Assessing the oil vulnerability of net oil importing countries in Europe

Carla Oliveira Henriques[a,b,c], Maria Elisabete Neves[a,d,*], Alexandre Lima[a], Duc Khuong Nguyen[e,f]

[a] Polytechnic of Coimbra, Coimbra Business Research Centre|ISCAC, 30 Coimbra, Portugal
[b] INESC Coimbra – DEEC, University of Coimbra, Polo 2, 3030-290 Coimbra, Portugal,
[c] Univ Coimbra, CeBER, Faculty of Economics, Av Dias da Silva 165, 3004-512 Coimbra
[d] University of Trás-os-Montes and Alto Douro| CETRAD, Vila Real, Portugal
[e] IPAG Business School, Paris, France
[f] International School, Vietnam National University, Hanoi, Vietnam

Abstract

This work proposes the use of the Weighted Russel Directional Distance Model method to assess the oil vulnerability of net oil importing countries in Europe. The evaluation factors chosen for this purpose were the Gross Domestic Product per capita corrected by purchasing power parity; the strategic oil reserves; the Cost, Insurance and Freight price of oil imports; the weight of oil in the energy mix; and an adaptation of the Shannon-Wiener index weighted by an index of political stability and absence of terrorism (as a measure of the diversity of oil suppliers in each importing country). Results show that Slovakia and the Czech Republic managed to perform better, despite their dependence on a sole supplier, at the expense of higher levels of nuclear power and coal in their energy mixes. France and Sweden also showed low vulnerability because also relied on the development of nuclear power, and, more recently, on renewable energy. Despite their great dependence on oil, Spain has the most diverse supplier base, while the Netherlands has the highest levels of Gross Domestic Product. Finally, whereas Portugal exhibits significant vulnerability due to the weight of oil in its energy mix, Poland and Hungary consistently performed worse, owing to their heavy reliance on a single supplier, Russia.

Keywords: Energy security, oil vulnerability, WRDDM, Europe.

1. Introduction

Oil is often called "black gold" since it is the most widely used energy source on the planet, and it is also a resource used in highly productive industries, such as the plastic industry (Gasser, 2020). The easiness of extraction, transport and refining has made oil the energy source of choice worldwide (Alekhina and Yoshino, 2018).

Despite countries' commitment to reducing their dependence on fossil fuels, their regular supply has been vital for the economic and social development of developed countries (Gupta, 2008). In this way, particularly after the two global oil crises, the security of oil supply has been present in the main political agendas across the world (Yang et al., 2014; Iqbal et al., 2019).

Oil and petroleum products still represent a relevant European (EU) share of the energy mix, and the EU has come to be progressively reliant on imported sources of oil to satisfy its domestic demand. Therefore, energy policy in the EU needs to prudently contemplate the position of oil and petroleum products in its future energy mix and how risks related to high dependency on oil imports can be alleviated (Cambridge Econometrics, 2020).

Import dependency has been especially high for crude oil in the EU, since imports in 2018 represented 96% of gross inland oil consumption, against 83% and 44% import dependency for gas and solid fuels supply, respectively (Cambridge Econometrics, 2020). More than two-thirds of the EU's final demand for oil and petroleum products is channeled to the transportation sector (Cambridge Econometrics, 2020). This creates an

additional energy dependency issue since it is difficult to find short-term alternatives for gasoline and diesel, and as such, customers must assimilate fluctuations in oil prices. The location, country, or oil field from which the oil is imported also represents a significant part of oil dependency. This is especially true when it comes to vulnerability to supply security and environmental concerns. In 2018, Russia accounted for around 31% of EU crude oil imports, while Nigeria and Sub-Saharan Africa accounted for 10%, the Middle East accounted for 21%, and North Africa accounted for 9% (Cambridge Econometrics, 2020). A sizable fraction of EU oil imports come from geopolitically unstable countries where terrorism, internal and border conflicts, or wars have increased. As a result, EU consumers and sectors face an increased risk of oil supply disruptions and shortages.
In 2019, oil and its derivatives accounted for 36.4 % of the total energy mix available in the EU[1].
In this context, energy security and the threats that surround it are the issues that most guide the interactions of politicians and dominant regimes in the world. The EU has recognized that it is essential to ensure adequate levels of energy security, which should never be compromised, especially with the growing geopolitical threats that large producers are continuously facing, with the price fluctuations of various energy products and the disruptions in the supply of large suppliers due to political disparities (Elbassoussy, 2019). The EU's growing dependence on a limited number of energy suppliers, especially Russia, has led the EU to adopt a new strategy to diversify its sources of supply (Elbassoussy, 2019). In this framework, Table 1 depicts the strategic policies that the EU has adopted to mitigate its dependency on oil imports.

Table 1: Strategic policies to mitigate EU's dependency on oil imports

Measure	Description
The Energy Union Framework	Established in 2015 to ensure that the EU's energy supply was secure, affordable, and sustainable. Main goals: Reduce dependence on energy imports and diversify energy supply to reduce exposure to supply shocks from geopolitical risk.
EU Energy Security Strategy	Launched in May 2014, mainly due to the Russian annexation of Crimea. Main goals: Tackle the risks related to heavy reliance on unstable energy supplies. Boost domestic energy production and vary sources of supply by negotiating with new trade partners
The Oil Stocks Directive	Enacted in 2009, the Oil Stocks Directive helps reducing the impacts of oil supply disruptions. Main goals: EU Member States are obliged to sustain stocks of crude oil and/or petroleum products corresponding to at least 90 days of net imports or 61 days of consumption (whichever is higher).
Vehicle Emissions Regulation	The European Parliament and Council adopted in 2019 legislation (EU/2019/631) establishing emissions performance standards for new cars and vans. The EU also launched its first-ever emissions standards for heavy-duty vehicles (EU/2019/1242), Main goals: Foster the production of zero-emission and low-emission (i.e., more than twice as efficient as the average vehicle in 2019-20) heavy- duty vehicles.
The Revised Renewable Energy Directive	The Revised Renewable Energy Directive (RED II) was enacted in 2018. Main goals: Increase advanced fuels, including renewable electricity and 'second-generation' biofuels.

Source: Cambridge Econometrics (2020)

Thus, the assessment of the vulnerability of countries to energy crises has been the subject of study by several authors. In this context, we highlight the literature reviews of several indicators aimed at evaluating the energy security of the countries provided in Kruyt et al., (2009), Valdés (2018), Ang et al. (2015), Erahman et al. (2016), Apergis et al. (2015)

[1]https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2a.html#:~:text=In%202019%2C%20the%20energy%20mix,fossil%20fuels%20(both%2013%20%25)

and Bandura (2008), which served as the basis for the study of 63 indicators by Gasser (2020). The latter concluded that the panoply of indicators proposed in the literature lacks transparency, particularly regarding the selection and standardization of the set of criteria selected for the construction of indicators, stating that only a scarce number of studies perform the sensitivity or robustness analysis of the results obtained.

In this context, the Data Envelopment Analysis (DEA) methodology can be particularly useful for assessing the performance of countries in terms of energy security (the decision-making units (DMUs) under analysis), because it allows considering different evaluation factors simultaneously, which are viewed as inputs (factors to be minimized) and outputs (factors to be maximized). Besides, DEA enables the identification of benchmarks (in terms of best practices) and provides information regarding the required adjustments that need to be operated in the evaluation factors of countries with inefficient performances, to obtain efficient performances. Additionally, this methodology allows performing the robustness analysis regarding the results obtained, evaluating the extent to which the countries remain efficient or inefficient, because of the introduction of small disturbances in the evaluation factors. Finally, this methodology also allows assessing the evolution of countries' productivity in terms of energy security, i.e., whether the variations in productivity are due to efficiency gains or technological progress.

Therefore, this work aims to contribute to the existing literature on the use of DEA in the proposal of a global indicator of the performance of net oil importing countries in terms of energy security. For this purpose, the evaluation factors typically used in the scientific literature were selected. Thus, countries consider as controllable outputs the Gross Domestic Product (GDP) per capita (PC) at power purchasing parity (PPP) and strategic oil reserves (both to maximize), as a non-controllable input the Cost, Insurance and Freight (CIF) price of oil imports, as a controllable input the weight of crude oil in the energy mix, and as undesirable input (considering the rationality of the higher its value, the better) an adaptation of the Shannon-Wiener index (as a measure of the diversity of oil suppliers in each importing country). To this end, 15 net oil importing countries from the EU, together with the United Kingdom, were chosen, considering the period from 2013 to 2014 and from 2014 to 2019. The period analyzed allows evaluating the influence of the recent and unexpected drop in the spot price of crude oil on the energy security of all the chosen countries and the impact of the Russian annexation of Crimea in May 2014. The performance of each country was measured through the Weighted Russel Directional Distance Model (WRDDM) DEA methodology, since it is a non-radial and non-oriented model, making it possible to evaluate different adjustments both in inputs and outputs. On the other hand, a robustness analysis was performed regarding the results obtained, as well as an analysis of the variation of productivity across the time horizon considered.

This study is aimed at answering the following research questions:

Which countries have the highest level of vulnerability to oil supply?

Which factors had the greatest influence on the level of vulnerability of each country?

Are the results obtained robust in the event of disturbances in the values of the evaluation factors used?

Which factors contributed the most to the productivity gains recorded?

This paper is structured as follows: In Section 2, a literature review is presented, which seeks to justify the motivation of the present study and the choice of the methodology followed. In Section 3, the methodology used in this work is described. In Section 4, the data and assumptions considered in their collection are presented. In Section 5, the results obtained are described. Finally, the main conclusions of this study are presented, and future research work is suggested.

2. LITERATURE REVIEW

The global financial crisis of 2008 had a significant impact on the oil market. Joo et al. (2020) concluded that the volatility in the oil market increased sharply during the period of the great financial crisis of 2008. In the same vein, Lahmiri (2016) concluded that the 2008 financial crisis affected the volatility of 26 crude markets, making them less predictable.

Baumeister and Kilian (2016) later tried to explain the reasons behind the abrupt drop in crude oil prices between 2013 and 2014 and concluded that this phenomenon was primarily due to the decline in global economic activity and production volume, related to the unexpected growth of shale oil exploration in the United States of America (USA). In the same vein, Mead and Stiger (2015) concluded that the main reason for the drop in oil prices in 2014 was the oversupply largely stimulated by the USA.

Crude oil prices also have a strong impact on countries' GDP, regardless of being net importers or net exporters. In this sense, Mendoza and Vera (2010) concluded that oil price shocks had a positive effect on Venezuela's economy, causing an increase in its GDP between 1984 and 2008. Similarly, Mukhtarov et al. (2021) showed, through a Structural Vector Autoregressive model, that crude oil price shocks positively affected GDP PC in Azerbaijan.

Also, to study the impact of fluctuations in the price of crude oil on the economy of oil exporting and importing countries, Taghizadeh-Hesary et al. (2019) concluded, with the use of a Simultaneous Equation Modeling model, that the oil price shocks had a positive and statistically significant influence (except in the case of Indonesia) on the GDP growth rate in the case of crude exporting countries. For importing countries and their economic partners, they were divided into four groups (A, B, C and D). The results of the first group (A), made up of Germany, Italy, the Netherlands, and Poland, suggest that the oil price shocks translate into a decline in the GDP growth rate. For Group B, consisting of Japan, China, South Korea, Vietnam, China, Taipei, Singapore, and Hong Kong, except for Vietnam and China and Taipei, crude oil price increases have a statistically significant and negative effect on the GDP growth rates of these countries. For Group C, composed of Belarus and Ukraine, there is a positive and statistically insignificant effect of the shocks on the increase in crude oil price on the GDP growth rate. Finally, in group D, composed of the USA, India, and Turkey, it is possible to see the negative and statistically significant effect of the increase in crude oil prices on the GDP growth rate.

Analogously, Gozgor et al. (2016) studied the relationship between the shocks of the increase of crude oil prices between 1970 and 2013 and the macroeconomic performance of ten member countries of the Association of Southeast Asian Nations (ASEAN), namely Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. These authors concluded that there was a statistically significant correlation between crude oil prices and GDP PC, and it was found that the increase in the price of oil by 10% led to an increase of 1.8% in real GDP PC, in most economies belonging to ASEAN.

Due to the impact that oil has on the global economy, the diversity of oil suppliers is essential to ensure the energy security of countries (Rajan and Hughes, 2014). One of the indicators typically used to measure this diversity is the Shannon-Wiener index. In this context, Chalvatzis and Loannidis (2017) used the Shannon-Wiener index as a measure of the diversity of sources of supply to study energy security in the EU.

Also, in the field of energy security, Nordaus (1974) considers that crude reserves play an important role in combating supply insecurity. In the same vein, Taylor and Doren (2005) claim that strategic oil reserves have been almost unanimously seen by politicians as one of the best means of protecting nations against possible shocks in oil supply.

According to Ren and Yumeng (2015), in the case of China, its high external dependence on crude oil significantly increases the risk of a possible supply rupture. In this way, the security of oil supply has become increasingly important, and the process of creating strategic crude oil reserves has become a concern. However, the costs of holding these reserves will inevitably increase. In this way, governments need to choose the optimal levels of oil reserves, to reach an optimal compromise solution between security in supply and the costs of holding these reserves. The same authors concluded that oil reserves fluctuate according to the stability of oil supply prices, as well as price elasticity. Hence, the higher the elasticity, the greater the crude oil reserves. In the same vein, Guo et al. (2020) state that the larger the crude oil reserves, the lower the negative impacts on society in the event of a possible supply rupture.

All member countries of the International Energy Agency (IEA) have mandatory strategic oil reserves equivalent to at least ninety days of consumption of total net imports (IEA, 2018). In the event of a severe collapse in oil supply, IEA members may make these reserves available on the oil market as part of collective action. On the other hand, within the EU, the Directive 2009/119/EC obliges the Member States to hold stocks of crude oil and or petroleum products equivalent to at least 90 days of net imports or 61 days of consumption (whichever is higher).

For all the reasons mentioned so far, the scientific literature has been prolific in the proposal of energy security indicators. In this context, Kruyt et al. (2009) present a review of several energy security indicators, dividing them into four groups: those assessing availability, accessibility (in geopolitical and economic terms) and their acceptability (in environmental and social terms). Recently, starting from the survey of energy security indicators conducted by Valdés (2018), Ang et al. (2015), Erahman et al. (2016), Apergis et al. (2015) and Bandura (2008), Gasser (2020) analyzed 63 indicators that allow assessing the performance of countries in terms of energy security and concluded that there is a lack of transparency, specifically, concerning the selection and standardization of metrics to instantiate these indicators and that only a few provide the sensitivity or robustness analysis of the results obtained.

In this way, we will use the DEA methodology, which can be particularly useful in this context, because it allows considering different evaluation factors simultaneously. Furthermore, this approach allows the identification of benchmarks (in terms of best practices) and provides information regarding the adjustments that need to be operated on the evaluation factors of countries with inefficient performances to become efficient. This methodology also allows performing the robustness analysis of the results obtained, assessing the extent to which countries remain efficient or inefficient in terms of energy security, in case of minor disturbances in the evaluation factors occur. Finally, this methodology allows us to study the evolution of countries' productivity in terms of energy security, i.e., whether the variations in productivity are due to efficiency gains or technological progress.

Table 2: Application of DEA in studies on energy safety and efficiency.

Author	DEA Methodology	Goal	Region	Time horizon	Evaluation factors
Hu e Kao (2007)	Input-oriented CCR *model*	Set *efficient* energy saving targets for APEC countries	Asia Pacific Region	1991-2000	*Capital* stocks (*input*); Labor Force (*input*); Energy consumption (*input*). GDP corrected by PPP (*output*).
Zhou e Ang (2008)	Model DDF, WRDDF Model and *Slack Based Measure* Model oriented *to energy inputs* .	Measuring energy efficiency	OECD countries	1997-2001	*Capital* stocks (*input*); Labor force (*input*); Coal consumption (*input*); Oil consumption (*input*); Consumption of natural gas (*input*); Consumption of other fuels (*input*); GDP corrected by PPP (*desirable* output); CO2 emissions (*undesirable* output).
Song et al. (2013)	CCR model of super efficiency oriented to *inputs - Bootstrap*	Analyze energy efficiency	Brazil, Russia, India, China and South Africa	2009-2010.	Economically active *population (input*); Capital formation rate (*input*); Energy consumption (*input*); GDP at current prices (*output*).
Zhang et al. (2013)	*Two phase* DEA	Assess the safety of oil imports.	China	1993-2011.	Ratio of China's oil imports to global imports; Geopolitical concentration of the oil market; Dollar volatility index; Crude oil price volatility; Ratio of the value of oil imports to GDP; Risk of breakage of trade routes; Dependence on oil imports; Diversification of oil suppliers.
Zeng et al. (2017)	Input-oriented DEA-*linked approach*	Analyse the energy security of the Baltic countries.	Baltic States	2008-2012.	Energy intensity (*input*); Energy trade balance (*output*); Energy weight in the Consumer Price Index (*input*); Electricity price for the average industry (*input*); Dependence on energy imports (*input*); Diversification of oil suppliers (*input*); Diversification of *energy mix* (*input*); Weight of renewable energies no *energy mix* (*output*); Carbon intensity (*input*).

Despite the advantages associated with the application of the DEA methodology in the evaluation of countries' performance in terms of energy security, there is still a lack of scholarly attention (see Table 2). In general, the studies presented in Table 2 validate the importance of the DEA methodology in evaluating the performance of countries in the context of energy security; however, according to the information available to date, none of the studies included in this table performs the robustness analysis of the results obtained, nor does it consider any variations in productivity. Additionally, the models typically used in the literature are radial and oriented and do not provide a comprehensive analysis of efficiency performance. Thus, this study provides an additional contribution to the existing literature, by proposing the evaluation of sixteen European countries using the WRDDM DEA model, which is a non-oriented and non-radial model, seeking to address some of the previously identified limitations.

3. Methodology

In this study, the WRDDM model was used since because it is a non-radial and non-oriented model, which in addition to technical inefficiency, allows the consideration of different levels of reduction for inputs and expansion for outputs. Besides, this methodology makes it possible the assignment of different weights to the evaluation factors, according to the preferences of the decision-maker (Chen et al., 2015). This model has the following formulation (Eq. 1):

$$\max \beta_o^R = max\ (w_y(\sum_r \varpi_{yg}^r \alpha_o^r) + w_x(\sum_i \varpi_x^i \zeta_o^i))$$
$$\text{s.t. } \sum_{j=1}^n \lambda_j y_{rj} \geq y_{ro}^c + \alpha_o^r g_{yr},\ r = 1, \ldots, s,$$
$$\sum_{j=1}^n \lambda_j x_{ij} \leq x_{io} - \zeta_o^i g_{xi},\ i = 1, \ldots, m,$$
$$\sum_{j=1}^n \lambda_j = 1,$$
$$\lambda_j \geq 0\ (\forall_j), \qquad (1)$$

where the vectors of the inputs and outputs of DMU_o are given by $\mathbf{x_o}$ and $\mathbf{y_o}$, respectively. Variables ζ_o^i and α_o^r portray individual inefficiency measures for each input and output, respectively. All variables, except for β_o, are non-negative. As for the values of w_y and w_x, these correspond to the overall importance given to outputs and inputs, and their sum should make up the value of one. However, different priorities can still be assigned to the valuation factors individually, i.e.: $\sum_r \varpi_y^r = 1$, $\sum_i \varpi_x^i = 1$. Finally, the values g_{yr} and g_{xi} correspond to the directional vectors, coinciding with the original values of the outputs and inputs, respectively.

For the measure of inefficiency, when this indicator shows the value of zero ($\beta_o^R = 0$), the DMU under analysis will be considered efficient.

The set of reference DMUs for the inefficient DMUs is determined by solving the following formulation (Eq. 2), assuming that $\alpha_o^{r*}$and ζ_o^{i*} are obtained in the optimal solution of (Eq. 1):

$$\max \sum_r s_r^+ + \sum_i s_i^-,$$
$$\text{s.t. } \sum_{j=1}^n \lambda_j y_{rj} - s_r^+ = y_{ro} + \alpha_o^{r*} g_{yr},\ r = 1, \ldots, s,$$
$$\sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{io} - \zeta_o^{i*} g_{xi},\ i = 1, \ldots, m,$$
$$\sum_{j=1}^n \lambda_j = 1,\ \lambda_j \geq 0\ (\forall_j),$$
$$s_r^+ \geq 0\ (\forall_r),$$
$$s_i^- \geq 0\ (\forall_i) \qquad (2)$$

Considering the optimal solution of (Eq. 2), (α_o^{r*}, ζ_o^{i*}, s_r^{+*}, s_i^{-*}, λ_j^*) , the set of efficient DMUs that are considered a reference of best practices for inefficient DMU_o is obtained as follows (Eq. 3):

$E_o = \{j: \lambda_j^* > 0, j = 1, \ldots, n\}$. (3)

The point of the efficient frontier, which can be associated with a linear combination of the inputs and outputs of the reference DMUs, is represented by the following expression (Eq. 4):

$(\hat{\boldsymbol{x}}_o, \hat{\boldsymbol{y}}_o) = (\sum_{j \epsilon E_o} \lambda_j^* \boldsymbol{x}_j \ , \sum_{j \epsilon E_o} \lambda_j^* \boldsymbol{y}_j \ )$. (4)

The measure of inefficiency obtained from the WRDDM model can be transformed into a measure based on slack variables through the following transformation (Eq. 5):

$\max \ (w_y(\sum_r \varpi_y^r \frac{s_r^{+\prime}}{g_{yr}}) + w_x(\sum_i \varpi_x^i \frac{s_i^{-\prime}}{g_{xi}}))$

s.t. $\sum_{j=1}^n \lambda_j y_{rj} = y_{ro} + s_r^{+\prime}$, $r = 1, \ldots, s$,

$\sum_{j=1}^n \lambda_j x_{ij} = x_{io} - s_i^{-\prime}$, $i = 1, \ldots, m$,

$\sum_{j=1}^n \lambda_j z_{uj} = z_{uo} - s_u^{-\prime}$, $u = 1, ..., q$,

$\sum_{j=1}^n \lambda_j = 1$, $\lambda_j \geq 0$, $j=1, \ldots, n$,

$s_r^{+\prime} \geq 0 \ (\forall_r)$, $s_i^{-\prime} \geq 0 \ (\forall_i)$, $s_u^{-\prime} \geq 0 \ (\forall_u)$ (5)

Since slack variables can be distinct, the objective function given in (Eq. 5) reproduces all inefficiencies, allowing to achieve the maximum increase and reduction of all outputs and inputs, respectively.

Since $(s_r^{+*\prime}, \ s_i^{-*\prime}, s_u^{-*\prime}, \lambda_j^*)$ is the optimal solution to problem (Eq. 5), the overall inefficiency measure obtained from the WRDDM method is given by (Eq. 6)):

$(w_y(\sum_r \alpha_o^{r^{*\prime}}) + w_x(\sum_i \zeta_o^{i*\prime}))$, where $\alpha_o^{r*\prime} = \varpi_y^r \frac{s_r^{+\prime}}{g_{yr}}$ e $\zeta_o^{i*\prime} = \varpi_x^i \frac{s_i^{-\prime}}{g_{xi}}$. (6)

3.1. ROBUSTNESS ANALYSIS

The sensitivity and the robustness analysis of efficiency scores, based on super-efficiency approaches, has been studied in the literature (Zhu, 1996, 2001, 2003). In this study, this tool is particularly important to evaluate the impact taht potential disruptions might have on the indicators employed in the evaluation of the performance of the net oil importing European countries in terms of their oil supply security, i.e., in the performance scores (efficiency) of the countries (DMUs).

Thus, disturbances in the value of each factor given in an interval (Eq. 7) are considered. This interval is obtained by applying a tolerance, δ common to all factors (Henriques and Marcenaro, 2020):

$x_{ij}^L = x_{ij}(1-\delta) \leq x_{ij} \leq x_{ij}(1+\delta) = x_{ij}^U$, $\quad z_{ij}^L = z_{ij}(1-\delta) \leq z_{ij} \leq z_{ij}(1+\delta) = z_{ij}^U$ and $y_{ij}^L = y_{ij}(1-\delta) \leq y_{ij} \leq y_{ij}(1+\delta) = y_{ij}^U$. (7)

The Inputs (controllable and non-controllable) and outputs of the DEA model (Eq. 1) are given in a positive range of variation, respectively, i.e., $[x_{ij}^L, x_{ij}^U]$, $[z_{ij}^L, z_{ij}^U]$ and $[y_{ij}^L, y_{ij}^U]$. On the other hand, directional vectors correspond to the original interval values of inputs and outputs (controllable) and are given by $[g_{xi}^L, g_{xi}^U]$ and $[g_{yr}^L, g_{yr}^U]$, respectively. Additionally, the same weights are assigned to all DMUs.

Two scenarios are considered: one optimistic and the other pessimistic. In the first scenario, the outputs are decreased and the inputs of all DMUs except for the DMU under evaluation are increased (i.e., the efficiency of DMU_o under evaluation increases, while the efficiency of the remaining DMUs decreases). In the second scenario, the opposite situation is verified.

The upper limit, $(1 - \beta_o^{LR})$, of the efficiency interval value, $[(1 - \beta_o^{UR}), (1 - \beta_o^{LR})]$, for DMU_o is obtained by solving the following linear programming problem, corresponding to the optimistic scenario (Eq. 8):

$\max \beta_o^{LR} = max \ (w_y(\sum_{r \ \epsilon \ O} \varpi_y^r \alpha_o^r) + w_x(\sum_{i \ \epsilon \ I} \varpi_x^i \zeta_o^i))$

s.t. $\sum_{j\neq o}\lambda_j y_{rj}^L \geq y_{ro}^U + \alpha_o^r g_{yr}^U, r = 1, \dots, s,$
$\sum_{j\neq o}\lambda_j x_{ij}^U \leq x_{io}^L - \zeta_o^i g_{xi}^L, i = 1, \dots, m,$
$\sum_{j\neq o}\lambda_j z_{uj}^U \leq z_{uo}^L, u = 1, \dots, q,$
$\sum_{j\neq o}\lambda_j = 1, \lambda_j \geq 0, j=1, \dots, n.$ (8)

The lower bound, $(1-\beta_o^{UR})$, of interval, $[(1-\beta_o^{UR}), (1-\beta_o^{LR})]$, for DMU_o is calculated by solving the following linear programming problem, corresponding to the pessimistic scenario (Eq. 9):

max $\beta_o^{UR} = max\ (w_y(\sum_{r\,\epsilon\,O}\varpi_y^r\alpha_o^r) + w_x(\sum_{i\,\epsilon\,I}\varpi_x^i\zeta_o^i))$
s.t. $\sum_{j\neq o}\lambda_j y_{rj}^U \geq y_{ro}^L + \alpha_o^r g_{yr}^L, r = 1, \dots, s,$
$\sum_{j\neq o}\lambda_j x_{ij}^L \leq x_{io}^U - \zeta_o^i g_{xi}^U, i = 1, \dots, m,$
$\sum_{j\neq o}\lambda_j z_{uj}^L \leq z_{uo}^U, u = 1, \dots, q,$
$\sum_{j\neq o}\lambda_j = 1, \lambda_j \geq 0, j=1, \dots, n.$ (9)

By considering (Eq. 8) and (Eq. 9), it becomes clear that $1-\beta_o^{UR} \leq 1-\beta_o^{LR}$.
According to the previous efficiency intervals, DMUs can be classified into three subsets as follows: $E^{++} = \{j \in J : (1-\beta_o^{UR}) \geq 1\}$, $E^{+} = \{j \in J: (1-\beta_o^{UR}) < 1 \text{ e } (1-\beta_o^{LR}) \geq 1\}$ and $E^{--} = \{j \in J: (1-\beta_o^{LR}) < 1\}$, where J is the index set of DMUs ($j=1, \dots, n$).
Therefore, DMUs can be classified as E^{++} (strongly efficient), E^{+} (potentially efficient), and E^{--} (strongly inefficient).

3.2. PRODUCTIVITY ANALYSIS

The Malmquist Index and the Luenberger productivity indicator were developed to evaluate efficiency changes over time (Chambers et al., 1998). These productivity indices are obtained from the efficiency scores calculated based on the DEA models and allow measuring the total factor productivity (TFP). TFP can be decomposed into Technological Change and Efficiency Change (Färe et al., 1994). Technological Change assesses the movements of the production frontier. The Efficiency Change assesses changes in the position of a DMU on the efficient frontier.
In this context, we were based on the Luenberger Productivity Indicator as a measure of TFP, because several authors suggest that this indicator has advantages over the Malmquist Index (Chambers et al., 1998; Balk et al., 2008).
To evaluate the structure of the change in TFP, Färe et al. (1994) proposed the decomposition of TFP into technological change (TECHCH) and efficiency change (EFFCH). The TFP evaluated using the WRDDM model is obtained as follows (Eq. 10) (Fuji et al., 2014):

$$TFP_t^{t+1} = \frac{1}{2}\{\vec{D}^{t+1}(x_k^t, y_k^t, b_k^t) - \vec{D}^{t+1}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1}) + \vec{D}^{t}(x_k^t, y_k^t, b_k^t) - \vec{D}^{t}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1})\}, \quad (10)$$

where x_k^t and x_k^{t+1} are the inputs of DMU_k in the years t and $t+1$, y_k^t and y_k^{t+1} are the outputs of DMU_k for the years t and $t+1$, and b_k^t and b_k^{t+1} are the undesirable inputs of DMU_k for the years t and $t+1$. $\vec{D}^t(x_k^t, y_k^t, b_k^t)$ and $\vec{D}^{t+1}(x_k^t, y_k^t, b_k^t)$ are the productive inefficiencies of year t evaluated across the frontiers of efficiency over the years t and $t+1$, respectively. On the other hand, $\vec{D}^t(x_k^{t+1}, y_k^{t+1}, b_k^{t+1})$ and $\vec{D}^{t+1}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1})$ are the productive inefficiencies of year $t+1$ evaluated through the frontiers of efficiency over the years t and $t+1$, respectively.
Then, TFP can be decomposed into TECHCH and EFFCH, as given in (Eq. 11), (Eq. 12) and (Eq. 13).

$$TECHCH_t^{t+1} = \frac{1}{2}\{\vec{D}^{t+1}(x_k^t, y_k^t, b_k^t) + \vec{D}^{t+1}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1}) - \vec{D}^t(x_k^t, y_k^t, b_k^t) - \vec{D}^t(x_k^{t+1}, y_k^{t+1}, b_k^{t+1})\}, \quad (11)$$

$$EFFCH_t^{t+1} = \vec{D}^t(x_k^t, y_k^t, b_k^t) - \vec{D}^{t+1}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1}), \quad (12)$$

$$TFP_t^{t+1} = TECHCH_t^{t+1} + EFFCH_t^{t+1}. \quad (13)$$

The TECHCH for any DMU only corresponds to changes in the efficient frontier from the point of view of that DMU, not necessarily indicating whether the DMU moves the production frontier towards the most desirable direction.

Thus, to identify the DMUs responsible for moving the frontier towards the most desirable direction, the so-called "innovative" (see Färe et al., 1994), it is necessary to verify the following three conditions (Eq. 14), (Eq. 15) and (Eq. 16):

$$TECHCH_{t,k}^{t+1} > 0, \quad (14)$$

$$\vec{D}^t(x_k^{t+1}, y_k^{t+1}, b_k^{t+1}) < 0, \quad (15)$$

$$\vec{D}^{t+1}(x_k^{t+1}, y_k^{t+1}, b_k^{t+1}) = 0. \quad (16)$$

(Eq. 14) means that the production frontier shifts towards the most desirable direction, i.e., more outputs are generated or less inputs are used from t year to t + 1 from the standpoint of DMU_k.

(Eq. 15) imposes that the production of DMU_k in year t + 1 takes place outside the frontier line (production technology) of year t (i.e., technical change has happened), implying that the production technology of DMU_k in year t + 1 improves regarding that of year t. Therefore, the inefficiency score of DMU_k in year t + 1, which is assessed regarding the production technology of year t, is lower than zero. Finally, (Eq. 16) establishes that DMU_k must operate on the frontier line in period t + 1.

4. DATA AND ASSUMPTIONS

The sample of this study consists of fifteen EU member countries (Germany, Austria, Belgium, Slovakia, Spain, France, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, the Czech Republic, and Sweden), together with the United Kingdom. The choice fell primarily on the EU's net oil importing countries for which data existed.

The time horizon of the analysis (2013 and 2014, 2014 and 2019) contemplates the impact of the recent and unexpected drop in the spot price of crude, the effect of Russian annexation of Crimea in May 2014, and the pre-pandemic year (as it is the year for which there were the most recent data).

The choice of indicators was based on the literature review and are presented in Table 3.

Table 3: 1Indicators used in the DEA model.

Designation	Definition	Unit	Reference	Source
GDP PC PPP (Controllable output)	GDP per capita corrected by PPP	US dollar ($)	Hu and Kao (2007), Zhou and Ang (2008)	World Bank[2]
STOCKS (Controllable output)	Strategic oil reserves[3]	Number of consumption days each country has in terms of strategic reserves	Nordaus (1974), Taylor and Doren (2005), Ren and Yumeng (2015), Guo et al. (2020)	IEA[4]
PRICE (Non-controllable input)	Price of oil delivered at the border of the	CIF price ($/t)	Zhang et al. (2013)	UE - European

[2]Source: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD.

[3]In this case, since the available data are monthly, an annual average of oil reserves was made.

[4]Source: https://www.iea.org/articles/oil-stocks-of-iea-countries.

Designation	Definition	Unit	Reference	Source
	importing country, which includes all charges relating to insurance and freight to the destination			Commission[5], UK - IEA[6]
OIL IN ENERGY MIX (Controllable input)	Weight of oil in total primary energy sources (energy mix)	%	Zeng et al. (2017)	Eurostat[7]
SHANNON INDEX (Bad input)	Shannon-Wiener Index weighted by an index of political stability and absence of terrorism[8]	Dimensionless	Chalvatzis and Loannidis (2017)	Imports - European Commission[9], Political stability index and absence of terrorism - World Bank[10]

Table 4 presents descriptive statistics for the global sample of countries in relation to the different inputs and outputs. Data on the input and output values can be obtained in Tables A.1 to A.3 from Appendix A.

4. RESULTS

Table 5 shows the descriptive statistics of the outputs and inputs for efficient and inefficient countries.

As it would be expected, efficient countries present values for outputs, on average, higher than those of inefficient countries, in all years analyzed, with the opposite occurring in case of desirable and controllable inputs. Also, both efficient and inefficient countries reinforced their strategic crude oil stocks in 2019 and have significantly increased their GDP PC PPP. Additionally, inefficient countries have significantly improved their supplier diversification.

For the price of crude oil imports (a non-controllable input), there are no significant differences in the average of efficient countries compared to inefficient countries.

Finally, for the Shannon-Wiener index (bad input), the average value of this indicator is higher in efficient countries, when compared to inefficient ones, showing that the countries with the best performance have a higher level of diversification of oil suppliers.

Figure 1 shows the ranking of countries in terms of performance in oil supply security, as well as the number of times each country was considered a benchmark. Tables B.1. to B.3 from Appendix B provide the efficiency scores reached by all countries throughout the time horizon considered.

[5]Source: https://ec.europa.eu/energy/data-analysis/eu-crude-oil-imports_en.

[6]Source: https://www.iea.org/countries/united-kingdom.

[7]https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2a.html#:~:text=In%202019%2C%20the%20energy%20mix,fossil%20fuels%20(both%2013%20%25)

[8] The index calculation formula is as follows:

$\sum_{i=1}^{n} X_i . LN(X_i) . B_i$

where X_i corresponds to the weight of imports from supplier “i”, and “B_i” represents the country's index of political stability and lack of terrorism "i”.

[9]Source: https://ec.europa.eu/energy/data-analysis/eu-crude-oil-imports_en.

[10]Source: http://info.worldbank.org/governance/wgi/.

Table 4: Descriptive statistics of all indicators used for all years analyzed.

	2013				2014				2019			
	Average	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Deviation**	**Minimum**	**Maximum**
GDP PC PPP	36 875.05	9 140.09	24 498.66	49 241.52	38 406.72	9 825.59	25 475.50	51 968.19	48 097.44	14 683.81	30 869.15	89 431.40
STOCKS	135.86	36.85	103.50	234.08	136.09	26.42	109.42	195.17	156.60	74.15	106.33	381.33
PRICE	109.03	1.21	106.78	110.63	99.06	2.23	95.55	103.81	64.18	0.99	62.24	65.79
%OIL IN ENERGY MIX	0.3399	0.1001	0.1848	0.5094	0.3509	0.0999	0.1814	0.4966	0.3568	0.0953	0.2058	0.5198
SHANNON INDEX	1.2686	0.7281	0.0100	2.2725	1.3198	0.6815	0.0100	2.2280	1.3636	0.6355	0.0100	2.2317

Table 5: Descriptive statistics of all indicators used, both for efficient and inefficient DMUs for all years analyzed.

	2013				2014				2019			
	Efficient DMUs											
	Average	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Deviation**	**Minimum**	**Maximum**
GDP PC PPP	39 273.21	8 189.78	28 002.50	49 241.52	39 680.09	8 776.17	26 642.11	51 968.19	49 646.09	17 593.30	30 869.15	89 431.40
STOCKS	143.46	49.66	103.50	234.08	138.55	29.07	110.83	195.17	159.29	89.49	106.58	381.33
PRICE	109.03	1.43	106.78	110.63	98.95	2.50	95.55	103.81	63.92		62.24	65.03
%OIL IN ENERGY MIX	0.30	0.09	0.18	0.42	0.34	0.10	0.18	0.50	0.35	0.12	0.21	0.52
SHANNON INDEX	1.35	0.75	0.01	2.27	1.48	0.65	0.01	2.23	1.42	0.74	0.01	2.23
	Inefficient DMUs											
	Average	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Devation**	**Minimum**	**Maximum**	**Average**	**Standard Deviation**	**Minimum**	**Maximum**
GDP PC PPP	34 476.90	9 939.75	24 498.66	47 885.31	35 605.30	12 458.40	25 475.50	51 154.46	46 106.33	10 868.03	33 956.82	58 649.67
STOCKS	128.27	17.65	112.17	164.58	130.70	21.28	109.42	160.83	153.14	55.15	106.33	267.58
PRICE	109.02	1.05	107.61	110.38	99.30	1.71	96.28	100.39	64.52	0.87	63.49	65.79
%OIL IN ENERGY MIX	0.38	0.10	0.23	0.51	0.36	0.11	0.24	0.5	0.36	0.05	0.3038	0.4582
SHANNON INDEX	1.18	0.74	0.03	2.03	0.97	0.67	0.17	1.69	1.28	0.51	0.6983	1.8888

Overall, across the period studied, Slovakia, Spain, the Czech Republic, the Netherlands, France, and Sweden stand out, always remaining less vulnerable throughout the time horizon considered (i.e., these countries always show efficiency scores above 1). On the other hand, the countries that emerge for negative reasons are Poland, Hungary, and Portugal

The countries that have significantly improved their efficiency score (i.e., decreased their vulnerability) are Greece (from 2013 to 2014) and Ireland (mainly from 2014 to 2019). Contrastingly, the United Kingdom (from 2014 to 2019) and Austria (from 2014 to 2019) suffered a significant degradation in their efficiency scores (i.e., increased their vulnerability).

As for the fact that Slovakia has achieved (in all the years studied) the best efficiency scores, the results obtained may be associated with a significant improvement in energy efficiency due to technological innovation and structural changes operated in the Slovak economy (Baláž et al., 2020). In addition to these factors, in all the years analyzed, Slovakia was the country that presented the lowest weight of oil in its energy mix (from 18.1% to 21.3%). The fact that nuclear power plants supply 60% of its energy, while biofuels and bio-waste have essentially replaced coal in the generation of heat and energy, has allowed the country to retain a reasonably high rate of energy self-sufficiency (Kochanek, 2021).

Regarding Spain, 2013 was the year in which the lowest weight of crude oil was obtained in the energy mix. In addition, this country obtained the highest value of the Shannon-Wiener index, having recorded the highest number of oil suppliers (23), compared to 2014 (21) and 2019 (19). Similar results in terms of the diversity of oil suppliers were also reported in Gupta (2008) and Radovanović et al. (2017).

The fact that the Czech Republic occupies third place in the efficiency ranking in 2013 and 2014, and fourth place in 2019, is due to the low weight of oil in its energy mix (18.08% in 2013, 20.97% in 2014 and 22.37% in 2019). A potential explanation for this, regards the main component of the Czech Republic's energy mix (in all the years analyzed), which is solid fossil fuels, such as coal. Nevertheless, as of May 2015, the Czech Republic's energy plan called for a decline in coal-fired electricity generation in the upcoming years, which was supposed to be offset by a fall in electricity exports. In fact, nuclear power puts the Czech Republic in fourth place among the EU's biggest electricity exporters (Kochanek, 2021).

While in the case of the Netherlands the good performance in terms of oil supply security is mainly related to the strategic levels of crude oil reserves and GDP PC PPP, the low vulnerability of France across the time horizon considered might be related to a strong exploitation of nuclear energy in this country that leads to a weight of oil in its energy mix lower than the average EU levels (De Rosa et al., 2021). In two recent studies, Šprajc et al. (2019) and Fu et al. (2021) ranked France and the Netherlands in the 10 best performing countries according to the Energy Trilemma Index.

In the case of Sweden, the evolution of its efficiency score stands out from year to year (reaching, in 2019, the second-best score of the sample of countries studied), as well as the fact that it is the country that was most often considered as a benchmark. Previous studies have also ascertained that Sweden showed high level of energy security (Radovanović et al., 2017; Fu et al., 2021). As an explanatory factor for this development, Sweden had reasonable levels of dependence on crude oil, which have declined over the years. It should also be noted that (in all the years analyzed) renewable energy sources have the greatest weight in the country's energy mix. Additionally, in July 2019, about 5% of all Swedish buildings met the near-zero energy buildings. Finally, it is worth mentioning that Sweden also experienced an energy transition in the power sector with

the development of nuclear energy, as well as an energy transition in the heating sector with the development of biomass-fueled boilers (Millot et al., 2020).

Greece achieved a significant improvement in its efficiency score, mainly between 2013 and 2014, remaining an efficient country in 2019. The fact that this country is geographically close to its oil suppliers makes it possible to obtain relatively more attractive CIF import prices than its counterparts, and it also has access to a greater diversity of oil suppliers. Even though Greece is a weak and oil dependent country, it can be claimed that some important steps, have been taken toward the objective of becoming a transit country and an actor in the energy games with positive outcomes particularly after the recent economic turmoil that this country faced, (Arman et al., 2021). Figure 2 shows the contribution of each indicator to the inefficiency recorded in more vulnerable countries.

In the case of Italy and Germany, in 2013, their scores are very close to efficiency. However, in 2014, although very residual, the weight of oil in the total available energy sources (about 34 %) and strategic reserves (143 days of consumption) were the indicators that contributed to the inefficiency recorded in Germany. For this latter country, in 2019, the only indicator that contributed to its inefficiency was strategic reserves (about 127 days of consumption). In addition to what has already been stated, it is worth noting that, despite the expansion of renewable energy in Germany's energy transition (called Energiewende) in recent decades, towards the diversification of its electricity mix, the share of renewable energy in other sectors (e.g., transport and heating/cooling) has not increased proportionally due to a strong concern on the electricity sector (Chen et al., 2019). Indeed, some scholars claim that Germany's Energiewende was about electricity rather than energy change (Chen et al., 2019). In reality, little progress has been made in achieving energy transition in the heating and transportation sectors. Furthermore, its attempts to increase energy efficiency have been insufficient (Su et al., 2019). The country has not reduced its reliance on energy imports. Instead, it has incentivized the deployment of renewables in less-than-ideal markets with low financial returns. As a result, fossil fuels continue to be the primary source of energy of this country.

For Belgium, in 2013, strategic reserves (133 days of consumption) were the main factor contributing to inefficiency (when compared to its efficient peers). The weight of oil in the energy mix (40%) was also a factor that contributed to the inefficiency of this country. In 2019, the indicator that contributed to its inefficiency was the value of strategic reserves when contrasted with it is benchmarks (164 days of consumption). In fact, Su et al. (2019) recently assessed Belgium as one of the countries with low effectiveness in several energy policy areas under scrutiny, i.e., energy efficiency, promotion of renewables and GHG emission reduction.

As a part of Greece's assessment in 2013, GDP PC PPP ($26,000), strategic reserves (112 days of consumption) and the weight of oil in the basket of available energy sources (46%) were the factors that contributed to attaining an efficiency score lower than one.

As far as Portugal is concerned, in 2013, the indicators that contributed to obtaining an efficiency score below one were GDP PC PPP ($28,000), strategic reserves (122 days of consumption) and the weight of oil in the energy mix (46%), respectively. In 2014, GDP PC PPP (29,000 $) and strategic reserves (109 days of consumption) were the indicators that most weighed on the country's classification as inefficient. Finally, in 2019, the most influential factors were strategic reserves (125 days of consumption), followed by GDP PC PPP (36,900$) and the weight of oil in the energy mix (45.82%).

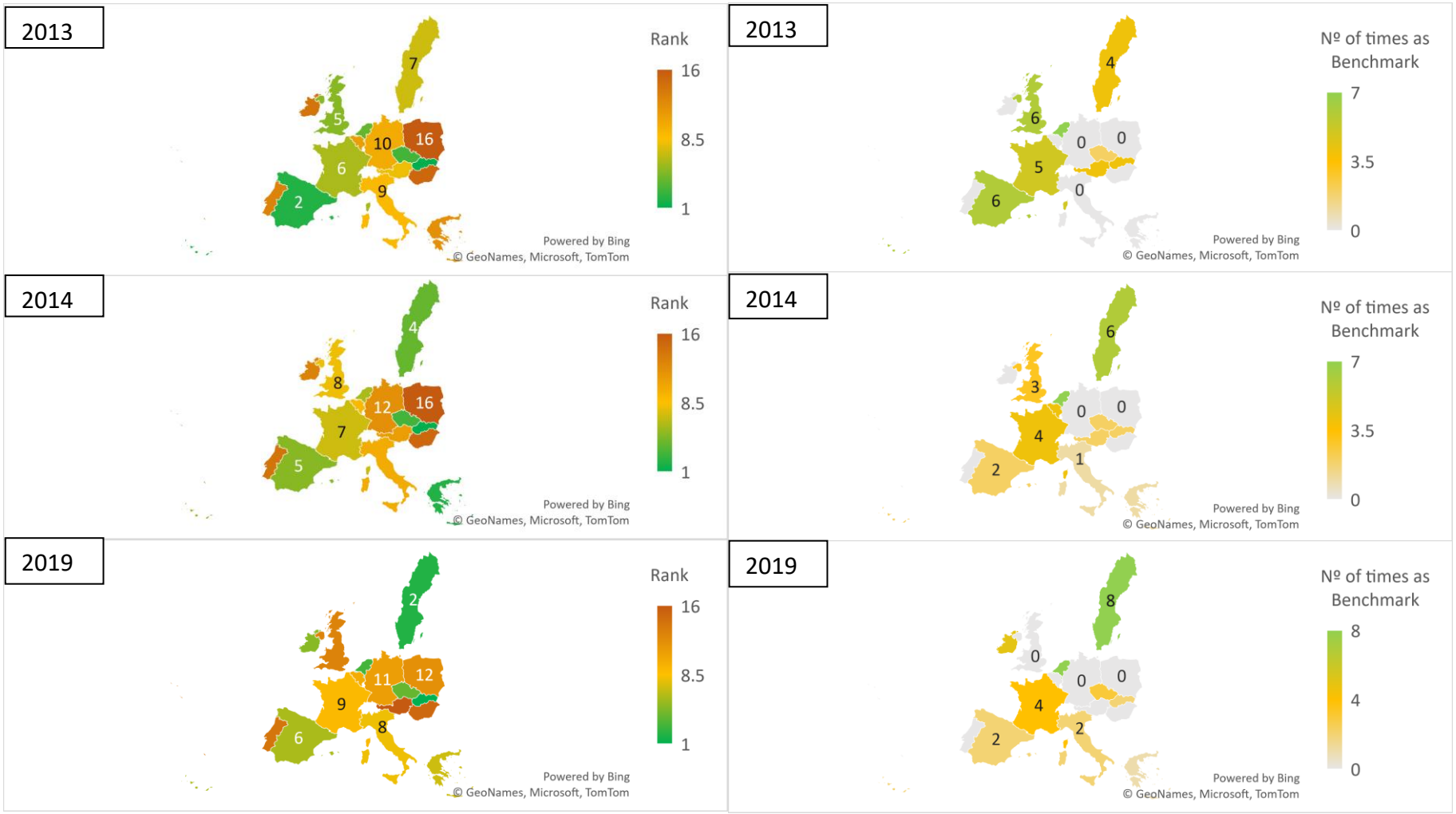


Figure 1: Ranking of the efficiency scores and number of times that countries were considered as benchmarks of best practices.

For Ireland, in 2013, the most preponderant factors for its inefficiency were strategic reserves (114 days of consumption), the weight of oil in its energy mix (51%) and the Shannon-Wiener index (0.74). In 2014, the factor with the greatest contribution to inefficiency was the Shannon-Wiener index (with a value of 1). The influence of strategic reserves (about 114 days of consumption) and the percentage of oil in its energy mix together had an impact on inefficiency equivalent to the Shannon-Wiener index. In this context, these results corroborate Glynn et al. (2014) and Glynn et al. (2017) past findings, which also considered Ireland highly dependent on oil imports, with lack of fuel diversity, particularly in residential heating and in the transportation sector

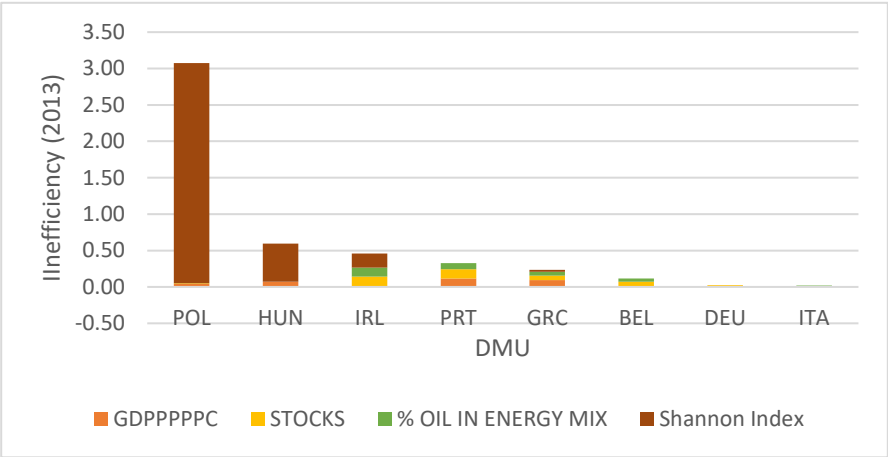
In the case of Hungary, in 2013, the Shannon-Wiener index (about 0.24) contributed the most of its inefficiency, followed by GDP PC PPP ($24,500). For 2014, the Shannon-Wiener index (0.4224) was again the indicator that most contributed to the inefficiency of this country. In addition to this indicator, GDP PC PPP parity ($25,600) also contributed to the inefficiency rating, though not as significantly. Finally, in 2019, the Shannon-Wiener index (0.6983) continues to make a strong contribution to inefficiency, followed by strategic reserves (164 days of consumption) and GDP PC PPP ($34,000).

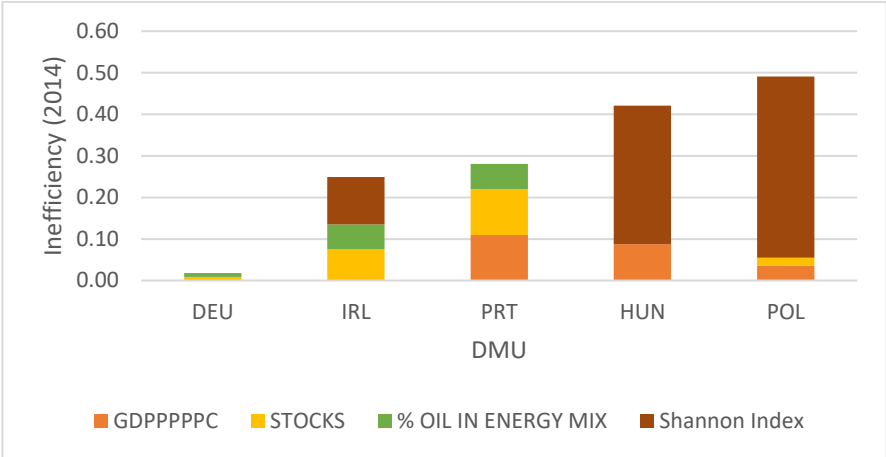
The fact that crude oil is the second largest source of primary energy after natural gas in this country and that the most important suppliers of oil are Russia and Iraq (two high risk countries) help explaining its vulnerability (Kochanek, 2021).

For Poland, in 2013, the factor that best explains the inefficiency of this country was the Shannon-Wiener index (0.0319). GDP PC PPP (24,600$) and strategic reserves (119 days of consumption) also contributed to a score below one; however, with a much lower proportion compared to the Shannon-Wiener index. In 2014, the conclusions are very similar to those drawn in 2013, with the exception that, in addition to the GDP PC PPP (25,500 $) the strategic reserves of crude oil (126 days of consumption) also made their contribution, although very residual, compared to the weight of the Shannon-Wiener index (approximately 0.1738). Finally, regarding 2019, the factors that contributed to inefficiency were strategic reserves (118 days of consumption), GDP PC PPP (34,200$) and, in a very residual way, the Shannon-Wiener index (0.8404). The fact that Poland is the only Visegrad Group country (composed of the Czech Republic, Slovakia, Poland, and Hungary) that does not have nuclear energy in its energy balance might help explain these findings. Furthermore, the recent EU requirements imposing limits on climate change force the economy to decarbonize, which is an incredibly tough challenge for this country, given its reliance on coal in electricity power generation (Kochanek, 2021).

In the United Kingdom, in 2019, the Shannon-Wiener index (0.7199) was the factor that most contributed to its inefficiency. This result could be related to the negative impact that Brexit (the UK's exit from the EU) has had on managing supply and energy demand (UKERC, 2019).

Finally, it follows the case of Austria, which in 2019 had strategic reserves (106 days of consumption) as the main responsible for its inefficiency.





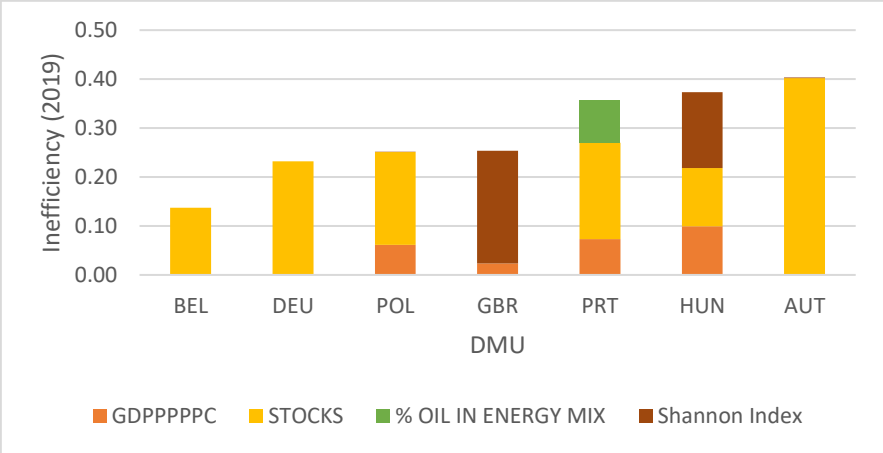


Figure 2: Decomposition of inefficiency.

Figures 3 and 4 (Tables B.4 to B.6 from Appendix B) contain information on the percentage variations of the projections obtained in relation to the actual values for each indicator of inefficient countries. For 2013, for changes in GDP PC PPP, the countries that need to make the biggest adjustments were Portugal (70.30%), Greece (55.86%) and Hungary (44.04%). Therefore, these countries, when compared to their benchmarks, should have presented a higher value for GDP PC PPP, for their input levels. Regarding strategic reserves, the variations of Ireland (86.67%), Portugal (74.61%) and Belgium (47.88%) stand out (for negative reasons). To perform better, these countries should have increased their strategic reserves to reduce their oil supply vulnerability. Regarding the weight of oil in the total energy mix, the variations observed in Ireland (-24.09%), Portugal (-17.34%) and Greece (-10.71%) should be operated. It can be concluded that these countries should reduce their consumption of crude oil in favor of increasing the consumption of other energy sources at their disposal. Finally, it is possible to conclude that the indicator where the actual values and projections are more divergent is in the Shannon-Wiener index, and the value of this indicator in Poland is the one that stands out the most (1,814.77% variation). This country has little diversity of crude oil suppliers in terms of the percentage of imported crude from each supplier (96.6% of the crude imported by Poland comes from Russia, 3.37% originates in Norway and 0.03% in Kazakhstan), i.e., there is a strong dependence on a specific supplier. On the other hand, the number of suppliers in each country is also a determining factor in the calculation of the Shannon-Wiener index, so the fact that this country has three oil suppliers is another factor that contributes to its vulnerability. Hungary also has a strong divergence between the value of projections and the real value for this indicator (312.12% variation). In its list of suppliers, Hungary presents Iraq (5.9% of imports) and Russia (94.1% of crude oil imports). Regarding the index of political stability and absence of terrorism, Russia and Iraq have values of 22.7% and 4.74%, respectively, i.e., low values that aggravate volatility. It should also be highlighted the variation between projections and the actual value of the Shannon-Wiener index in Ireland (115.82%). In this case, Ireland has four oil suppliers, namely Algeria, Libya, Nigeria, and Norway, with crude import percentages of approximately 11%, 11.14%, 14.4% and 63.5%, respectively. Thus, the low value of the Shannon-Wiener index is mainly due to the strong dependence on crude from Norway, even though Norway has a strong index of political stability and absence of terrorism (95.26%).

In 2014, in the context of changes in GDP PC PPP, Portugal (65.8 %) and Hungary (52.28 %) stand out once more for the worst reasons. As far as strategic oil reserves are concerned, Portugal (66.2 %) and Ireland (45.09 %) emerge for the worst reasons. In the case of Portugal, the country recorded a value of strategic reserves corresponding to approximately 109 days of consumption. For Ireland, the value of strategic reserves was about 114 days of consumption. Thus, according to the results obtained, Portugal and Ireland should have strategic reserves of about 182 and 165 days of consumption, respectively. In this way, these countries should increase their strategic stocks to be better prepared for possible ruptures from their usual suppliers. Regarding the differences between the actual values and the projections in the weight of oil in the total energy sources available, the figures obtained in Portugal (-12.14 %) and Ireland (-12.04 %) are highlighted once again. In the case of Portugal, oil weighted around 45% of its total energy mix, a figure that reflects a relatively significant level of dependence on this raw material (well above the European average). In the same vein, Ireland recorded a weight of around 50 %. Finally, regarding the variation between the original values and the projections in the Shannon-Wiener index, the values obtained for Hungary (261.41%) and Poland (200.15 %) are of concern (again). In the case of Hungary, the figure is

justified by the fact that the country has four crude oil suppliers (Azerbaijan, Iraq, Russia, and Saudi Arabia), namely Iraq (which supplies about 7 % of the oil consumed in Hungary), which has a low rate of political stability and absence of terrorism (2.38 on a scale of 0 to 100). The fact that around 90 % of the oil imported by Hungary came from Russia shows a high level of dependence and vulnerability, which has a significant weight on the low result obtained in the Hungarian Shannon-Wiener index. As far as Poland is concerned, the country has four oil suppliers. Like Hungary, Poland has Iraq as its supplier, a country with a low rate of political stability and no terrorism. The strong dependence on imports from Russia (about 94%) is another very influential factor in the low value of the Shannon-Wiener index.

In 2019, concerning the changes between GDP PC PPP and its projections, Hungary, Portugal, and Poland have the main notoriety for the worst reasons. Regarding the difference between the real value of strategic oil reserves and their projections, the figures obtained in Austria (240.78 %), Germany (139.52 %) and Portugal (118.06 %) stand out. Regarding the variations in the weight of oil in the energy mix, for Portugal, this weight should ideally be 38 %, instead of 46 %. Finally, for the Shannon-Wiener index, it can be concluded that the values obtained for the United Kingdom (138.13 %) and Hungary (92.88%) also show up for the worst reasons. In what concerns to the United Kingdom (with a real value of 0.7199), in 2019, it had twelve crude oil suppliers (Algeria, Azerbaijan, Canada, Denmark, Egypt, Gabon, Libya, Nigeria, Norway, Russia, Saudi Arabia and the USA), with the largest suppliers being Norway (40.33 % of total imports) and the USA (with 25.81% of total imports). Hence, the fact that around 66% of total imports come from only two countries shows a certain level of vulnerability and exposure to possible ruptures in crude oil supply, even though in those countries the index of political stability and absence of terrorism shows reasonable values (57.62 and 92.38 for the USA and Norway, respectively). In the case of Hungary, like the years previously analyzed, it shows a bad performance regarding the value reached for the Shannon-Wiener index (0.6983). In 2009, this country presented a list of five suppliers (Colombia, Iraq, Kazakhstan, Russia, and the USA). Once again, the weight of imports from Russia in total imports in 2019 is quite high (76 %). Together with the fact that around 11.84 % of imports in 2019 originated in Iraq (a country that had a political stability and absence of terrorism index of 1.9 this year), these were the most influential facts for reaching a low Shannon-Wiener index.

Figure 3: Original value of GDP PPP PC and STOCKS vs. the corresponding projection for all years.

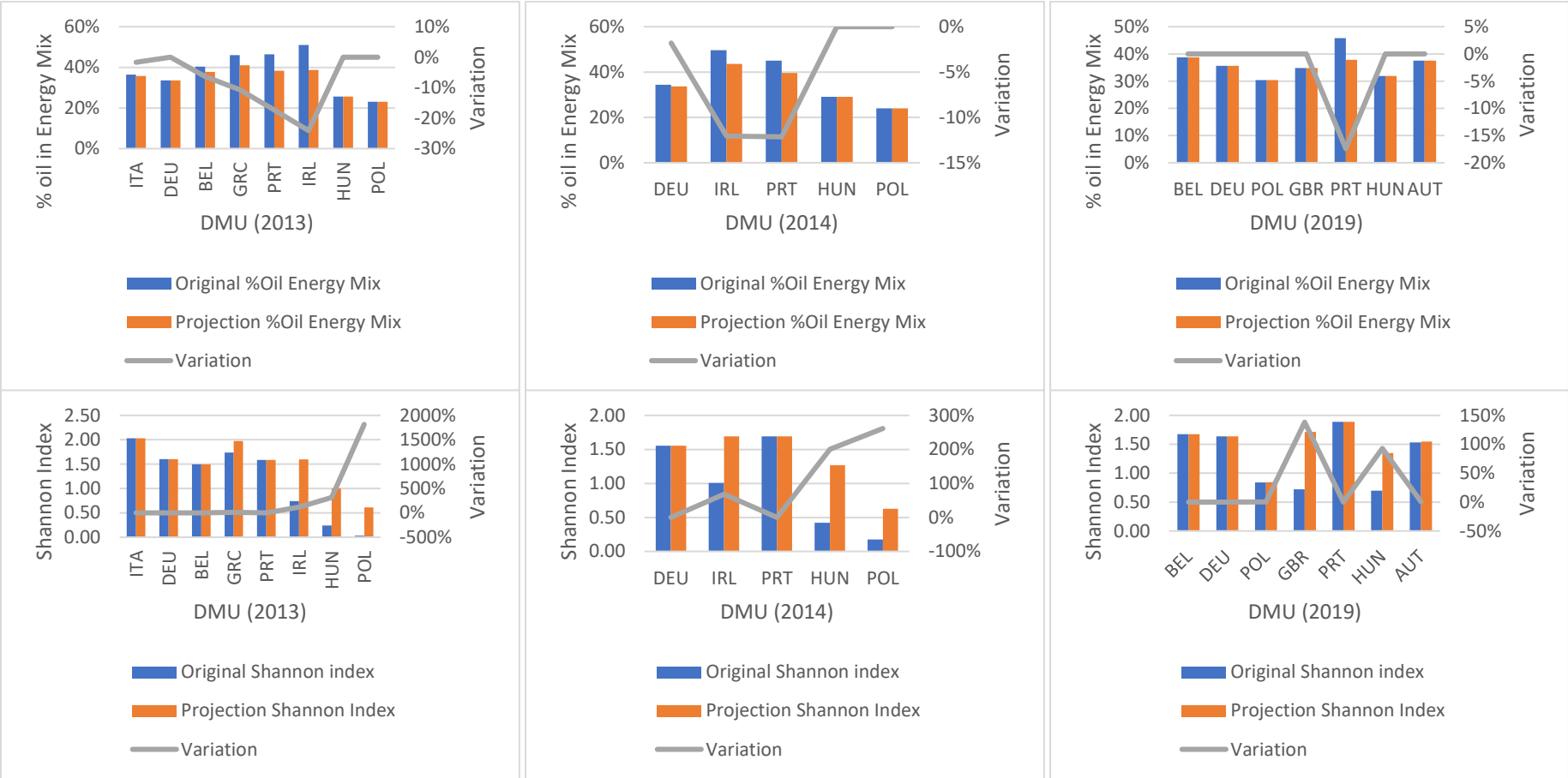


Figure 4: Original value of %OIL IN ENERGY MIX and SHANNON INDEX vs the corresponding projection for all years.

4.1. ROBUSTNESS ANALYSIS

The robustness analysis was performed considering disturbances introduced to the factors under scrutiny of 5% and 10%, respectively.

According to the results obtained and shown in Figure 5 (see also Tables B.7 to B.9 from Appendix B), it can be concluded that in 2013, if all indicators were disturbed by 5%, the only robustly efficient countries are the Czech Republic, France, the Netherlands, Spain, Sweden, and the United Kingdom. If the perturbation of all indicators is 10%, all countries become only potentially efficient.

In 2014, if indicators were perturbed by 5%, the countries that remain robustly efficient are Slovakia, Sweden, and the United Kingdom. If the perturbation of all indicators is 10%, all countries will once again become only potentially efficient.

Finally, for the year 2019, if 5% and 10% disturbances are considered, only Ireland, the Netherlands and Sweden are robustly efficient, with the remaining countries being potentially efficient.

It should be noted that Sweden was the only country that was robustly efficient in all the scenarios of perturbation (except for 2013 and 2014 for penalties of 10%) of the evaluation factors and years considered.

It should also be noted that despite Slovakia being considered the country with the best results (in all the years studied), in the years 2013 and 2019 this country had the worst efficiency scores if penalties of the evaluation factors were considered at 5% and 10%, respectively. Thus, the results obtained for Slovakia are not robust, contrary to what was found for Sweden. It can, therefore, be concluded that Slovakia shows some vulnerability to possible economic and political events that negatively influence the indicators used.

4.2. PRODUCTIVITY ANALYSIS

According to Figure 6, it is possible to observe that the country that achieved the highest productivity gains between 2013 and 2014 was Poland (despite remaining highly vulnerable), mainly because of technological progress. These outcomes are related to the fact that Poland has obtained another crude oil supplier, Iraq, also increasing its proportion of imports from Kazakhstan (from 36,000 barrels in 2013 to 4,277,000 barrels in 2014). As for its efficiency gains, their increase is also explained, fundamentally, by the improvement of the Shannon-Wiener index. Between 2014 and 2019, this country was again the country with the highest productivity gains. These gains were influenced by the improvement of the Shannon-Wiener index from 0.1738 (2014) to 0.8404 (2019). This positive variation can be explained by the increase in the number of oil suppliers, from four (2014) to seven (2019), due to the inclusion of Angola, Nigeria, Saudi Arabia and the United Kingdom, and the exclusion of Iraq. The growth of GDP PC PPP and the strategic oil reserves also influenced these results. In terms of efficiency gains, the growth of the Shannon-Wiener index shows again a preponderant weight.

Hungary also recorded technological progress and efficiency gains between 2013 and 2014. As in Poland, technological progress significantly outweighs efficiency gains. Regarding technological progress, the main contribution is associated with the improvement of the Shannon-Wiener index (in 2013 it was 0.2433, and in 2014 it was 0.4224). This improvement is because Hungary has increased its number of suppliers from three to five through the inclusion of Azerbaijan and Saudi Arabia. As for the efficiency gains, there is also the positive influence of the Shannon-Wiener index. In addition, there is a positive influence of GDP PC PPP that registers an increase from 24,500 $ (2013) to 25,650 $ (2014). For the period between 2014 and 2019, productivity gains, namely technological progress, are then again largely due to the increase in the Shannon-Wiener index. This outcome is sustained by the country's increased number of

suppliers from four (2014) to five (2019), through the inclusion of the USA, Kazakhstan and Colombia, and the exclusion of Azerbaijan and Saudi Arabia. Since then, the level of dependence on imports from Russia (the main supplier) has fallen by around 14.81 %.

In the case of Ireland, between 2013 and 2014, technological progress remains the factor that most contributes to productivity gains. Technological progress is mainly due to the favorable evolution of the Shannon-Wiener index, which increased from 0.74 (2013) to 1.01 (2014). This positive change was due to the increase in the number of suppliers, from four (2013) to five (2014), including Canada. Regarding efficiency gains, there has also been a favorable evolution of the Shannon-Wiener index, the weight of crude oil in the total energy mix and the strategic oil reserves.

In the case of Greece, between 2013 and 2014, the productivity gains recorded are due exclusively to efficiency gains. Thus, all indicators contributed to the increase in the country's efficiency performance. Between 2014 and 2019, technological progress and efficiency losses were recorded at the same time. Strategic reserves, which increased from 113.5 (2014) to 147.42 (2019) days of consumption, made a particularly positive contribution to technological progress.

In the case of Belgium, between 2013 and 2014, technological progress and efficiency gains are recorded, the latter of which overlap technological progress. Thus, the efficiency gains are mainly due to the increase in strategic reserves, from 132.5 (2013) to 160.33 (2014) days of consumption. Between 2014 and 2019, technological progress and efficiency losses were recorded at the same time. In the case of technological progress, the predominant indicator was strategic reserves, which increased from 160.33 (2014) to 164.42 (2019) days of consumption.

Sweden faced technological progress between 2013 and 2014, mainly due to the weight of oil in the energy mix, which saw its value reduced from 24.92% (2013) to 24.25% (2014). There was also a positive influence of strategic reserves, which changed from 115.33 (2013) to 129.75 days of consumption (2014). In the period between 2014 and 2019, technological progress and efficiency gains were obtained. Technological developments were mainly motivated by the decrease in the weight of crude oil in available energy sources between 2014 (24.25 %) and 2019 (20.58 %). In the case of efficiency gains, these were largely influenced by the growth of strategic oil reserves, from 129.75 (2014) to 210.25 (2019) consumption days.

For Portugal, between 2013 and 2014, the productivity gains obtained were due, almost exclusively, to technological progress. Thus, the increase in GDP PC PPP was the indicator that contributed most significantly to it (in 2013 its value was 28,000 $, and in 2014 28,750 $). Additionally, strategic oil reserves and the weight of crude oil in the energy mix also had a positive influence. Between 2014 and 2019, technological progress was recorded. Then again, strategic oil reserves, which increased from 109.42 (2014) to 125.33 (2019) days of consumption, were responsible for this result.

As for Slovakia, between 2013 and 2014, productivity gains were based on technological progress and efficiency gains. The strategic reserves and the weight of crude oil in the total energy sources available were responsible for these gains. Regarding the period from 2014 to 2019, efficiency gains overlapped technological progress. The weight of oil in the energy mix was the indicator that most contributed to the efficiency gains recorded. Technological progress was particularly influenced by the growth of GDP PC PPP, which went from 29,900 $ (2014) to 32,500 $ (2019).

Regarding Germany, between 2013 and 2014, there was only technological progress, thanks to the increase in GDP PC PPP, strategic oil reserves and the percentage of oil in the energy mix. In the period between 2014 and 2019, the country recorded remarkable technological progress, however, at the same time there were significant efficiency losses,

driven by the sharp decrease in the strategic oil reserves, from 143.17 (2014) to 126.67 (2019) days of consumption. From the technological progress side, the GDP PC PPP and the Shannon-Wiener index were the indicators that contributed to this evolution.

In the case of the Netherlands, between 2013 and 2014, efficiency losses and technological progress occurred at the same time, the latter overcoming efficiency losses. Thus, the main motivations for this progress were GDP PC PPP and strategic oil reserves. Between 2014 and 2019, productivity gains have been almost equivalent to efficiency gains and technological progress. Thus, strategic reserves were the main motivation for the efficiency gains. As for technological progress, this was essentially motivated by the growth of GDP PC PPP from $ 49,300 (2014) to $59,500 (2019).

Italy and Austria recorded no significant gains or losses of productivity between 2013 and 2014. For Italy, between 2014 and 2019, productivity gains were not significant and were mainly related to technological progress. On the other hand, between 2014 and 2019, in Austria, there was strong technological progress, but at the same time sharp efficiency losses. Strategic reserves were the most influential indicator in this situation, through their decrease from 111.5 (2014) to 106.33 (2019) days of consumption.

In the case of France, between 2013 and 2014, the country recorded a slightly loss of efficiency, driven by the decrease in the Shannon-Wiener index from 1.9713 (2013) to 1.9581 (2014). Between 2014 and 2019, there was only technological progress in this country.

As for the United Kingdom, between 2013 and 2014 there were no significant productivity gains. However, between 2014 and 2019, the proportion of technological progress and efficiency losses were the same as those recorded in Germany. The main reason for the efficiency losses was the sharp decrease in the Shannon-Wiener index, from 1.2735 (2014) to 0.7199 (2019). This decrease can be explained by the decrease in the number of suppliers from eighteen (2014) to twelve (2019), as well as by the fact that in 2019 65.41 % of total oil imports originated in the USA (25.53 %) and Norway (39.88 %). Brexit influenced the reduction of the number the United Kingdom oil suppliers. In terms of technological developments, this was mainly motivated by the evolution of GDP PC PPP and strategic oil reserves.

Regarding Spain, between 2013 and 2014, productivity losses were exclusively related to efficiency losses. These results were a consequence of the slight degradation of the Shannon-Wiener index from 2013 (2.27) to 2014 (2.23). Between 2014 and 2019, only technological progress was reached, motivated by a favorable evolution of all indicators.

Finally, the country where the greatest loss of productivity occurred, because of both technological retrogression and efficiency losses, between 2013 and 2014, was the Czech Republic. The weight of crude oil in the energy mix and the Shannon-Wiener index were the main responsible for these findings. Between 2014 and 2019, the country recorded technological progress, mainly motivated by the favorable evolution of GDP PC PPP, strategic oil reserves and the weight of oil in the energy mix.

Finally, Tables 6 and 7 show which countries became innovators between 2013 and 2014 and between 2014 and 2019. In 2014, out of the eleven efficient countries, only seven become innovators regarding 2013, whereas in 2019, out of the nine efficient countries, eight manage to become innovators regarding 2014.

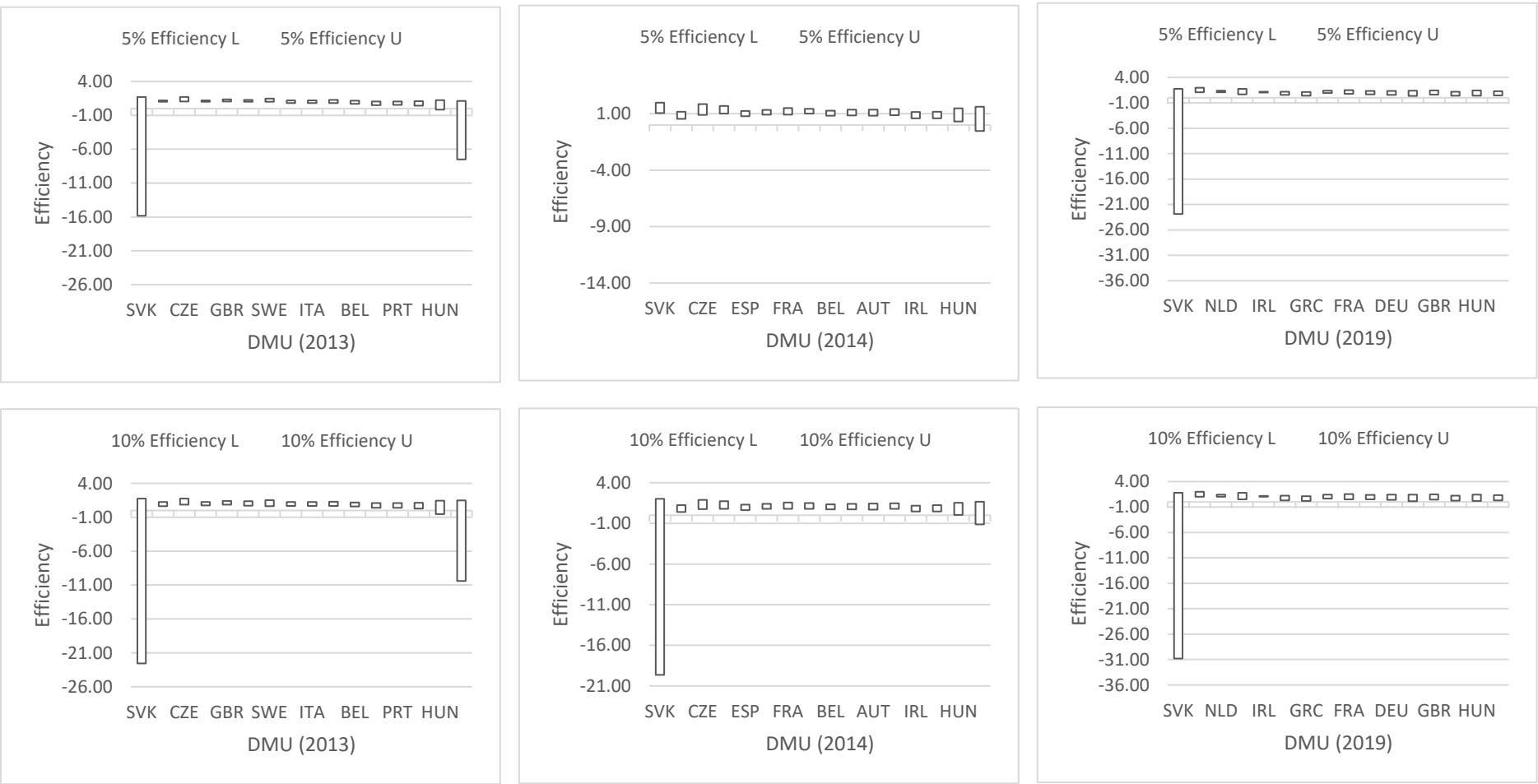


Figure 5: Results of robustness analysis for the years analyzed.

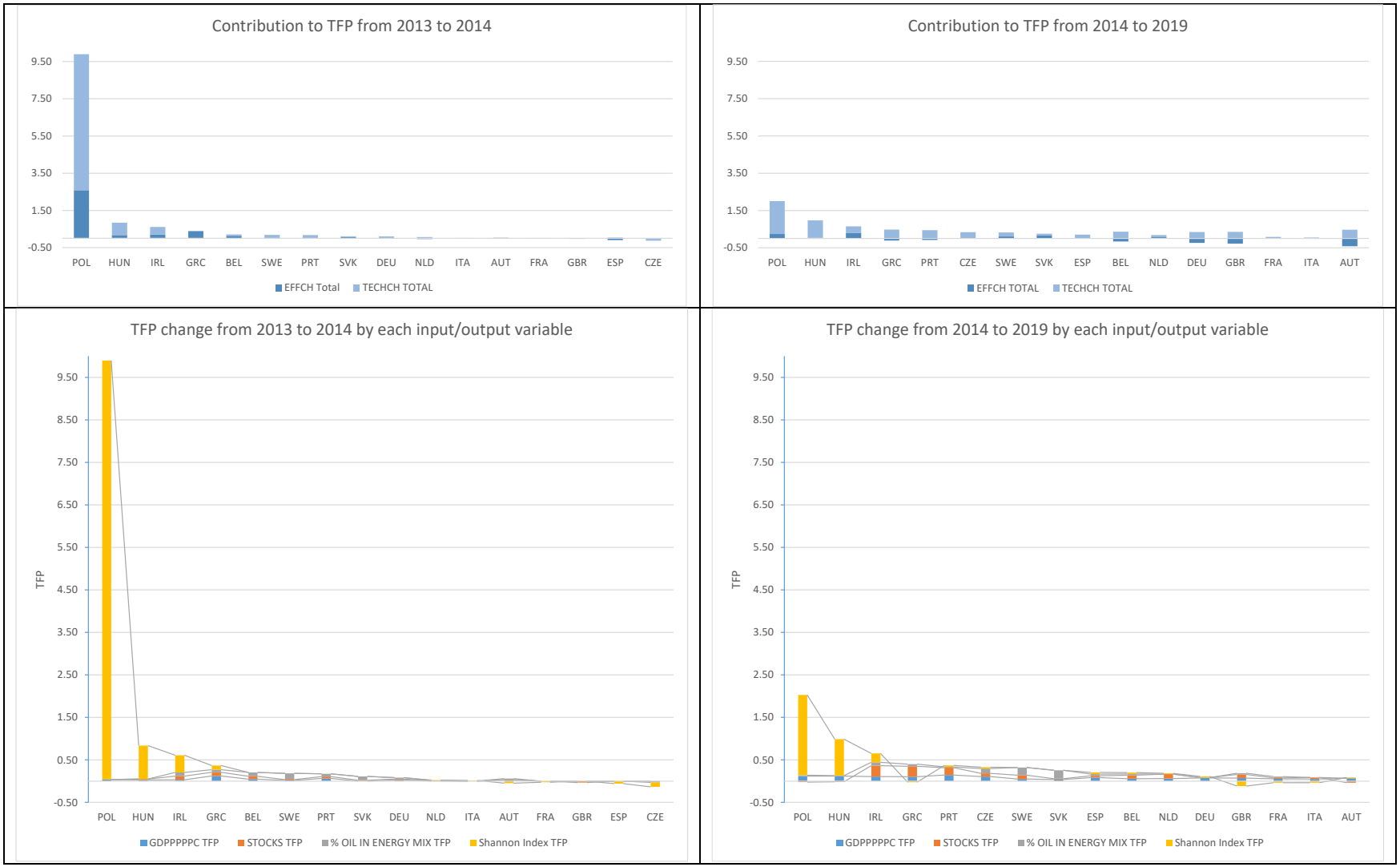


Figure 6: Productivity changes according to efficiency gains and technological progress

Table 6: Countries which became innovators between 2013 and 2014.

Countries	GDPPPPPC	STOCKS	% OIL IN ENERGY MIX	Shannon-Index	Overall conclusion
AUT	innovator	innovator	innovator		innovator
BEL	innovator				innovator
ITA			innovator	innovator	innovator
NLD	innovator	innovator			innovator
SVK		innovator	innovator		innovator
ESP				innovator	innovator
SWE	innovator	innovator	innovator		innovator

Table 7: Countries which became innovators between 2014 and 2019.

Countries	GDPPPPPC	STOCKS	% OIL IN ENERGY MIX	Shannon-Index	Overall conclusion
CZE	innovator	innovator	innovator		innovator
GRC		innovator		innovator	innovator
IRL	innovator	innovator			innovator
ITA	innovator	innovator			innovator
NLD	innovator	innovator		innovator	innovator
SVK	innovator	innovator			innovator
ESP	innovator	innovator		innovator	innovator
SWE	innovator	innovator	innovator		innovator

5. CONCLUSIONS

Currently, oil still plays a major role in the European energy mix. In this context, energy security and its permanent threat play a prominent role in the European political agenda. Indeed, with the growing geopolitical threats that large producers consistently face, price fluctuations in various energy products and disruptions in the supply of large suppliers, the EU considers it is essential that countries' energy security is never compromised. On the other hand, the EU's growing dependence on a limited number of energy suppliers, notably Russia, has encouraged the adoption of a new strategy to diversify European supply sources.

Thus, the literature has been prolific in the proposal of indicators to evaluate the vulnerability of countries to energy crises (e.g., Kruyt et al., (2009), Valdés (2018), Ang et al. (2015), Erahman et al. (2016), Apergis et al. (2015), Bandura (2008) and Gasser (2020)).

Nevertheless, the panoply of indicators proposed in the literature to evaluate energy security still lacks transparency and few contemplate productivity and robustness analysis (Gasser, 2020).

In this context, the main objective of this work is to assess the energy vulnerability of fifteen EU net oil importing countries, together with the United Kingdom, within the years 2013, 2014 and 2019. The period considered in the analysis includes the impact of the recent and unexpected drop in the spot price of crude oil, the influence of Russian annexation of Crimea in May 2014 and the pre-pandemic year (as it is the year for which there were the most recent data).

Hence, we employ the DEA methodology, which can be particularly useful since it allows to incorporate into de analysis different evaluation factors that contribute to the security of oil supply, identifying the benchmarks (in terms of best practices). On the other hand, this evaluation tool allows determining the adjustments that need to be operated on the assessment factors of inefficient countries in terms of oil supply security to achieve efficiency. This methodology also allows addressing one of the flaws identified in the literature regarding the proposed indicators, regarding the possibility that it offers to perform the robustness analysis of the results obtained, evaluating the extent to which the DMUs (countries) remain efficient or inefficient (vulnerable or not), because of the introduction of small disturbances in the evaluation factors. Finally, this methodology is still useful because it allows evaluating the evolution of countries' productivity in terms of energy security, differentiating the variations that correspond to efficiency gains from those that consist of technological progress.

The indicators used in the present study were chosen according to scientific literature. Thus, GDP PC PPP and strategic oil reserves were used as controllable outputs, the CIF price of oil imports was employed as an uncontrollable input, the weight of crude oil in the energy mix was viewed as a controllable input and an adaptation of the Shannon-Wiener index weighted by an index of political stability was considered a bad input from the perspective that the higher its value, the better.

Since the models typically used in the literature are radial and oriented, the performance of each country was measured using the WRDDM method. This is a non-radial and non-oriented model, providing a more comprehensive view in terms of efficiency, as it assesses the adjustments that need to be made to achieve efficiency in both inputs and outputs at the same time. On the other hand, the fact that it contemplates adjustment possibilities in different proportions for the evaluation factors makes it possible to carry out a more realistic analysis. Finally, to fill one of the gaps identified in the literature, a robustness analysis was performed to the results obtained, as well as an analysis of the productivity in the time horizon under scrutiny.

The results show that countries such as Slovakia, the Czech Republic, Sweden, France, the Netherlands, and Spain were consistently considered the most efficient countries in terms of oil supply security. While the first four countries obtained this classification because they had low weight levels of oil in their energy mixes, the Netherlands managed to attain high levels of GDP PC PPP and Spain had the highest diversity of oil suppliers. On the other hand, countries such as Hungary, Poland and Portugal had the worst performances in terms of oil supply security. While for the first two countries the main factors responsible for this classification were the low diversity of suppliers and the low value of strategic reserves, for Portugal the high levels of oil dependence in its energy mix explain these findings.

According to the robustness analysis performed, the results obtained show that Slovakia's classification as efficient is not robust, since if small disturbances are introduced in the data under evaluation, this country attains the worst position of the ranking.

The productivity analysis shows that, in the case of inefficient countries, which presented productivity gains, technological progress was the main reason behind this outcome. In this context, the Shannon-Wiener index was the factor that most contributed to technological progress, showing results consistent with the strategy of diversification of supply sources implemented by the EU. Thus, it is verified that the countries that performed worse in terms of oil supply security, made a significant effort in combating their vulnerability and exposure in face of potential disruptions in the oil supply. Nevertheless, to improve their performance, these countries should consider other types of strategies, namely related to increasing energy efficiency, fostering low-emission vehicles, and replacing fossil fuel consumption with other types of renewable energy sources.

In this context, it is important to mention that while certain EU Member States have successfully supported renewables (for example, Germany, Spain, France, and Italy), others have consistently opposed them, such as Poland, Hungary, the Czech Republic, and Slovakia. These latter countries had a coordinated action against both the EU renewable energy directives and the EU electricity market reforms. Nevertheless, Slovakia and the Czech Republic managed to remain less vulnerable to oil supply at the cost of a high proportion of nuclear power and coal in their energy mixes. Furthermore, certain countries benefited geographically (for example, Sweden), but others need greater financial situations and know-how to engage in renewables (e.g., Hungary, Poland, and the Czech Republic, and Slovakia).

Furthermore, Hungary and Poland, which showed higher vulnerability to oil supply disruptions, are heavily dependent on oil imports, rely on Russia as their main source, and are located on Europe's periphery. Because these nations' living standards are often lower, their citizens are more exposed to an increase in energy prices. Furthermore, these nations have a

significant workforce working in fossil fuel sectors, weak infrastructure, and greater capital costs than Western Europe, making investment in renewables particularly unappealing to them (Pérez et al., 2019).

Countries with lower vulnerability to oil supply disruptions (for example, Spain, France, Italy and Sweden) regard renewable energy investment as an economic and industrial opportunity that allows them to diversify their energy portfolio and minimize energy imports. Most of these countries are in Western Europe, have a higher GDP, more established energy markets, and superior infrastructure. Because their residents have higher levels of income, they are less sensitive to increases in energy prices and are willing to pay a higher price to avoid increased environmental responsibilities. Furthermore, these nations employ a sizable amount of their workers in the renewable energy industry, which provides them with economic benefits even at the expense of increased taxes and levies (Pérez et al. 2019).

Overall, it is possible to conclude that the competing energy paths identified by the study's findings might jeopardize the EU Energy Strategy and the Energy Union. In light of these findings, the EU must advocate for measures that ensure that the economic advantages of renewable energy reach Eastern European countries, making renewable energy a key priority on their political agendas (Henriques et al., 2022). Western European nations might compensate by offering low-interest loans or funding infrastructure projects that help Eastern European countries to adjust their labor and industry to the energy transition while simultaneously lowering GHG emissions. Western clean-tech manufacturing might potentially be located in Eastern European countries, which would benefit both Western corporations and Eastern European countries due to low salaries.

As a future research line, it would be interesting and relevant to study the vulnerability of countries to Natural Gas supply, particularly with the current Russia-Ukraine crisis.

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Appendix A – Data

Table A.1 – Input and output data for the countries studied in 2013.

2013	OUTPUT	OUTPUT	INPUT NON-CONTROLLABLE	INPUT	BAD INPUT = GOOD OUTPUT
DMU	**GDPPPPPC**	**STOCKS**	**PRICE**	**% OIL IN ENERGY MIX**	**Shannon Index**
AUT	47922.05	112.75	110.63	0.37	1.92
BEL	43671.12	132.50	108.32	0.40	1.49
CZE	30818.11	132.75	110.26	0.19	0.77
FRA	39523.86	103.50	109.58	0.30	1.97
DEU	44993.89	141.83	109.38	0.34	1.60
GRC	25947.94	112.17	107.61	0.46	1.74
HUN	24498.66	164.58	109.14	0.26	0.24
IRL	47885.31	113.50	110.38	0.51	0.74
ITA	36314.70	120.67	109.97	0.36	2.03
NLD	49241.52	208.08	108.52	0.40	1.64
POL	24567.51	119.08	107.65	0.23	0.03
PRT	27936.04	121.83	109.74	0.46	1.59
SVK	28002.50	134.42	107.29	0.18	0.01
ESP	32434.00	106.75	106.78	0.42	2.27
SWE	46312.39	115.33	108.90	0.25	0.92
GBR	39931.23	234.08	110.27	0.31	1.33

Note: AUT – Austria, BEL – Belgium, CZE – Czech Republic, FRA- France, DEU – Deutschland, GRC – Greece, HUN – Hungary, IRL – Ireland, ITA – Italy, NLD – Netherlands, POPL – Poland, PRT – Portugal, SVK – Slovakia, ESP – Spain, SWE – Sweden, GBR – Great Britain

Table A.2 – Input and output data for the countries studied in 2014.

2014	OUTPUT	OUTPUT	INPUT NON-CONTROLLABLE	INPUT	BAD INPUT = GOOD OUTPUT
DMU	**GDPPPPPC**	**STOCKS**	**PRICE**	**% OIL IN ENERGY MIX**	**Shannon Index**
AUT	48799.72	111.50	103.81	0.37	1.75
BEL	51968.19	160.33	98.49	0.45	1.65
CZE	32502.48	133.92	102.13	0.21	0.88
FRA	40144.03	110.83	99.38	0.31	1.96
DEU	47011.55	143.17	99.73	0.34	1.55
GRC	26642.11	113.50	95.55	0.50	1.57
HUN	25642.56	160.83	100.39	0.29	0.42
IRL	51154.46	114.25	99.87	0.50	1.01
ITA	36194.87	124.08	99.09	0.37	2.17
NLD	49233.22	178.58	99.33	0.41	1.80
POL	25475.50	125.83	96.28	0.24	0.17
PRT	28742.44	109.42	100.22	0.45	1.69
SVK	28996.87	151.50	95.63	0.18	0.01
ESP	33525.74	114.83	97.07	0.42	2.23
SWE	47184.67	129.75	97.94	0.24	0.99
GBR	41289.08	195.17	100.07	0.33	1.27

Table A.3 – Input and output data for the countries studied in 2019.

2019	OUTPUT	OUTPUT	INPUT NON-CONTROLLABLE	INPUT	BAD INPUT = GOOD OUTPUT
DMU	**GDPPPPPC**	**STOCKS**	**PRICE**	**% OIL IN ENERGY MIX**	**Shannon Index**
AUT	58649.67	106.33	64.49	0.38	1.53
BEL	54709.47	164.42	63.78	0.39	1.68
CZE	43005.55	115.92	63.82	0.22	1.00
FRA	49377.13	109.17	64.98	0.30	1.99
DEU	55891.20	126.67	64.43	0.36	1.64
GRC	30869.15	147.42	62.24	0.52	1.90
HUN	33956.82	163.83	64.05	0.32	0.70
IRL	89431.40	106.58	65.03	0.50	0.93
ITA	44850.93	137.42	64.70	0.36	2.23
NLD	59469.08	381.33	63.96	0.40	1.62
POL	34151.79	117.83	63.49	0.30	0.84
PRT	36871.84	125.33	65.79	0.46	1.89
SVK	32557.19	117.75	62.88	0.21	0.01
ESP	42185.59	107.75	62.84	0.44	2.17
SWE	55068.77	210.25	64.82	0.21	0.98

GBR	48513.50	267.58	65.58	0.35	0.72

Appendix B - Results

Table B.1 – Ranking of efficiency scores for the countries studied in 2013.

Rank	**DMU**	***Score***	**Number of times considered *Benchmarks***
1º	SVK	1.37	4
2º	ESP	1.19	6
3º	CZE	1.12	2
4º	NLD	1.07	7
5º	GBR	1.05	6
6º	FRA	1.04	5
7º	SWE	1.04	4
8º	AUT	1.02	4
9º	ITA	0.98	0
10º	DEU	0.98	0
11º	BEL	0.88	0
12º	GRC	0.77	0
13º	PRT	0.67	0
14º	IRL	0.54	0
15º	HUN	0.41	0
16º	POL	-2.07	0

Table B.2 – Ranking of efficiency scores for the countries studied in 2014.

Rank	**DMU**	***Score***	**Number of times considered *Benchmarks***
1º	SVK	1.85	2
2º	GRC	1.15	1
3º	CZE	1.08	2
4º	SWE	1.04	6
5º	ESP	1.04	2
6º	NLD	1.03	7
7º	FRA	1.03	4
8º	GBR	1.03	3
9º	BEL	1.02	4
10º	ITA	1.01	1
11º	AUT	1.01	2
12º	DEU	0.98	0
13º	IRL	0.75	0
14º	PRT	0.72	0
15º	HUN	0.58	0
16º	POL	0.51	0

Table B.3– Ranking of efficiency scores for the countries studied in 2019.

Rank	**DMU**	***Score***	**Number of times considered *Benchmarks***
1º	SVK	1.44	2
2º	SWE	1.15	8
3º	NLD	1.10	8
4º	CZE	1.06	3
5º	IRL	1.06	5
6º	ESP	1.05	2
7º	GRC	1.05	1
8º	ITA	1.03	2
9º	FRA	1.02	4
10º	BEL	0.86	0
11º	DEU	0.76	0
12º	POL	0.75	0
13º	GBR	0.75	0
14º	PRT	0.64	0
15º	HUN	0,63	0

Rank	DMU	*Score*	Number of times considered *Benchmarks*
16º	AUT	0,60	0

Table B.4 – Percentage changes of the projections against the original data for inefficient countries in 2013.

	GDP PPP PC	STOCKS	%OIL	SHANNON
DMU	**Variation (%)**	**Variation (%)**	**Variation (%)**	**Variation (%)**
ITA	5.90%	0.00%	-1.68%	0.00%
DEU	0.00%	13.95%	0.00%	0.00%
BEL	5.92%	47.88%	-6.36%	0.00%
GRC	55.86%	38.21%	-10.71%	13.50%
PRT	70.30%	74.61%	-17.34%	0.00%
IRL	0.00%	86.67%	-24.09%	115.82%
HUN	44.04%	0.00%	0.00%	312.12%
POL	24.53%	5.62%	0.00%	1.814.77%

Table B.5 – Percentage changes of the projections against the original data for inefficient countries in 2014.

	GDP PPP PC	STOCKS	%OIL	SHANNON
DMU	**Variation (%)**	**Variation (%)**	**Variation (%)**	**Variation (%)**
DEU	0.00%	5.35%	-1.79%	0.00%
IRL	0.00%	45.09%	-12.04%	68.27%
PRT	65.85%	66.20%	-12.14%	0.00%
HUN	52.28%	0.00%	0.00%	200.15%
POL	21.59%	11.61%	0.00%	261.41%

Table B.6 – Percentage changes of the projections against the original data for inefficient countries in 2019.

	GDP PPP PC	STOCKS	%OIL	SHANNON
DMU	**Variation (%)**	**Variation (%)**	**Variation (%)**	**Variation (%)**
BEL	0.00 %	82.54 %	0.00 %	0.00 %
DEU	1.57 %	139.52 %	0.00 %	0.00 %
POL	36.95 %	113.74 %	0.00 %	0.35 %
GBR	14.16 %	0.00 %	0.00 %	138.13 %
PRT	43.73 %	118.06 %	-17.42 %	0.00 %
HUN	59.52 %	71.38 %	0.00 %	92.88 %
AUT	0.57 %	240.78 %	0.00 %	0.75 %

Tabela B.7 – Variation of the efficiency scores due to data perturbations (5% and 10%) in 2013.

		Efficiency score for data perturbations of 5%		**Efficiency score for data perturbations of 10%**	
DMU	**Original Efficiency Score**	***Lower bound***	***Upper bound***	***Lower bound***	***Upper bound***
AUT	1.02	0.82	1.2	0.67	1.27
BEL	0.88	0.69	1.15	0.58	1.19
CZE	1.12	1.03	1.71	0.86	1.75
FRA	1.04	1	1.3	0.71	1.38
DEU	0.98	0.81	1.27	0.69	1.31
GRC	0.77	0.52	1.04	0.38	1.11
HUN	0.41	-0.15	1.26	-0.55	1.45
IRL	0.54	0.41	1.11	0.29	1.15
ITA	0.98	0.81	1.19	0.66	1.26
NLD	1.07	1.01	1.2	0.76	1.24
POL	-2.07	-7.51	1.14	-10.38	1.5
PRT	0.67	0.54	1.05	0.42	1.1
SVK	1.37	-15.82	1.71	-22.56	1.76
ESP	1.19	1.02	1.22	0.62	1.26
SWE	1.04	1.01	1.47	0.62	1.51
GBR	1.05	1.03	1.36	0.85	1.4

Tabela B.8 – Variation of the efficiency scores due to data perturbations (5% and 10%) in 2014.

		Efficiency score for data perturbations of 5%		**Efficiency score for data perturbations of 10%**	
DMU	**Original Efficiency Score**	***Lower bound***	***Upper bound***	***Lower bound***	***Upper bound***
AUT	1.01	0.82	1.36	0.70	1.43
BEL	1.02	0.83	1.27	0.74	1.32
CZE	1.08	0.90	1.86	0.75	1.90
FRA	1.03	0.93	1.49	0.77	1.55
DEU	0.98	0.86	1.42	0.77	1.48
GRC	1.15	0.53	1.18	0.41	1.23
HUN	0.58	0.30	1.48	0.05	1.53
IRL	0.75	0.58	1.14	0.46	1.18
ITA	1.01	0.84	1.35	0.71	1.41
NLD	1.03	0.92	1.34	0.79	1.39
POL	0.51	-0.53	1.61	-1.12	1.66
PRT	0.72	0.60	1.16	0.48	1.24
SVK	1.85	1.06	1.98	-19.64	2.02
ESP	1.04	0.78	1.25	0.63	1.32
SWE	1.04	1.02	1.68	0.77	1.72
GBR	1.03	1.01	1.44	0.78	1.49

Tabela B.9 – Variation of the efficiency scores due to data perturbations (5% and 10%) in 2019.

		Efficiency score for data perturbations of 5%		**Efficiency score for data perturbations of 10%**	
DMU	**Original Efficiency Score**	***Lower bound***	***Upper bound***	***Lower bound***	***Upper bound***
AUT	0.60	0.44	1.31	0.28	1.35
BEL	0.86	0.66	1.32	0.53	1.39
CZE	1.06	0.66	1.76	0.51	1.80
FRA	1.02	0.78	1.51	0.49	1.56
DEU	0.76	0.57	1.35	0.42	1.42
GRC	1.05	0.41	1.14	0.22	1.14
HUN	0.63	0.41	1.42	0.21	1.46
IRL	1.06	1.04	1.16	1.03	1.18
ITA	1.03	0.91	1.39	0.64	1.46
NLD	1.10	1.08	1.38	1.05	1.43
POL	0.75	0.37	1.41	0.16	1.46
PRT	0.64	0.43	1.17	0.23	1.24
SVK	1.44	-22.88	1.77	-30.80	1.82
ESP	1.05	0.57	1.20	0.32	1.26
SWE	1.15	1.06	1.97	1.01	2.00
GBR	0.75	0.61	1.45	0.47	1.48