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The Path to a Sustainable Energy Europe: An Analysis of the Transition from Fossil Fuels to Renewable Energy

Cătălin-Laurențiu Rotaru[1], Diana Timiș[2], Giani-Ionel Gădinaru, Ph.D.[3], Emilia Țițan, Ph.D.[4], Daniela-Ioana Manea, Ph.D.[5]

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Abstract

The main purpose of this study is to investigate the application of predictive analytics techniques in the energy field and to identify strategies to stimulate renewable energy production. The analysis begins by examining four key indicators: renewable energy, gas price, gas consumption and renewable energy consumption through a detailed descriptive analysis. Visual graphs are built to get an overview of the evolution of the energy sector in the period 2011-2020 with the help of Tableau software. The analysis is supported by the use of the Random Forest algorithm as a prediction model, considering critical indicators such as gas price, gas consumption and renewable energy consumption. The prediction results provide insight into anticipating changes in renewable energy production in the European countries studied. At the same time, the study highlights the current situation of renewable energy in Europe and identifies the necessary measures for its sustainable development through the analysis of specialized literature. It also examines the way in which big data management, facilitated by technologies such as smart meters and drone sensors, can help improve the energy sector. This research offers valuable results, providing insights into the evolution of renewable and fossil energy, as well as a detailed comparison of renewable

[1] Doctoral student at the Bucharest University of Economic Studies, e-mail: rotarucatalin17@stud.ase.ro
[2] Doctoral student at the Bucharest University of Economic Studies, e-mail address: timisdiana16@stud.ase.ro
[3] Professor at the Bucharest University of Economic Studies, Member of Institute of national economy, Romanian Academy, e-mail address: giani.gradinaru@csie.ase.ro
[4] Professor at the Bucharest University of Economic Studies, Member of Institute of national economy, Romanian Academy, e-mail address: emilia.titan@csie.ase.ro
[5] Professor at the Bucharest University of Economic Studies, Member of Institute of national economy, Romanian Academy, e-mail address: daniela.manea@csie.ase.ro

energy, gas prices, gas consumption and trends in renewable energy consumption. By integrating predictive analytics techniques, data management and renewable energy-specific indicators, this study makes an innovative contribution to energy systems analysis. Its focus on European countries contributes to the understanding of the growth potential of renewable energy generation in this region.

Keywords: Renewable energy, sustainability, energy consumption, fossil fuels, random Forest, predictive analysis
JEL: K32, Q20, Q40, Q41

Introduction

The growth of renewable energy in Europe has been supported by a sound policy and regulatory framework. The Renewable Energy Directive, implemented in 2009, played a key role in setting binding targets for renewable energy consumption and establishing a framework for cooperation between EU member states. This provided a solid basis for the expansion of renewable energy across Europe. In order to transpose the objectives of the Directive into action plans, the Member States developed National Action Plans for renewable energy. The plans outline each country's specific renewable energy targets, sectoral contributions and policy measures to promote the use of renewable energy (Maes et al., 2015). Feed-in Tariffs (FiTs) and Renewable Energy Support Schemes have been instrumental in stimulating renewable energy generation. FiTs provide long-term contracts to renewable energy producers, guaranteeing a fixed price for the electricity they generate. This mechanism encouraged investment in renewable energy projects and stimulated market growth. In addition, support schemes such as auctions and power purchase agreements have stimulated competition and reduced the costs of renewable energy technologies (Pyrgou et al., 2016). As stated by Xu et al. (2023) by 2022 Europe also implemented carbon pricing mechanisms to accelerate the transition to low-carbon technologies. Emissions trading schemes and carbon taxes have incentivized businesses and industries to reduce their carbon footprint and invest in cleaner energy alternatives. These mechanisms have played a crucial role in aligning economic activities with environmental goals.

To support the deployment of renewable energy and ensure the seamless integration of intermittent sources into the grid, Europe has invested in grid infrastructure and energy storage technologies. Cross-border interconnections have facilitated the exchange of renewable energy between countries, ensuring efficient use of resources and increasing grid stability. Smart grid technologies have been implemented to improve network management, flexibility and demand response capabilities (Michalak and Wolniak, 2023).

Mostafa et al. (2022) define predictive analytics as powered by advanced machine learning algorithms and data-driven insights, is a breakthrough technology for the energy sector. Predictive analytics involves using historical data, statistical modeling, and artificial intelligence to forecast future outcomes and trends. In the energy sector, this technology enables companies to make accurate predictions and take action based on insights from data manipulation. One of the main use cases of predictive analytics in the energy sector is predictive maintenance. By combining IoT and machine learning, utilities can monitor real-time data from sensors installed in their infrastructure. This allows them to identify potential asset failures and predict the remaining useful life of machinery. With this information, utility providers can take proactive steps to avoid power outages, optimize maintenance activities and reduce costs. Another important application of predictive analytics is adapting energy production to fluctuating demand. With the increase in renewable energy sources and the emergence of new consumers, accurate forecasting of electricity demand has become more complex. By analyzing historical consumption data, weather patterns and other variables, predictive analytics helps utilities align their production with future demand. This ensures efficient allocation of resources, prevents overproduction or shortages and optimizes power generation. In addition, predictive analytics plays a significant role in improving the customer experience. By leveraging data from IoT assets, smart grids and customer interactions, utilities can gain critical customer insights. This information allows them to implement personalized tariff plans, provide personalized experiences and encourage energy conservation (Pandey et al., 2023). Predictive analytics also helps utilities avoid unexpected outages by identifying potential risks to assets and maintaining critical infrastructure.

The main objective of this study is to highlight the usefulness of predictive analysis methods in the energy sector and to identify measures to increase renewable energy production, characterized as sustainable growth. In order to achieve this general objective, other secondary objectives have been drawn up and will be addressed individually. The study begins with the exploratory analysis of four main indicators: share of renewable energy, gas price, gas consumption and renewable energy consumption. Initially, through the Tableau software, a comparative analysis of the energy sector for the years 2011 and 2020 will be carried out. With the help of this first step, the research wants to highlight an overview of the indicators in order to properly analyze the data to be used. By using descriptive analysis, parameters corresponding to each indicator will be selected, which will later be entered into the Random Forest prediction algorithm, after it will be trained using the associated training data. The Random Forest algorithm will provide a forecast for the share of sustainable renewable energy that can be generated at European level, taking into account 3 indicators: gas consumption, renewable energy consumption and gas price as input factors.

Gas consumption is the first important indicator chosen. The choice of this indicator is based on the objective of the European Union to reduce the consumption of fossil energy through the use of renewable energy. At the same time, the choice of the second indicator – Renewable energy consumption was based on the first indicator. The need for an upward pattern of green energy consumption arises because, without it, it is not possible to decrease fossil energy consumption. In order to identify strategies to reduce the consumption of fossil energy, the price of gas was chosen as the third indicator. Simultaneously, as a secondary objective, the study aims to observe whether an increase in the price of gas will have a positive effect on the consumption of renewable energy. Finally, all these indicators are used to forecast the average share of renewable energy that Europe should achieve in order to make the transition to sustainability. Meanwhile, by using the Random Forest algorithm particular to predictive analysis, one achieves our goal of exploring the main objective of the research. In the analysis, one starts from the assumption that the price of gas will not bear a sudden increase, which could affect consumers. Alongside this, the concept that reducing the use of fossil energy can lead to an increase in demand for renewable energy will be explored and evaluated.

Review of the scientific literature

Predictive analytics in the energy sector is revolutionizing the way energy companies operate, optimize resources and plan for the future. By using advanced data analysis techniques and machine learning algorithms, predictive analytics enables energy companies to make more informed decisions, improve efficiency and adopt a sustainable approach to energy generation and consumption (Assad et al., 2022). One of the key areas where predictive analytics is crucial is demand forecasting. Accurate prediction of power demand is essential for effective load balancing, resource allocation and power generation planning. By analyzing historical consumption patterns, weather data and other relevant variables, energy companies can gain valuable information about future demand trends. This allows them to optimize their operations, prevent power outages, reduce costs and increase customer satisfaction. Accurate demand forecasting also facilitates the integration of renewable energy sources into the grid, ensuring a reliable and stable energy supply (Ahmad et al., 2020).

According to Esteban, Zafra and Ventura (2022), predictive analytics plays a vital role in equipment maintenance and reliability. By monitoring real-time data from sensors and using advanced analytics algorithms, energy companies can predict when machines and components are likely to break down or require maintenance. This proactive approach, known as predictive maintenance, minimizes unplanned downtime, extends asset life and lowers maintenance costs. It improves the reliability and overall efficiency of power generation and transmission infrastructure. In addition, predictive analytics provides valuable information for energy trading and pricing strategies. In his research Abdel-Aal, (2005) concluded the fact that by analyzing historical market data, consumption patterns, weather forecasts and other relevant factors, energy companies can predict future price fluctuations and optimize their trading decisions. This helps them identify profitable opportunities, manage risks and maximize revenue generation. Predictive analytics also sustains the development of dynamic pricing models, allowing energy providers to offer flexible pricing plans based on anticipated demand and market conditions.

In the context of renewable energy integration, predictive analytics plays a crucial role in optimizing the integration of renewable energy sources into the existing energy grid. By analyzing weather patterns, solar irradiation data, wind speeds and other factors, predictive analytics can forecast renewable energy generation levels. This information helps grid operators to manage imbalances between energy demand and supply, improve grid stability and use renewable resources efficiently. It also helps optimize energy storage by ensuring efficient use of battery systems and other energy storage technologies (Wang et al., 2019).

In today's increasingly competitive market, energy utilities face the challenge of meeting customer expectations while maximizing efficiency and profitability. Fortunately, data analytics presents a valuable solution to address these concerns and unlock numerous benefits for energy companies. One of the key benefits of data analytics is its ability to impro ve customer targeting and segmentation. By understanding consumer behavior and identifying customer groups, energy utilities can develop a deeper understanding of customer needs and preferences. Moreover, data analysis enables energy utilities to offer efficient and flexible tariff and rebate programs (Jeong et al., 2022). By studying customer usage patterns and understanding their preferences, companies can make better decisions about the incentives they offer. This personalized approach increases customer satisfaction and encourages conscious energy consumption. Improved billing and payment options are another benefit of data analytics. With a wealth of user information at their disposal, energy utilities can customize billing processes based on factors such as rate class, program participation and energy conservation efforts. This level of customization not only improves accuracy, but also the overall customer experience (Barik et al., 2023). Finally, data analysis helps prevent energy theft. While smart meters already offer better resistance to tampering, analytics goes a step further by advancing the detection of power thieves. By analyzing monthly consumption and energy bills, discrepancies and anomalies can be identified, allowing utilities to detect and prevent revenue loss due to fraud (Zhang et al., 2022).

To harness the power of predictive analytics, utility providers often rely on business intelligence tools such as Tableau (Yang et al., 2022). These tools enable the visualization and analysis of large amounts of data, the sharing of information between systems and teams, and the incorporation of information into customer-facing applications and websites. By leveraging predictive analytics, energy companies can optimize their operations, comply with regulatory requirements, ensure data privacy and security, and drive innovation in the sector.

The utilities sector faces four key challenges: reducing leakage, changing usage patterns, the emergence of a new energy economy and meeting ambitious environmental targets. To meet these challenges, the adoption of open-source, data-driven models are required. To effectively address the challenges posed by decarbonisation, companies and investors need to take a holistic approach. This involves considering alternative energy solutions and investment needs. Integrating whole systems models provides visibility into these complex dynamics, enabling organizations to make informed decisions aligned with business objectives and cost reduction objectives. The main recommendations underpinning utility sector decarbonisation are prioritizing consumer-centric decision-making, using integrated data sources along the value chain and placing whole-systems models at the forefront of infrastructure implementation (Nußholz et al., 2023). As the water sector commits to delivering net zero emissions by 2030, insights derived from open data are crucial to generating systemic responses to environmental challenges. By harnessing these insights, the industry can effectively transition to a sustainable future. Thus, predictive analysis and machine learning has an important role in the decarbonization of the utility sector.

Europe has made significant progress in diversifying its energy mix by capitalizing on different sources of renewable energy. Solar energy, which includes photovoltaic technologies and concentrated solar energy, has seen substantial growth and significant cost reductions over the past 10-12 years. Photovoltaic installations have become more and more common on rooftops, and solar farms more widespread. At the same time, concentrated solar energy technologies have been implemented in sunny regions, and all these advances will contribute significantly to renewable energy capacity in Europe (Vezzoni, 2023). Wind power has also emerged as a prominent contributor to the renewable energy portfolio of many European countries. Onshore turbine wind farms have sprung up across the continent and offshore wind installations, located in North Sea waters and other suitable locations, have further supported Europe's renewable energy generation.

Biomass, which includes solid biomass, biogas and biofuels, is another main driver of the evolution of the energy sector in Europe playing a crucial role in the renewable energy mix. Biomass resources, derived from organic matter such as agricultural waste and forest residues, have been used for heat production, electricity generation and transportation fuels. The constant use of biomass has contributed to the reduction of greenhouse gas emissions and the promotion of circular economy principles. Hydropower, although a relatively mature technology, continues to generate renewable energy in Europe. Existing hydro plants, some of which have been in operation for decades, have been upgraded to increase efficiency and capacity. At the same time, the construction of new small-scale hydropower projects also contributed to the overall renewable energy capacity. Geothermal energy, harnessed from the Earth's heat, has attracted attention in some European countries, particularly in Iceland, Italy and Turkey, where geothermal installations have been developed to provide a sustainable and reliable source of heat for residential, industrial and agricultural applications (Sayed et al., 2021).

The renewable energy sector plays a key role in addressing the pressing challenges of climate change and in the transition to a sustainable energy future. To accelerate the adoption and efficiency of renewable energy sources, it is essential that a comprehensive set of measures should be implemented. Governments need to establish meaningful policy frameworks that promote the development of renewable energy. This includes setting ambitious renewable energy targets, implementing supporting legislation and providing financial incentives such as feed-in tariffs and tax credits. Clear and stable policies provide the necessary market certainty to attract investment and stimulate innovation in renewable energy technologies. Increasing investment in research and development is important to promote renewable energy technologies. Governments, together with private sector entities, should allocate substantial funds to support research and development initiatives, focusing on areas such as energy storage, grid integration and efficiency improvements. Collaboration between academia, industry and research institutions will drive innovation and facilitate the commercialization of innovative technologies.

Raising public awareness and promoting education about the benefits of renewable energy are essential to promoting an enabling environment. Governments should implement public campaigns to educate individuals, communities and businesses about renewable energy technologies, their environmental advantages and long-term cost savings. In addition, educational institutions should incorporate renewable energy topics into their curricula to equip the workforce with the skills needed to grow the sector. International collaboration and knowledge sharing are vital to accelerating the growth of the renewable energy sector. Governments, organizations and stakeholders should actively participate in international forums, such as the United Nations Framework Convention on Climate Change (UNFCCC), to exchange best practices, harmonize standards and encourage cooperation in the field research, development and implementation of renewable energy (UNFCCC, 1992). Additional, tariffs and support schemes play a crucial role in stimulating the deployment of renewable energy technologies. They create favorable economic conditions that attract investment, reduce technology costs through economies of scale, and stimulate the growth of a robust renewable energy market. Feed-in tariffs and support schemes provide a stable and predictable income stream, reducing investment risks and attracting private sector participation. The success of integrated tariffs and support schemes depends on sound policy design and long-term commitment from governments. Clear regulations, streamlined permitting processes and stable policy frameworks are essential to attracting investment and maintaining investor confidence. Regular monitoring, evaluation and adjustments of measures on this aspect are necessary to ensure the effectiveness and efficiency of these support mechanisms (Li et al., 2022).

In the review of scientific literature, there are various works that have analyzed renewable energy and related fields starting from various assumptions and objectives. Zaman, Goschin and Danciu (2007) researched this topic considering trends and different influencing factors within the requirements, criteria and principles of sustainable development. Energy efficiency was assessed by the ratio of GDP to energy consumption and energy efficiency in the European Union, including the new candidate countries, was also examined using multifactorial econometric modeling. Teiușan and Rof (2013) emphasized in their work the need to capitalize on the production of electricity from renewable sources as a possible alternative for the future. They also highlighted the importance of understanding and tracking the costs associated with this type of production. The works aimed primarily to provide an overview of the subject based on the existing literature; secondly, to evaluate Romania's adherence to the European Union specifications for the promotion of renewable energy sources, as presented in the Official Journal; and thirdly, to use econometric tools to track and forecast costs related to renewable electricity production. Regarding the analysis of the relationships between renewable energy and other economic indicators, there are works in the specialized literature that have thoroughly addressed the topic. In his article, Behame (2012) examined the causal relationship between renewable energy consumption and economic growth in Western European countries during the period 1995–2010. The findings of the causality test revealed a bidirectional relationship between economic growth and renewable energy consumption in both the long and short term. Consequently, it was concluded that the countries included in the analysis have the potential to reduce their dependence on foreign oil by replacing it with renewable energy sources. This underlines the importance of harnessing Romania's hydropower potential and effective cost management in hydropower production. Similar to previous research, Zaman and Goschin (2006) tested whether energy efficiency is correlated with several influencing factors such as: Gross National Income per capita (GDP), energy imports, renewable fuel and waste, energy consumption per capita, services as a percentage of GDP and others; using a linear regression model to measure the influence of these factors on the variation in GDP per unit of energy use in Europe in 2003.

In order to justify the indicators chosen in the developed study, several works were identified based on the specialized literature that studied the encouragement and growth of renewable energy starting from analyses based on the price of gas. For example, Sarmiento et al. (2021) selected advanced modeling techniques to analyze the complex interactions between natural gas prices, technology choices, system costs, and emissions in the energy sectors of Mexico and the United States. The integrated approach enabled a comprehensive assessment of the various factors contributing to the performance of the energy system under different natural gas price scenarios. A common finding across studies is the impact of high natural gas prices on technology choices, both in the short and long term. At high prices, energy systems tend to rely more on short-term carbon-intensive technologies due to the relatively lower costs of fossil fuel generation. However, in the long run, high natural gas prices stimulate investment in renewable energy sources, leading to a reduction in carbon emissions over time. This transition to renewables investment is critical to meeting climate goals and reducing reliance on carbon-intensive technologies. Contrary to previous research, Wang et al. (2022) developed a study that proposes a robust mathematical model to simulate these changes in China's electricity structure and hydrogen production in response to varying natural gas prices. The study introduced a comprehensive mathematical model designed to analyze the implications of fluctuating natural gas prices on the electricity market and hydrogen supply. By applying this simulation model, the researchers aim to gain insight into how high natural gas prices impact China's energy landscape. The simulation results demonstrate that under a low-carbon tax policy, high natural gas prices tend to favor the development of low-cost non-renewable energy production at the expense of renewable energy production. In both of the previously highlighted pieces of research, the price of gas was used as an indicator of the analysis to study the potential of renewable energy.

Taking into account the fact that in the present research the Random Forest algorithm will be used as a prediction algorithm and not a classification algorithm, it would be appropriate to highlight some similar works. Khajavi and Rastgoo (2023) created a study that has used a combination of Random Forest, SVR and response surface methodology to effectively predict CO2 emissions.

By combining these methods, the researchers leveraged their respective strengths to improve the accuracy of predictions and address the complexity of the relationship between CO2 emissions and road transport factors. Following accuracy assessment, the study used various statistical indices including *standard error* (SE), *root mean square error* (RMSE), *mean absolute percentage error* (MAPE), *mean absolute error* (MAE), *relative absolute error* (RAE) and *coefficient of determination* (R2). The results of the study indicate that Random Forest with Slime Mold algorithm achieves the best accuracy in the testing process with an R2 value of 0.9641. This demonstrates the efficiency of the Random Forest algorithm and its usefulness as a prediction algorithm.

As in the example from the preceding paragraph, multiple sources from the specialized literature have been identified, demonstrating in their analyses that Random Forest performs with higher accuracy than other algorithms. In the paper "Evaluation of logistic regression and random forest classification based on prediction accuracy and metadata analysis" by Wålinder (2014), it was concluded that predictions made using the Random Forest and Logistic Regression algorithms are correlated, with Random Forest performing slightly better. Additionally, the study "Mixed random forest, cointegration, and forecasting gasoline prices" (Escribano and Wang, 2021) employed the Random Forest algorithm for weekly gasoline price forecasts, where it exhibited superior performance in providing the most accurate weekly gasoline price forecasts. Hence, considering the aforementioned findings and with the aim of introducing an element of innovation to the work, the utilization of a complex machine learning model such as Random Forest was desired.

In concluding our review of the specialized literature, it is noteworthy that climate policy concerning the utilization of green energy has evolved over the years. Initially, the European Union aimed for a transition towards a low-carbon emissions system. However, as climate objectives improved, a new direction emerged, one that aspired to completely eliminate greenhouse gases and attain climate neutrality through the exclusive use of green energy. These goals, as outlined in the European Green Deal (European Commission, 2021), have a target year of 2050 and delineate a well-defined strategy being developed at the European Union level. In his research John Szabo effectively emphasizes this concept (Szabo, 2021), highlighting that the transition to green energy was a response to a prior phase where the primary objective was solely the reduction of carbon emissions.

Research methodology

The main purpose of the analysis is to determine the appropriate magnitude by which certain components of fossil and renewable energy would need to increase or decrease in order to achieve a sustainable increase in the percentage of renewable energy produced by certain European nations. Thus, the research aims to predict the percentage of renewable energy produced by a country taking into account three components: gas consumption expressed in millions of tons of oil, renewable energy consumption expressed in millions of tons of oil and the price of gas expressed in Euro per Giga Joule (GJ).

In order to obtain the intended results, the components included in the research will be analysed initially. Afterwards, taking into account the statistical decisions, the Random Forest algorithm will be used to predict the increase or decrease of the mentioned components so as to obtain an increase in renewable energy in the studied European countries.

Descriptive analysis aimed at determining the input values of the Random Forest decision tree will be performed using Python software in the Google Colab environment. The same environment was also used for running the prediction algorithm. At the same time, visual graphs will be made using the business intelligence tool specific to predictive analysis Tableau to be able to identify main patterns in the data and to be able to highlight the preliminary results of the analysis.

The data source for this study was obtained from the official Eurostat website, covering the period 2011-2020 for 23 European countries: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain and Sweden. Data were processed from four separate Excel documents and their integration was done using Tableau Prep software. The selected period was chosen mainly due to the economic stability and the few crises, both economic and of another nature. As we are all aware, the year 2021 proved to be an atypical one due to the COVID-19 crisis. Despite having data available from 2021 in Eurostat database, in order to establish a linear trend and conduct a representative analysis, we concluded that 2021 could not serve as a reference year. As a result, we restricted our analysis period to end at the year 2020. The indicators used in the analysis are presented in Table 1.

Table 1. Description of Indicators

Name of Indicator	Description of Indicator	Units of measurement	Data source
Share of renewable energy	Share of renewable energy consumption in final gross energy consumption	Percent	Eurostat.eu
Gas price	The price at which natural gas is sold in the market for medium-sized domestic consumers	Euro per GJ	Eurostat.eu

Gas consumption	Domestic gas consumption	The equivalent of one million tons of oil	Eurostat.eu
Renewable energy consumption	Household consumption of energy from renewable sources	The equivalent of one million tons of oil	Eurostat.eu

Source: Created by the authors using data sourced from the official Eurostat website (Eurostat, 2023/a)

As a first step, an exploratory analysis of the data will be carried out using the correlation matrix of the component values highlighted in Table 2. The values are standardized according to the formula (1):

$$x_{stand} = x - \frac{\mu}{\sigma} \quad (1)$$

- μ – Average of observations.
- x – The observation.
- σ – The standard deviation of the observation.

In order to analyze the link between indicators, Table 2 is constructed with the correlation matrix.

According to the highlighted correlation matrix, the Renewable Energy Consumption component can be observed as strongly correlated with the Gas Consumption component, the coefficient having a value of 0.85. Considering the result, it can be concluded that an increase in the value of gas consumption can lead to an increase in the consumption of renewable energy.

Table 2. Correlation matrix of components

	Renewable energy consumption	**Share of renewable energy**	**Gas price**	**Gas consumption**
Renewable energy consumption	1	0.019	0.3	0.85
Share of renewable energy	0.019	1	0.33	-0.31
Gas price	0.3	0.33	1	0.16
Gas consumption	0.85	-0.31	0.16	1

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

At the same time, there is a moderate negative correlation between Share of renewable energy and Gas Consumption, which supports the previous result, indicating that gas consumption can increase if the share of renewable energy decreases, this result being an expected one, highlighting the behavior of consumers who tend to replace energy sources depending on their availability and related costs.

The weakest correlation is between Gas Consumption and its price with a coefficient value of 0.16, which leads to the conclusion that the price does not strongly affect gas consumption. This is an expected result because, in the absence of another source of energy, consumers will continue to use gas for the main needs of houses.

Also, the significance of the correlation matrix is tested (see Table 3) and all the correlation is revealed as statistically strong and significant.

Table 3. P-value significance for correlation matrix

Renewable energy consumption	0.000000e+00	3.406188e-01	4.098142e-51	0.000000e+00
Share of renewable energy	3.406188e-01	0.000000e+00	4.387553e-64	-3.806650e-54
Gas price	4.098142e-51	4.387553e-64	0.000000e+00	5.016311e-16
Gas consumption	0.000000e+00	3.806650e-54	5.016311e-16	0.000000e+00
	Renewable energy consumption	**Share of renew-able energy**	**Gas price**	**Gas consumption**

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

Results and discussion

The exploratory analysis begins with the highlighting of the forecast component Share of renewable energy, followed by the exploratory analysis of the Gas Price component, this component is the most volatile in the data set, but the years 2011 and 2020 were chosen respectively because during the analyzed period the price of gas was approximately linear. To be able to use the Gas Price component in the Random Forest algorithm, it is necessary to associate a parameter with it. This parameter is established according to the results obtained in the exploratory analysis and the information extracted from the specialized literature studied. The exploratory analysis ends once with the last indicator of interest for the study developed Renewable energy consumption. The analysis with descriptive statistics can be found in Table 4.

Table 4. Descriptive Statistics

Denumire Indicator	Mean	Standard deviation	Min	25%	50%	75%	Max	Average percentage difference 2011-2020
Share of renewable energy	20.65	10,97	2,87	13.17	17.82	26.75	60.12	3.83%
Gas price	16.67	5,5	7,51	12,5	16,01	19.56	34.08	0.30%
Gas consumption	8187	12512	43	623	1963	9185	53196	-0.24%
Renewable energy consumption	2420	3616	4198	754	1702	4301	17308	2.63%

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

On average, the selected European countries produce about a quarter of the required energy using renewable sources. The standard deviation is half the mean, and half the countries are below the mean. Sweden is one of the European countries that stands out as having a very high proportion of renewable energy, in 2020 reaching a percentage of approximately 60%. Figure 1 reveals the trend of gas prices.

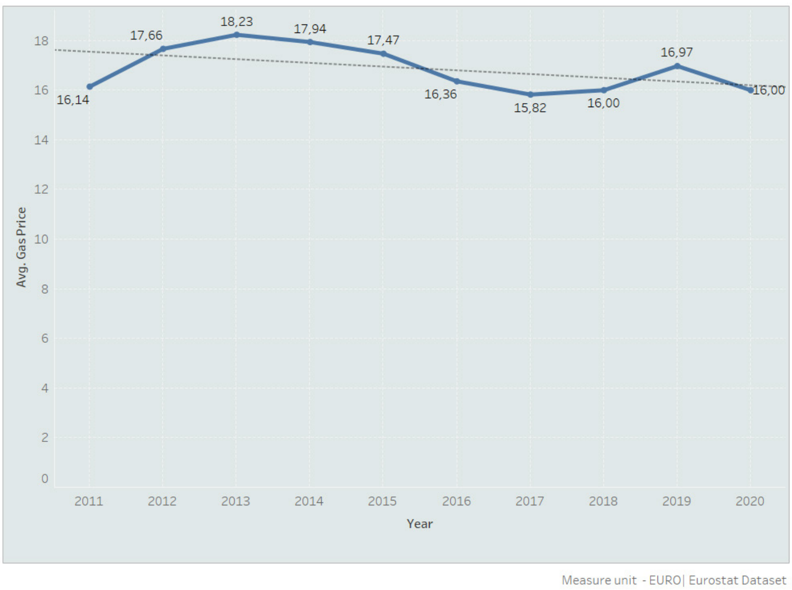

Figure 1. Average Gas price evolution over years
Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

In the period 2011-2020, the average gas price showed a decreasing linear trend, without significant standard deviations. However, there were outlier countries where the gas price reached as high as 34 euros, such as Sweden in 2013. The median gas price was similar to the average gas price, indicating that most countries were grouped around the average value, without significant differences in prices. Only 25% of countries had prices higher than 16 Euro per GJ in the selected period, with the highest gas prices in Sweden in 2011 and France in 2020.

The average of the analyzed European countries is 8177 million tons of oil equivalent, with a very large standard deviation, due to the existence of countries with high gas consumption, such as Germany, which consumed 51813 tons in 2020. Half of the countries recorded a gas consumption four times lower than the average: Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Croatia, Lithuania, Latvia, Ireland, Luxembourg, Hungary, Austria, Portugal, Romania, Slovenia, Slovakia, Sweden. Meanwhile, 25% of the selected countries have a consumption value of more than 9000 tons: Germany, France, Italy, Spain and Poland.

At the level of the countries included in the analysis, the average consumption of renewable energy is lower than the standard deviation, with some countries consuming significantly more renewable energy compared to others. For example, Germany consumed 17,308 million tonnes of oil equivalent of renewable energy in 2020, while some countries, such as Romania, saw only a slight increase in renewable energy consumption during the selected period, rising from 3,650 to 3,856 million tons. Analyzing Table 4, it can be seen that only a quarter of the countries included in the study recorded consumption greater than 4301 million tons. The average year-over-year percentage difference between 2011 and 2020 is 2.63%. The overall average is low because in 2014, consumption decreased by 4.64%, probably due to the drop in oil prices. This has led to an increase in the consumption of cheaper fossil energy.

To understand the evolution of the proportion of renewable energy produced, a table was built (see Table 5). This type of chart is used to visualize the absolute or relative values the observation of which contributes to the total results. In the research carried out, the tree map represents the distribution of renewable energy produced by each country in the total energy production in the years 2011 and 2020.

Table 5. Share of renewable energy in European countries 2011 versus 2020 in percentages

Country	% of Total Share of Renewable Energy 2011	Share of Renewable Energy % 2011	% of Total Share of Renewable 2020	Share of Renewable Energy % 2020
Sweden	11.89%	47.63%	10.87%	60.12%
Latvia	8.35%	33.48%	7.62%	42.13%
Austria	7.87%	31.55%	6.61%	36.55%
Estonia	6.37%	25.52%	5.44%	30.07%
Croatia	6.34%	25.39%	5.61%	31.02%
Portugal	6.14%	24.60%	6.15%	33.98%
Denmark	5.84%	23.39%	5.73%	31.68%

Romania	5.43%	21.74%	4.43%	24.48%
Slovenia	5.23%	20.94%	4.52%	25.00%
Lithuania	4.98%	19.94%	4.84%	26.77%
Bulgaria	3.53%	14.15%	4.22%	23.32%
Hungary	3.49%	13.97%	2.51%	13.85%
Spain	3.29%	13.18%	3.84%	21.22%
Italy	3.21%	12.88%	3.68%	20.36%
Germany	3.11%	12.47%	3.49%	19.31%
Czechia	2.73%	10.95%	3.13%	17.30%
France	2.70%	10.81%	3.46%	19.11%
Slovakia	2.58%	10.35%	3.14%	17.35%
Poland	2.58%	10.34%	2.91%	16.10%
Ireland	1.65%	6.61%	2.92%	16.16%
Belgium	1.57%	6.30%	2.35%	13.00%
Netherlands	1.13%	4.52%	2.53%	14.00%

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/b)

Exploratory analysis of the available data set shows that there is only one country that has significantly high renewable energy production – Sweden. The value of the share of renewable energy is increased by approximately 13 percent between 2011 and 2020. According to the results, Lithuania can be called a developing country regarding green energy, the value of the share of renewable energy increasing during the analyzed period by approximately 8 percent. Both countries indicated an increase in green energy production, thus making a significant contribution to the average percentage value of the analyzed European countries. Overall, all countries included in the study indicated an increase in electricity production from renewable sources, with the average rate of all countries in the period 2011-2022 being 3.83%. At the opposite pole, Germany stands out with a low proportion of green energy both in 2011 and in 2022, a surprising result considering its economic position and the fact that it is a technologically developed country. In the analyzed period, it indicated an increase of only 5-6 points. In the context of our analysis, the share of renewable energy is considered as the output of the decision tree, therefore no input parameter will be selected for the Random Forest.

Table 5 compares the change of gas pricess in a number of European countries in 2011 ans in 2020. In 2011, Sweden had the highest gas price of 33 Euros per GJ, followed by Denmark – 29 Euros per GJ and Austria with 19 Euros. In 2022, gas prices fell by an average of 0.05%, based on the difference in average values between the two years. While most countries indicated a decrease in the price of gas, the Netherlands had a significant increase, moving from fifth position in 2011 to first position in 2020, having the most expensive gas among European countries. One of the countries that has made significant progress in reducing gas prices is Hungary, where a decrease in gas prices of 7 Euros per GJ is observed between 2011 and 2022. Romania remains one of the countries with the lowest fossil fuel prices, with a slight growth in the maximum year analyzed.

In 2021, due to political reasons, the gas price no longer followed the linear stability it had between 2011 and 2022, and entered a sudden increase reaching a European average of 70 Euros per GJ. In 2022, due to the start of the war between Ukraine and Russia, the price showed strong volatility, reaching a value of 339 Euros per GJ on August 26, and ending the year with an average of 109 Euros per GJ.

To be able to use the Gas–Price component in the Random Forest algorithm, it is necessary to associate a parameter with it. Due to its volatility, this parameter is established according to the results of the information extracted from the specialized literature studied. Thus, the increasingly strict European sustainability policies and the regional political instability in Europe regarding the year 2022 will be taken into account and the value of 109 Euros per GJ will be chosen for the average gas price.

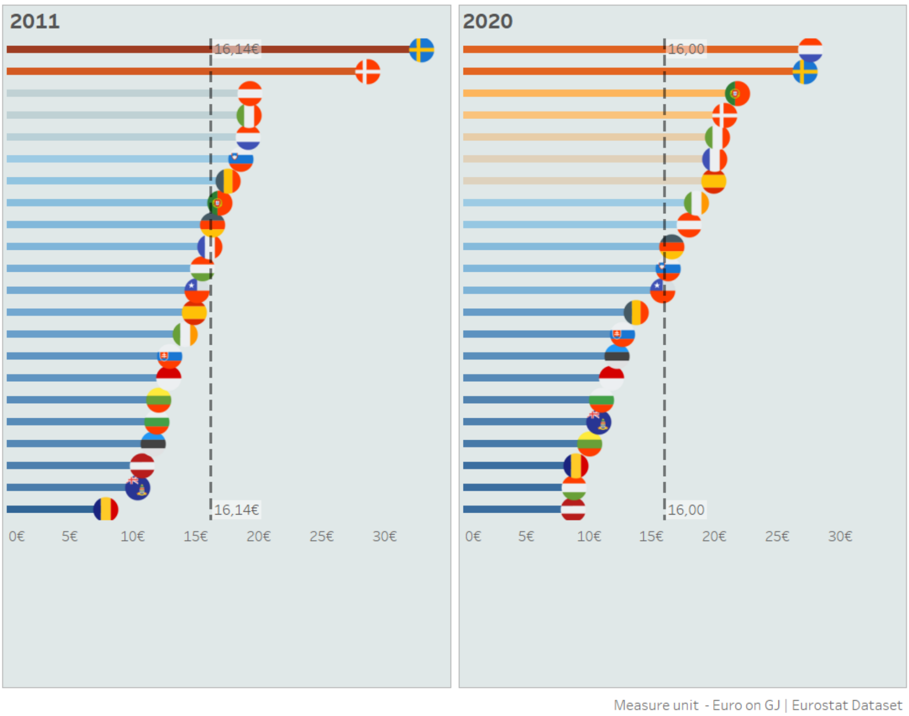

Figure 2. Gas price in European countries 2011 versus 2020 – Euro per GJ

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

The average of the analyzed European countries is 8177 million tons of oil equivalent, with a very large standard deviation, due to the existence of countries with high gas consumption, such as Germany, which consumed 51813 tons in 2020 (see Figure 2). Half of the countries recorded a gas consumption four times lower than the average: Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Croatia, Lithuania, Latvia, Ireland, Luxembourg, Hungary, Austria, Portugal, Romania, Slovenia, Slovakia, Sweden. Some 25% of the selected countries have a consumption value of more than 9000 tons: Germany, France, Italy, Spain and Poland.

Both in 2011 and in 2022, Germany is the largest gas consumer in Europe, with Italy and France in the top 3. These three countries have outliers compared to the countries included in the study and one can call them outliers. One of the reasons that can explain this result is that these three countries are countries with a developed economy. According to Table 5, the map of Europe is divided into two main groups: countries showing high gas consumption, represented by Central and Western European countries due to their highly developed economies, and countries showing lower gas consumption, such as countries in Eastern Europe.

Between 2011 and 2020, the annual percentage difference (YoY) was calculated, indicating a decrease in gas consumption in the selected countries of approximately 3% between the two years, with an average decrease of -0.24% (see Table 6). The average is low because gas consumption has either increased or decreased during the selected period. For example, in 2013-2014, gas consumption decreased by 11.20%, followed by an increase between 2014 and 2015 of 0.3%. For this component, the input parameter used for the Random Forest model will be decided based on the difference between the 3% period of the YoY values. Since the research aims to predict prices for the year 2023, the value of the second quartile, namely the value of 1963, will be considered.

Table 6. Percentage difference: Gas Consumption over years

Year	% Percentage difference Gas Consumption
2012	2.56%
2013	2.38%
2014	-11.20%
2015	3.20%
2016	4.07%
2017	0.88%
2018	0.11%
2019	-1.47%
2020	-2.71%
Avg.	-0.24%

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

Similar to the component associated with gas consumption, Germany, together with France, represent a positive outlier in terms of green energy consumption, having the highest level of consumption. Slovenia has the largest percentage increase between the two periods, with a consumption of 550 million tons of renewable energy in 2011 and 1159 million tons in 2020, resulting in an increase of 108.9%. This is followed by Luxembourg, with 91.3% and the Netherlands together with Italy with an approximately equal increase of 63%. Considering that European policies are becoming stricter regarding the use of fossil fuels, and the consumption of renewable energy is expected to maintain an upward trend, one will consider the average consumption of renewable energy in the analyzed period, which is 2420 million tons, as an input parameter for the Random Forest model (see Figure 3).

Considering the preliminary results and the fact that there were countries in the dataset that recorded outliers for one or more of the components presented in the exploratory analysis part, these outliers should be excluded according to the rule of 3 standard deviations from the mean. To remove these values, both the maximum and minimum level for an observation to be considered an outlier will be calculated, so any observation outside this range will be excluded from the analysis using the following formula (2):

$$\mu - 3 * \sigma =< x =< \mu + 3 * \sigma \quad (2)$$

μ – Mean of observations.
x – The observation.
σ – The standard deviation of the observation.

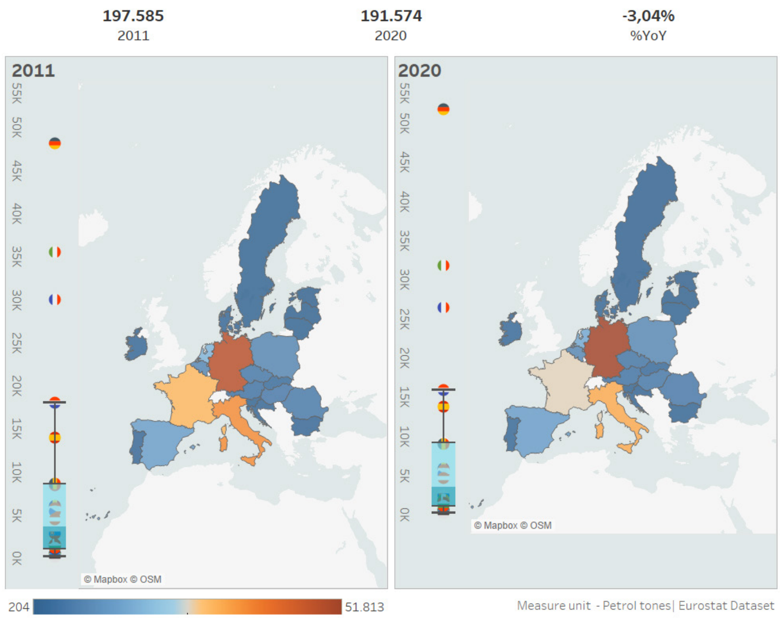

Figure 3. Gas consumption in European countries 2011 versus 2020 – million tonnes of oil equivalent
Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

The initial number of observations included in the analysis was 2420, and after removing outliers it was reduced by 120 rows. Thus, a new data set consisting of only 2300 observations was obtained. Random Forest can also be applied without cleaning the database, because it is a machine learning algorithm that can handle missing values and zero values. However, it can also take discrete and continuous input parameters as input variables.

One aims to forecast the percentage growth of renewable energy production based on the input data obtained from the above exploratory analysis, for the European countries studied. This aspect facilitates the establishment of the renewable energy threshold that one needs to reach to ensure sustainability at the level of the group of countries analyzed.

To apply the Random Forest machine learning algorithm, the input values selected from the descriptive analysis, such as gas price of 109 Euro per GJ, renewable energy consumption of 2420 million tons of oil equivalent, and gas quantity consumption will be used to determine if these parameters influence the increase in the percentage of renewable energy (Figure 4).

After running, Random Forest predicts that using the three variables specified above, namely gas price of 109 Euro per GJ, renewable energy consumption at 2420 million tons of oil equivalent and gas quantity consumption, the percentage of renewable energy should be of 29%. Although Random Forest is more of a classification algorithm and not a time series one, if one assumes that the input values for Random Forest will reach the chosen levels in 2023, then the predicted percentage will reach the specified level by then. The result is valid because the accuracy of the model is 95%.

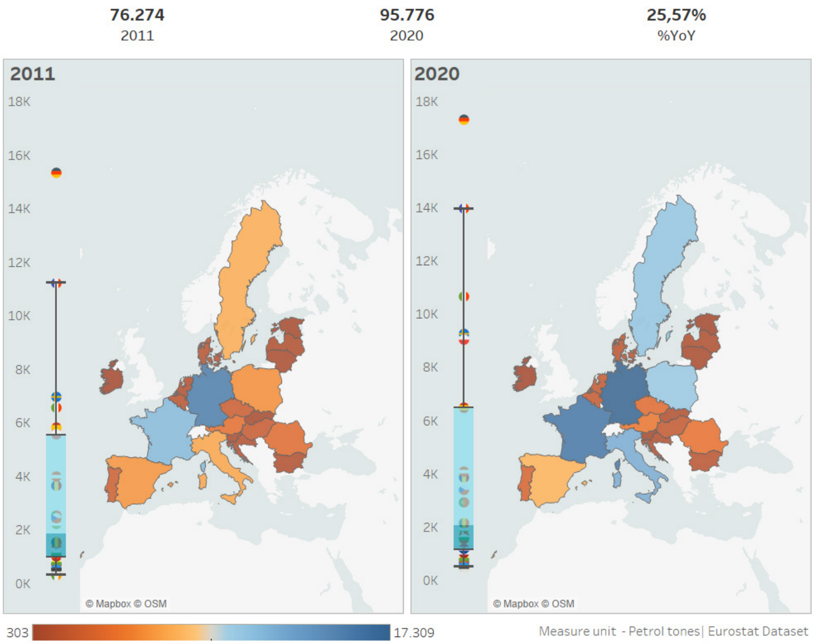

Figure 4. Energy consumption from renewable sources in European countries 2011 versus 2020 – million tonnes of oil equivalent

Source: Created by the authors using data sourced from the official Eurostat website for the period 2011-2020 (Eurostat, 2023/a)

The usefulness of the predictive analysis used consists in identifying the percentage of renewable energy that the analyzed group of European countries will reach, without having a sudden increase in the price of gas, a percentage that is represented by the value 29% for the group of analyzed European countries. Acording to a research (Crabtree et al., 2011), the relationship of increasing consumption of renewable energy through increasing consumption of fossil energy is demonstrated by the fact that, in the early stages of the transition to renewable energy, there could be challenges in terms of integration into the existing energy infrastructure. In this way, this fact could lead to the use of certain fossil fuel power plants as backup sources to stabilize the grid when renewable sources fluctuate (for example, on cloudy days for the sun or on calm days for the wind). However, the goal is to progressively minimize the need for fossil fuel backup as renewable technologies improve and become more efficient and reliable.

Conclusion

Europe has made significant progress over the past decade in renewable energy deployment and capacity building. The region has demonstrated a strong commitment to transitioning to cleaner and more sustainable energy sources, reducing greenhouse gas emissions and promoting energy independence. Wind power has emerged as a renewable energy source, making major progress in deployment in Europe with substantial capacity additions in both onshore and offshore wind installations. Countries like Denmark have been at the forefront of this transition, investing in wind farms and harnessing the power of strong coastal winds.

Advances in wind turbine technology, along with favorable policies and incentives, have contributed to the rapid growth of wind power across the continent. Solar power has also seen capacity growth in Europe. Falling costs of photovoltaic panels, along with supportive policies and feed-in tariffs, have led to the widespread adoption of solar energy systems. Countries such as Spain, Italy and the Netherlands have seen substantial solar PV installations, both on a residential and industrial scale, contributing to the renewable energy mix. Furthermore, the integration of solar PV systems into buildings and infrastructure has become common, encouraging energy self-sufficiency and reducing dependence on traditional energy sources.

Data analysis suggests a strong positive correlation between renewable energy consumption and gas consumption in the European countries studied. The increase in gas consumption leads to an increase in the consumption of renewable energy, suggesting that the replacement of fossil energy sources with renewable ones can be done by increasing the use of gases because the technology does not yet allow the stabilization and favorable meteorological conditions to develop renewable energy in a linear context. A moderate negative correlation is also observed between the share of renewable energy and gas consumption. In other words, a decrease in the share of renewable energy can lead to an increase in gas consumption, indicating that users tend to rely on available and economically accessible energy sources. The price of gas does not seem to have a significant impact on gas consumption. Even in the presence of other energy sources, consumers continue to use gas as a convenient option for their primary energy needs. This result was expected, because in reality, gas consumers do not have the option of using renewable energy sources without making an investment in equipment.

The exploratory analysis of renewable energy consumption shows a significant increase in the use of this type of energy in most European countries. This suggests that strict European policies on sustainability and increased awareness of the environment and climate change have helped promote the use of renewable energy. The use of the Random Forest algorithm allowed the forecasting of the percentage of renewable energy that European countries will reach in the future using the input data obtained from the exploratory analysis. This result predicts that the percentage of renewable energy should be 29%, suggesting that the transition to cleaner energy sources will continue in the future. Thus, predictive analysis confirms its usefulness by demonstrating that the percentage of renewable energy will definitely increase. Although it is not sustainable for consumers to have a sudden increase in the price of gas by increasing utility budgets, one possible strategy to continue increasing the percentage of renewable energy is represented by the increase in the price of gas.

The findings indicate that although the transition to renewable energy is progressing positively, factors such as the price of gas and the availability of renewable energy sources need to be taken into account in order to ensure an efficient and sustainable transition. From this point of view, gas consumption can represent another factor that will help to increase renewable energy, by substituting it in moments of lack of use of renewable energy. Overall, the data analysis suggests that European countries should continue to promote policies and measures that support the growth of renewable energy consumption and reduce dependence on fossil energy sources, in order to achieve the objectives of sustainability and combating climate change. This aspect is currently achieved through the implementation of programs such as the European Green Deal.

It should be noted that these conclusions are based on the data available and the analysis carried out to date. In the future, new data and developments in the energy field may bring about changes in the observed trends. Therefore, it is recommended that monitoring and data analysis continue, with the aim of making informed and appropriate decisions on energy and environmental policy.

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