.973 | 0.981 | 0.980 | 0.989 | 1.000 | 0.992 | 1.000 | 1.000 | 1.000 | 0.997 | 0.999 | 0.991 | 0.992 | 1.000 | 1.000 | 1.000 |
| Korea | 0.483 | 0.498 | 0.499 | 0.489 | 0.490 | 0.491 | 0.486 | 0.488 | 0.494 | 0.522 | 0.510 | 0.518 | 0.538 | 0.554 | 0.558 | 0.552 | 0.548 | 0.529 | 0.548 |
| Latvia | 0.930 | 0.844 | 0.855 | 0.791 | 0.809 | 0.818 | 0.906 | 0.919 | 0.921 | 0.981 | 0.970 | 0.964 | 0.929 | 0.950 | 1.000 | 0.996 | 0.975 | 0.898 | 0.930 |
| Lithuania | 1.000 | 0.969 | 0.930 | 0.912 | 0.822 | 0.839 | 0.788 | 0.660 | 0.637 | 0.984 | 0.843 | 0.787 | 0.891 | 0.973 | 0.994 | 0.879 | 0.905 | 0.894 | 0.888 |
| Luxembourg | 1.000 | 1.000 | 1.000 | 1.000 | 0.997 | 0.989 | 1.000 | 1.000 | 0.998 | 1.000 | 0.992 | 1.000 | 0.991 | 1.000 | 0.998 | 0.999 | 1.000 | 0.998 | 1.000 |
| Mexico | 0.730 | 0.832 | 0.840 | 0.841 | 0.829 | 0.765 | 0.713 | 0.672 | 0.621 | 0.643 | 0.637 | 0.623 | 0.619 | 0.656 | 0.681 | 0.682 | 0.704 | 0.745 | 0.765 |
| Netherlands | 0.869 | 0.866 | 0.888 | 0.897 | 0.910 | 0.917 | 0.917 | 0.879 | 0.899 | 0.909 | 0.925 | 0.929 | 0.949 | 0.953 | 0.981 | 0.849 | 0.909 | 0.910 | 0.917 |
| New Zealand | 0.867 | 0.832 | 0.816 | 0.754 | 0.719 | 0.698 | 0.737 | 0.674 | 0.696 | 0.767 | 0.736 | 0.714 | 0.723 | 0.713 | 0.702 | 0.717 | 0.720 | 0.699 | 0.709 |
| Norway | 1.000 | 0.967 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.996 | 0.992 | 0.985 | 0.982 | 0.996 | 0.995 | 1.000 | 1.000 |
| Poland | 0.740 | 0.858 | 0.940 | 0.944 | 0.868 | 0.856 | 0.768 | 0.639 | 0.619 | 0.694 | 0.649 | 0.596 | 0.623 | 0.678 | 0.635 | 0.634 | 0.679 | 0.677 | 0.655 |
| Portugal | 0.701 | 0.703 | 0.741 | 0.789 | 0.771 | 0.763 | 0.761 | 0.742 | 0.733 | 0.750 | 0.738 | 0.805 | 0.904 | 0.929 | 0.907 | 0.839 | 0.841 | 0.801 | 0.793 |
| Slovakia | 0.584 | 0.530 | 0.554 | 0.640 | 0.602 | 0.537 | 0.546 | 0.545 | 0.527 | 0.658 | 0.576 | 0.554 | 0.630 | 0.619 | 0.627 | 0.588 | 0.606 | 0.599 | 0.600 |
| Slovenia | 0.584 | 0.609 | 0.619 | 0.597 | 0.571 | 0.588 | 0.561 | 0.565 | 0.521 | 0.634 | 0.683 | 0.721 | 0.825 | 0.811 | 0.827 | 0.875 | 0.874 | 0.829 | 0.799 |
| Spain | 0.756 | 0.753 | 0.754 | 0.721 | 0.718 | 0.712 | 0.710 | 0.710 | 0.722 | 0.746 | 0.740 | 0.764 | 0.793 | 0.830 | 0.821 | 0.794 | 0.810 | 0.802 | 0.789 |
| Sweden | 0.836 | 0.841 | 0.880 | 0.867 | 0.888 | 0.884 | 0.866 | 0.840 | 0.859 | 0.972 | 0.882 | 0.857 | 0.881 | 0.866 | 0.845 | 0.831 | 0.827 | 0.814 | 0.814 |
| Switzerland | 0.977 | 0.955 | 0.964 | 0.951 | 0.999 | 0.972 | 0.976 | 1.000 | 0.997 | 0.959 | 0.994 | 0.994 | 0.983 | 1.000 | 0.996 | 0.985 | 0.997 | 0.995 | 1.000 |
| Turkey | 0.723 | 0.970 | 0.811 | 0.743 | 0.691 | 0.632 | 0.587 | 0.566 | 0.570 | 0.620 | 0.574 | 0.568 | 0.597 | 0.592 | 0.600 | 0.592 | 0.589 | 0.574 | 0.630 |
| United Kingdom | 0.988 | 0.973 | 0.969 | 0.982 | 0.993 | 0.986 | 0.979 | 0.990 | 0.995 | 1.000 | 0.979 | 1.000 | 0.998 | 0.995 | 0.978 | 0.976 | 0.985 | 1.000 | 1.000 |
| US | 0.956 | 0.991 | 1.000 | 1.000 | 0.986 | 0.983 | 0.993 | 0.999 | 0.992 | 1.000 | 0.998 | 1.000 | 1.000 | 0.995 | 0.991 | 0.993 | 1.000 | 1.000 | 1.000 |
| Mean | 0.838 | 0.850 | 0.856 | 0.849 | 0.841 | 0.821 | 0.811 | 0.795 | 0.790 | 0.839 | 0.821 | 0.817 | 0.830 | 0.840 | 0.838 | 0.833 | 0.836 | 0.829 | 0.830 |
| St. Dev. | 0.145 | 0.140 | 0.140 | 0.140 | 0.147 | 0.143 | 0.151 | 0.163 | 0.170 | 0.146 | 0.157 | 0.164 | 0.157 | 0.154 | 0.154 | 0.151 | 0.146 | 0.147 | 0.148 |

**Table 6.** Total factor energy efficiency means for 10-year window ($w$ = 10).

| Average by Term | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia | 0.839 | 0.886 | 0.878 | 0.860 | 0.844 | 0.837 | 0.833 | 0.841 | 0.842 | 0.843 | 0.843 | 0.845 | 0.868 | 0.875 | 0.883 | 0.882 | 0.895 | 0.896 | 0.896 |
| Austria | 0.730 | 0.734 | 0.758 | 0.740 | 0.765 | 0.769 | 0.786 | 0.780 | 0.790 | 0.806 | 0.819 | 0.803 | 0.807 | 0.807 | 0.808 | 0.798 | 0.790 | 0.786 | 0.786 |
| Belgium | 0.783 | 0.813 | 0.854 | 0.859 | 0.832 | 0.804 | 0.807 | 0.790 | 0.783 | 0.816 | 0.825 | 0.806 | 0.823 | 0.849 | 0.833 | 0.821 | 0.809 | 0.818 | 0.802 |
| Canada | 0.768 | 0.790 | 0.797 | 0.777 | 0.765 | 0.766 | 0.781 | 0.819 | 0.814 | 0.833 | 0.811 | 0.811 | 0.810 | 0.811 | 0.829 | 0.854 | 0.873 | 0.868 | 0.878 |
| Chile | 0.872 | 0.850 | 0.874 | 0.874 | 0.836 | 0.703 | 0.655 | 0.655 | 0.583 | 0.704 | 0.614 | 0.570 | 0.560 | 0.580 | 0.629 | 0.626 | 0.634 | 0.639 | 0.623 |
| Colombia | 1.000 | 0.982 | 0.944 | 0.880 | 0.842 | 0.809 | 0.729 | 0.703 | 0.668 | 0.714 | 0.688 | 0.654 | 0.649 | 0.648 | 0.619 | 0.639 | 0.638 | 0.654 | 0.660 |
| Czech Republic | 0.517 | 0.502 | 0.502 | 0.511 | 0.498 | 0.504 | 0.496 | 0.469 | 0.477 | 0.527 | 0.521 | 0.522 | 0.528 | 0.541 | 0.526 | 0.510 | 0.537 | 0.545 | 0.540 |
| Denmark | 0.919 | 0.927 | 0.929 | 0.935 | 0.927 | 0.926 | 0.891 | 0.887 | 0.906 | 0.993 | 1.000 | 0.996 | 1.000 | 0.981 | 0.979 | 0.980 | 0.954 | 0.953 | 0.931 |
| Estonia | 0.812 | 0.757 | 0.688 | 0.619 | 0.624 | 0.643 | 0.615 | 0.566 | 0.632 | 0.818 | 0.718 | 0.658 | 0.629 | 0.628 | 0.642 | 0.687 | 0.678 | 0.621 | 0.590 |
| Finland | 0.701 | 0.719 | 0.741 | 0.744 | 0.752 | 0.738 | 0.769 | 0.761 | 0.775 | 0.821 | 0.808 | 0.777 | 0.792 | 0.811 | 0.812 | 0.812 | 0.794 | 0.796 | 0.777 |
| France | 0.938 | 0.952 | 0.962 | 0.953 | 0.954 | 0.954 | 0.968 | 0.980 | 0.972 | 0.977 | 0.979 | 0.982 | 0.986 | 0.987 | 1.000 | 0.995 | 0.996 | 0.996 | 1.000 |
| Germany | 0.878 | 0.891 | 0.907 | 0.897 | 0.914 | 0.917 | 0.921 | 0.933 | 0.935 | 0.935 | 0.932 | 0.952 | 0.976 | 0.959 | 0.973 | 0.978 | 0.976 | 0.979 | 0.983 |
| Greece | 0.656 | 0.664 | 0.680 | 0.637 | 0.672 | 0.720 | 0.667 | 0.659 | 0.696 | 0.807 | 0.832 | 0.886 | 0.953 | 0.971 | 0.965 | 1.000 | 0.988 | 0.938 | 0.950 |
| Hungary | 0.524 | 0.562 | 0.564 | 0.565 | 0.521 | 0.535 | 0.543 | 0.552 | 0.549 | 0.634 | 0.607 | 0.618 | 0.637 | 0.641 | 0.626 | 0.630 | 0.651 | 0.636 | 0.613 |
| Iceland | 1.000 | 1.000 | 1.000 | 0.997 | 0.999 | 1.000 | 0.982 | 0.981 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 0.981 | 0.955 | 0.934 | 0.913 | 0.908 | 0.906 |
| Ireland | 0.770 | 0.781 | 0.795 | 0.783 | 0.801 | 0.760 | 0.755 | 0.782 | 0.802 | 0.885 | 0.988 | 0.988 | 0.889 | 0.945 | 0.883 | 0.938 | 0.929 | 0.974 | 1.000 |
| Israel | 0.698 | 0.711 | 0.757 | 0.796 | 0.805 | 0.787 | 0.785 | 0.779 | 0.785 | 0.829 | 0.807 | 0.768 | 0.756 | 0.805 | 0.811 | 0.805 | 0.781 | 0.771 | 0.780 |
| Italy | 0.989 | 0.995 | 0.978 | 0.962 | 0.956 | 0.965 | 0.967 | 0.975 | 0.967 | 0.967 | 0.962 | 0.971 | 0.984 | 0.988 | 0.987 | 0.977 | 0.953 | 0.941 | 0.934 |
| Japan | 0.908 | 0.917 | 0.921 | 0.929 | 0.947 | 0.954 | 0.965 | 0.975 | 0.962 | 0.997 | 1.000 | 0.998 | 0.993 | 0.997 | 0.991 | 0.992 | 1.000 | 1.000 | 1.000 |
| Korea | 0.408 | 0.421 | 0.430 | 0.429 | 0.439 | 0.451 | 0.460 | 0.472 | 0.486 | 0.520 | 0.506 | 0.513 | 0.530 | 0.542 | 0.542 | 0.535 | 0.530 | 0.514 | 0.532 |
| Latvia | 0.930 | 0.844 | 0.855 | 0.788 | 0.802 | 0.793 | 0.857 | 0.849 | 0.844 | 0.904 | 0.908 | 0.892 | 0.878 | 0.922 | 0.996 | 0.988 | 0.956 | 0.875 | 0.930 |
| Lithuania | 0.957 | 0.866 | 0.780 | 0.744 | 0.676 | 0.716 | 0.701 | 0.611 | 0.609 | 0.945 | 0.826 | 0.753 | 0.840 | 0.896 | 0.888 | 0.768 | 0.797 | 0.792 | 0.786 |
| Luxembourg | 1.000 | 1.000 | 1.000 | 1.000 | 0.989 | 0.978 | 0.998 | 1.000 | 0.993 | 1.000 | 0.977 | 0.862 | 0.970 | 0.987 | 0.990 | 0.996 | 1.000 | 0.997 | 1.000 |
| Mexico | 0.622 | 0.709 | 0.716 | 0.709 | 0.698 | 0.660 | 0.633 | 0.616 | 0.591 | 0.633 | 0.623 | 0.606 | 0.595 | 0.616 | 0.623 | 0.618 | 0.628 | 0.653 | 0.666 |
| Netherlands | 0.836 | 0.834 | 0.853 | 0.855 | 0.871 | 0.883 | 0.888 | 0.850 | 0.872 | 0.893 | 0.912 | 0.917 | 0.936 | 0.938 | 0.961 | 0.836 | 0.892 | 0.893 | 0.900 |
| New Zealand | 0.759 | 0.728 | 0.714 | 0.659 | 0.633 | 0.633 | 0.677 | 0.644 | 0.676 | 0.756 | 0.723 | 0.695 | 0.694 | 0.675 | 0.663 | 0.675 | 0.678 | 0.662 | 0.677 |
| Norway | 0.959 | 0.967 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.984 | 1.000 | 0.997 | 0.988 | 0.985 | 0.979 | 0.982 | 0.995 | 0.995 | 1.000 | 1.000 |
| Poland | 0.655 | 0.769 | 0.844 | 0.813 | 0.727 | 0.721 | 0.653 | 0.556 | 0.563 | 0.661 | 0.623 | 0.578 | 0.603 | 0.647 | 0.593 | 0.588 | 0.621 | 0.609 | 0.584 |
| Portugal | 0.632 | 0.632 | 0.661 | 0.696 | 0.689 | 0.696 | 0.710 | 0.709 | 0.716 | 0.745 | 0.730 | 0.795 | 0.890 | 0.918 | 0.898 | 0.834 | 0.837 | 0.797 | 0.792 |
| Slovakia | 0.530 | 0.477 | 0.496 | 0.550 | 0.510 | 0.464 | 0.479 | 0.491 | 0.491 | 0.623 | 0.550 | 0.534 | 0.604 | 0.590 | 0.599 | 0.575 | 0.594 | 0.588 | 0.600 |
| Slovenia | 0.578 | 0.593 | 0.600 | 0.571 | 0.547 | 0.562 | 0.539 | 0.539 | 0.508 | 0.631 | 0.666 | 0.689 | 0.778 | 0.748 | 0.749 | 0.780 | 0.787 | 0.740 | 0.712 |
| Spain | 0.694 | 0.712 | 0.706 | 0.690 | 0.687 | 0.685 | 0.686 | 0.690 | 0.699 | 0.732 | 0.735 | 0.762 | 0.787 | 0.813 | 0.804 | 0.785 | 0.797 | 0.787 | 0.774 |
| Sweden | 0.780 | 0.783 | 0.818 | 0.811 | 0.830 | 0.829 | 0.823 | 0.800 | 0.805 | 0.910 | 0.851 | 0.838 | 0.869 | 0.863 | 0.841 | 0.827 | 0.824 | 0.812 | 0.811 |
| Switzerland | 0.917 | 0.905 | 0.919 | 0.912 | 0.964 | 0.944 | 0.960 | 0.988 | 0.980 | 0.938 | 0.976 | 0.978 | 0.971 | 1.000 | 0.996 | 0.985 | 0.997 | 0.995 | 1.000 |
| Turkey | 0.625 | 0.857 | 0.707 | 0.634 | 0.600 | 0.574 | 0.546 | 0.541 | 0.558 | 0.614 | 0.571 | 0.565 | 0.593 | 0.590 | 0.599 | 0.590 | 0.583 | 0.573 | 0.616 |
| United Kingdom | 0.881 | 0.894 | 0.906 | 0.923 | 0.938 | 0.950 | 0.957 | 0.975 | 0.986 | 1.000 | 0.976 | 0.998 | 0.994 | 0.985 | 0.977 | 0.976 | 0.985 | 0.999 | 1.000 |
| US | 0.901 | 0.905 | 0.913 | 0.927 | 0.946 | 0.959 | 0.968 | 0.976 | 0.977 | 1.000 | 0.995 | 0.995 | 0.990 | 0.985 | 0.986 | 0.992 | 0.999 | 1.000 | 1.000 |
| Mean | 0.783 | 0.793 | 0.796 | 0.785 | 0.778 | 0.773 | 0.769 | 0.762 | 0.764 | 0.822 | 0.808 | 0.799 | 0.815 | 0.824 | 0.823 | 0.816 | 0.819 | 0.811 | 0.812 |
| St. Dev. | 0.159 | 0.151 | 0.149 | 0.150 | 0.158 | 0.158 | 0.163 | 0.173 | 0.172 | 0.146 | 0.158 | 0.162 | 0.159 | 0.158 | 0.159 | 0.159 | 0.153 | 0.155 | 0.157 |

In both analyses, the top 10 countries are the same: the developed countries Luxembourg, Norway, the US, France, Japan, the UK, Switzerland, Italy, Iceland and Denmark are recognised as the most efficient, with an average overall TFEE greater than 0.970 for the 5-year window and greater than 0.940 for the 10-year window. The bottom five countries are also the same in both analyses: Turkey, Hungary, Slovakia, the Czech Republic and Korea.

The position of most OECD countries remained the same in both windows. A significant alteration was the reduction of average annual TFEE for Chile, Colombia and Estonia. This decline was due to a massive increase in $CO_2$ emissions from 2000 to 2018 (67%, 64% and 54%, respectively, while the overall average was 5%). The growth of $CO_2$ emissions was associated with capital usage growth of 173%, 258% and 154%, respectively, for those countries.

There is no large deviation in the ranks of countries according to the selected window, as can be seen in column 8 of Table 4. A zero or positive rank deviation indicates that the countries are operating stably regardless of window size or number of observations. However, there are several exceptions. For example, Iceland is ranked six positions better in the 10-year window than in the 5-year window. Tables 5 and 6 show that Iceland was fully efficient in 8 out of 19 terms, with the lowest efficiency score of 0.800 in the 5-year window and 0.906 in the 10-year window analysis.

On the other hand, a negative deviation of rank shows that countries adapt to faster (cleaner and more energy efficient) technological changes and deliver better performance in a shorter time window. For example, the US is ranked four and the UK three positions better in the 5-year window than the 10-year window analysis (Table 4). This result is contrary to findings of low $CO_2$ emission efficiency in the US (25th of 25 countries from 2013 to 2017), which takes into consideration primary energy consumption and population size as inputs [76]. Even though the US is the key $CO_2$ emitter of all OECD countries, it is also a key GDP contributor, which makes it one of the best-ranked countries according to TFEE.

Considering individual efficiencies presented in Tables 5 and 6, most countries followed an upward TFEE trend, as shown in Figure 2. On the other hand, some countries had decreased relative energy efficiency during the observed period by more than 1% annually. For example, Chile, Colombia and Estonia had decreased TFEE due to increased $CO_2$ emissions, as already explained. Furthermore, Lithuania declined from its position as an energy-efficient country in 2000 to an inefficient country in 2018. This drop is shown in Tables 5 and 6 for 2018, with the average TFEE = 0.888 and 0.786 for the 5-year and 10-year windows, respectively. The energy efficiency decline is due to a significant capital increase of 178% for the same period, while keeping similar levels of other inputs and outputs. New Zealand is another country showing the same efficiency dynamics, with a capital increase of 106% from 2000 to 2018, which caused declines in TFEE from 0.867 to 0.709 in the 5-year window and 0.759 to 0.677 in the 10-year window. These countries need to react faster and produce lower carbon emissions, along with intensifying capital, by introducing innovative energy-efficient technology.

### *4.2. Contributions of Multiple Factors to Efficiency Based on Panel-Data Regression Model*

In the second stage of the analysis, we investigated the impact of sustainable economic and financial development indicators on total factor energy efficiency score using the panel-data Tobit model (Equations (7) and (8)). The opposite impact was also investigated by a linear regression model. All models were constructed using statistical Stata software [80]. The obtained results in the following section provide the answers to research questions RQ3 and RQ4.

#### 4.2.1. Contributions of Sustainable Economic Development

Table 7 shows the outcomes of the panel-data Tobit regression model using average TFEE scores obtained by the 5-year and 10-year DEA window analysis as dependent variables. The chosen sustainable economic development indicators presented in Table 2 were employed as explanatory (independent) variables. The Tobit regression models are statistically significant in both cases, with a value *of* $p = 0.0000$. The panel variance contributes more than 70% to total variation in TFEE, as a consequence of TFEE variation during the observed period (rho ≈ 0.768 for $w = 5$ and 0.723 for $w = 10$). The coefficients of adjusted net savings (ANS) and industry value-added (Industry) carry a negative sign, and are statistically significant at the level of $p < 0.001$. An increase of one unit in ANS might cause TFEE to decline by 0.004 regardless of window length, while an increase of Industry could reduce the 5-year and 10-year TFEE score by 0.005 and 0.007, respectively.

**Table 7.** Tobit regression model results of sustainable economic development variable analysis.

| TFEE ($w$ = 5) | Coef. | Std. Err. | z | $P > \|z\|$ | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| ANS | −0.004018 | 0.000985 | −4.080 | 0.000 | −0.005949 | −0.002087 |
| GDP pc | 0.000001 | 0.000001 | 1.080 | 0.282 | −0.000001 | 0.000003 |
| Industry | −0.005445 | 0.001527 | −3.570 | 0.000 | −0.008437 | −0.002453 |
| Urban | −0.000119 | 0.001349 | −0.090 | 0.929 | −0.002763 | 0.002524 |
| Renew E | 0.006004 | 0.010383 | 0.580 | 0.563 | −0.014346 | 0.026354 |
| _cons | 0.985239 | 0.118606 | 8.310 | 0.000 | 0.752776 | 1.217702 |
| /sigma_u | 0.119695 | 0.019473 | 6.150 | 0.000 | 0.081528 | 0.157862 |
| /sigma_e | 0.065855 | 0.001961 | 33.580 | 0.000 | 0.062010 | 0.069699 |
| rho | 0.767635 | 0.0605029 | | | 0.634115 | 0.868512 |
| Prob > $chi^2$ | = | 0.000 | | | | |
| TFEE ($w$ = 10) | Coef. | Std. Err. | Z | P>\|z\| | [95% Conf. Interval] | |
| ANS | −0.004193 | 0.000839 | −5.000 | 0.000 | −0.005839 | −0.002548 |
| GDP pc | 0.000009 | 0.000001 | 4.410 | 0.000 | 0.000002 | 0.000004 |
| Industry | −0.007713 | 0.001294 | −5.960 | 0.000 | −0.010249 | −0.005176 |
| Urban | 0.001705 | 0.001105 | 1.540 | 0.123 | −0.000460 | 0.003870 |
| Renew E | 0.019746 | 0.008519 | 2.320 | 0.020 | 0.003048 | 0.036443 |
| _cons | 0.799461 | 0.094377 | 8.470 | 0.000 | 0.614485 | 0.984437 |
| /sigma_u | 0.092393 | 0.012201 | 7.570 | 0.000 | 0.068479 | 0.116306 |
| /sigma_e | 0.057194 | 0.001634 | 35.000 | 0.000 | 0.053991 | 0.060397 |
| rho | 0.722963 | 0.054726 | | | 0.606949 | 0.819104 |
| Prob > $chi^2$ | = | 0.000 | | | | |

The outcomes of the 10-year TFEE score are positively correlated with GDP per capita at a significance level of $p < 0.001$ and renewable energy consumption (Renewable E) at a level of $p < 0.05$. An increase of one unit in GDP per capita will increase the 10-year TFEE score by 0.0000028, while renewable energy consumption (Renewable E) will contribute 0.0197. However, these variables do not have a significant correlation with the 5-year TFEE score. Therefore, we can conclude that increased GDP per capita and renewable energy consumption will have a gradual long-term impact on increasing TFEE scores. The urbanisation factor does not have a statistically significant effect on TFEE.

For further insight, the contribution of TFEE to ANS was examined by setting ANS as a dependent variable and TFEE as an independent variable together with all other sustainable economic development indicators. The panel data linear regression analysis shows that the increased average TFEE score indicates a slight reduction in ANS with statistical significance at the level of $p < 0.01$. The increase in average TFEE score for the 5-year window by 0.01 (1%) might cause ANS to decrease by 0.055, while the rise in average TFEE score for the 10-year window may cause a reduction of ANS by 0.081. Therefore, TFEE, GDP per capita and Industry are significant factors with a positive impact on ANS. From our results, it can be concluded that TFEE has no full effect on obtaining sustainable economic development.

#### 4.2.2. Contributions of Sustainable Financial Development

Table 8 shows the outcomes of the panel-data Tobit regression model using TFEE scores obtained by the 5-year and 10-year DEA window analysis as dependent variables, as in the previous analysis. However, for this current analysis, the selected indicators of sustainable financial development, presented in Table 2, were used as explanatory (independent) variables to investigate their impact on TFEE. The Tobit regression models are statistically significant in both cases with a value *of* $p = 0.0000$. The panel variance contributes more than 85% to total variation in TFEE (rho ≈ 0. 0.911 for $w$ = 5 and 0.885 for $w$ = 10).

**Table 8.** Tobit regression model results for sustainable financial development variable analysis.

| TFEE ($w$ = 5) | Coef. | Std. Err. | Z | $P > \|z\|$ | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| FD | 0.000216 | 0.000133 | 1.620 | 0.106 | −0.000046 | 0.000477 |
| FM | −0.075980 | 0.038203 | −1.990 | 0.047 | −0.150860 | −0.001110 |
| FI | −0.451370 | 0.052162 | −8.650 | 0.000 | −0.553600 | −0.349130 |
| RD | 0.028597 | 0.008829 | 3.240 | 0.001 | 0.011292 | 0.045901 |
| H | 0.007501 | 0.003075 | 2.440 | 0.015 | 0.001474 | 0.013528 |
| FDI | 0.000032 | 0.000243 | 0.130 | 0.894 | −0.000440 | 0.000508 |
| _cons | 1.043029 | 0.048460 | 21.520 | 0.000 | 0.948049 | 1.138008 |
| /sigma_u | 0.175687 | 0.021930 | 8.010 | 0.000 | 0.132704 | 0.21867 |
| /sigma_e | 0.054809 | 0.001580 | 34.700 | 0.000 | 0.051713 | 0.057906 |
| rho | 0.911306 | 0.020861 | | | 0.863090 | 0.945574 |
| Prob > chi$^2$ | = | 0.000 | | | | |
| TFEE ($w$ = 10) | Coef. | Std. Err. | Z | $P>\|z\|$ | [95% Conf. Interval] | |
| FD | 0.000284 | 0.000130 | 2.18 | 0.029 | 0.000029 | 0.000539 |
| FM | 0.012506 | 0.036456 | 0.34 | 0.732 | −0.058950 | 0.083957 |
| FI | −0.360030 | 0.050475 | −7.13 | 0.000 | −0.458960 | −0.261100 |
| RD | 0.048495 | 0.008554 | 5.67 | 0.000 | 0.031730 | 0.065260 |
| H | 0.016429 | 0.002999 | 5.48 | 0.000 | 0.010552 | 0.022307 |
| FDI | −0.000057 | 0.000238 | −0.24 | 0.810 | −0.000520 | 0.000409 |
| _cons | 0.788811 | 0.044105 | 17.89 | 0.000 | 0.702367 | 0.875254 |
| /sigma_u | 0.149550 | 0.018274 | 8.18 | 0.000 | 0.113733 | 0.185367 |
| /sigma_e | 0.053654 | 0.001544 | 34.75 | 0.000 | 0.050628 | 0.056680 |
| rho | 0.885962 | 0.025494 | | | 0.828017 | 0.928445 |
| Prob > chi$^2$ | = | 0.000 | | | | |

The coefficients of RD expenditure (RD) and health expenditure (H) variables carry a positive sign, and they are statistically significant at the level of $p < 0.001$ and 0.05, respectively. An RD increase by one unit might cause an increase in the 5-year TFEE score by 0.029, while one unit of H might elevate the 5-year TFEE score by 0.008. Looking at the 10-year window, a rise of one unit in RD increases TFEE by 0.048, and an increase of one unit in H increases TFEE by 0.016. The outcomes of the 5-year and 10-year TFEE scores are negatively correlated with financial institutions (FI) at a significance level of $p < 0.001$. The rise of FI by one point will likely cause a decline of the average 5-year and 10-year TFEE scores by 0.451 and 0.360, respectively. The rise of financial markets (FM) decreases the average five-year TFEE by 0.076 ($p < 0.05$), but it is not statistically significant for longer time span analysis.

The factor of domestic credit to the private sector by banks (FD) has a slight but statistically significant impact on the 10-year average TFEE score (coefficient = 0.000284, $p < 0.05$). Accordingly, the impact of FD is more predictable for a more extended period with no large technological changes.

We also explored the impact of the average TFEE change on FD. With a lack of more suitable indicators, we used only one indicator, FD, as a proxy for sustainable financial development. For that purpose, we used panel-data linear regression with FD as a dependent variable and the average 5-year or 10-year TFEE as an independent variable together with FM, FI, RD, H and FDI indicators. The coefficients show that the increase in average 10-year TFEE score by 0.01 (1%) indicates a raise in FD by 0.23 (significance at $p < 0.05$). There is no statistical significance of changing the 5-year TFEE score. In the long run, TFEE has a positive influence on sustainable financial development.

## 5. Discussion

A difference in energy efficiency among OECD countries can be explained by various factors, such as economic structure, industrialisation, energy mix and the implementation of energy efficiency policies that have an influence on energy efficiency [23].

The DEA window model systematically revealed the dynamic changes of TFEE scores. Based on the empirical results, the average TFEE values vary between 0.516 and 0.998 in the 5-year window and 0.487 and 0.991 in the 10-year window. These findings are in line with the results of a study on 25 OECD countries for 2013–2017 [76], where the authors investigated primary energy consumption separately from $CO_2$ emission and environmental and economic efficiency. Five developed countries, Luxembourg, Norway, the US, France and Japan, were recognised as the most efficient. The bottom five countries were Turkey, Hungary, Slovakia, the Czech Republic and Korea. These results are in line with those of Li et al. [81], showing that these countries have low energy efficiency. Among all OECD countries, Turkey has the highest energy demand because it depends on imports for energy. Korea has high $CO_2$ emissions, more than twice as high as the average. Hungary, Slovakia and the Czech Republic have carried out structural economic and energy reforms. Even though they are experiencing economic growth, their energy efficiency is low. However, they are obligated to reach set targets in energy saving and efficiency [82]. Therefore, the results will inevitably show that energy efficiency is usually higher in developed countries than in developing countries [17,35].

Iceland was fully efficient in 8 out of 19 items. According to Bulut and Durusu-Ciftci [83], Iceland's energy intensity was at a very low sustainable level from 1980 to 2005, with visible growth from 2005 to 2010 and a declining trend afterwards. Thus, Iceland outperforms other countries in the wider 10-year time span, excluding Norway and Luxembourg, due to their constant low and declining trend of energy intensity. Furthermore, the US, the UK and Italy are among the top 10 countries. They have the best policies for devaluating physical assets, and their motive for quickly replacing older and less energy-efficient assets with newer innovative and energy-efficient ones lies in their carbon taxation laws [84].

OECD countries show a slight upward average energy efficiency trend during the observed period, as presented in Figure 2. Implementing energy efficiency policies brought positive results in terms of raising energy efficiency. By using renewable energy, applying energy efficiency measures and funding cleaner and more energy efficient technologies, they achieved improved energy efficiency that led to economic and financial benefits. Thus, developed countries had the highest TFEE (Luxembourg, Norway, the US, France, Japan, the UK, Switzerland, Italy, Iceland and Denmark), while developing countries had lower TFEE (among which Turkey, Hungary, Slovakia, the Czech Republic and Korea had the lowest scores). Some countries, such as Chile, Colombia and Estonia, had a decline of TFEE due to increased capital, which led to higher $CO_2$ emissions. The US had the highest TFEE, increasing both GDP and $CO_2$ emissions. By obtaining energy efficiency, OECD countries will achieve one of the SDGs.

Our findings on the contribution of sustainable economic development to energy efficiency show that the variables adjusted net savings (ANS) and industry value-added (Industry) negatively impact TFEE. The explanation may be found in the fact that most industries use fossil fuels, and energy usage is dominant. A rise in industry output increases energy consumption, but reduces energy efficiency [85]. However, industry (mostly transport and construction) is still seen as a means for achieving and improving energy efficiency.

On the other hand, positive correlations are found between the variables GDP per capita and renewable energy consumption (Renewable E) and TFEE. Our results are similar and in line with those of Azhgaliyeva et al., Pan et al. and Ohene-Asare et al. [15,46,50], showing a positive relationship between economic development and energy efficiency, i.e., increased economic development (GDP per capita) influences the rise in TFEE. Furthermore, renewable energy consumption increases energy efficiency. However, Sadorsky [86] showed the opposite results: that income increases energy intensity (i.e., decreases energy efficiency), but the influence of urbanisation is mixed. The synergy among GDP per capita, renewable energy and energy efficiency is the key to obtaining sustainable economic development. From our results, it can be concluded that TFEE has no full effect on obtaining sustainable economic development.

Our findings on the contributions of sustainable financial development variables on energy efficiency are contrary to those of Adom et al. [53] in the case of Ghana (a non-OECD country). They showed that financial development influences a decline in energy intensity (i.e., increased energy efficiency). We found that an increase in the financial institutions (FI) indicates a decrease of the energy efficiency factor in OECD countries in a five-year period. That led to the conclusion that the same rules and policies are not applicable to OECD and non-OECD countries. Deichmann et al. [40] concluded that energy intensity (opposite to energy efficiency) is negatively correlated with economic growth in poor countries, but the decrease rate slows by reaching a higher development level. Chen, Huang and Zheng [52] found that financial development has a limited impact on energy intensity in OECD countries. Furthermore, Pan et al. (2019a) [45] and Ziaei (2015) [56] confirmed that financial development influences energy intensity (i.e., energy efficiency). FDI is not a statistically significant indicator, which is in line with the results of Hübler and Keller [57]. The reason for our results might lie in the non-linear trend curve of FDI (Figure 1), which complicates predicting and establishing links between variables. The results of our study are in line with the results of studies edited by Costa-Campi et al. [87] proving that innovation and RD improve energy efficiency. From our results, it can be concluded that in the long run, TFEE has a positive influence on sustainable financial development.

OECD countries have recorded an increase in energy efficiency (i.e., decrease in energy intensity) and a decrease in energy consumption by shifting to electricity, structural changes (especially in manufacturing) and changes in consumer behaviour [82]. Even so, these improvements are not at the level that can reach sustainable development goals related to energy and carbon emissions [88].

## 6. Conclusions

World economies have an obligation to face increasing energy consumption and carbon emissions. The EU states have declared that they intend to be climate-neutral by 2050 (Net Zero $CO_2$ Emissions by 2050). The Sustainable Development Goals include actions to reduce energy consumption by energy efficiency and the use of renewable energy. Energy efficiency is a cost-effective way to obtain decreased energy consumption and carbon emissions, which will lead to climate change mitigation. Therefore, energy efficiency is set as a target of sustainable development. While previous studies focused on the relationship between economic growth, energy consumption and financial development, this study focuses on the relationship between energy efficiency and sustainable economic and financial development in OECD countries for the period 2000–2018. OECD countries have established policies aimed at obtaining sustainable economic and financial development. This study presents an original and novel research approach and fills in the research gap by investigating the relationship between energy efficiency and sustainable economic and financial development, while previous studies usually explored the link between energy efficiency and economic growth.

The research consisted of two stages. The first stage assessed the total factor energy efficiency, obtaining two outputs, desirable GDP and undesirable $CO_2$ emissions. The results show a slight upward trend of average energy efficiency in OECD countries after the world economic crisis. However, energy efficiency differs among OECD countries. Developed countries have higher energy efficiency than developing countries. For example, Luxembourg, Norway, the US, France, Japan, the UK, Switzerland, Italy, Iceland and Denmark (developed countries) have the highest total factor energy efficiency, while Turkey, Hungary, Slovakia, the Czech Republic and Korea (developing countries) have the lowest. The US has the highest TFEE, but also the highest GDP and $CO_2$ emissions.

The second stage investigated the link between total factor energy efficiency and sustainable economic and financial development. Achieving sustainable economic and financial development is possible if energy efficiency policies have been established. Access to credits and FDI inflows, which bring new energy-saving technology, can increase energy efficiency. On the other hand, energy efficiency can be improved by higher sustainable economic growth and financial development. The results of this study show that adjusted net savings (ANS) and industry value-added (Industry) have a negative impact on TFEE (i.e., they decrease the TFEE score), while GDP per capita and renewable energy consumption have a positive impact (i.e., they increase the TFEE score). Urbanisation is not statistically significant for TFEE. Additionally, the results show that increased energy efficiency leads to decreased carbon emissions. On the other hand, regarding sustainable financial development, RD and health expenditure have a positive influence and FI has a negative influence on TFEE. FDI has no statistically significant influence on TFEE. In the long run, TFEE has a positive effect on sustainable financial development (FD).

Some policy implementations are needed in order to obtain sustainable economic and financial development. Our findings indicate a need to implement energy efficiency policies, introduce energy efficiency technologies, improve energy efficiency in particular industries and diversify energy sources, especially in developing OECD countries. Furthermore, the development of financial institutions and markets and clean FDI are needed in order to provide funds, and sustainable and green finance are needed to obtaining sustainable development goals, such as increased energy efficiency, reduced carbon emissions and sustainable economic growth. OECD strategies should be based on policies that aim to achieve a balance in the relationship between energy efficiency and sustainable economic and financial development.

The limitation of this research is the general lack of data for all OECD countries, especially data concerning sustainable financial development. Since developed OECD countries have a higher energy efficiency than developing OECD countries, future work will be devoted to comparing OECD and non-OECD countries to determine the total factor energy efficiency and ways to improve it by using DEA slacks-based measurement (SBM) and the Malmquist index. A further analysis of the total factor energy efficiency can be performed to examine the connection between the level of development and access to funds. Other factors that influence energy efficiency can also be investigated in further research.

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## Appendix A

**Table A1.** Relevant literature on TFEE, the relationship between energy efficiency and economic and financial development. DEA: data envelopment analysis; SBM: slacks-based measurement.

| Authors | Period | Country | Input Variables | Output Variables | Methodology | Results |
|---|---|---|---|---|---|---|
| Hu and Wang, 2006 | 1995–2002 | Regions in China | Labour, capital stock, energy consumption | Real GDP | DEA | Regional energy efficiency improved during observed period; U-shaped relationship between income and energy efficiency |
| Zhou and Ang, 2008 | 1997–2001 | 21 OECD countries | Capital stock, labour force, four categories of energy consumption | GDP and $CO_2$ emissions | DEA, linear programming models | Three models were compared; findings show different results depending on the model |
| Honma and Hu, 2008 | 1993–2003 | Regions in Japan | Labour employment, private and public stocks, 11 energy sources | GDP | DEA | Inland regions and most regions along the sea achieve energy efficiency |
| Lenz et al., 2018 | 2008–2014 | 28 EU countries | Labour, capital, energy | GDP and $CO_2$ and SOx emission | DEA SBM | Energy efficiency does not incorporate carbon pollution |
| Song et al., 2013 | 2009–2010 | BRICS countries | Capital formation rate, number of the economically active population, energy consumption | GDP | DEA SBM | Energy efficiency in BRICS countries is low, but there is an increasing trend |
| Chang, 2020 | 2010–2014 | EU 28 countries | Real capital stock, labour force, fossil fuel energy consumption | Real GDP | DEA, metafrontier analysis | Models for energy efficiency in the EU are Denmark, Sweden, Luxembourg and the UK |
| Chien and Hu, 2007 | 2001–2002 | OECD and non-OECD countries | Labour, capital stock, energy consumption | GDP | DEA | OECD economies have higher technical efficiency than non-OECD countries. |
| Zhang et al., 2011 | 1980–2005 | 23 Developing countries | Labour force, capital stock, energy consumption | GDP | DEA window | Highest rise in total energy efficiency in China due to effective energy policy U-shape between income and TFEE is found |
| Borozan, 2018 | 2005–2013 | EU regions | Gross fixed capital formation, total final energy consumption, employment rate of 15–64 age group | GDP | DEA, Tobit regression | Most EU regions have energy efficiency; more developed economies have higher energy efficiency |
| Simsek, 2014 | 1995–2009 | OECD | Labour, capital, energy consumption | GDP, $CO_2$ emissions | DEA, bad output index | Results differ among countries due to inputs used; inefficiency occurs by using labour, oil, and natural gas as inputs; inefficient economy produces GDP with high $CO_2$ emissions |
| Zhao et al., 2018 | 2015 | 35 BRICS countries | Energy, capital, labour | GDP, carbon emissions | Three-stage DEA model | Energy-saving and $CO_2$ emission reduction are highest in economies with low TFEE |
| Lin and Xu, 2017 | 2006–2015 | Regions in China | Labour, capital, energy | Real GDP, $SO_2$ emissions, chemical oxygen | DEA, Tobit regression model | TFEE is low and unbalanced throughout regions; environmental regulations affect TFEE |

**Table A1.** *Cont.*

| Relationship between energy efficiency (energy intensity) and economic and financial development | | | | | | |
|---|---|---|---|---|---|---|
| **Authors** | **Period** | **Country** | **Input Variables** | **Relationship between variables** | **Methodology** | **Results** |
| Lan-yue et al., 2017 | 1996–2013 | Nine countries in different stages of development | Energy use per capita, population, GDP at market prices | Energy intensity and economic output | 3GR model | Energy consumption (EC), economic output (EO), and energy intensity (EI) have a linear relationship;<br>EC is codetermined by EO and EI effects;<br>Developed countries show similar effects of EO and EI on economic growth, energy consumption, and emission decline;<br>interactive EO and EI effects co-determine EC |
| Deichmann et al., 2018 | 1990–2014 | 137 countries | Energy consumption, GDP, population, value added of agriculture, services and industry | Energy intensity and economic growth | Flexible piecewise linear regression model | EI negatively correlated with economic growth but decreasing rate slows by 25% after income per capita reaches $5000<br>Structural changes are important for EI level; in poor countries, EI decline is expected as economies develop |
| Mohmood and Ahmad, 2018 | 1995–2015 | 19 European countries | Energy intensity, real GDP growth rate, population, taxes, energy prices | Economic growth energy intensity | Neoclassical growth framework, causality | Economic growth and energy intensity have an inverse relationship;<br>declining trend of energy intensity in all observed European countries due to energy-saving techniques and change in structure of GDP towards lower energy consuming sectors; higher economic growth, higher promotion of energy efficiency |
| Destais et al., 2007 | 1950–1999 | 44 countries | Primary energy consumption, population, GDP | Economic development, energy intensity | Panel smooth transition regression models | No linear relationship between income and energy demand; threshold is determined by income level |
| Lin and Abudu, 2019 | 1990–2014 | Regions Sub Saharan Africa | GDP, gross capital formation, labour force, total primary energy consumption | Economic development, energy intensity | Translog production approach, regression | In countries with lower GDP per capita, energy intensity is higher; higher energy intensity leads to higher $CO_2$ intensity |
| Zhong, 2016 | 1995–2009 | 41 countries (27 EU and rest of major economies) and 35 sectors | GDP, GDP pc, energy consumption, trade data | Economic development, energy intensity | Input-output model, multilevel mixed-effects model | Advanced economies show change in energy use on supply side is larger than on demand side<br>Key role of energy intensity is changing in sectors; U-shape exists between income and energy intensity |
| Pan et al., 2019 | 1985–2015 | Bangladesh | Energy intensity, industrial share of GDP, ratio of international trade to GDP, GDP per capita, number of patents | Energy intensity, economic development | Path model (extension of multiple linear regression) | Industrialisation has a direct linear impact on energy intensity; trade openness has a direct negative influence on energy intensity |

**Table A1.** *Cont.*

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|---|---|---|---|---|---|---|
| Ohene-Asare et al., 2020 | 1980–2011 | 46 African countries | Capital stock at current PPP, labour, total primary energy consumption, GDP, $CO_2$ emissions | Total factor energy efficiency, economic development | DEA SBM, bootstrapped truncated regression model, two-equation system | Economic development and technology have positive effects on energy efficiency; bi-causal relationship exists between TFPP and economic development |
| Pan et al., 2020 | 1990–2013 | 35 European countries | Capital, labour, GPD, GDP per capita, population, energy utilisation and consumption | Energy efficiency, economic development | Stochastic frontier production function model | U-shape exists between energy efficiency and income per capita; increased labour and national prices reduce energy efficiency |
| Yang and Li, 2017 | 2003–2014 | China | Labour, capital, fixed asset investment in energy industry economised with different ownership structures | Annual regional GDP, general budget revenue of local government, number of patents authorised in China | Multivariable constrained nonlinear functions based on DEA SBM model | Investment in energy efficiency brings the highest energy efficiency to Beijing and Shanghai; other regions obtain low energy efficiency by investment regardless of ownership structure |
| Azhgaliyeva et al., 2020 | 1990–2016 | 44 OECD and non-OECD countries | Energy intensity, GDP, electricity prices, fossil fuel, industry value added per GDP, trade per GDP | Economic and financial development, energy intensity | Regression | Higher GDP per capita and energy prices lead to energy intensity decline; five energy-efficiency policies (fiscal taxes, standards and labelling, grants and subsidies, strategic planning and support, government direct investment) lead to lower energy intensity |
| Shahbaz, 2012 | 1971–2009 | Portugal | $CO_2$ emissions, energy intensity per capita, financial development (real domestic credit to private sector per capita), economic development (GDP per capita) | Economic and financial development, energy intensity | ARDL, VECM Granger causality | Variables are cointegrated for a long-run relationship; economic growth and energy intensity increase and financial development reduces $CO_2$ emissions |
| Canh et al., 2020 | 1997–2013 | 81 economies | Production and consumption energy intensity, GDP per capita, industry value added % GDP, trade, urban population FDI net inflows, energy oil prices, overall financial development, financial institutions, financial markets indices, etc. | Financial development, energy intensity | GMM estimators, inclusive estimation strategy for empirical robustness | Energy intensity is observed as production (associated with technology development) and consumption (associated with urbanisation and affluence) energy intensity; financial institutions and oil price shocks decrease production energy intensity; financial markets reduce consumption energy intensity |
| Chen, Huang and Zheng, 2019 | 1990–2014 | 21 OECD and 77 non-OECD countries | Energy intensity, financial development (domestic credit to private sector by bank, private credit by deposit money banks to GDP, Chin-Ito index), share of urbanisation, population aged 65 and above, service value added % GDP, GDP growth, total factor productivity | Financial development, energy intensity | Two-way fixed-effects model | Financial development has a negative effect on the energy intensity for non-OECD countries and a limited impact on the energy reduction for OECD countries due to the maturity of the financial systems |

**Table A1.** *Cont.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Adom et al., 2019 | 1970–2016 | Ghana | Energy intensity, prices of electricity and price, vectors of financial development indicators and other control variables, technological spillovers (trade openness), industry value-added % GDP | Financial development, energy intensity | Dynamic OLS | Financial development lowers energy intensity; government should stimulate financial sector and form energy efficiency policies, establish green banks for green investment |
| Aydin and Onay, 2020 | 1990–2015 | BRICS countries | $CO_2$ emissions, financial development index, energy intensity | Financial development, energy intensity, carbon emissions | Panel smooth transition regression model | Three threshold levels of energy intensity exist; above the threshold point, financial development causes environmental pollution |
| Pan et al., 2019 | 1976–2014 | Bangladesh | Trade openness, financial development (market capitalisation to GDP ratio, banks' private credit to GDP ratio), technological innovation, energy intensity | Financial development, trade openness, technological innovation, energy intensity | DAG technique, SVAR model | Financial development, trade openness, and technological innovation affect energy intensity |
| Ziaei, 2015 | 1989–2011 | 13 European and 12 Asia and Oceania countries | Energy consumption, $CO_2$ emissions, ratio of domestic credit to private sector to GDP, stock traded turnover ratio | Financial development, energy consumption, $CO_2$ emissions | Panel VAR model | Different results in different countries; financial development influences $CO_2$ emissions and vice versa; energy consumption affects $CO_2$ emissions Markets with higher levels of asset development affect energy consumption; financial development attracts FDI and new technology, which influence economic growth and energy intensity |
| Hübler and Keller, 2010 | 1975–2004 | 60 developing countries | Total primary energy supply, energy intensity, share of industrial value added % GDP, net inflows of FDI % GDP, imports % GDP, official development assistance, total income, GDP per capita | Foreign direct investments (FDI), energy intensity | OLS, regression | Foreign direct investments inflow lowers energy intensity in developing countries |
| Jiang et al., 2014 | 2003–2011 | 29 Chinese provinces | Energy intensity, GPD per capita, investments, capital–labour ratio, FDI, energy reserve, spatial spillover effects | Energy intensity, income, FDI | Durbin error model | FDI has a negative spatial spillover impact on energy intensity |

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