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Exploring Empirical Correlations Among Energy Efficiency, Energy Productivity, Energy Use and Economic Development in EU Countries

Mihai Adrian TUDOR [1]
Laura VASILESCU [2]
Laurentiu MIHAI [3]
Catalina SITNIKOV* [4]

[1] University of Craiova, Faculty of Sciences, Craiova, Romania; adrian_mihai61@yahoo.com
[2] University of Craiova, Faculty of Economics and Business Administration, Craiova, Romania; laura.vasilescu@edu.ucv.ro
[3] University of Craiova, Faculty of Economics and Business Administration, Craiova, Romania; laurentiu.mihai@edu.ucv.ro
[4] Faculty of Economics and Business Administration, University of Craiova; catalina.sitnikov@edu.ucv.ro

Abstract: *Energy is a crucial component of industrial development and the provision of essential services, as well as an essential element of economic development. Therefore, improving the integration of environmental and energy-efficiency concerns into environmental, economic, and social policies is an essential task for all nations. During the last decades, the trends in energy consumption are determined by economic activities, demographics, lifestyle changes, and weather. In these contexts, the objective of the current research will be to analyse and evaluate the correlations between energy efficiency, energy productivity, energy use and economic development using the linear regression method. Based on the results and the validated/invalidated hypothesis, the paper will propose, also, ways and means for a positive correlation and influence among the studies variables.*

Keywords: *energy efficiency, energy productivity, energy consumption, economic growth, EU countries*
JEL CODES: Q40, Q50

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1. Introduction

Energy is a crucial component of industrial development and the provision of essential services, as well as an essential element of economic development. The impact of energy-related issues which cause pollution is cause for concern. Additionally, energy should be evaluated in relation to energy consumption, but we should keep in mind that most consumption behaviours have significant environmental effects, this being a major issue for all the entities involved, both at national and international level.

Consequently, integrating environment and efficiency related concerns into public policies becomes an essential priority for nations around the globe. These policies aim to develop and implement specific strategies, in different domains, with the purpose of increasing efficient energy consumption behaviours and lowering our environmental impact. These measures need to incorporate specific, measurable, achievable and realistic goals as well as financial or fiscal incentives. (UNECE, 2023).

In addition to energy efficiency public strategies and measures, the trends in energy consumption are determined by economic activities, demographics, lifestyle changes, and weather, all of these having a significant impact on total energy consumption.

The "Energy Efficiency Directive (EED - 2012/27/EU)" was enacted in December 2012 (EU, 2012) as an effort to boost the progress made in energetic efficiency. The EED includes obligatory measures such as energy conservation programmes, energetic audits, energy services, and energy efficiency funds. Directive (EU) 2018/2002, referring to the legislative background for 2030 and beyond, amended this provision. Its central component is a revised energy efficiency goal for 2030 of at least 32.5 % decrease in energy usage compared to the benchmarks (EU, 2018). The 32.5 % target for 2030 corresponds to an EU-27 consumption of 846 million tonnes of oil equivalent (Mtoe) for final energy and 1,128 million tonnes of oil equivalent (Mtoe) for primary energy in 2030 (EAA, 2022)

The regulation was revised in the context of the "Comprehensive Clean Energy for all Europeans" program, which has the purpose of supporting the shift from primary energetic resources to green energy resources while lowering the carbon footprint.

Contents of the energy mix and levels of demand indicate ecological pressures caused by energy usage. The form and scale of ecological effects linked to energy use, such as emissions of air pollutants, exhaustion of resources, water contamination, emissions of greenhouse gases, and radioactive waste build-up, are highly dependent on the quantity and characteristics of fuel, as well as the reduction methods in use (EU, 2023).

Increasing numbers of nations rely on energy efficiency objectives as a way of overcoming new issues related to global warming, non-regenerable resources and an increase reliance on imports related to energy (Roman-Collado & Economidou, 2021). At the national level, industry policy measures frequently include financial incentives, regulatory measures, fiscal measures, voluntary agreements, and white certificate programs (Bertoldi & Mosconi, 2020).

Reducing unemployment and at the same time, developing the national economy, as well as its energetic efficiency could result in a situation where everyone benefits. This strategy is becoming increasingly acknowledged globally, as evidenced by its prominence in the recovery strategies of developed nations after the recession (MED-ENEC, 2013).

The aim of the current study is to analyse and evaluate the correlations between energetic efficiency, energy productivity, energy consumption and economic growth using the linear regression model.

The article is organized in four sections, which follow a logical flow. Section 2 offers a review of relevant literature regarding the correlation between the energy consumption (primary and final), energy efficiency and productivity and economic growth (measured by gross domestic product, inflation and employment) in the new international context. Section 3 introduces the research goals, model and methods. Section 4 includes the discussion of the findings of our research and hypothesis testing using the linear regression model. In the last section, we present the implications (both theoretical and practical) of our research endeavour, together with the study's limitations and recommendations for future research directions.

2. Literature review

Changes in the energy environment over time posed a constant challenge for nations in the modern era, as the production capacity of the national economy is dependent on them. Throughout the last two centuries, this energy transition has supported the growth of population and production.

Energy is a crucial component of the EU's economic and social environment. Therefore, it is unsurprising that energetic efficiency is one significant element of EU's Energy Policy and closely related to its three primary pillars: sustainability, security, and competitiveness (Deloitte, 2016)

Recently, the energetic efficiency policy at the EU-27 level has developed significantly, with main policies such as (EU, 2023):

- “The Energy Labelling Directive” (1994) enforces mandatory labels regarding energy efficiency on consumer products
- “The Energy Performance in Buildings Directive” (2002), the primary European Union directive regarding buildings’ energy efficiency
- “The Ecodesign Directive” (2005), which implements measures supporting the setting of minimum energetic efficiency standards for household appliances;
- “The Energy Efficiency Directive” (2012), which represents European Union's primary act regarding energetic efficiency, addressing all areas and establishing an extensive energetic efficiency strategy for each member state, aiming to focus on efficient energy acquisition;
- The 2018 amendment to the 2012 directive establishes rules and regulations for meeting the 2020 and 2030 energy efficiency goals. Priority must be given to energy efficiency in order to achieve the 2030 climate target.
- In July 2021, the EC introduced a proposition in the "Delivering on the European Green Deal" package, promoting “energy efficiency first” as an overarching principle of EU energy policy and highlighting its relevance and significance in both policy and investment decisions.
- The REPowerEU plan, which was unveiled in May 2022, proposed raising the bar for reducing the EU's reliance on oil and gas imports from the Russian Federation.
- EU countries can contribute to the achievement of the EU objective by establishing indicative national contributions based on a mix of factors that mirror national conditions (GDP per capita, savings in energy, energetic efficiency, and reduction in fixed energy usage levels).

Under the Energy Efficiency Directive, EU-27 members may set their national goals on “primary energy consumption” (PEC), “final energy consumption” (FEC), primary and final energy reductions and intensity.

Both at European and national levels, the primary mandatory goal for policies related to energy demands needs to be articulated in terms of Primary Energy Consumption (PEC), as a PEC target encompasses lowering energy consumption levels as well as transitioning to a lower carbon footprint energy mix (Deloitte, 2016). Each Member State should define their own PEC goals, considering their particular energetic composition, their economic development and structure.

In addition, every nation in the EU may employ other metrics, such as FEC goals or energy intensity targets, based on their particular circumstances, to track its evolution and evaluate the impact of energy efficiency-related policies (Deloitte, 2016).

Most energy transition models depend on the well-documented correlation between energy consumption and gross domestic product (GDP) in order to sustain continuous economic growth (Baptiste et al., 2022; Hannesson, 2009). Ucan et al. (2014) tested the cointegration of a long-term connection between real GDP, both classic and green energy usage, the release of greenhouse gases, and R&D using a heterogeneous panel. These assumptions are supported by Topolewski (2021) as well, who states that there is a one-way correlation between economic development and energy usage levels.

The correlation between energy consumption and economic development is another essential relationship. The growth of national economies is dependent upon a variety of factors, such as the energy usage levels (Komarova et al., 2012). Along with the growing global economy, there is a consistent ascending tendency in PEC and a persistent shift in the structure of energetic consumption.

Bekun et al. (2019) identify the trend towards greening and carbon reductions as a significant contemporary factor in the structural change of energy consumption. In light of new climate trends, it is necessary to analyse the correlation between energy usage levels, energy efficiency, and economic growth.

Various authors approach the relationship between energy consumption levels, energy efficiency, and economic development in different ways: by identifying further influences (Tiba et al., 2016) or by assessing a variety of gains to scale via data envelopment analysis (Sueyoshi and Goto, 2023).

Furthermore, the energetic efficiency was examined in terms of cost reduction (Gerarden et al., 2015) or policy impacy (Gillingham et al., 2009; Gvozdenac-Uroevic, 2010).

The relationship between energy production, consumption, and efficiency has been studied using general equilibrium analysis (Hanley et al., 2006), as well as a bidirectional causal relationship between economic development and stable politics, investment, and dependence on fossil fuels (Menegaki and Ozturk, 2013).

The connection between energetic consumption levels and economic development is supported by four testable hypotheses: growth, conservation, feedback, and neutrality. The feedback hypothesis is based on the interdependent relationship between energy usage levels and national economic development, whereas the neutrality hypothesis assumes that energy usage has a comparatively insignificant influence on economic development (Apergis and Payne, 2012).

Energy is currently an essential industrial component in all nations, alongside labour and capital, and energetic usage is a fundamental metric of prosperity and economic development. In this context, an in-depth analysis of the connection between PEC and FEC, energy efficiency, and economic development could disclose essential elements for future development in a changing environment and in response to new energetic challenges.

3. Methodology and empirical data

3.1. Data and variables

In order to conduct this research, we have used data provided by Eurostat for all EU-27 member states: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain, Sweden, Bulgaria, Croatia, Czech Republic, Cyprus, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Romania, Slovenia and Slovakia. We must mention that our paper employs a more varied approach, taking into account both developed and developing countries and the observed period being from 2011 to 2021. This aspect leads to a large variety of values for the considered variables.

The macroeconomic indicators analyzed in this paper are:

- PEC (Primary energy consumption)
- FEC (Final energy consumption)
- Gross domestic product per capita (GDP per capita)
- IR (Inflation rate)
- EM (Employment)
- EE (Energy efficiency)
- EP (Energy productivity)

Description of the research variables

Primary Energy Consumption (PEC) determines the states' total energy requirements, except non-energy related uses of energetic resources (e.g., petrol used for chemical production rather than combustion). "Primary Energy Consumption" includes the energy use of final consumers, such as agriculture, manufacturing, households, transport, or other services, as well the energetic sector's usage for energy production and transformation, as well as losses related to energy distribution, transformation and transmission.

Final energy consumption (FEC) refers to the final usage of energy in a member state, except non-energy related uses of energetic resources (e.g. the production of chemicals with natural gas). Unlike PEC, this indicator does not include the power that the energetic sector uses, neither the losses that occur during energy distribution and transformation. FEC is included in the EU Sustainable Development Goals (SDG) indicator set as part of SDG 7 on affordable and sustainable energy, which is included in the European Commission's Priorities under the "European Green Deal".

The trend in FEC provides comprehensive evidence for the various end consumers' efforts to reduce energy consumption and its associated effects on the environment. It can be used to track and assess the efficiency of critical policies aimed at influencing energetic use and efficiency.

The *gross domestic product (GDP)* "measures economic activity and is calculated as the difference between the value of all goods and services produced in a country the value of any goods and services used in their production" (Fernando, 2023). The volume index of GDP per capita is expressed in Purchasing Power Standards (PPS) relative to the European Union average of 100. GDP and energy consumption have a positive correlation. Several variables influence the member states' energetic intensity, but energy efficiency is by far the most crucial. (Stern, 2018)

The inflation rate (IR) is the rate of price increase over a specific period. Usually, inflation is a comprehensive measure, reflecting the overall increase in prices or the rise in a country's cost of living. The wholesale power markets are heavily influenced by the price of natural gas. In 2023 and beyond, electricity prices are also projected to increase substantially, although inflation fluctuates widely by area. The supply-demand balance across energy markets remains close, and the unpredictable nature of factors such as Russian supplies and post-COVID demand recovery could continue to drive prices up. These are only slight improvements to the present energy-driven inflation climate (Byers, 2021).

Energy price disruptions have led to a rise in global inflation and stricter financial conditions, which have hampered global economic growth. In response to this crisis, several nations started using their strategic petroleum reserves, which could lead to shortages and rises in prices in 2023 and beyond (Fleck, 2022).

Employment (EM) is an indicator that refers to hired persons. For this study, the following employment categories by gender, age, and economic activity were chosen: measure unit – 1000 age 20 – 64.

Energy efficiency (EE) refers to the ratio between energy outputs and inputs and is expressed as a percentage ranging from 0% to 100%. Energetic efficiency is seen as a strategic objective for the Energy Union and highlights the importance of energetic efficiency a significant principle of the EC.

By consuming energy more efficiently, energy demand can be decreased, resulting in a decrease in the release of GHG and other pollutants and decreased demand for energy facilities. Globally, energetic efficiency has led to significant reductions in energy use patterns (Erbach, 2015).

Energy productivity (EP) is "the ratio of economic output per unit of gross available energy" (Mayer, 2023). Gross available energy refers to the energetic resources required to meet the total demand of all consumers in a specific area. The economic output is reported either in EUR in volumes connected in a series to 2010 (as reference year) at specific exchange rates, or in PPS (Purchasing Power Standard) units.

3.2. Model

The statistical analysis of data and the model's development was carried out using the Python programming language, which is a popular software widely used for its extensive collection of libraries, which are valuable for analytics and complex calculations. The various steps used in the model's development are showcased in figure 1.

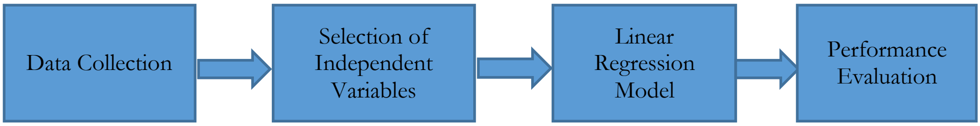

Figure 1. Modelling steps
Source: authors' own concept

The first step is the data collection for the seven variables. Linear Regression is a statistical supervised learning technique used to forecast a quantitative variable by developing a linear relationship between the variable and one or more independent features. Generally, linear regression analysis can be used for both creating a linear model, as well as for determining suitable input variables. In this step, the important objectives are: choosing an appropriate number of predictor variables and identifying the correlation between the dependent and the independent variables, generating a model given in the following form:

$$Y = \delta_0 + \delta_1 X_1 + \delta_2 X_2 + \cdots + \delta_n X_n \quad (1)$$

In the above equation, δ_0, $\delta_1, \ldots, \delta_n$ are regression coefficients, which must be approximated based on the researchers' observations. One of the most used approaches is curve fitting with the least square method, aiming to reduce the distance between actual and predicted values. In our statistical analysis, we also tested quadratic model

$$Y = \delta_2 X^2 + \delta_1 X + \delta_0 \qquad (2)$$

and cubic models,

$$Y = \delta_3 X^3 + \delta_2 X^2 + \delta_1 X + \delta_0 \qquad (3)$$

in order to find the optimal relationship for each hypothesis,

The tests, based on the validation criteria, have indicated that linear regression method is the most accurate for the analyzed hypotheses.

Consider the following simple linear regression model:

$$Y = \delta_1 X + \delta_0 \qquad (4)$$

where X is the independent variable and Y is the dependent variable. The terms δ_0 (intercept parameter) and δ_1 (slope parameter) are the regression coefficients.

Suppose that a sample of n sets of paired observations $(X_i, Y_i),\ i = 1,2,\dots,n$ is available. These observations are assumed to satisfy the following simple linear regression model

$$Y_i = \delta_1 X_i + \delta_0,\quad i = 1,2,\dots,n \qquad (5)$$

The principle of least squares calculates the parameters δ_0 and δ_1 by reducing the sum of squares of the difference between the observed values and the line in the scatter diagram. Considering this idea, the values of parameters δ_1 and δ_0 so that the MSE (Mean Squared Error) is minimal are

$$\delta_1 = \frac{\sum_{i=1}^{n}(Y_i X_i - \overline{YX})}{\sum_{i=1}^{n}\left(X_i^{\,2} - \overline{X}^2\right)} \quad (6)$$

$$\delta_0 = \overline{Y} - \delta_1 \overline{X}, \quad (7)$$

where, $\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$ and $\overline{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$.

In our analysis we employ the linear regression model incorporating the squared residual coefficient (R^2), which is recognized in literature as the deterministic coefficient and root mean squared error (RMSE) as a global validation criteria:

$$RMSE = \frac{\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}{n}, \quad (8)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2} \quad (9)$$

where Y_i is the actual value of the $k-th$ element of the dependent variable Y and $\widehat{Y}_\iota$ is the estimated value assigned by the regression model. Both the RMSE and the R^2 measure a model's goodness of fit and utilize the squared difference between predicted and actual values. They measure the magnitude of errors in the predictions made by a regression model. The squared residual coefficient specifically looks at the squared difference for each individual data point, while the RMSE considers the root of average of these squared difference across the entire dataset. If the squared residual coefficient are close to 1, as well as if the root mean squared error has lower values relative to the response variable's scale, the regression model has a higher quality This aspect represents the last step from model building.

3.3. Empirical Estimation Using Regression Models

The descriptive statistical analysis presented in Table 1 is showing a large number of observations (324), the values indicating a high degree of diversity regarding of the selection of countries included in the database. The values of the macroeconomic indicators for each country were obtained as the arithmetic mean of the values of these variables in the interval 2011-2021.

Table 1 Overview of the Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
EM	324	6839.177	9302.381	205.93636	38550.727
EE	324	50.164	71.873	0.83	290.796
GDP	324	100.039	44.117	50.0	271.090
PEC	324	50.173	71.871	0.8363	290.790
EP	324	7.019	3.353	2.2836	16.704
IR	324	1.502	0.579	0.21818	2.645
FEC	324	35.905	50.331	0.5909	213.481

Source: authors' own concept

Our research endeavour seeks to understand the correlation between the variables involved in the investigation in order to gain a better grasp of the economic context described. A common way of measuring the linear correlation between two variables is using the Pearson correlation coefficient. It can register values between -1 and 1 as follows:

- -1 reveals a perfectly negative linear relationship
- 0 reveals a lack of linear correlation
- 1 reveals a perfectly positive linear correlation.

In our case, we can create a correlation matrix (Fig.2), which is a square table that shows the correlation coefficients between several variables.

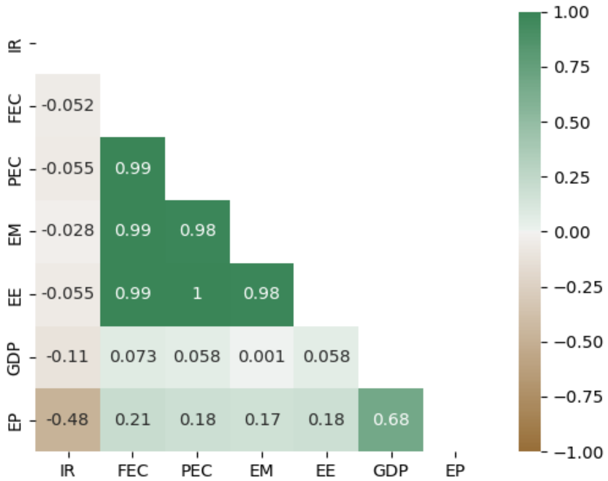

Figure 2. Correlation matrix
Source: authors' own concept

Each cell from the figure 2 matrix displays the relationship between two variables. For instance, the highlighted cell indicates that the Pearson Correlation between PEC and FEC is 0.99, indicating a strong positive correlation between the two variables.

The scatter matrix shown in figure 3 gives us a much more intuitive visualization of the correlation matrix regarding the linearity correlation between the considered variables.

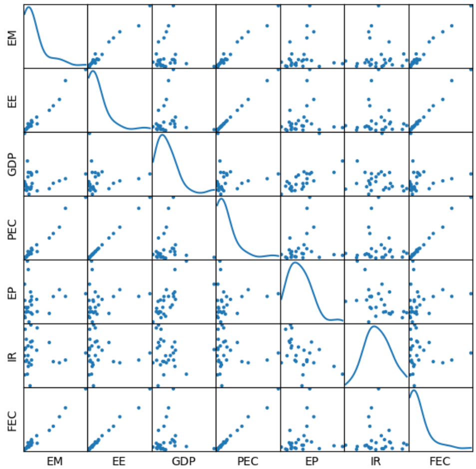

Figure 3. Scatter matrix
Source: authors' own concept

In contrast, the correlation matrix can be used a diagnostic tool for regression. A fundamental presumption of multiple linear regression models is that none of the model's independent variables are significantly correlated with one another. When two independent variables are strongly correlated, this leads to multicollinearity, which can make the regression model difficult to interpret.

Hypothesis of the study

Hypothesis 1. Correlation between Primary Energy Consumption (PEC) and Final Energy Consumption

Hypothesis 2. Influence of Final Energy Consumption (FEC) on Energy Efficiency (EE)

Hypothesis 3. Correlation between Energy Efficiency (EE) and Employment (EM)

Hypothesis 4. Correlation between Energy Productivity (EP) and Gross Domestic Product (GDP)

Hypothesis 5. Correlation between Energy Efficiency (EE), Energy Productivity (EP) and Employment (EM)

Hypothesis 6. Influence of Final Energy Consumption (FEC) on Energy Productivity (EP)

Hypothesis 7. Correlation between Energy Efficiency (EE) and Gross Domestic Product (GDP)

Hypothesis 8. Correlation between Energy Efficiency (EE) and Inflation (IR)

Hypothesis 9. Correlation between Energy Productivity (EP) and Inflation (IR)

The research model and variable correlations are presented in the figure 4.

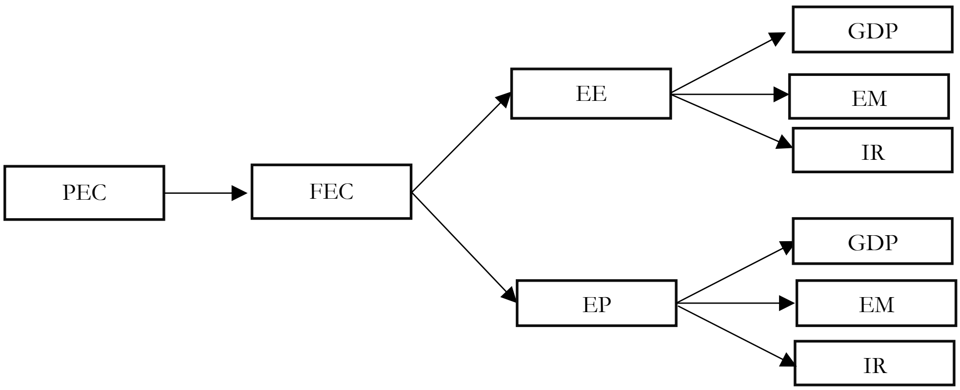

Figure 4. Research model and variables correlations
Source: authors' own concept

4. Results and Discussion

This section presents the findings of our study, which resulted from the validation or invalidation of the 9 proposed hypotheses.

Hypothesis H1. Influence of PEC on FEC.

PEC indicates the total national energy demand, while FEC measures to what final users' actual usage. The difference pertains mostly to the energetic sector usage as well as the losses coming from the transformation and distribution of energy. For 2030, the EU has an energy efficiency target of 1.128 Mtoe for PEC and 846 for FEC (Eurostat, 2021).

According to Kolosok et al. (2020), the fact that PEC is decreasing while FEC is increasing can be interpreted as a favourable indication of improved economic efficiency.

Some Member States focus on minimising their PEC (by improving the efficiency of electricity production or reducing network losses), while others concentrate on reducing their ultimate energy consumption. France, for example, concentrates on q using a sector-specific bottom-up approach. In addition to primary and final energy consumption, Poland concentrates on energy intensity (Deloitte, 2016).

Defining the primary objectives in terms of FEC ignores the energy sector's potential energy efficiency gains. Advocates of FEC objectives claim that this indicator is closely linked to action and operates on the demand side.

At individual national level, the emphasis needs to be placed on enforceable goals expressed in PEC values rather than FEC, since PEC goals includes both lower levels of energy consumption as well as the transition to a smaller carbon footprint energy mix (Deloitte, 2016).

The correlation based on hypothesis 1 aims to determine the impact that "Final energy consumption" has on "Primary energy consumption". First, our findings have shown a significant positive linear correlation among the two variables, since the Pearson correlation coefficient has a high value (0.99). The linear regression model's coefficients are 0.9590 and 0.69651 and verify a type (4) relationship as follows:

$$Y_{FEC} = 0.9590 + 0.69651 \cdot X_{PEC}$$

The regression function is represented graphically in figure 5, where can be seen that the variable X_{PEC} have positive influences, meaning its increasing values lead to Y_{FEC}. increasing as well

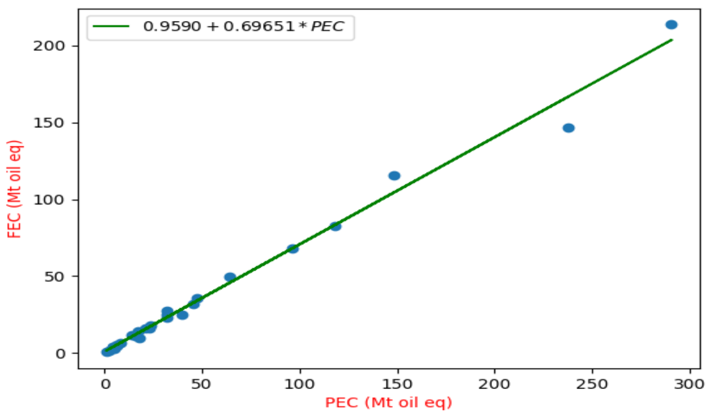

Figure 5. The graphical representation of the regression function (PEC and FEC)
Source: authors' own concept

Regarding the overall performance of the model underlying Hypothesis H1, $R^2 = 0.9892$ and $RMSE = 5.1267$. We note that RMSE has a low score relative to scale of the response variable, which is on the order of 10^2. In addition, the R^2 score is high, referring that the correlation between the independent variable X_{PEC} and the dependent variable Y_{FEC} is very close. The values of two indicators confirm the accuracy of the regression model and, therefore, the prediction's quality.

Our analysis reveals a robust and positive correlation between final energy consumption and primary energy consumption among EU countries. As final energy consumption increases, so does primary energy consumption, indicating that energy demand at the final consumption level has a significant impact on the overall primary energy consumption within the EU. The positive correlation between these variables implies that policies aimed at reducing energy consumption at the final user level could potentially lead to a decrease in primary energy demand. Governments and policymakers should concentrate on enhancing energetic efficiency measures in various sectors to save energy and improve economic efficiency. Energy efficiency measures in industries, buildings, transportation, and other sectors can lead to reduced primary energy usage, resulting in cost reductions and increased productivity. By managing and optimizing their energy use, EU member states can enhance their economic competitiveness, attract funding, and create a more sustainable and resilient economy.

Moreover, the validated hypothesis highlights the significant influence of energy consumption on the EU's members economic development. As the final energy consumption increases, so does the demand for primary energy resources, which can act as both a driver and a constraint on economic expansion. Policymakers should take into account the implications of energy usage patterns on sustainable economic development and adopt measures that promote energy productivity and efficiency. The findings suggest that addressing final energy consumption patterns could contribute to enhancing energy security and sustainability in the EU. A strong reliance on fossil fuels can expose EU countries to variations in global energy markets and geopolitical risks. By reducing primary energy consumption through energy efficiency measures as well as by decreasing their dependence on primary energy sources, they can enhance their energy security, decrease their exposure to external energy supply disruptions and price volatility and reduce their carbon footprint.

The need to address the influence of FEC on PEC can drive R&D investments in more efficient technologies and green energy resources. This, in turn, can stimulate innovation, foster new industries, and create job opportunities, contributing to economic growth and prosperity. This empirical evidence provides valuable insights for policymakers, businesses, and investors seeking to align their strategies with energy trends and economic performance. Moreover, it emphasizes the need for a holistic approach to energy planning, taking into account both the supply dynamics and the demand influences on energy consumption.

Hypothesis H2. Influence of FEC on EE.

The relationship between energy efficiency and usage is intrinsic. Better energy efficiency can result in significant decreases in energy use, assuming mechanisms have been put place to prevent residual effects. Significant reductions of ecological challenges, such as carbon and air pollution emissions, can result from reduced energy usage due to energy efficiency advancements and behavioural adjustments.

Energetic efficiency is a cost-efficient strategy for decreasing final energy usage without lowering the country's economic output. At the same time, increasing energetic efficiency also addresses the major energy issues of climate change, energy security, and competitiveness (EEA, 2015).

The correlation based on Hypothesis H2 aims to determine the impact that “Final energy consumption” has on “Energy efficiency”. A first important aspect is the strong positive linear correlation between the FEC and EE, since the Pearson correlation coefficient has a high value (0.99). The linear regression model’s coefficients are -0.83179 and 1.42029 and verify a type (4) relationship as follows:

$$\mathrm{Y_{EE}} = -0.83179 + 1.42029 \cdot \mathrm{X_{FEC}}$$

Figure 6 is showing the regression function’s chart, where it can be seen that the variable X_{EE} have positive influences, meaning that an increase in X_{EE} generates an increase in Y_{FEC}.

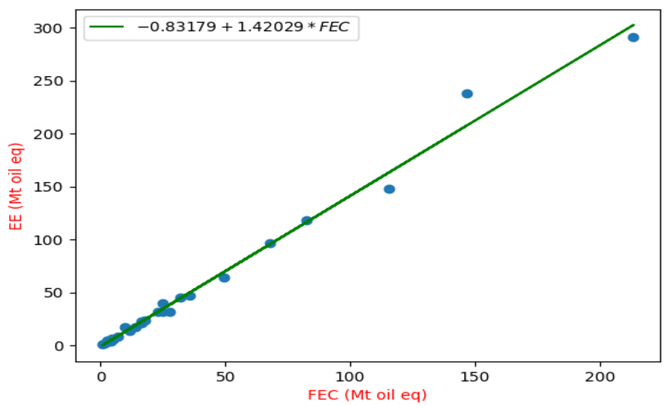

Figure 6 Graphical representation of the regression function (FEC and EE)
Source: authors’ own concept

Regarding the model performance, we obtain $R^2 = 0.9893$ and $RMSE = 7.342$. Based on the fact that RMSE has a low score compared to the scale of response variable, which is on the order of 10^2 and the R^2 score is close to 1, we can confirm accuracy of the regression function and of the prediction.

This hypothesis's validity has several implications in terms of cost savings, competitiveness, energy security, environmental sustainability, innovation and technological advancements, infrastructure development, energy poverty reduction, policy and regulatory framework, long term economic sustainability and the transition to clean energy.

Moreover, it implies that EU countries can achieve greater energy efficiency gains by focusing on reducing final energy consumption. By optimizing resource usage and adopting energy-saving measures, these nations can enhance their economic productivity and reduce their overall energy expenditure. At the same time, improving energy efficiency can enhance the competitiveness of EU industries in the global market. Energy-efficient production processes result in lower operational costs, making EU goods and services more attractive to international buyers and investors. The findings support the alignment of energy transition efforts with energy efficiency goals. EU countries can prioritize energy efficiency as part of their energy policy objectives, fostering a sustainable and low-carbon energy future while simultaneously promoting economic growth.

Moreover, the relationship between these two variables also implies that EU-27 member states can reduce their carbon footprint by enhancing energy efficiency through lower final energy consumption. Decreased energy consumption results in lower GHG emissions and contributes to meeting global warming mitigation targets. Improving energetic efficiency can also lead to reduced energy costs for households and businesses. Lower energy bills can improve the affordability of energy for households, leading to increased disposable income and potential economic stimulus.

Furthermore, our findings suggest that, at a national level, there is a need for appropriate policy and regulatory frameworks to promote energy-efficient practices. Governments may offer incentives, tax breaks, or subsidies to encourage energy-saving behaviours and investments in energy-efficient technologies. At the same time, national authorities should focus on upgrading and retrofitting existing energetic infrastructure. This can stimulate construction and related industries, generating economic activity and employment opportunities. The pursuit of energy efficiency can drive investments in novel technologies' R&D. Technological advancements in energy efficiency can create new markets, foster the growth of green industries, and lead to job creation in the clean energy industry. Energetic efficiency strategies can complement the transition to clean and renewable energy sources. By reducing overall energy consumption, EU countries can optimize green energy usage and accelerate the shift away from conventional fuels, promoting a sustainable energy future.

Hypothesis H3. Influence of EE on EM.

Investing in energy efficiency offers significant advantages in job creation. Thus, energy efficiency investments generate both more jobs than investing in fossil fuel or renewable energy plants. In fact, investments in energetic efficiency may lead to the fulfilment of both employment and energy goals, supporting a decrease in energy demand, while creating numerous skilled jobs. It's important to note that, according to MED-ENEC (2013), investing in energy efficiency results in a higher ratio of jobs per EUR than equivalent alternative fuel investments.

The correlation based on Hypothesis H3 aims to determine the impact that "Energy efficiency" has on "Employment". We should mention that the Pearson correlation coefficient has a high value (0.98) which indicates a significant positive linear correlation between the EE and EM. The linear regression model's coefficients are 475.24393 and 127.15969 and verify a type (4) relationship as follows:

$$Y_{EM} = 475.24393 + 127.15969 \cdot X_{EE}$$

Figure 7 highlights the regression function's chart and shows the fact that X_{EE} have positive influences, which means that an increase in its values will lead to the increase in Y_{EM}.

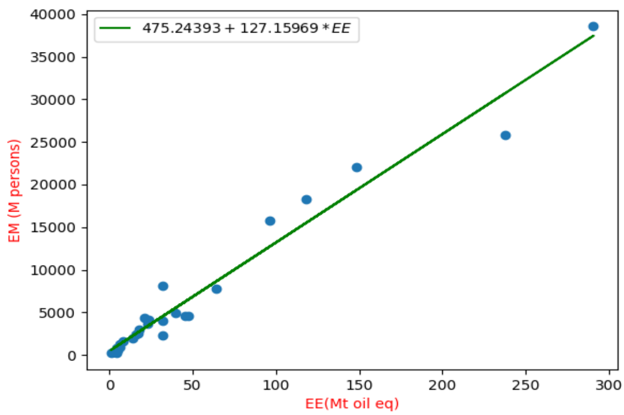

Figure 7. The graphical representation of the regression function (EE and EM)
Source: authors' own concept

The performance indicators of the regression function for Hypothesis 2 are: $R^2 = 0.9652$ and $RMSE = 170.3658.$ We point out that the score of $RMSE$ is low compared to the scale of response variable, which is on the order of 10^4.The high score of R^2 indicates high level of correlation between independent variable EE and dependent variable EM.

The analysis reveals a direct and positive correlation between energy efficiency and employment among EU countries, a fact that has multiple economic implications for EU-27 n terms of job creation, competency development, cost reduction and increased competitively for businesses, national economic growth, as well as public policies and innovation and technological advancements. As energy efficiency improves, employment opportunities increase, indicating that energy-efficient practices positively impact employment rates.

The validation of this hypothesis implies that policies and strategies promoting energetic efficiency may lead to job creation and foster economic development. Investments in efficient technologies and strategies can result in increased employment across various sectors, contributing to overall economic prosperity. Moreover, developing energy efficiency requires a skilled workforce capable of implementing and managing energy-saving measures. Consequently, the findings support the development of workforce training programs, enhancing human capital, and increasing employability within the labour market.

Energy-efficient strategies can lead to cost savings for businesses through reduced energy consumption, as well as increased market competitively. Lower operational costs can positively impact business profitability, allowing companies to reinvest in their ventures and potentially expand and, at the same time, might lead to more competitive pricing, attracting both domestic and international customers, thereby creating more job opportunities.

Our findings suggest that a national level, the positive correlation between energetic efficiency and employment can contribute to overall economic growth. Increased employment rates lead to higher consumer spending, boosting demand for goods and services, and stimulating economic activity.

The validation of Hypothesis H3 underscores the importance of prioritizing energetic efficiency in economic measures. It highlights energetic efficiency as a significant driver of employment growth, economic competitiveness, and sustainable development within the EU countries. Policymakers should view energy efficiency as a strategic tool to achieve multiple economic objectives simultaneously, such as job creation, environmental protection, and energy security

Hypothesis H4. Influence of EP on GDP.

The correlation between economic development and energy demand has long been accepted as axiomatic. As economies develop, the demand for energy rises; if energy supplies are limited, GDP growth in turn slows.

The most recent global energy outlook indicates that there is a divergence between the degree of economic development and consumer demand for energy, which will become even more noticeable in the coming decades. Businesses will continue to require energy to operate, and national economies will need it to develop. However, the curve of energy demand might flatten as a consequence of emerging technologies and other larger trends (Sharma et al., 2019).

There is a robust positive correlation between energy consumption and GDP, even if energetic productivity is declining in recent years and registers lower values in more developed countries. Although energy efficiency has been shown to be a significant factor that influence the national energy productivity, Stern (2018) mentions the rebound effect which might contribute to diminishing returns regarding investments in energetic efficiency aiming to reduce energy intensity

The correlation based on Hypothesis H4 aims to determine the impact that "Energy productivity" has on "GDP". We note that there is a moderate positive linear correlation between the EP and GDP the Pearson correlation coefficient having the value (0.68). This aspect shows us even from this point on the possibility of obtaining a weaker correlation between the two variables. The linear regression function's coefficients are 38.20830 and 8.93625 and verify a type (4) relationship of as follows:

$$\mathrm{Y_{GDP}} = 38.20830 + 8.93625 \cdot \mathrm{X_{EP}}$$

Furthermore, figure 8 shows the chart of the regression function, highlighting that the variable $\mathrm{X_{EP}}$ have positive influences, meaning that its increasing values lead to the increase in $\mathrm{Y_{GDP}}$.

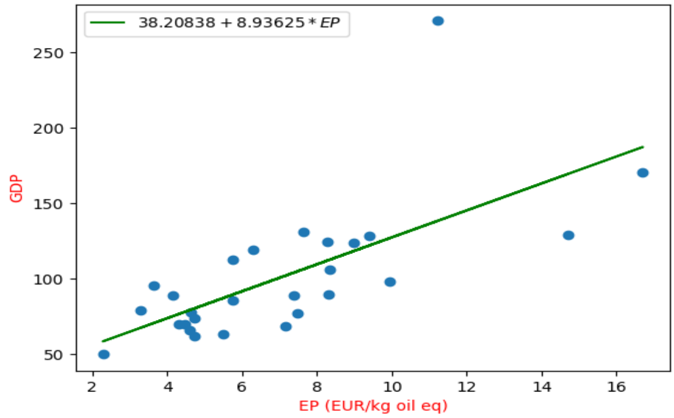

Figure 8. The graphical representation of the regression function (EP and GDP)
Source: authors' own concept

Considering the values obtained for the performance indicators of the model, $R^2 = 0.46150$ and $RMSE = 31.7694$, we can partially validate the Hypothesis H4 from the point of view of statistical analysis.

The partial validation of Hypothesis H4 suggests that energy productivity improvements can drive economic growth in EU countries. Higher energy productivity means producing more goods and services with the same or less energy input, resulting in increased economic output and enhanced competitiveness in the global market. Thus, EU countries can optimize energy usage and reduce overall energy consumption while maintaining or increasing economic output. This resource efficiency can lead to cost savings and greater economic resilience. The pursuit of higher energy productivity encourages investment in R&D of innovative energy-efficient technologies. Technological advancements in energetic productivity can lead to new industries, employment, and economic diversification, all of these leading to a growth in GDP.

Energy productivity improvements can lead to increased tax revenue and higher GDP, which can positively impact public finance and fiscal policy. Governments may have more resources to allocate towards infrastructure, social programs, and other development projects.

Moreover, improving energy productivity contributes to sustainable economic development by decoupling economic growth from increased energy consumption. This supports the EU's efforts to shift to a more sustainable economy with a lower carbon footprint.

At the same time, the positive correlation between these two variables suggests that higher energy productivity can lead to an increase in commercial activities and employment. It can drive the need for a skilled workforce capable of implementing energy-efficient practices, thus, confirming the implications of H3, which states that energetic efficiency contributes to the development of the employment rate of EU-27.

The validation of H4 highlights the importance of energetic productivity as a key driver of economic development within the EU countries. It underscores the significance of promoting energy-efficient practices and technologies to foster economic prosperity while reducing environmental impact. From an economic perspective, energy productivity improvements offer a pathway for achieving multiple objectives, including economic growth, environmental sustainability, and energy security.

Hypothesis H5. Influence of EE and EP on EM.

The correlation based on Hypothesis H5 aims to determine the impact that "Energy productivity" and "Energy efficiency" have on "Employment". We note that the Pearson correlation coefficient having the value (0.18) for independent variables(EE, EP). This observation eliminates any suspicion of multicollinearity, as one of the main assumptions of multiple linear regression is that the independent variable are not correlated.

The linear regression function's coefficients are 6854.1777 and 1309.1654, 4505.61290, while verifying a type (1) relationship:

$$\mathrm{Y_{EM}} = 6854.1777 + 1309.1654 \cdot \mathrm{X_{EE}} + 4505.61290 \cdot \mathrm{X_{EP}}$$

Figure 9 highlights the regression function's graphical representation

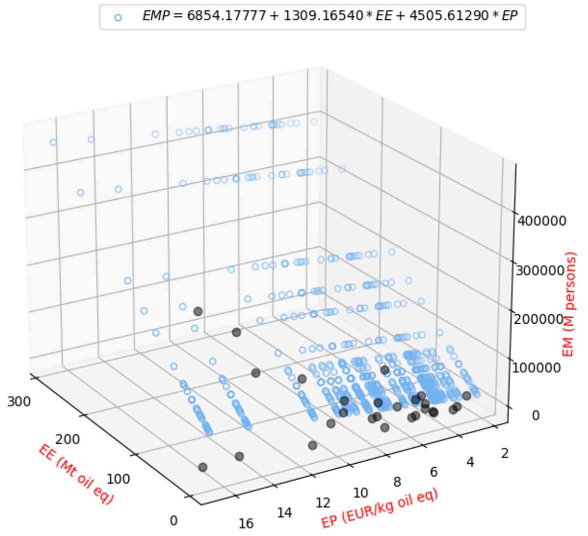

Figure 9. The regression function (EE, EP and EM)
Source: authors' own concept

Regarding the performance indicators of the model, we obtain $R^2 = 0.3997$ and $RMSE = 201.021$, Despite the fact that R^2 score has a moderate value, we note that RMSE is scoring low relative to the scale of response variable, which is on the order of 10^5. In this context, Hypothesis H5 is partially validated.

The validation of Hypothesis H5 suggests that promoting energy productivity and energetic efficiency can stimulate employment and drive economic development in EU countries. Increased employment opportunities can lead to higher consumer spending and investment, contributing to overall economic prosperity. Enhancing energy productivity and energy efficiency may require a skilled workforce capable of implementing energy-saving measures. Consequently, the findings support the development of workforce training programs, enhancing human capital and increasing employability within the labour market.

Moreover, higher energy productivity and energy efficiency can boost the competitiveness of EU countries in the global market, which in turn may lead to an increased demand for skilled workforce. Improved productivity leads to lower production costs, making EU goods and services more competitive, potentially attracting foreign investments, and fostering economic growth, all of which are factors that inevitably will lead to the development of the employment rate. Improving energetic efficiency means using energy more efficiently, resulting in cost savings for businesses and households. Lower energy costs can positively impact business profitability, allowing companies to reinvest in their ventures and potentially expand, thus creating more job opportunities.

Furthermore, the pursuit of higher energy productivity and energy efficiency encourages investment in R&D of energy-efficient technologies. Technological advancements in these areas can lead to new industries, job creation, and economic diversification.

Finally, recognizing the influence of energetic productivity and efficiency on the employment rate can inform energy-related policies. Governments can develop incentives, tax breaks, and regulations to encourage businesses to adopt energy-efficient practices, fostering job creation and economic growth.

The validation of Hypothesis H5 highlights the significance of promoting energy productivity and energy efficiency as key drivers of employment growth and economic development within EU-27. It underscores the importance of energetic policies that create synergistic effects on both employment and sustainability goals. From an economic perspective, investing in energy efficiency and productivity initiatives can offer a pathway to achieve multiple objectives, including economic growth, social welfare, and environmental sustainability.

In the last part of this section, we present the hypotheses that could not be validated by the regression analysis performed considering the validation criteria, given in the Table 2.

Table 2 Regression Results

Hypothesis	**R^2 Value Linear Model**	**Quadratic Model**	**Cubic Model**
Influence of EE on GDP	0.0033	0.0138	0.0142
Influence of FEC on EP	0.0423	0.0439	0.0441
Influence of EE on IR	0.0030	0.0045	0.0452
Influence of EP on IR	0.2293	0.2370	0.2394

Source: authors' own concept

We note that the R^2 score is very low for the hypotheses studied both in the linear model and in the quadratic and cubic models, which means that the correlation between the dependent variable and independent variable is very week. On the other hand, the low value of this validation indicator (R^2) is a direct consequence of the Pearson correlation coefficient (see fig.2), which indicates a limited linear relationship in the case that we consider the linear regression model.

5. Conclusions

The seventh Sustainable Development Goal (SDG) highlights the need for global economies to increase their efforts to improve energetic efficiency. It has been discovered that energy efficiency improvements stimulate economic growth, although empirical evidence to support this claim remains divided. How energy consumption affects energy efficiency and energy productivity, as well as the correlation between these factors and economic development, require further study in the context of recent international crises and political challenges.

On a global scale the energy market is undergoing significant transformations due to factors such as: a growing need for accessible energy; diminishing resources and soaring prices; lowering carbon footprints; and increasing competitiveness of clean energy sources.

Regarding energy use, there is a significant correlation between primary and final energy consumption (H1). Our findings have shown that member states should prioritize PEC targets rather than FEC targets, since the former includes both a reduction in energy use as well as the transition to a more efficient, lower carbon emission energy mix (Deloitte, 2016) Each member state should define its own PEC targets, taking into consideration its economic growth, its distinctive energy balance, and its economic structure.

Our findings suggest, through the validation of H1, the importance of managing energy consumption effectively in order to enhance economic efficiency and sustainability. EU countries should focus on implementing policies that encourage energy efficiency, promote green energy, and foster technological progress to maximize energy productivity while ensuring sustained economic development and environmental preservation.

The correlation between EE and energy consumption is also close (H2). Thus, enhanced energetic efficiency can result in significant reductions in energy usage patterns, which can result in significant decreases in environmental stresses (emissions of greenhouse gases and air pollution).

The validation of H2 highlights the crucial role of reducing final energy consumption in achieving energetic efficiency and sustainable economic development within the EU countries. Emphasizing energy-saving measures and promoting energy-efficient technologies can lead to positive economic outcomes, including enhanced competitiveness, reduced environmental impact, and improved energy security. By acknowledging and acting upon these empirical correlations, EU countries can foster a greener and more resilient economy, ensuring a prosperous and sustainable future.

Energy consumption and gross domestic product are also positively correlated (H4), which underlines energy efficiency as an important factor which influences the national economy's energy productivity. At the same time, we should not overlook the rebound effect which, according to Stern (2018), will limit the utility of energy efficiency developments for the reduction of energy intensity. This correlation showcases the impact of higher energetic productivity in driving economic development and enhancing the GDP of EU member states. Focusing on energy efficiency and resource optimization can only lead to positive economic outcomes, including increased competitiveness in the global market, sustainable economic development, an increase in the standard of living and enhanced energy security. By recognizing and acting upon these empirical correlations, EU countries can position themselves for economic success while advancing their commitment to sustainable and resilient economic growth.

Making investments in energy efficiency will result in reduced energy consumption, which helps to save money, increase productivity, generate job opportunities, and boost the economy directly. Local energetic efficiency will stimulate development in other areas which will have a positive effect on employment (MED-ENEC, 2013). Consequently, the impact of energetic efficiency on economic development is felt on GDP, employment, and energy prices (inflation rate).

Moreover, our paper has shown that there is a direct correlation between EE, EP and EM (H3 and H5). H3's validity accentuates the pivotal role of energy efficiency in fostering employment growth and stimulating economic development within the EU countries. Emphasizing energy-efficient practices and technologies can lead to positive economic outcomes, including job creation, enhanced competitiveness, and progress towards environmental and energy sustainability objectives. By recognizing and acting upon these empirical correlations, EU countries can shape a prosperous and resilient economy while advancing their commitment to sustainable development. At the same time, the partial confirmation of H5 emphasizes the impact of higher energetic productivity and efficiency on increasing employment and fostering economic prosperity within the EU countries. Prioritizing these factors can lead to positive economic outcomes, including job creation, enhanced competitiveness, and progress towards sustainable and resilient economic development.

Energetic efficiency is a most cost-effective strategies for lowering final energy consumption without decreasing the level of national economic development. Increasing energetic efficiency additionally tackles the crucial issues of global warming, energetic security, and competitiveness (EEA, 2015).

Thus, energetic efficiency becomes an important measure that developing and developed countries can use to protect their energy future while also seeking prosperous and sustainable development.

In order to fulfil these goals, national authorities have to overcome challenges and use energetic efficiency opportunities using important instruments such as:

- Laws, policies and regulations, such as improved building codes and household appliance standards;
- Financial and fiscal incentives: grants and government subsidized credits that offer investors security in order to minimise their risks and maximize their returns;
- Support administrative policies and information: training and reforms regarding prices and subsidies
- Raising the awareness level: improving understanding and will help gather support for government measures, regulations and investments.

At the EU level, the EC established the Energy Union Strategy which encompasses ambitious goals, aiming to develop a low carbon energy system which will be secure, competitive and sustainable. Some of the main aims of this strategy are to lower carbon emissions by at least 40% of the 1990 levels, until 2030, to increase the use of energy from renewable sources by at least 32% and to ensure significant reductions in energy use, while providing security, competitivity and sustainability in the energy sector.

The Commission Communication of 25.02.2015 called "A framework strategy for a resilient energy union with a forward-looking climate change policy' established five dimensions of the Energy Union Strategy, one of which is related to the decrease of energy demand. The European Union's fulfilment of its energy and climate targets is depending on the prioritisation of energetic efficiency. Moreover, another communication regarding the "European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate-Neutral Economy" highlights the importance of energetic efficiency as a primary principle in reaching a carbon neutral economy by 2050 (EU, 2019).

Increasing energy efficiency is an important measure on long term in order to avoid demand exceeding supply and it can help rebuilding the greener and more-vibrant economies. Also, providing clean and efficient energy will conduct to environmental protection, cost savings, employment creation and provide many other social benefits.

In the present circumstances, energetic efficiency has shown significant potential for economic development and lowering GHG emissions, but at the same time, the progress is happening rather slowly, a fact that is impacting consumers, business as well as the environment.

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Author Contributions

Conceptualization, C.S. and L.V.; methodology, C.S., L.V. and M.A.T.; software, M.A.T.; validation, C.S, L.V.; M.A.T and L.M.; formal analysis, C.S. and L.M.; data curation, C.S. and L.V.; writing—original draft preparation, L.V.; writing—review and editing, L.M.

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