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Detecting the Factors that Affect Renewable Energy Consumption

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Abstract

The study of sustainability and renewable energy is very important in the present decade, as they help achieve the countries' sustainable development goals by 2030. Education, science, technology, and innovation play an essential role in supporting the growth and quality of sustainable development. Therefore, in the present work, we aim to study the impact of school enrollment (SE) and GDP on clean energy usage in various countries. The data are downloaded from the World Data Bank. The results are obtained by applying descriptive and inferential statistical methods. The results reveal that SE and GDP are negatively correlated with renewable energy consumption (REC). The regression analyses are also performed to explain the renewable energy by the two variables. Different regression models are compared, and it is concluded that cubic regression models can be used to predict REC based on SE and GDP.

Keywords
Renewable energy consumption, Sustainable development goals, Regression analyses, School enrolment, GDP.

1. Introduction
The industry has entered a new phase with the latest Industry 4.0 solutions (Zhang et al. 2021), in which digitalization of manufacturing processes, circular economy, and sustainability play important roles. The digital revolution, sustainability, climate protection, and closing material cycles have become the leading drivers for transformation and development from globalization and specialization toward digitalization and a circular economy (Mohan and Katakojwala 2021). Education, science, technology, and innovation also play an important role in supporting the growth and quality of sustainable development. With the advancements in economic developments, consumption, in general, has also been increasing, including the consumption of energy, particularly electric energy (Kwilinski 2018). Several sectors have reported high electric energy consumption (Kwilinski 2018). The industrial sector occupies the top of this list. The transport sector and households are as well leading in electric energy consumption.

The main issue with the increasing tendency of global energy consumption concerns environmental pollution and climate change. Therefore, many countries consider the possibility of using renewable energy and green innovation technologies. It is of great interest to study the development of renewable energy sources and consumption, as they offer the possibility to substitute fossil fuels and they can help in reducing CO_2 emissions (Miskiewicz 2021). As explored by UNESCO in their Science Report (UNESCO, 2015), education plays a vital role in achieving the 2030 Agenda for Sustainable Development goals. Education helps increase the quality of the economies, and researchers greatly contribute to improving innovative technologies. The Science Report of UNESCO (2021) pointed out the importance of gross domestic expenditure on research and development. With the help of such support, researchers have published more than 150 thousand scientific works on modern technologies, including artificial intelligence, energy, biotechnology, etc. The importance of renewable energy is the focus of many researchers, particularly the study of factors that might influence the level of renewable energy consumption.

1.1 Objectives

In the present study, we focus on the high-tech industry, sustainability, and renewable energy and explore their relations based on publicly available data from the World Data Bank. We aim to present the impact of SE and GDP on the usage of clean energy.

2. Literature Review

With the help of understanding the determinants of renewable energy, the possibility of accelerating the process of resolving climate change issues will increase (Ritchie et al. 2020). Therefore, the study of sustainability and renewable energy is very important in the present decade, as they help to achieve the sustainable development goals of the countries by 2030.

In a recent study, Kilinc-Ata and Dolmatov (2023) analyze renewable energy from a financial perspective. The findings of this study report a positive relationship between renewable energy capacity and expenditures on research and development, economic growth, and renewable energy policy. This research work as well finds out an inverse relationship between renewable energy investment and CO_2 emissions, electricity, and energy use. A significant negative role of energy consumption and education on environmental quality has been reported by Zafar et al. (2021) who also found a negative effect of secondary school enrolment on CO_2 emissions. The empirical study of Hajdukovic (2021) reports macroeconomic factors that affect renewable energy consumption, such as government consumption and public investment. Marra (2020) reports that in countries with higher levels of education, income growth has a negative effect on renewable energy consumption. There have been several applications of different methodologies and models to study and estimate the relationships between clean energy and various factors. One of these approaches introduced by Fang (2018) evaluates renewable energy industries, including wind, solar, and hydropower as well as biomass energy based on the revised Diamond Model. Oluoch et al.(2021) also studied the factors that affect renewable energy consumption. They limited their study to Sub-Saharan Africa and applied panel data analysis. They considered GDP per capita, CO_2 emissions, education index, and life expectancy index as the main factors. In a similar study, Polcyn et al. (2022) investigated the main factors that affect the renewable energy sources in European countries between the years 2000 and 2018. They performed panel data analysis and concluded that CO_2 emissions and GDP have a positive and significant impact on the growth of renewable energy consumption. On the other hand, the total labor force, gross capital formation, and energy consumption in the industry have negative effects.

3. Methods

First, we perform a basic statistical analysis, considering the years 2018 and 2019, and summarize the data by descriptive statistics (mean, median, variance, and standard deviation). We plot the histogram for these variables in order to analyze their distribution and possible patterns in the data. Then, we calculate the correlation coefficient to examine the strength and direction of the linear relationship between every pair of variables. Furthermore, we aim to conduct a simple regression analysis to explain the REC by SE and GDP. We model the relationship between the variables by the different nonlinear regression models with and without transformation options and compare those by the goodness of fit measures, coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), and standard error. Besides these, the assumptions are checked by the normal probability plot and residual analyses.

4. Data Collection

World Data Bank is one of the most comprehensive data sources, with more than 2000 variables for all the countries and a wide time range. In this study, regarding the availability of the data, 91 countries are included for the year 2018. Each year contains information for renewable energy consumption, SE, and GDP that relate to a specific country. REC (% of total final energy consumption) is defined as the share of renewable energy in total final energy consumption. SE is defined as the gross enrollment ratio, which is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown. GDP per capita (current US$) is the gross domestic product divided by the midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for the depreciation of fabricated assets or for the depletion and degradation of natural resources. Data are in current U.S. dollars. The main descriptive statistics of the variables are given in Table 1.

Table 1. Descriptive statistics for the three variables

	REC	SE	GDP
n	91	91	91
Mean	24.9519	95.2152	18499.3425
Median	21.0500	100.0798	9446.7171
Std. Deviation	19.1339	25.93429	20616.2474
Variance	366.1090	672.5880	425029656.239

The descriptive results show that 91 countries consume renewable energy on average 24.9519% of total energy. We also observe a rather big variation in the values of REC in the different countries, ranging from 1.57 to 85.22%. The median REC is 21.9519% and the variance is 366.109. Also, SE has a mean of 95.2152% with a variance of 672.588. The average GDP of 91 countries is 18499.3425 US$ with a standard deviation of 20616.24 US$. The variables are also summarized by plots. Figures 1-3 present histograms for the three variables. The figures show that most of the values lie toward the left so, the distribution of the REC and GDP per capita are positively skewed. On the other hand, Figure 2 displays that most of the values lie in the center, so a more symmetric distribution for SE.

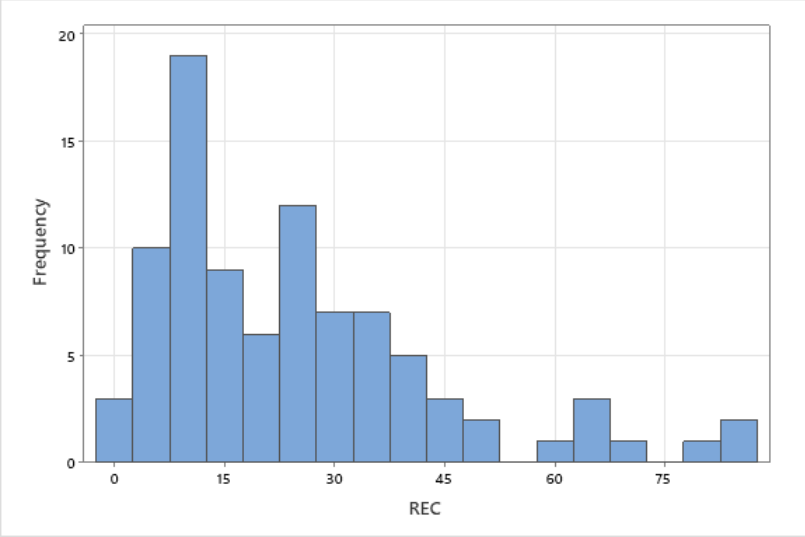

Figure 1. The histogram of renewable energy consumption

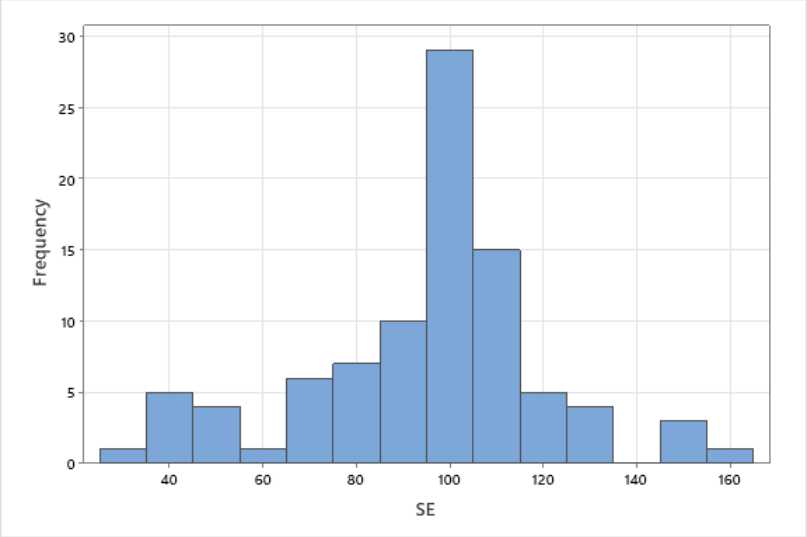

Figure 2. The histogram of SE

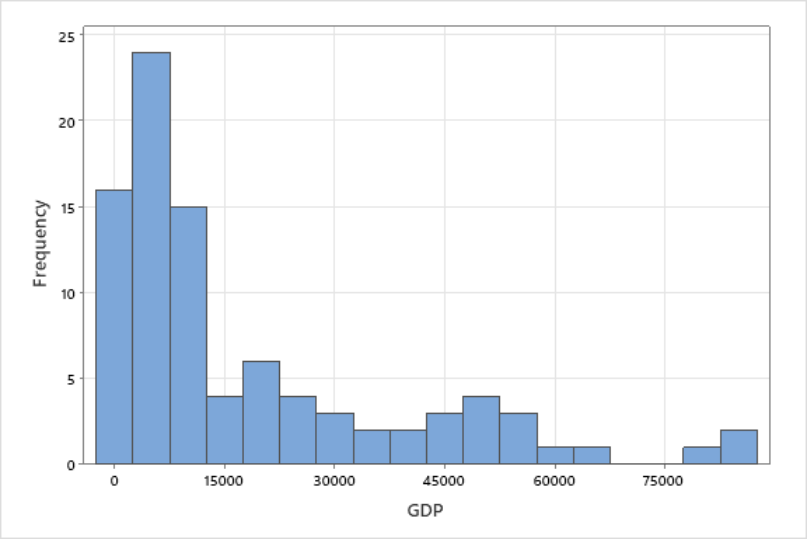

Figure 3. The histogram of GDP per capita

5. Results and Discussion

5.1 Numerical and Graphical Results

The correlation analysis is used to determine the relationship between the dependent variable and the independent variables. To determine the strength and direction between the dependent and independent variables, Pearson correlation analysis is used. The results of the correlation given in Table 2 show that the correlation coefficient value between REC and SE is -0.438, and its p-value is 0.000, which indicates that a moderate negative and significant relationship is present between the REC and SE. Also, the correlation coefficient value between REC and GDP is -0.223, and its p-value is 0.034, which indicates that there exists a weak negative and significant relationship between the REC and GDP per capita. Also, the correlation coefficient value between GDP per capita and SE is 0.604 and its p-value is 0.000 which indicates that there is a strong positive and significant relationship between the GDP and SE.

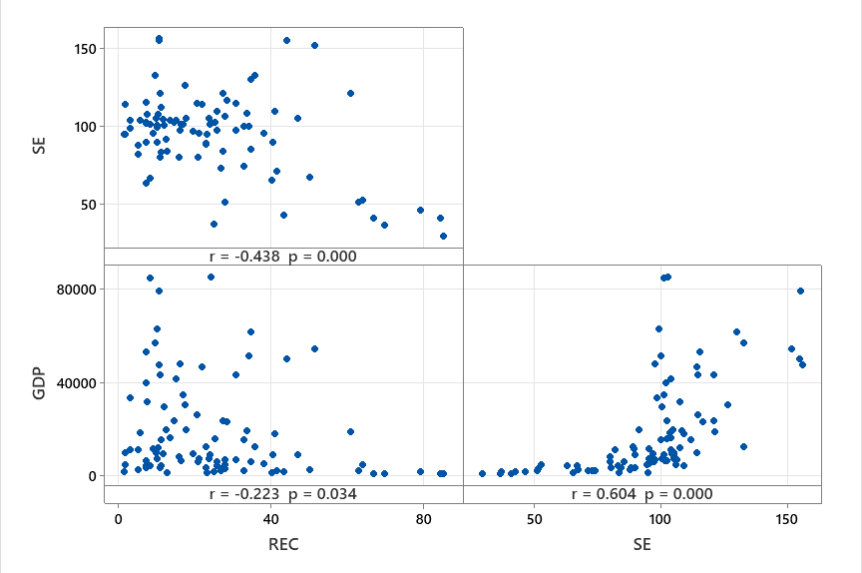

Figure 4. Pearson correlation matrix plot of REC, SE and GDP

Since Figure 4 shows nonlinear relationships, different statistical models are tested to determine the relationship between the variables. In this study, we use regression analysis to model the dependent variable by the independent variables. We define the REC as the dependent variable and analyze two models in which SE and GDP are independent variables. We consider the standard errors and R^2 in our comparisons.

Model 1: The cubic regression model with SE:

$$\widehat{REC} = 180.677 - 4.198(SE) + 0.03474(SE)^2 - 9.0\text{E}^{-5}(SE)^3 \quad (1)$$

The ANOVA table given in Table 2 shows that the p-value of the F statistic is 0.000, indicating that the cubic regression model is statistically significant in predicting REC on the base of SE. In addition, the significance of the regression coefficients is also tested, Table 3. The p-values of these tests indicate that all the regression coefficients are significant and impact REC. Figure 5 demonstrates the REC and SE scatter plot along with the fitted regression model. The model gives an R^2 of 46.6% and a standard error of 14.2216.

Table 2. Model 1: ANOVA table

Source	DF	SS	MS	F	P
Regression	3	15353.8	5117.92	25.30	0.000
Error	87	17596.0	202.25		
Total	90	32949.8			

Table 3. Model 1: Regression coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	180.7	31.1	5.82	0.000
SE	-4.20	1.16	-3.63	0.000
SE^2	0.0347	0.0130	2.67	0.009
SE^3	-0.000090	0.000045	-1.98	0.050

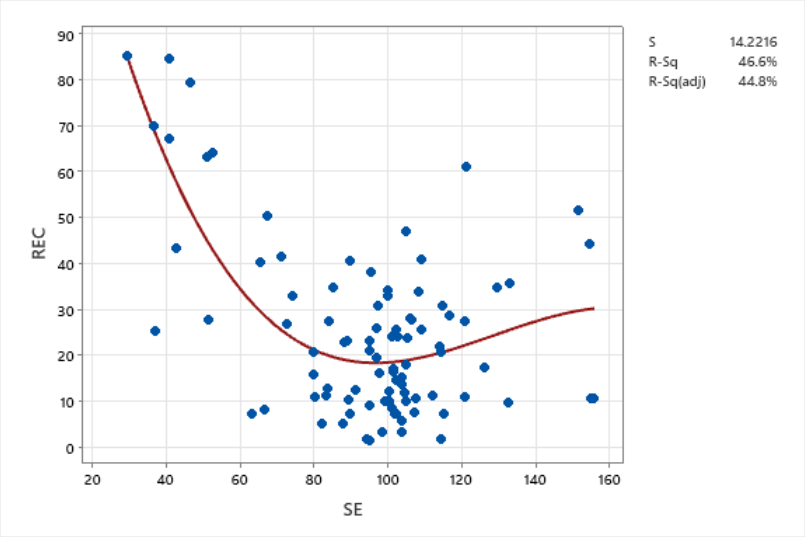

Figure 5. Model 1: Fitted equation plot

A similar analysis is conducted for GDP. Several nonlinear models are compared and the following model is observed as the best model that can be used to explain REC by GDP.

Model 2: The cubic regression model with GDP:

$$\widehat{REC} = 1945 - 1390(log10(GDP)) + 333.2(log10(GDP))^2 - 26.50(log10(GDP))^3 \quad (2)$$

The low p-value indicates that the combined effect of GDP, the square of GDP, and the cube of GDP have a significant impact on REC, Table 4. Table 5 gives specific information about the regression coefficients: They are also significant. The graphical representation of the model is illustrated in Figure 6. The statistics display in the graph give the model R^2 and standard error, which are 33.0% and 15.9284, respectively.

Table 4. Model 2: ANOVA table

Source	DF	SS	MS	F	P
Regression	3	10876.7	3625.56	14.29	0.000
Error	87	22073.1	253.71		
Total	90	32949.8			

Table 5. Model 2: Regression coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	1945	624	3.12	0.002
GDP	-1390	488	-2.85	0.005
GDP^2	333	126	2.65	0.010
GDP^3	-26.5	10.7	-2.48	0.015

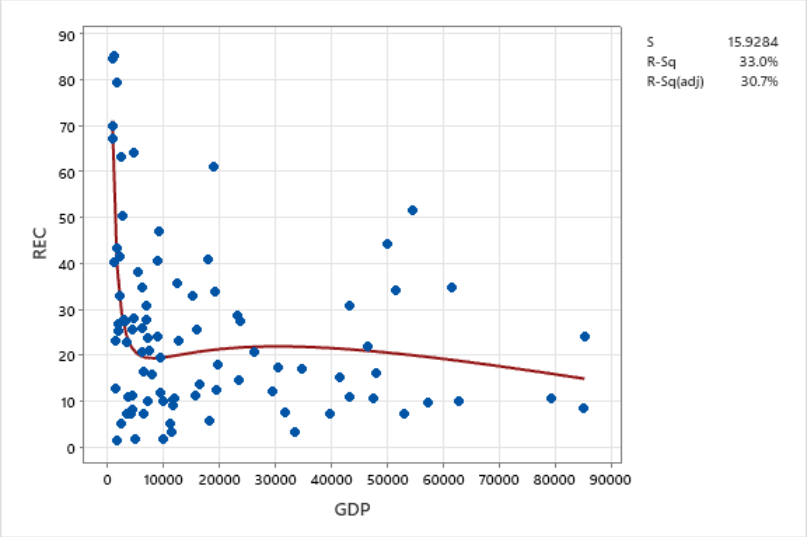

Figure 6. Model 2: Fitted equation plot

5.2 Proposed Improvements

In both of the models, although the R^2 are not high enough, they are the highest of the models that only GDP and SE are considered. The main reason for observing relatively low R^2 values is the effect of factors that are not presented in the models.

6. Conclusion

The study's main objective is to investigate how education and countries' economy contributes to the use of clean energy in different countries. We considered secondary school enrollment and GDP as the indicators for the factors, and the results show that SE negatively and significantly impacts renewable energy consumption. Also, the results show that when the GDP increases, then REC also decreases which means GDP has a negative impact on REC. The regression analysis results show that the cubic regression model is the best model that can be used to explain the REC by SE compared to the other nonlinear regression models. Similarly, the cubic regression model with log transformation of the independent variable is the best fit for the REC based on the GDP.

This study is limited to 2 variables. Although these variables impact renewable energy consumption, the R^2 values and model results show that new variables should be added to the models.

References

Fang, K., Zhou, Y., Wang, S., Ye, R., and Guo, S., Assessing national renewable energy competitiveness of the G20: A revised Porter's Diamond Model, *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 719–731, 2018, https://doi.org/10.1016/j.rser.2018.05.011

Hajdukovic, I., Interactions among macroeconomic policies, the energy market and environmental quality, *Environmental Economics and Policy Studies*, vol. 23, pp. 861–913, 2021, https://doi.org/10.1007/s10018-021-00305-x.

Kilinc-Ata, N. and Dolmatov, I.A., Which factors influence the decisions of renewable energy investors? Empirical evidence from OECD and BRICS countries, *Environmental Science and Pollution Research*, vol. 30, pp. 1720–1736, 2023. https://doi.org/10.1007/s11356-022-22274-8

Kwilinski, A., Mechanism of formation of industrial enterprise development strategy in the information economy, *Virtual Economics*, vol. 1, pp. 25, 2018, https://doi.org/10.34021/ve.2018.01.01(1).

Kwilinski, A., Mechanism of modernization of industrial sphere of industrial enterprise in accordance with requirements of the information economy, *Marketing and Management Innovation*, vol. 4, pp. 116–128, 2018, https://doi.org/10.21272/mmi.2018.4-11

Marra, A. and Colantonio, E., The path to renewable energy consumption in the European Union through drivers and barriers: A panel vector autoregressive approach, *Socio-economic Planning Sciences*, vol. 76, 100958, 2020, https://doi.org/10.1016/j.seps.2020.100958.

Miskiewicz, R., The impact of innovation and information technology on greenhouse gas emissions: A case of the Visegrád Countries, *Journal Risk Financial Management*, vol. 14, pp. 59, 2021, https://doi.org/10.3390/jrfm14020059.

Mohan, S. and Katakojwala, R., The circular chemistry conceptual framework: A way forward to sustainability in industry 4.0, *Current Opinion in Green and Sustainable Chemistry*, vol. 28, 100434, 2021, https://doi.org/10.1016/j.cogsc.2020.100434.

Oluoch, S., Lal, P., and Susaeta, A., Investigating factors affecting renewable energy consumption: A panel data analysis in Sub Saharan Africa, *Environmental Challenges*, vol. 4, 100092, 2021, https://doi.org/10.1016/j.envc.2021.100092.

Polcyn, J., Us, Y., Lyulyov, O., Pimonenko, T., and Kwilinski, A., Factors influencing the renewable energy consumption in selected European Countries, *Energies*, vol. 15, no. 1, 2022. https://doi.org/10.3390/en15010108.

Ritchie, H., Roser, M., and Rosado, P., CO_2 and greenhouse gas emissions, Published online at OurWorldInData.org, Available: https://ourworldindata.org/co2-and-greenhouse-gas-emissions, 2020.

Schneegans, S., Lewis, J., and Straza, T., UNESCO science report: the race against time for smarter development, Available: https://unesdoc.unesco.org/ark:/48223/pf0000377433.locale=en, 2021.

Soete, L., Schneegans, S., Eröcal, D., Angathevar, B., and Rasiah, R., UNESCO science report: towards 2030 – Executive summary, Available: https://uis.unesco.org/sites/default/files/documents/unesco-science-report-towards-2030-ex-sum-en.pdf, 2015.

Zafar, Sinha, A., Ahmed, Z., Qin, Q., and Zaidi, S.A.H., Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation Countries, *Renewable and Sustainable Energy Reviews*, vol. 142, 110868, 2021, https://doi.org/10.1016/j.rser.2021.110868

Zhang, C., Chen, Y., and Chen, H., Industry 4.0 and its implementation: a review, *Information Systems Frontiers*, pp. 11, 2021, https://doi.org/10.1007/s10796-021-10153-5

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