Renewable Energy in the European Union: The State of the Art and Directions of Development

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Abstract: The transition of the energy system in the European Union (EU) from non-renewable to renewable energy aims to guarantee the energy supply, reduce greenhouse gas emissions, reduce energy costs, and lead to industrial development, growth, and occupation. The revised renewable energy directive EU/2023/2413 raises the binding renewable target for the EU in 2030 to a minimum of 42.5%. This means almost doubling the existing share of energy from renewable sources in the EU. This study is concerned with presenting state-of-the-art regarding renewable energy sources in EU countries, predicting the share of renewable energy in 2030, and investigating the relationships between this share and the reduction of greenhouse gas emissions. The results of the research indicate a significant relationship between increasing renewable energy sources and decreasing greenhouse gas emissions in the EU.

Key-Words: - energy production, renewable energy sources, renewable energy targets, sustainable development, electricity production capacities, greenhouse gas emissions.

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1 Introduction

The negative effects of fossil fuels on the natural environment over the past decades caused renewable energy sources (RESs) to play a crucial role in today's world. Reducing the consumption of fossil fuels, increasing the interest in alternative energy sources such as solar, wind, geothermal, hydro, tidal, and biomass energy. RESs have a significant importance in reducing carbon dioxide and other harmful gasses. Consequently, many governments and organizations, including the European Union, support renewable energy policy. Directions of the EU energy policy include the development of RESs, the improvement of energy efficiency and security of fuel and energy supplies, the diversification of the electricity generation structure, and the reduction of negative effects of the energy sector on the environment, [1].

RESs are a very important part of the concept of sustainable development and sustainable energy. Sustainable development of energy merges the RESs concept with economic, social, and environmental dimensions, [2]. The sustainable energy development process is supported within the EU energy policy through developing technologies dedicated to RESs, as well as cogeneration of thermal energy and electricity, [1]. It is noteworthy that energy efficiency is already considered at the level of product design, particularly by designing electrical devices, [3].

The use of RESs can affect positively consumers' electricity bills, particularly during high prices of fossil fuels, [4]. Moreover, RESs save fossil fuels, and they can reduce the EU's dependence on unpredictable suppliers of fossil fuels. In addition to this, RESs correspond to the growing ecological awareness of society, among other things, the harmful impact on the environment that results from using fossil fuels for energy production.

There are a few studies devoted to RESs in the EU. The role of renewable and non-renewable energy in CO_2 emissions for the EU was described in, [5]. The assessment of RESs in the years 2008-2014, and scenarios to achieve target 2020 was presented in, [6]. This assessment is based on three indicators: share of RESs, primary production of RESs per capita, and gross final consumption of RESs per capita. The share of RESs in the final energy consumption in the EU for the period 1995-2016 was described in, [7]. Changes in the energy structure among EU countries over the period 2008-2018 were presented in, [8]. This structure was described through indicators regarding renewable and biofuel energy consumption and production, share of renewable energy, electricity generation,

and inland consumption. The study investigating the relationship between economic growth and renewable energy consumption in the EU for years from 1995 to 2015 was illustrated in, [9], [10], [11], [12]. In turn, the impact of economic growth, renewable energy, tourism arrivals, and international trade on carbon dioxide emissions in the EU for the period 1995-2014 was presented in, [13]. RESs in the context of sustainable development and environmental security were presented in, [14], [15]. In turn, RESs from the perspective of energy security in the EU were described in, [16], [17]. The role of research and development expenditure in the transition from non-renewable to renewable energy in the EU was presented in, [18]. Also, the effect of financial development on renewable energy consumption was investigated in, [19]. Moreover, some research refers to a specific type of RESs, for example, photovoltaic, [20], [21] or wind energy, [21], [22], [23].

The literature review indicated that there is no current research devoted to RESs in the EU after 2018 and their impact on reducing the amount of greenhouse gases. The lack of studies dedicated to the mentioned area was the motivation to carry out relevant research in the recent years in this area. Moreover, this research investigates the possibility to achieve renewable energy targets for 2030, considering linear models based on regression analysis.

The paper is organized as follows: Section 2 includes the description of data collection and research hypotheses. Section 3 presents the results of data analysis and findings, including data analysis of RESs, predicting the share of renewable energy, and verifying research hypotheses. Section 4 presents a discussion and conclusion.

2 Data Collection and Hypotheses

The data was collected from European Statistical System (Eurostat) datasets, namely the area of sustainable development (sdg), environment (env), and energy (nrg). Among sustainable development indicators, there was selected the share of renewable energy in gross final energy consumption (sdg_07_40). This indicator belongs to Goal 7 of sustainable development named affordable and clean energy. Moreover, the share of renewable energy can be presented from the perspective of transport, electricity, and heating and cooling. At the moment of preparing this study (November 2023), Eurostat provides datasets for the years 2004-2021. Among datasets related to the environment, there were selected indicators regarding greenhouse gas emissions and air pollutants. These datasets include indicators determined for the years 2012-2021. The last dataset refers to the area of energy, and it includes electricity production capacities for renewables and wastes. This dataset also includes indicators determined for the years 2012-2021.

Apart from the mentioned Eurostat datasets, there was also collected data related to renewable energy targets that are accessible on the webpage of the European Commission, [24]. These targets were widespread in EU directives of renewable energy 2018/2001 and 2023/2413.

In this research, the following datasets were collected from Eurostat databases:

- the share of renewable energy in gross final energy consumption (data code: sdg_07_40);
- electricity production capacities for renewables and wastes (data code: nrg_inf_epcrw);
- air pollutants by source sector (data code: env_air_emis);
- greenhouse gas emissions by source sector (data code: env_air_gge).

This research aims to verify the following hypotheses:

H1: there is a significant dependence between increasing RESs and decreasing the amount of greenhouse gases in the EU;

H2: there is a significant dependence between increasing RESs and decreasing the amount of carbon monoxide in the EU;

H3: there is significant dependence between increasing RESs and decreasing the amount of sulphur oxides in the EU;

H4: there is significant dependence between increasing RESs and decreasing the amount of ammonia in the EU;

H5: there is a significant dependence between increasing RESs and decreasing the amount of particulates < 2.5μm in the EU;

H6: there is a significant dependence between increasing RESs and decreasing the amount of Particulates < 10 μm in the EU.

The verification of the above-presented hypotheses is carried out using regression analysis.

3 Data Analysis and Findings

This section consists of three parts: 1) data analysis regarding RESs in the EU; 2) predicting RESs; and 3) verifying research hypotheses.

3.1 Data Analysis of RESs

Data analysis refers to the presentation of the share of renewable energy in the EU in years 2004-2021, and the share of renewable energy in all EU countries in 2021. Moreover, data analysis includes the presentation of all renewable energy sources, as well as their distinction in the context of transport, electricity, and heating and cooling (data code: sdg_07_40).

Figure 1 illustrates the share of renewable energy in gross final energy consumption in the EU in the years 2004-2021. The share of renewable energy increased from 9.6% in 2004 to 21.8% in 2021. The annual increase of renewable energy in gross final energy consumption in the EU was about 0.71%. It is noteworthy that the share of renewable energy in 2020 (22.0%) was larger than in 2021. This can result from the restrictions related to the coronavirus pandemic (COVID-19), such as lockdowns and delays in public investment projects regarding RESs.

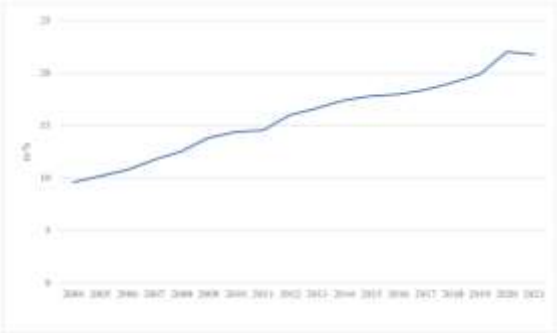

Fig. 1: The share of renewable energy in gross final energy consumption in the EU

Figure 2 presents the share of renewable energy in gross final energy consumption in all EU countries in 2021. The greatest share was in Sweden (62.6%), Finland (43.1%), and Latvia (42.1%). Twelve EU countries have a share above the EU average (21.8%), whereas fifteen countries are below this average.

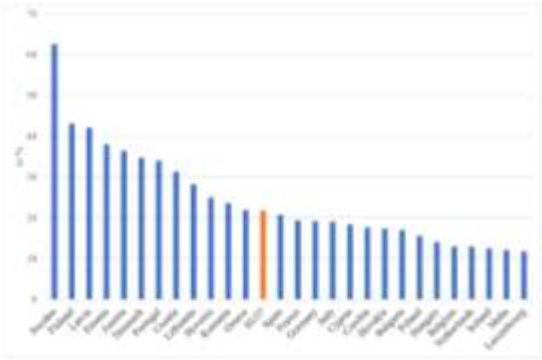

Fig. 2: The share of renewable energy in EU countries in 2021

Figure 3 illustrates the share of renewable energy sources in transport in the EU in the years 2004-2021. The share of RESs in transport increased from 1.4% in 2004 to 9.1% in 2021. The annual increase of renewable energy in transport in the EU was about 0.47%. The share of RESs in transport also decreased in 2021 compared to 2020 (10.2%).

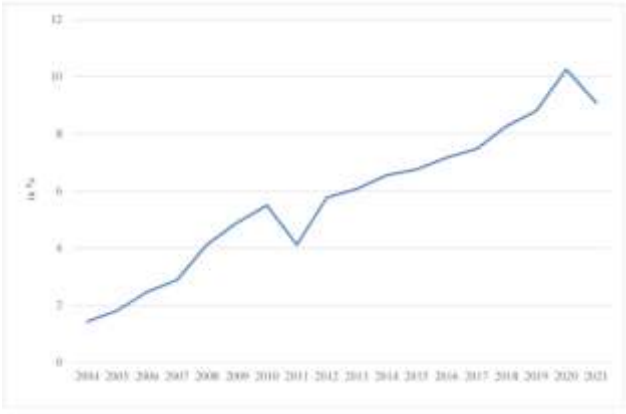

Fig. 3: The share of RESs in transport in the EU

Figure 4 presents the share of RESs in transport in all EU countries in 2021. The greatest share was in Sweden (30.4%) and Finland (20.5%). Seventeen EU countries have a share below the EU average (9.1%), whereas ten countries are above the average.

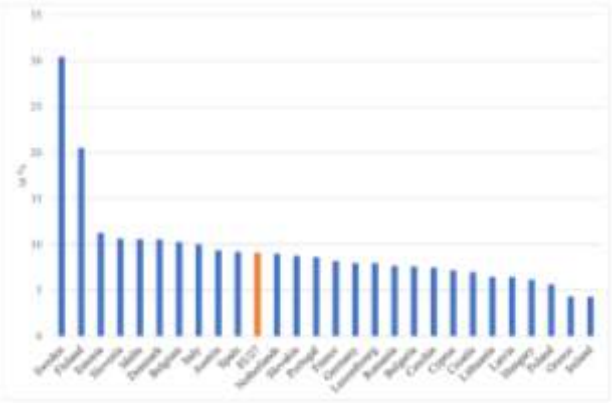

Fig. 4: The share of RESs in transport in EU countries in 2021

Figure 5 illustrates the share of renewable energy sources in electricity in the EU in the years 2004-2021. The share of RESs in electricity increased from 15.9% in 2004 to 37.5% in 2021. The annual increase of renewable energy in electricity in the considered period was about 1.35%.

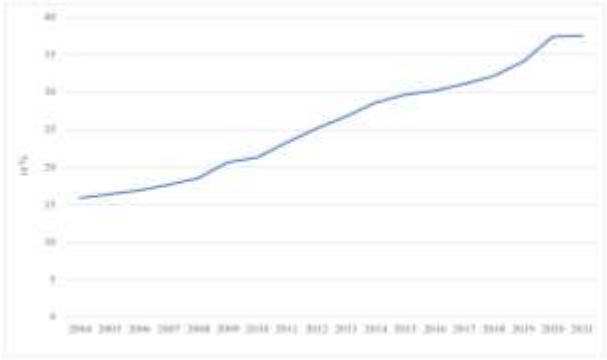

Fig. 5: The share of RESs in electricity in the EU

Figure 6 presents the share of RESs in electricity in all EU countries in 2021. The greatest share was in Austria (76.2%) and Sweden (75.7%). Seventeen EU countries have a share below the EU average (37.5%), whereas ten countries are above the average.

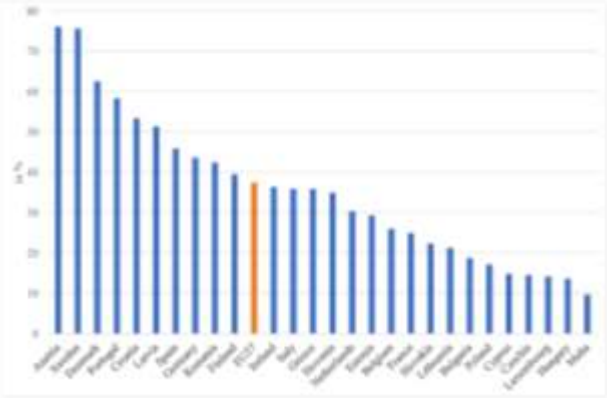

Fig. 6: The share of RESs in electricity in EU countries in 2021

Figure 7 illustrates the share of renewable energy sources in heating and cooling in the EU in the years 2004-2021. The share of RESs in heating and cooling increased from 11.7% in 2004 to 22.9% in 2021. The annual increase of renewable energy in heating and cooling in the considered period was about 0.66%.

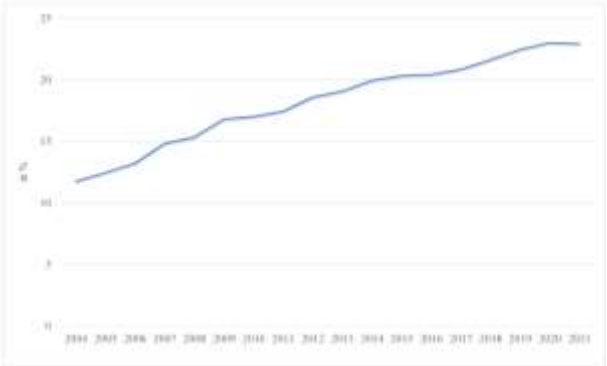

Fig. 7: The share of RESs in heating and cooling in the EU

Figure 8 presents the share of RESs in heating and cooling in all EU countries in 2021. The greatest share was in Sweden (68.6%), Estonia (61.3%), and Latvia (57.4%). Seventeen EU countries have a share above the EU average (22.9%), whereas ten countries are below this average.

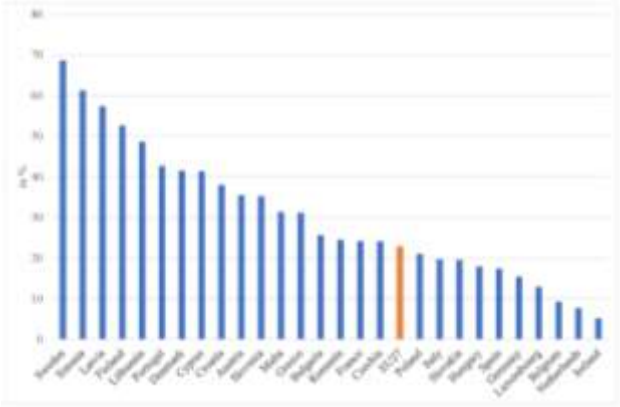

Fig. 8: The share of RESs in heating and cooling in EU countries in 2021

Figure 9 illustrates the electricity production capacities for renewables and wastes in the EU in the years 2012-2021. The greatest electricity production in 2021 was related to wind energy. Moreover, a significant part of electricity production in 2021 was provided by solar and hydro energy. It is noteworthy that wind and solar energy had a particularly large increase in the recent decade.

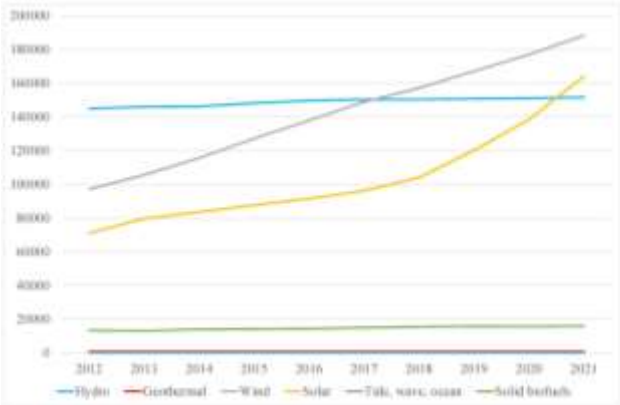

Fig. 9: Electricity production capacities for renewables in the EU (in Megawatt)

Figure 10 presents the share of electricity production capacities for renewables and wastes in the EU in two years: 2012 and 2021. Hydroenergy provided the greatest part of electricity production in 2012. Ten years later hydro energy provides a very similar volume of electricity production, but wind and solar energy have the greater share of electricity production. It is noteworthy that the share

of geothermal and tidal energy in electricity production in the EU is below one percent.

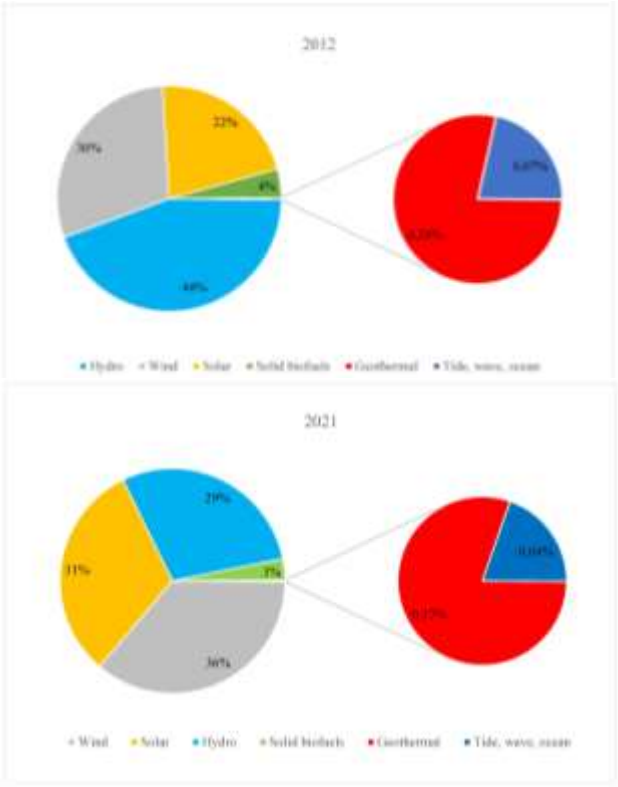

Fig. 10: The share of electricity production capacities for renewables in the EU in 2012 and 2021

3.2 Predicting the Share of Renewable Energy

According to the Renewable Energy Directive 2018/2001 EU established a binding renewable energy target for the EU in 2030 of at least 32%. However, the revised renewable energy directive EU/2023/2413 raises the binding renewable target for the EU in 2030 to a minimum of 42.5%, with the aspiration to reach 45%. This means almost doubling the existing share of energy from renewable sources in the EU, [24].

Achieving this target seems to be unrealistic, considering the annual increase in renewable energy in the last 20 years. This increase was on average about 0.71%. Figure 11 presents the linear model determined through regression analysis for renewable energy in gross final energy consumption in the EU. Using the linear model, the prediction of renewable energy in the EU will reach 28.5% in 2030. There should be exponential growth to reach the renewable energy target of 42.5% in 2030.

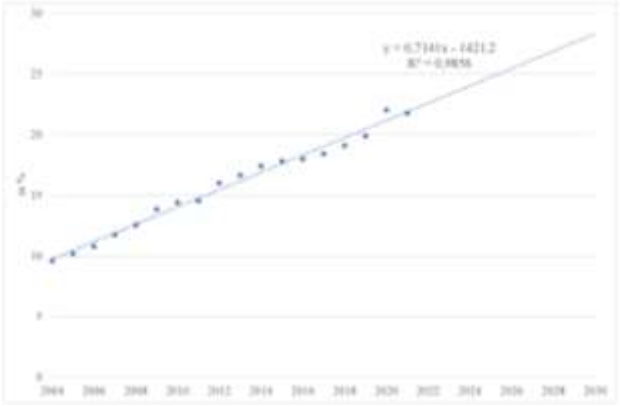

Fig. 11: Prediction of the share of renewable energy in gross final energy consumption in the EU

Figure 12 illustrates the prediction of renewable energy sources in transport in the EU in the period to 2030. The prediction of renewable energy in the EU reaches about 14% in 2030 using the linear model.

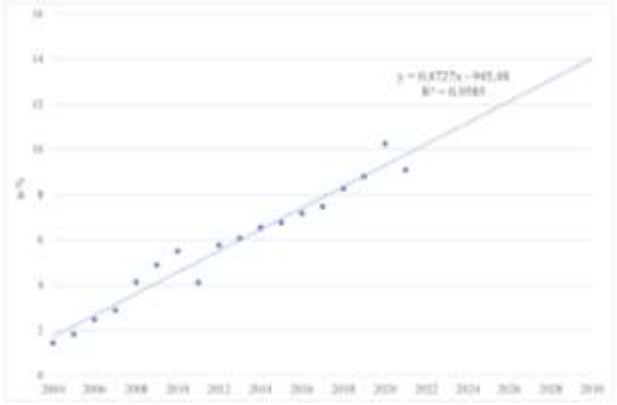

Fig. 12: Prediction of RESs in transport in the EU

Figure 13 presents the forecast of renewable energy sources for electricity in the EU in the years up to 2030. The prediction of renewable energy in the EU reaches about 50% in 2030 based on the linear model.

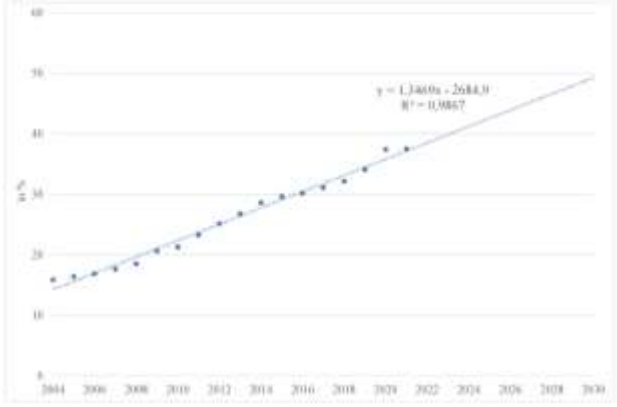

Fig. 13: Prediction of RESs in electricity in the EU

Figure 14 illustrates the prediction of RESs in heating and cooling in the EU in the period to 2030. The prediction of renewable energy in the EU is about 30% in 2030 using the linear model.

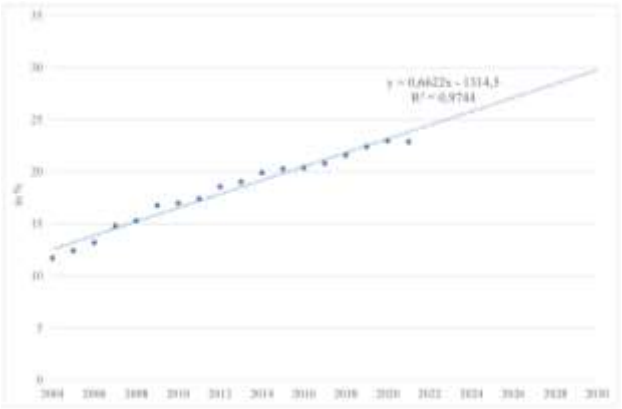

Fig. 14: Prediction of RESs in heating and cooling in the EU

3.3 Verifying Research Hypotheses

The first hypothesis refers to the dependence between renewable energy sources and greenhouse gases. Greenhouse gases include carbon dioxides, nitrogen oxides, methane, hydrofluorocarbons, perfluorocarbons, sulfur hexafluorides, and nitrogen trifluoride. Figure 15 presents the linear model for renewable energy sources and greenhouse gases on a scatter plot.

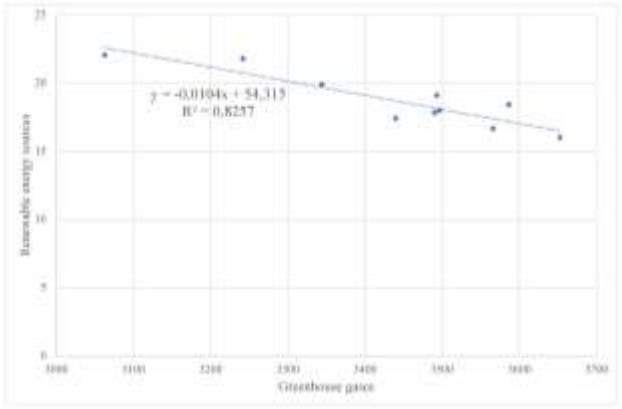

Fig. 15: Relationship between RESs and greenhouse gases

Table 1 includes statistics regarding the verification of considered hypotheses.

Table 1. Statistics related to the verification of hypotheses

Variable	**R square / p-value**	**t-stat / f-stat**
Greenhouse gases	0.825 / 2.33E-13*	6.156 / 37.89
Carbon dioxide	0.776 / 6.23E-13*	5.262 / 27.68
Carbon monoxide	0.926 / 0.234	10.048 / 100.95
Nitrogen oxides	0.991 / 1.64E-07*	29.651 / 879.20
Sulfur oxides	0.891 / 3.79E-09*	8.084 / 65.35
Ammonia	0.586 / 1.26E-09*	3.369 / 11.35
Particulates < 2.5μm	0.849 / 4.92E-10*	6.723 / 45.19
Particulates < 10 μm	0.816 / 7.47E-10*	5.963 / 35.55

*Note: * means the significance level at 0.05*

All considered hypotheses apart from H3 (Carbon monoxide) were positively verified for the significance level at 0.05. Moreover, all variables apart from ammonia have a significant correlation between RESs and exogenous variables. The increase in energy productivity from RESs results in decreasing the use of fossil fuels. Consequently, the amount of greenhouse gases is reduced. As a result, there is a significant negative correlation between RESs and the majority of exogenous variables. It is noteworthy that the presented methodology can be smoothly applied in other areas of business and economics.

4 Discussion and Conclusion

Renewables are a crucial factor in creating the EU energy system. The renewable energy directives obligate EU countries to adjust national renewable energy plans and achieve renewable energy targets. RESs enable to reduce greenhouse gas emissions, leading to less demand for fossil fuels, and improve energy stability in the EU through reducing dependency on unpredictable suppliers of fossil fuels.

The contribution of this research is the presentation of renewable energy sources in the EU over the last years, the prediction of the share of renewable energy in 2030, and the determination of relationships between this share and the reduction of greenhouse gas emissions. Previous research of RESs in the EU was carried out up to 2018, [6], [7], [8]. This study expands the assessment of RESs up to 2021 and considers the new renewable energy

directive EU/2023/2413 the revised renewable target in 2030. Compared to previous research [5], this study also includes regression analysis for RESs versus air pollutants and greenhouse gas emissions.

The obtained results indicate that achieving the revised renewable target (42.5%) in 2030 seems to be unrealistic, considering the current increase of RESs in the EU. The obtained results are similar to the results presented in, [25]. There should be enormous expenditures on investments of RESs to create an exponential growth of renewable energy and to reach this target in 2030. Moreover, the verified hypotheses indicate a significant relationship between increasing RESs and decreasing air pollutants and greenhouse gas emissions (apart from ammonia). Further research can refer to the impact of RESs on the level of sustainable development and economic growth from the perspective of the location of an EU country. For example, Mediterranean countries have better conditions for producing solar energy than Northern European countries.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The author contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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No funding was received for conducting this study.

Conflict of Interest

The author has no conflicts of interest to declare that is relevant to the content of this article.