Term Paper

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Patterns in Global Gross Domestic Product Relative to Energy Consumption

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I. Introduction

This paper examines the prominence of renewable and nonrenewable resources in global energy consumption, and the near-direct relationship that our current global energy-mix (the product-mix of energy consumption) has with global levels of economic output. My paper questions the geo-economics of natural resources as energy sources, while shining light on the weight that energy scarcity plays in economic growth. The course of humanity and its standard of living goes hand-and-hand with the availability to consume resources for energy. This relationship is not entirely direct but near direct, being that the trend is stronger in some countries over others and other unmeasurable variables pertaining to time periods of (mostly unpredictable and unpreventable) economic shock. Because our means of energy production is currently majorly unsustainable it is thus a growing threat to our biosphere and a leading motivator of anthropogenic activity (activity by humans that imposes negative effects on the environment and climate change, both directly and indirectly).

II. Previous Research

There has been a lot of previous research on the economics that motivate climate change, though none directly in-line with the objective of analyzing economic prosperity relative to our current energy-mix over the period of 1965 to 2022. Here renewable resources can be defined as those that can replenish themselves following their usage for energy by humans, including biofuels, solar, wind, and hydropower. Nonrenewable resources can be defined as primary commodities that cannot be naturally replenished by any means, including nuclear, gas, oil, coal, and traditional biomass.

The main resources used in energy are fossil fuels (coal, oil, and gas) including carbon emissions of those low-carbon products (fossil fuels from nuclear power), accounting for at least half of all individual and world consumption. The Input Data used has been sourced from *Our World in Data* and *The Federal Reserve Economic Data of St. Loui*s (FRED of St. Louis).

Our World in Data uses primary data from Energy Institute Statistical Review of World Energy for the global primary energy consumption in TWh, by source. Here they used a substitution method in efforts of accounting for the inefficiencies in fossil fuel production (the most long-term abused source of energy, globally). The measurement used here is terawatt, or the unit of measurement for energy or the amount of electricity heat produced, representative of one trillion-watt hours (10^12 watt-hours).

The *FRED of St. Louis* uses secondary data from the World Bank to calculate the global GDP, per capita. 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. The GGDP is GDP divided by midyear population.[1] It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

III. Methodology

This analysis uses time series research via Microsoft Excel. The dataset is coming from a secondary source, as the primary data had been calculated using the 'substitution method' in resource consumption, and the calculations required in finding GGDP.[2] Here we have a total of fifty-eight observations. We will use graphical techniques including histograms, time series plots and scatterplots. We will also use descriptive statistics (for scalable variables), as well as correlation and regression statistical analysis.

Listed below are the equations defining the functional specification (Eqn. 1), population regression equation (Eqn. 2) and sample regression equation (Eqn. 3)

Eqn. 1 $GGDP = f(GCRR, GCNR, Years)$

Eqn. 2 $GGDP = \alpha + \beta_{gcrr} GCRR + \beta_{gcnr} GCNR + \beta_{year} Year$

$$\text{Eqn. 3} \qquad GGDP = a + b_{gcrr}\,GCRR + b_{gcnr}\,GCNR + b_{year}\,Year$$

Our dependent variable here is levels of global economic output, measured by GGDP per capita. Our independent variables are the two categories of energy sources being consumed; renewable and nonrenewable resources, as well as Years, or the year the initial data was collected. The relationship between the dependent variable and independent variables is that global levels of economic activity are highly influenced by the consumption of resources for energy, as well as the year the data was taken. It can also be assumed that the amount of energy consumed globally is a reflection of the global level of economic output.

IV. Results

Our historically nonrenewable, fossil fueled crisis that has dominated energy system, results for three-quarters of global greenhouse gas emissions. In *Figure 1*, the histogram of all variables is a left, or positively skewed histogram of our dataset, inclusive of GGDP (per capita), global consumption of renewable resources (GCRR), nonrenewable resources (GCNR), for energy (in TWh)), and year. Though the visual given of the Year variable is arbitrary to this graph, the histogram is a display of the current imbalance of our energy-mix, as the measure of nonrenewable resources towers over those of renewables and are thus much more used. We can also see here how much more closely related patterns in levels of GGDP and nonrenewables are related in comparison to renewables. There are zero outliers, allowing us to assume that there are no errors within the inputted data.

In this analysis, our dependent variable is GGDP, and our independent variables are GCRR, GCNR, and Year. In *Figures 2 –4*, sequence charts have been created for each variable, both independent and dependent, over the timespan of 58 years. We date back to only 1965 as before this date not all resources being analyzed in this model were put into play yet. We can observe that there is a positive or upward trend in all three variables when placed individually relative to years. Independent variables GGDP, GCRN, and GCNR are volatile; they have shown in the charts that they can be changed by an outside factor and do not create a repeated pattern. Year is not analyzed here, as this is timeseries data.

It could be argued that the GCRN (*Figure 3*) is exponential when looking at the trendline. This could be due to the increased costs of nonrenewable resources for many geo-economic reasons or even recent innovations in the production of renewable energy resources in our energy-mix. Our other variables analyzed in *Figures 2 & 4* can be classified as linear, via their linear trendlines.

In the relationships visible via the scatterplots displayed in *Figures 5 – 7*, when the GCRN, GCNR, or Year variables are individually put relative to GGDP, the relationships are strong, positively correlated, and linear. There are no outliers in the correlation, and it is not heteroscedastic dispersion. All three variables have a homoscedastic or constant dispersion when correlated with GGDP, as the correlation is high or easily defined by the graphs. GGDP is most correlated with GCNR and Year, supporting our original assumptions.

Descriptive Statistics

In *Table 1*, we can see that the variables used in this analysis are positively skewed, as the mean is greater than the median for each variable (mode has been omitted in this model). The skewness for each variable lies within the symmetrical skewness range (between -2 and 2), favored closely to one side of the bounds of symmetry (heavily tailed), like our other graphical analyses but this is not alarming considering our hypothesis between GGDP and GCNR. Skewness should be disregard in terms of Year, as it is equal to zero. This variable does play a role in the correlation between the variables in this analysis but does not play a role in how we analyze symmetry.

When observing Years via kurtosis and other analyses, we can consider this variable in peakedness, but cannot measure the effects that other independent variables have on time, due to outside or unmeasurable influences. Though we can analyze how the year these correlations occurred for more empirical research.

We can see that the kurtosis for GGDP, GCNR, and Years are negative. For similar reasons as the skewness measurement of GCRN, the kurtosis for GCRN is positive. The measured kurtosis here is heavy-tailed. The peakedness here is lower around the renewable resources than the nonrenewable. We can see that the peak would be towards the right (kurtosis is greater in the correlation between GGDP, GCNR, and Years than that of GCRR).

Correlation Matrix

Looking at the Correlation Matrix in *Table 2*, The GGDP is highly correlated with all three independent variables but holds a higher correlation to nonrenewables. Again, this is due to our current global energy-mix. Global GDP is also closely (of high) correlation with the year the data was taken. A number of outside indicators effecting the level of global GDP for that year, including but not limited to the market crash in 2008, the COVID-19 pandemic, or other past causes of global economic shock.

These correlations agree with the original assumption that global GDP has a reliance on global energy consumption, and most directly correlated with GCNR and Years. This matrix further proves that the current global energy-mix dependance (weighted in nonrenewable resources) weighs most on global GDP (at 0.991), more than outside contributors that could be included in the year the data was taken, as well as (the less common usage of) renewable resources.

The regression correlation coefficient for GDP v. Year (at 0.988) also suggests high association, as this is a close number to the most correlated relationship. The dependent variable (global GDP) having multiple association between individual independent variables gives evidence of multicollinearity, as the increase of consumption of energy can also be a result of GGDP, and vice versa. (We can take in consideration similar linear association between GGDP and Year to back up the analysis of multicollinearity.)

Regression Results

Equation for Sample Regression Line.

			+	+	-
Eqn. 4	GGDP =	44,069.31	+ 0.12GCRR	+ 0.06GCNR	- 21.9Years
	t-stat	(2.59)**	(17.74)***	(12.47)*	(-2.49)
	p-value	(.01)	(.0)	(.0)	(.01)
	r (corr)		(.12)	(.06)	(-21.89)

n = 58 r-sq. = .997 F = 6,946.44*** F-Prob = .000 SE = 104.26

Confidence Intervals.

*	Significant at the	10%	level of significance (90% Sure, or "are below")
**	Significant at the	5%	level of significance (95% Sure, or "are below")
***	Significant at the	1%	level of significance (99% Sure, or "are below")

Results of an F-test for the entire model.

	Ho:	$b_{gcrn} = b_{gcnr} = b_{year} = 0$	(Null Hypothesis)
* 5%	Ha:	at least 1 b_i not equal to 0 (6,946.44 > 4.99)	(Alternate Hypothesis)

To further interpret the Regression Statistics in *Table 3*, the standard deviation is notably less than the mean for each variable and it can be concluded that the data is closely dispersed around the mean data or exhibits low dispersion. In the above F-test, we see that the null (Ho) and alternative hypothesis (Ha).

For this model we will accept the null hypothesis and reject the alternative hypothesis, as the F Significance is equal to 0.000 because we can assume that being the p-values are above the F-sig, that the model does not efficiently prove that it is more correlated when analyzed next to the independent variables (this model) than if it weren't. The P-Value is less than 0.05 for all variables and proves this model to be significant.

When looking at the results for our coefficient of determination (R-Squared, equal to 0.997 or 99.7%) we can conclude that that statistical model predicts the suggested outcome or assumption that the association between the dependent and independent variables is very strong; there is little variation between the independent variables.

The Standard Error values of our independent variables tell us that the GCRR (0.01) and GCNR (0.00) do not fall far from the regression line and support the accuracy of our original assumptions relative to GGDP. The greater Standard Error value seen in the Year variable also supports the idea that there are outside independent variables dependent on the Year variable.

V. Conclusions

The research presented here can be considered successful, as the coefficient of determination tells us that 99.7% of variation in the levels of GGDP by year (relative to 1965 to 2022) can be associated with the variation in amount of TWh consumption of both GCRR and GCNR by year, as well as by the year the data was taken from alone. All independent variables were predictive, though less predictive in the years variable. The initial assumption that the GGDP or global economic output levels are supported by the consumption of both renewable and nonrenewable energy can be considered true.

This data can be improved in terms of time accuracy. The dates measuring the Global TWh consumption are determined per year but not on the same date of each year like the data used measuring Global GDP. We assume here that the differences in the date (specifically, what month) the data has been recorded on should have little to no effect on this paper's findings. Another way this dataset could be altered to improve this analysis is by also calculating the energy used to produce the energy consumed in our question for all resources and not just fossil fuels. This gives us a more accurate idea of how much energy is being consumed in entirety over this timespan.

Global Public Policy Implications

Energy scarcity has obviously put an immense strain on the global energy demand as well as on nations to provide their people and firms with power to drive economic success. There are less-developed economies that are lacking in quality of life due to lack of access to energy or lack of production of energy in their countries. Like most means of characterizing a country, economic activity is a leading determinant in countries influence on climate change. While the largest economies have the highest contributions to greenhouse gas emissions, there are lesser economies with similar GHG emissions levels, though do not compare to these wealthier countries in terms of GDP. These improvements are indispensable to the gravity of our current climate threats. Efforts are restricted by the inevitable conflicting environmental and financial compromises that come along with the implementation of these cleaner means of energy production.

Energy efficiency policies and programs such as investment incentives and tax benefits encourage projects that contribute less to global anthropogenic emissions by reducing or offsetting energy usage of high CO_2 emission levels, increase investment incentives by corporations and governments to invest in climate change reversal, as well as raise the standards of corporate social responsibility and the perspective of consumer ideas within their markets.

When addressed at the level of consumer spending, consumer purchasing power has the power to shift the ability of corporations and governments to continuously ignore the need for the prioritization of climate change recovery in both the macro and micro economic realm. Using similar statistical methods, I plan to analyze this research further by looking at the relationships between GDP and energy consumption by each resource, and then the relationship between economic output and the availability of resources used for energy to a country. This analysis will determine how closely related the availability of renewable and nonrenewable resources is to the economic prosperity of a country.

The interest behind this relationship comes from the assistance underdeveloped countries should need to grow economically. Degrowth involves shrinking economies as a solution to extensive anthropogenic entropy, though is partially impractical. There is a happy medium of economic fluctuation that satisfies our living standards and the environment's remaining threshold for damage in implementing sustainable methods of regulation. With policies and programs that encourage global investment in sustainability either offsetting or replacing current unsustainable operations, a level of balance is achievable via lowered energy intensity while also increased energy efficiency.

VI. Bibliography

Global primary energy consumption by source; Renewable & Nonrenewable Resources (TWh)

Ritchie, H., Rosado, P., & Roser, M. (2023). Energy production and consumption. Retrieved from https://ourworldindata.org/energy-production-consumption

Constant Global Gross Domestic Product for the World (per capita)

World Bank, C. G. per capita for the W. [NYGDPPCAPKDWLD]. (2023). Retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/NYGDPPCAPKDWLD

VII. Appendix I: Input Data

Dataset used in this model.

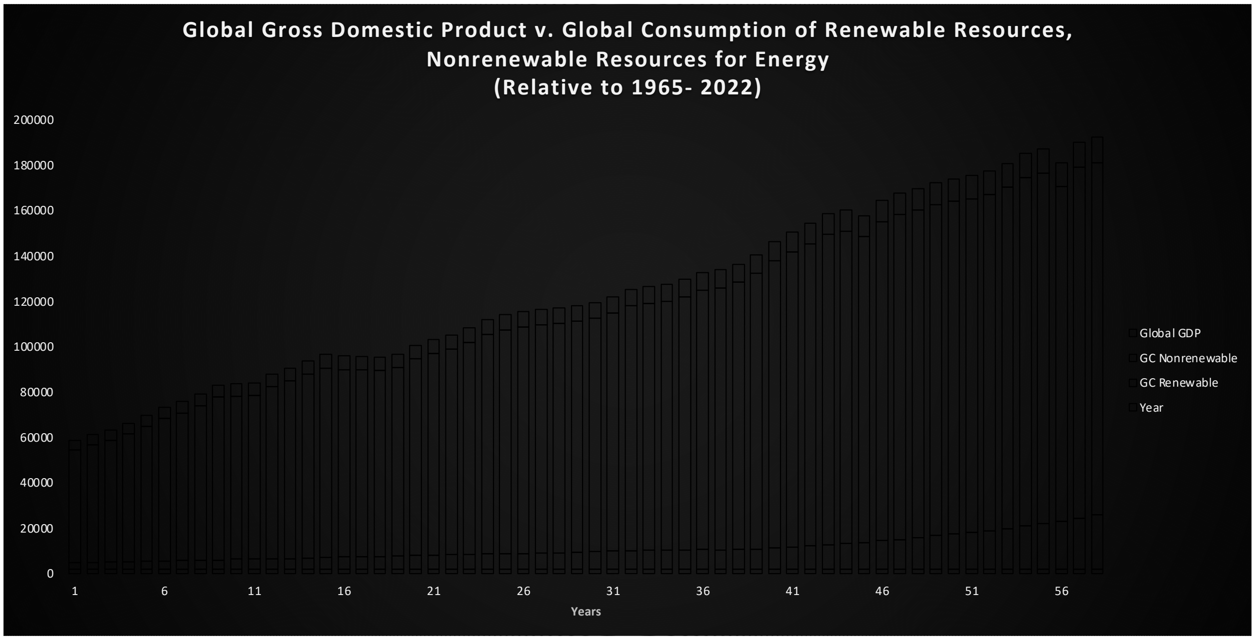
Year	GC Renewable	GC Nonrenewable	Global GDP
1965	2,794.8654	49,675.0040	4,249.7353
1966	2,980.0835	51,861.2778	4,399.6116
1967	3,045.7063	53,569.5422	4,489.9807
1968	3,210.8909	56,323.4973	4,660.3033
1969	3,399.2632	59,558.0573	4,829.8122
1970	3,567.2659	62,861.6110	4,918.1748
1971	3,729.8432	65,090.3692	5,022.7238
1972	3,906.8591	68,144.8703	5,200.3545
1973	3,967.4919	71,792.8557	5,425.6748
1974	4,353.3444	71,882.1988	5,418.3042
1975	4,406.1681	72,198.6517	5,353.4158
1976	4,401.6616	75,826.6655	5,537.9539
1977	4,556.4442	78,319.5925	5,665.5464
1978	4,931.9255	80,963.5769	5,798.1782
1979	5,185.2035	83,385.6516	5,935.2392
1980	5,307.0745	82,639.7996	5,941.8826
1981	5,425.3150	82,305.2358	5,952.5884
1982	5,554.1094	81,864.5724	5,864.5567
1983	5,813.4382	82,961.2510	5,912.9114
1984	6,034.8981	86,573.7447	6,085.1866
1985	6,164.3947	88,682.9834	6,203.0211
1986	6,280.2564	90,570.1334	6,301.9778
1987	6,380.4982	93,586.0120	6,423.2726
1988	6,586.2355	96,852.8850	6,603.7788
1989	6,599.6254	98,782.3890	6,731.1258
1990	6,863.4318	99,852.0407	6,800.8277
1991	7,032.2262	100,485.3760	6,779.8148
1992	7,059.3423	101,138.5374	6,807.3271
1993	7,474.8671	101,626.6276	6,825.2689
1994	7,548.9483	102,923.8440	6,946.0921

1995	7,956.0415	104,906.8340	7,054.2409
1996	8,064.3912	107,832.6897	7,197.8801
1997	8,241.8195	108,871.8200	7,371.0525
1998	8,335.9382	109,584.2090	7,472.8819
1999	8,437.1158	111,515.5472	7,633.0063
2000	8,626.9265	114,229.6076	7,871.1678
2001	8,417.7715	115,539.5540	7,923.5808
2002	8,622.0948	117,690.2427	8,001.0980
2003	8,650.3603	121,567.6532	8,145.0338
2004	9,311.3857	126,590.2405	8,402.1219
2005	9,684.4517	130,192.7365	8,629.5617
2006	10,143.5934	133,265.0027	8,899.2156
2007	10,505.4764	136,851.7840	9,174.6871
2008	11,310.4760	137,554.6386	9,249.2076
2009	11,558.0734	135,017.9500	9,013.6141
2010	12,449.8812	140,542.6760	9,309.0463
2011	12,999.6302	143,132.2823	9,503.6416
2012	13,816.1334	144,280.5837	9,641.6199
2013	14,704.6591	145,845.6516	9,791.4883
2014	15,422.2389	146,596.1720	9,970.7398
2015	15,977.1030	147,187.9790	10,156.9535
2016	16,870.1488	148,125.4250	10,321.1368
2017	17,858.4420	150,362.7160	10,549.8217
2018	18,990.9747	153,522.7750	10,777.8705
2019	19,985.8393	154,288.5047	10,941.9645
2020	21,134.4986	147,334.3070	10,499.6471
2021	22,323.9662	154,733.1970	11,037.2940
2022	23,848.6676	155,050.0074	11,287.1485

CLICK HERE: Link to Excel Document used to execute this analysis.

<u>VIII. Appendix II: Figure 1: Histogram *(All Variables)*</u>

Figure 1: Global Gross Domestic Product v. Global Consumption of Renewable Resources, Nonrenewable Resources for Energy (Relative to 1965- 2022).



<u>IX. Appendix III: Figures 2 - 4: Timeseries *(All Variables)*</u>

Figure 2: Global GDP

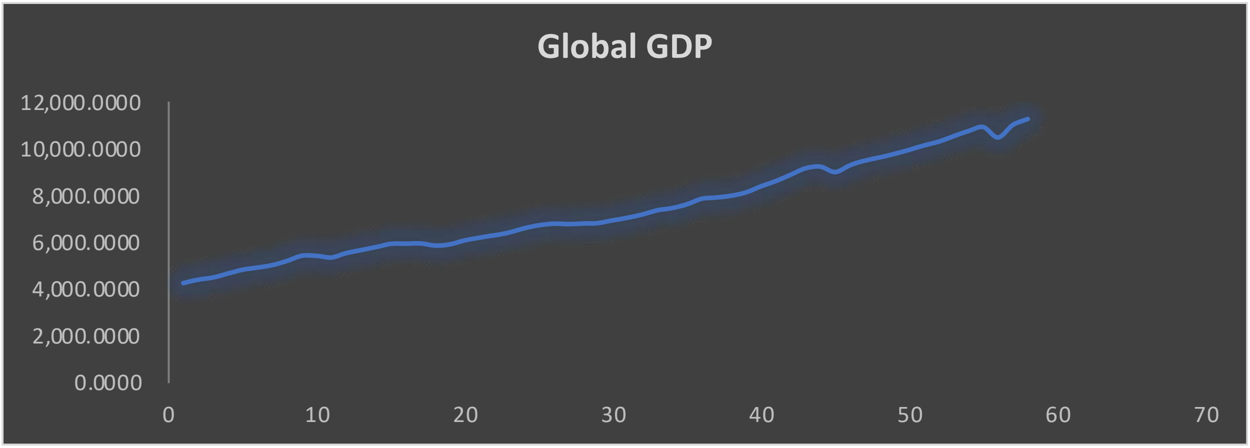


Figure 3: Global Consumption of Renewable Resources

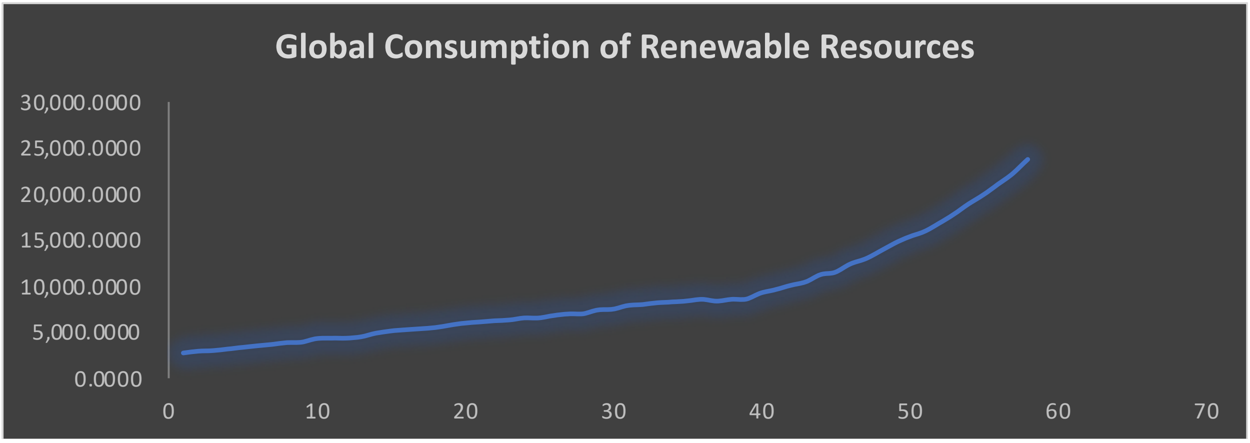
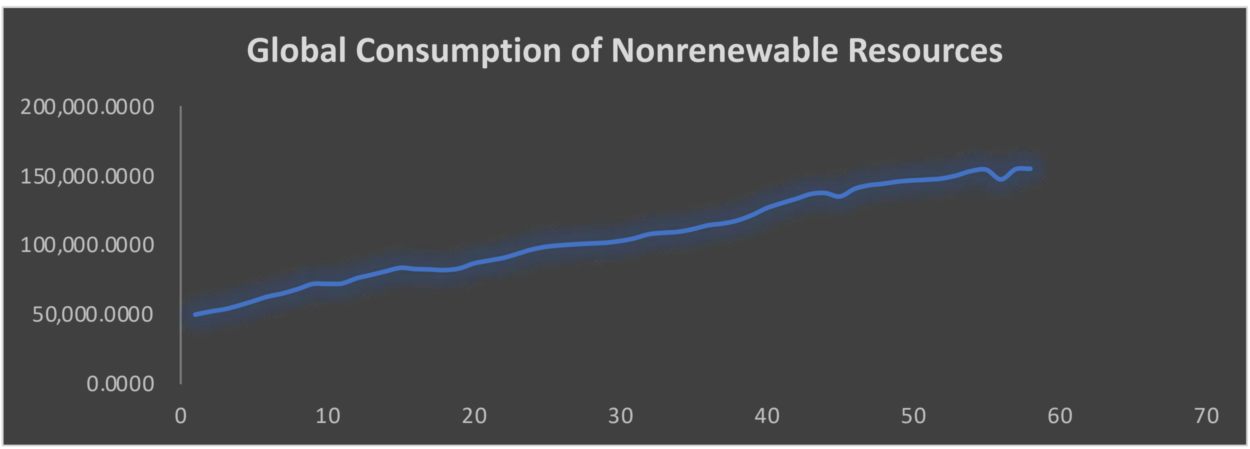


Figure 4: Global Consumption of Nonrenewable Resources



X. Appendix IV: Figures 5 - 7: Scatterplots *(Dependent Variable v. Each Independent Variable)*

Figure 5: Global GDP v. Global Consumption of Renewable Resources (Relative to 1965 - 2022)

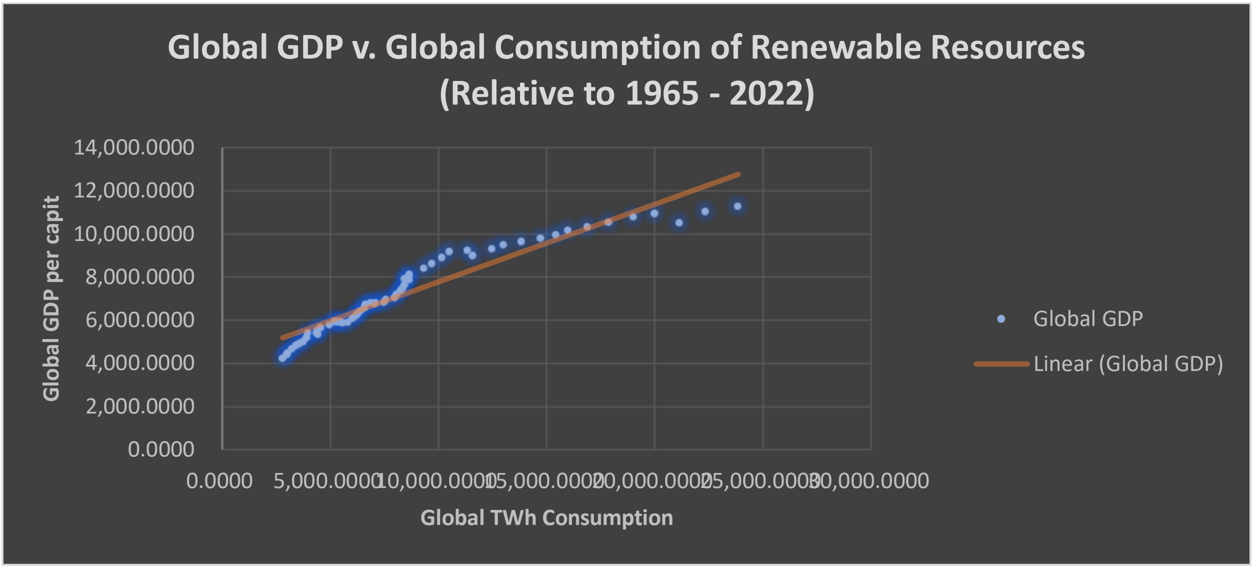


Figure 6: Global GDP v. Global Consumption of Nonrenewable Resources (Relative to 1965 - 2022)

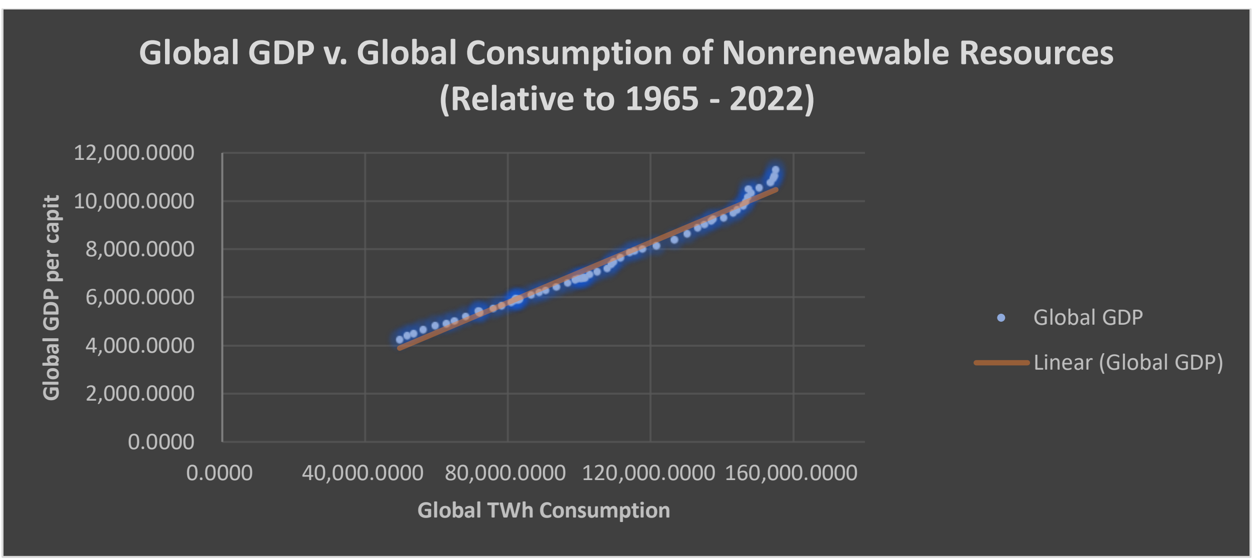
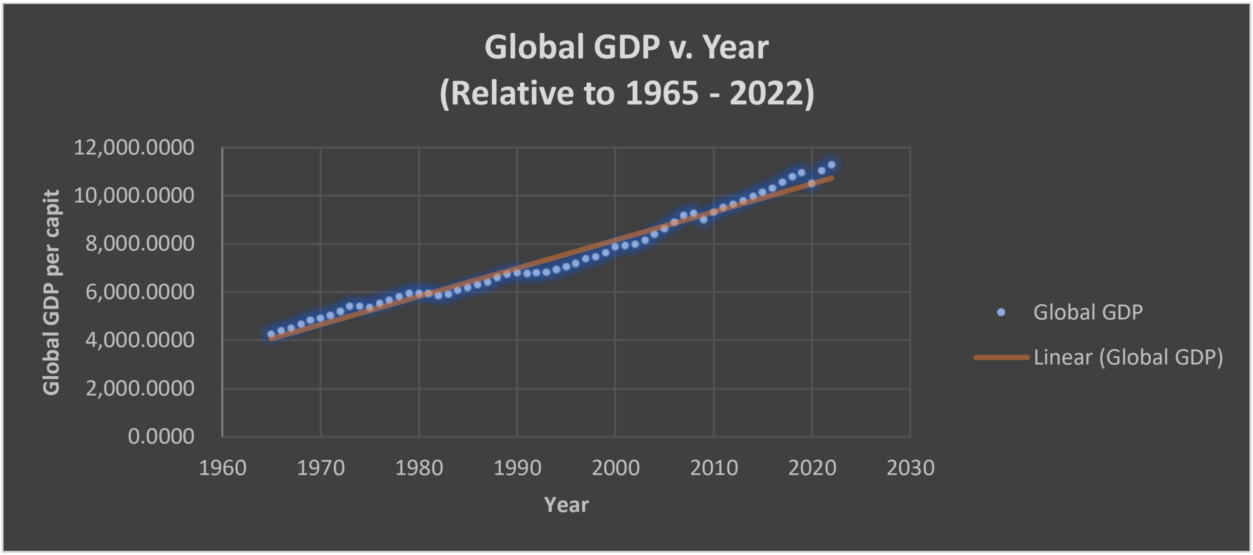


Figure 7: Global GDP v. Year (Relative to 1965 - 2022)



XI. Appendix V: Table 1: Descriptive Statistics *(Dependent Variable & Independent Variables)*

Table 1: Descriptive Statistics

		Global GDP	*GC Renewable*	*GC Nonrenewable*	*Year*	
central tendency	**Mean**	7,395.0235	8,944.9961	105,767.4420	1994	
central tendency	**Median**	6,885.6805	7,511.9077	102,275.2360	1994	
central tendency	**Mode**	#N/A	#N/A	#N/A	#N/A	(No Mode)
dispersion	**Standard Deviation**	1,996.1789	5,307.5669	31,680.0988	16.8869	
peakedness	**Kurtosis**	(1.0286)	0.6899	(1.1866)	(1.2000)	
symmetry	**Skewness**	0.3602	1.1922	0.0208	(0.0000)	
dispersion	**Range**	7,037.4133	21,053.8022	105,375.0030	57	
	Minimum	4,249.7353	2,794.8655	49,675.0040	1,965.0000	
	Maximum	11,287.1485	23,848.6676	155,050.0070	2,022.0000	
	Count	58	58	58	58	

XII. Appendix VI: Table 2: Correlation Matrix *(All Variables)*

Table 2: Correlation Matrix (Correlation Coefficients)

	Global GDP	*GC Renewable*	*GC Nonrenewable*	*Year*
Global GDP	1			
GC Renewable	0.956	1		
GC Nonrenewable	0.991	0.914	1	
Year	0.988	0.922	0.995	1

XIII. Appendix VII: Table 3: Regression Results *(Dependent Variable & Independent Variables)*

Table 3: Regression Results

Regression Statistics.

Regression Statistics	
Multiple R	0.999
R Square	0.997
Adjusted R Square	0.997
Standard Error	104.264
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	226,542,592.278	75,514,197.43	6,946.435	0.000
Residual	54	587,030.116	10,870.93		
Total	57	227,129,622.395			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*t- sig*
Intercept	44,069.31	17,020.62	2.59	0.01	0.01
GC Renewable	0.12	0.01	17.74	0.00	0.00
GC Nonrenewable	0.06	0.00	12.47	0.00	0.00
Year	(21.89)	8.78	(2.49)	0.02	0.01

Lower 95%	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
9,945.03	78,193.60	9,945.03	78,193.60
0.11	0.13	0.11	0.13
0.05	0.06	0.05	0.06
(39.49)	(4.29)	(39.49)	(4.29)

Items of Import				
1. Equation	Intercept	GC Renewable	GC Nonrenewable	Year
	44,069.31	0.12	0.06	(21.89)
2. F Statistic	6946.44			
3. R-Squared	0.997			
4. T Statistics	2.59	17.74	12.47	(2.49)
5. Standard Error	104.264			

Equation for Sample Regression Line.

Eqn. 4 $\qquad GGDP = 44{,}069.31 \overset{+}{+} 0.12GCRR \overset{+}{+} 0.06GCNR \overset{-}{-} 21.9Years$

t-stat	(2.59)**	(17.74)***	(12.47)*	(-2.49)
p-value	(.01)	(.0)	(.0)	(.01)
r (corr)		(.12)	(.06)	(-21.89)

n = 58   r-sq. = .997   F = 6,946.44***   F-Prob = .000   SE = 104.26

*	Significant at the	10%	level of significance	(90% Sure)
**	Significant at the	5%	level of significance	(95% Sure)
***	Significant at the	1%	level of significance	(99% Sure)

Results of an F-test for the entire model.

	Ho:	$b_{gcrn} = b_{gcnr} = b_{year} = 0$	(Null Hypothesis)
* 5%	Ha:	at least 1 b_i not equal to 0 (6,946.44 > 4.99)	(Alternate Hypothesis)

[1] https://fred.stlouisfed.org/series/NYGDPPCAPKDWLD
[2] https://ourworldindata.org/energy-production-consumption