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Relationship between CO_2 Emissions and Renewable Energy Production in the United States of America

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

This study investigates the relationship between carbon dioxide (CO_2) emissions and renewable energy production. In particular, the analysis considers whether there is a uniform relationship between CO_2 emissions and renewable energy production in the United States. The study uses CO_2 emissions, Gross Domestic Product (GDP), population, and renewable energy production data obtained from the U.S. census Bureau, U.S. energy information administration (EIA), and other reliable data sources. Multivariate analysis was combined with geographic information system (GIS) to visualize the variables in each state. Pearson Correlation Coefficient was also used in this study to probe into the relationship between CO_2 emissions, renewable energy production, GDP and population in a linear form. Results of this study through the data analysis revealed there was a significant positive correlation between population and CO_2 emissions, while GDP also showed positive correlation with CO_2 emissions. However, there was no specific pattern between renewable energy and CO_2 emissions; meaning that producing more renewable energy does not necessarily lead to less CO_2 emissions.

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1. INTRODUCTION

The state of the environment, especially on the depletion of the ozone layer, the rise in mean global temperatures, the loss of biodiversity and the degradation of large watersheds, has focused the attention of world communities for more than a decade. After the 1972 Stockholm conference on the Human Environment, the international community responded with the appointment of the Brundtland Commission, whose report in 1987 sparked heightened and increasingly concerned discussions [1]. The questions raised in the report formed much of the agenda at the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Rio Conference and Earth Summit. Following the signing of the 1992 Earth Summit, Kyoto protocol emerged from the UN Framework Convention on Climate Change (UNFCCC) with the legally binding agreement under which the industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% [2,3].

Despite Kyoto protocol which was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 [3], greenhouse gases especially carbon dioxide (CO_2) has received the most attention as it continues to increase in recent years [2]. According to Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, CO_2 has contributed the most to global warming and could have atmospheric lifetime of estimated between 30–95 years whereas Methane and Nitrous Oxide have mean atmospheric lifetime of 12 years and 114 years respectively [4,5]. Studies conducted by U.S. Environmental Protection Agency (EPA) in United States of America suggests that the composition of U.S. greenhouse gas emissions for CO_2 in 2014 was 81% followed by Methane 11%, Nitrous Oxide 6% and Fluorinated gases 3% [6]. In United Kingdom (U.K), final report in 2014 by National Statistics showed that CO_2 accounted for 82% greenhouse gas emissions. From the same report, Methane and Nitrous Oxide posted 10% and 4% respectively of UK's greenhouse gas emissions in 2014 [7]. Among the Organization for Economic Co-operation and Development (OECD) countries in Europe and Asia, CO_2 data in Fig. 1 show higher emissions in thousands of tons per annum in 2013 [8-11]. According to U.S. EPA report in 2016, Global CO_2 emissions from fossil fuels have been increasing at an alarming rate since 1900 [6,12,13]. As shown in Fig. 2, Global CO_2 emissions is expected to increase sharply as the world population increases which translates into more energy consumption and GDP growth [6,9,12-16].

Anthropogenic activities fueled partly by the pressures caused by human activities through growing demand for resources, global population growth, and increasing urbanization plays a key role in changing the carbon cycle both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere [5,6,9,14-18].

1.1 CO_2 Emissions and GDP Growth

The ratification of the Kyoto protocol re-kindled debates on the relationship between carbon dioxide emissions and economic growth. Shafik [19] found a linear relationship between per capita CO_2 emissions and per capita income. Schmalensee [20] found an 'inverse-U' shaped relationship between the per capita CO_2 emissions and per capita income. Such a shape is generally known as the Environmental Kuznets Curve in the literature. Gangadharan [21] analyzing two sets of cross-section data, from 36 countries in 1980 and 51 countries in 1995, found the slope of the per capita emissions versus per capita income curve to be positive everywhere except at the inflection point, where the slope is zero. In contrast, other studies have found direct evidence that supports a strictly monotonic relationship between GDP/capita and CO_2 [10,16,22-31].

1.2 CO_2 Emissions and Renewable Energy

The U.S. EPA reported that CO_2 emissions from the burning of petroleum, coal and natural gas constituted 81 percent of all U.S. man-made greenhouse-gas emissions in 2014 [6,12,16]. It directly links changes in carbon dioxide emissions levels with changes in energy usage. Many believe renewable energies, as carbon free energy sources, could provide a major solution to global warming and energy security. By now, most studies about the CO_2 emissions have focused on other variables more than renewable energy. Sadorsky [32] analyzed the relationship between renewable energy consumption, income, oil prices and CO_2 emissions in the Group of 7 (G7) economies over the period 1980-2005. Results showed that increases in real GDP per capita and carbon dioxide emissions per capita are found to be major drivers behind increases in G7 renewable energy consumption per capita. Menyah and Wolde-Rufael [33] used auto regression to study the relationship between carbon dioxide emissions, renewable energy consumption, nuclear consumption and real GDP for the US over the period 1960-2007. They found causality running from nuclear energy consumption to CO_2 emissions but no causality running from renewable energy consumption to CO_2 emissions. There is evidence of causality running from GDP to renewable energy.

1.3 Population and CO_2 Emissions

In support of the population growth and CO_2 emissions, early work of Cropper and Griffiths [34], Bruvoll and Medin [35], found monotonic relationships between population growth and CO_2 emissions, and various forms of environmental degradation associated with such growth. In particular, Shi [36] found that global population change over the last two decades was more than proportionally associated with growth in carbon dioxide emissions. His empirical findings were based on data collected from 93 countries over the period 1975–1996. A larger population results in increased demand for goods and services which could result in a chain reaction of problems such as increased pressure on natural resources and other negative externalities on the local, regional and global environment. Early work of Seldon and Song [37], found a strong negative relationship between population growth and environmental degradation. This finding means that population growth and expansion across the landscape causes increased awareness of environmental issues, resulting in more pressure to adopt environmental standards [37].

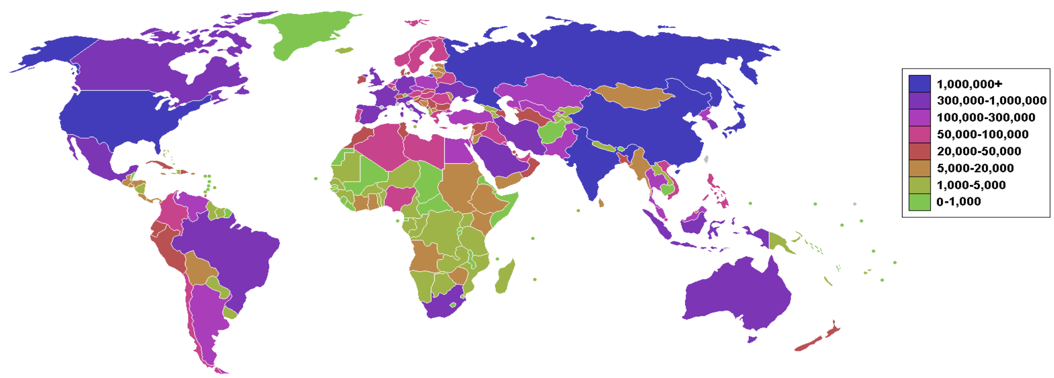


Fig. 1. Countries by carbon dioxide emissions in thousands of tons per annum in 2007 [11]

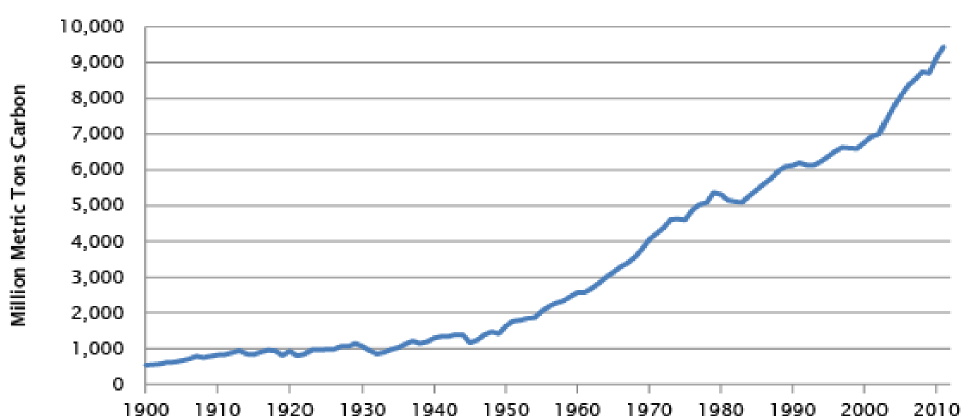


Fig. 2. Global carbon emissions from Fossil Fuels, 1900-2011 [16]

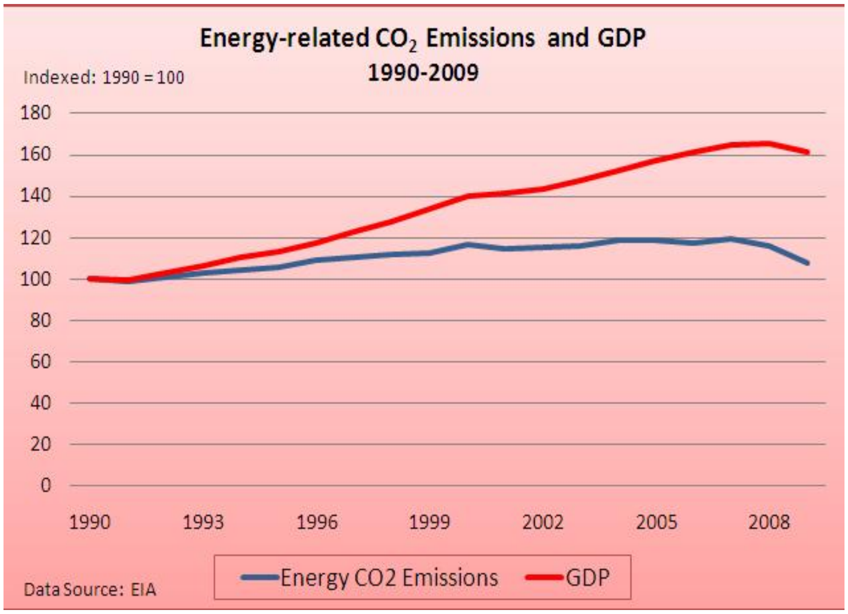


Fig. 3. Energy-related CO_2 emissions and GDP 1990-2009 [13]

1.4 Objectives of the Study

This study investigates the relationship between carbon dioxide emissions and renewable energy production. In particular, the goal is to examine whether a statistically significant relationship exists between CO_2 emissions and renewable energy production in the United States.

2. METHODOLOGY

Key variables: In this study key variables are CO_2 emissions and renewable energy production.

Variable classification: renewable energy production (interest variable), population, GDP considered as independent variables; while CO_2 emissions are supposed to be the dependent variable.

Identification of the variables:

Renewable energy production: renewable energy is a source of energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat. About 16% of global energy consumption comes from renewable energy, with 10% from traditional biomass, and 3.4% from hydroelectricity [9,14,15].

1- In this study renewable energy production in U.S is used to define the interest variable.
2- CO_2 emissions: CO_2 emissions are the amount of carbon dioxide that are emitted from human activities, measured in million metric tons.
3- GDP: Gross domestic product refers to the market value of all officially recognized final goods and services produced within a country in a given period; GDP per capita is often considered an indicator of a country's standard of living.
4- Population: value of this variable measured by the population in the middle of each year.

2.1 Data Type and Data Source

The data used for this study contained variables CO_2 emissions, GDP, population and renewable energy production in 2009. These data, were obtained from the U.S. Energy Information Administration (EIA), U.S. EPA and U.S. Census Bureau website [12,16,38,39].

2.2 Geographic Information Systems (GIS) Mapping

Esri's GIS mapping software (ArcMap) was used to visualize each of the variables in the U.S. by state. The data in Table 1 was entered into the attribute table. To assist in comparative analysis between CO_2 emissions and renewable energy production in each state in 2009, dot density mapping methods was used to show quantities.

2.3 Pearson Correlation Coefficient

In this study Pearson Correlation or Pearson's *r* technique was used to carry out statistical analysis. Before proceeding to the analysis it is important to explain briefly few concepts associated with Pearson Correlation Coefficient. This statistical method is widely used in the behavioral, social and medical sciences for investigating the relationship between two quantitative and continuous variables, for example, body mass index (BMI) and blood pressure [40,41], family size on savings and consumption [42-44], poverty and deforestation [45]. Pearson Correlation enables a researcher to test the strength and direction of a relationship between two quantitative or numerical variables ranges from negative (-1) to positive (+1) coefficient values. It assesses the degree to which two variables are linearly related or correlated [46]. A general assumption underlying the interpretation of Pearson Correlation is that both variables are each measured on a quantitative scale [46,47].

The SPSS version 22.0 statistical software package was used in this study. Pearson Correlation Coefficients were calculated using bivariate correlation analysis to examine whether a statistically significant relationship exists between CO_2 emissions, renewable energy production, GDP and population using data in Table 1. The effect of GDP and Population was controlled statistically to find out the relationship between carbon dioxide and renewable energy. Also, to aid data input, analysis and interpretation in SPSS software, the following abbreviations were used:

CO2 = CO_2 emissions
GDP = Gross domestic product
POP = Population
RENERGY = Renewable energy

3. RESULTS AND DISCUSSION

Table 2 shows correlations between CO_2 emissions and population. Table 3 presents information on correlations between CO_2 emissions and GDP. Table 4 shows correlations between CO_2 emissions and renewable energy. Correlations between CO_2 emissions and renewable energy with control GDP and population are presented in Table 5. Map 1 represent the spatial distribution of U.S. population by States in 2010. Map 2 shows U.S. total CO_2 emissions by States in 2009. The total renewable energy production by States in 2009 is shown in Map 3. Total GDP by each State in 2009 is presented in Map 4. Total renewable energy production per CO_2 emissions in 2009 which was created by combining Map 2 and Map 3 is reported in Map 5.

In Table 2, Pearson correlations analysis was conducted to examine whether a statistically relationship exists between CO_2 emissions and population. The results revealed a significant and positive relationship ($r = .85$, $N = 50$, $p = .00$). The correlations were strong in strength. Also, Pearson correlations results in Table 3 examined the correlation between CO_2 emissions and GDP. The result also shows a significant and strong positive relationship ($r = .81$, $N = 50$, $p = .00$). In Table 4 Pearson correlations analysis was conducted to examine the relationship between CO_2 emissions and renewable energy production. The results revealed a significant and positive relationship ($r = .28$, $N = 50$, $p = .05$). The low positive $r = .28$ indicates the correlations was weak in strength. A similar calculation was done in Table 5 showing correlations between CO_2 emissions and renewable energy by controlling GDP and population. The results revealed a significant and negative relationship ($r = -.18$, $N = 46$, $p = .23$). Again, the strength of the correlations was weak.

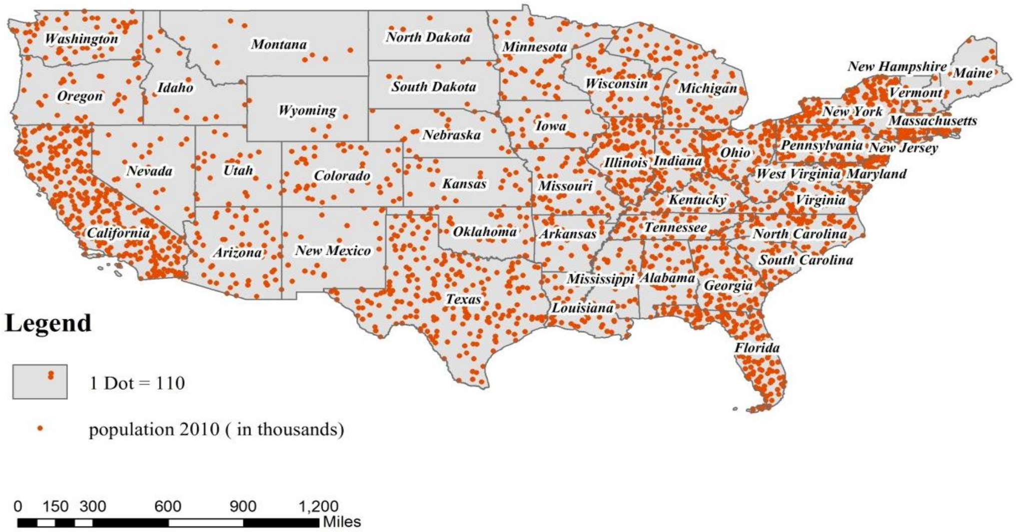
From foregoing analysis, CO_2 emissions and renewable energy production have a small positive correlation at (.05) in the absence of other factors. But when included and controlled for GDP and population the relationship changes. Conversely, relationships between CO_2 emissions and GDP, and CO_2 emissions and population were all significant ($p = .00$).

These statistical results generally correlated with Maps 1, 2 and 4, where there are almost positive relationship between population, total CO_2 emissions and GDP. This means that more populated States such as California, Texas, Florida, New York, Ohio and Illinois had more CO_2 emissions and higher GDP. On the other hand, few states such as Washington, Oregon, Idaho had relatively high renewable energy production considering their population, CO_2 emissions and GDP (Map 3). As shown in Map 5, there was no positive relationship between renewable energy production and CO_2 emissions. This not necessarily mean that if one state has higher production of renewable energy we can expect to see less CO_2 emissions as in the case of the state of California.

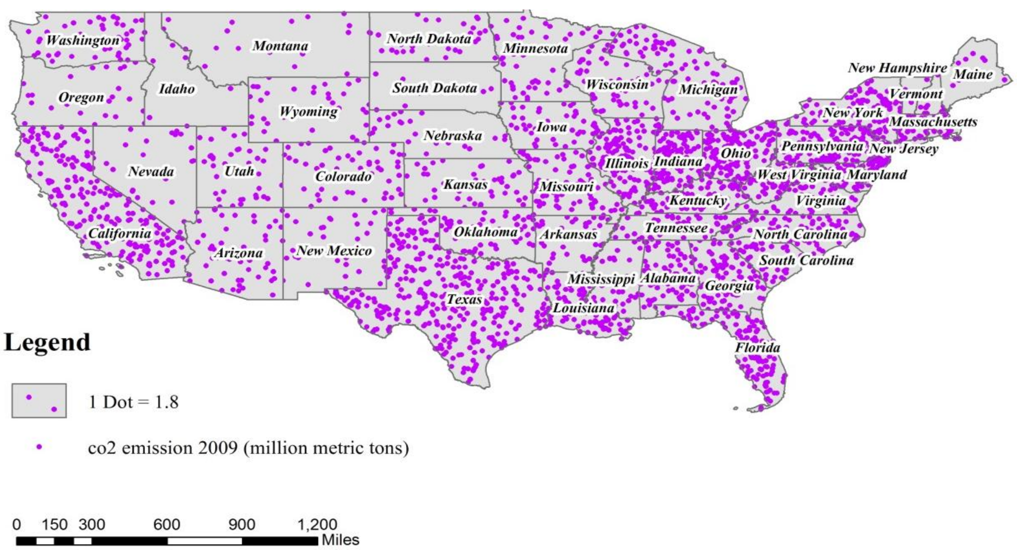
Table 1. All variables' data source: U.S. census bureau

State	Abb.	CO_2 emissions 2009 (million metric tons)	Population 2010 (in thousands)	GDP 2009 (current dollars)	Total renewable energy production 2009 (millions of kilowatt)
Alabama	AL	122.2750382	4779.736	166819	15585.23
Alaska	AK	37.9260201	710.231	45861	1337.28
Arizona	AZ	95.1229428	6392.017	249711	6629.67
Arkansas	AR	62.0693448	2915.918	98795	5778.26
California	CA	375.8438943	37253.956	1847048	53427.70
Colorado	CO	93.7430117	5029.196	250664	5131.70
Connecticut	CT	36.6167558	3574.097	227550	1268.28
Delaware	DE	11.7251820	897.934	60660	125.61
Florida	FL	226.9840713	18801.31	732782	4548.53
Georgia	GA	164.1764433	9687.653	394117	6084.85
Hawaii	HI	18.8564437	1360.301	65428	817.48
Idaho	ID	15.2098298	1567.582	53661	11301.58
Illinois	IL	226.4663779	12830.632	631970	3666.13
Indiana	IN	209.4309716	6483.802	259894	2209.31
Iowa	IA	84.0540013	3046.355	136062	8559.77
Kansas	KS	75.0121289	2853.118	122544	2876.07
Kentucky	KY	145.1356347	4339.367	155789	3681.18
Louisiana	LA	167.1443834	4533.372	205117	3600.31
Maine	ME	18.4684464	1328.361	50039	8149.92
Maryland	MD	71.6186547	5773.552	285116	2439.55
Massacussetts	MA	71.2048193	6547.629	360538	2430.33
Michigan	MI	164.7656787	9883.64	369671	3995.11
Minnesota	MN	93.0815693	5303.925	258499	7545.75
Mississippi	MS	59.8660193	2967.297	94406	1424.28
Missouri	MO	131.9961729	5988.927	237955	2391.50
Montana	MT	32.6652671	989.415	34999	10421.51
Nebraska	NE	46.8982495	1826.341	86411	882.52
Nevada	NV	39.7534401	2700.551	125037	4269.01
New Hampshire	NH	17.3162930	1316.47	59086	2878.43
New Jersey	NJ	111.0414111	8791.894	471946	991.91
New Mexico	NM	58.6807540	2059.179	76871	1851.35
New York	NY	175.6017785	19378.102	1094104	32082.11
North Carolina	NC	134.057883	9535.483	407032	7064.66
North Dakota	ND	51.7686694	672.591	31626	4484.35
Ohio	OH	238.1754828	11536.501	462015	1161.16
Oklahoma	OK	105.1538769	3751.351	142388	6481.85
Oregon	OR	41.2693245	3831.074	167481	37305.94
Pennsylvania	PA	246.4227372	12702.379	546538	6034.79
Rhode Island	RI	11.1650865	1052.567	47470	149.34
South Carolina	SC	80.9368360	4625.364	158786	4079.98
South Dakota	SD	14.7825945	814.18	38255	4859.21
Tennessee	TN	105.3970097	6346.105	243849	11162.43
Texas	TX	605.5016459	25145.561	1146647	22133.13
Utah	UT	65.1749276	2763.885	111301	1321.79
Vermont	VT	6.2814883	625.741	24625	1914.87
Virginia	VA	106.6646313	8001.024	409732	3896.15
Washington	WA	77.5479531	6724.54	331639	77977.38
West Virginia	WV	89.3321268	1852.994	61043	2387.53
Wisconsin	WI	96.7853529	5686.986	239613	3734.28
Wyoming	WY	63.9064380	564	36760	3192.78

Available:[38,39]



Map 1. U.S. population by state 2010



Map 2. U.S. total CO_2 emissions by states 2009

Table 2. Correlation between CO_2 emissions and population

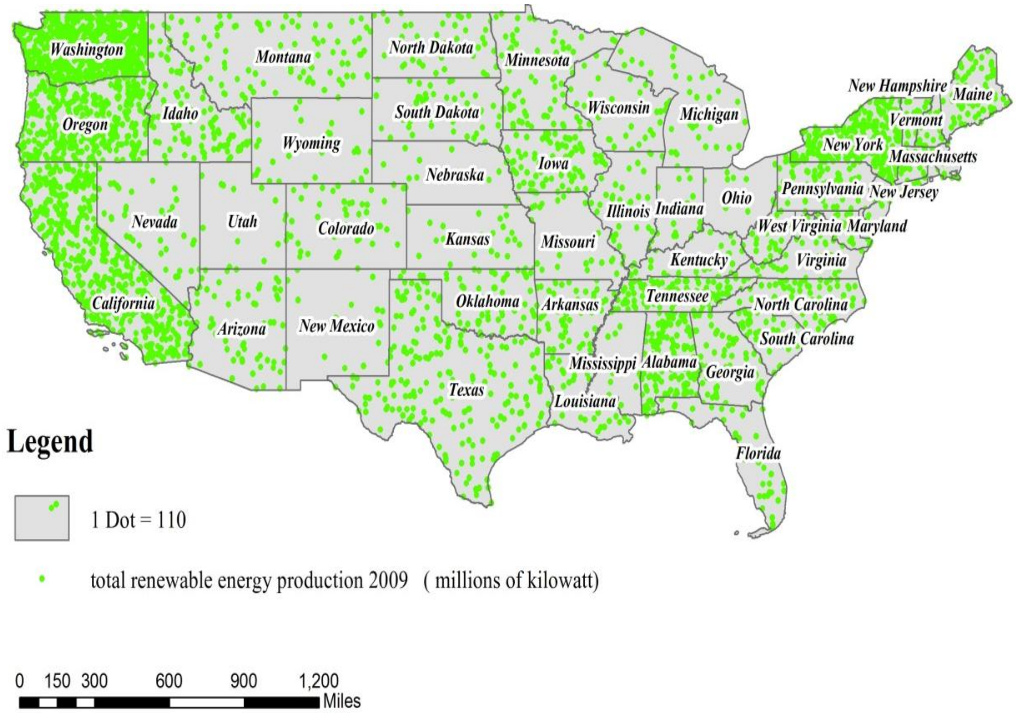
Correlations			
		CO2	**POP**
CO2	Pearson correlation	1	.854**
	Sig. (2-tailed)		.000
	N	50	50
POP	Pearson Correlation	.854**	1
	Sig. (2-tailed)	.000	
	N	50	50

***. Correlation is significant at the 0.01 level (2-tailed)*

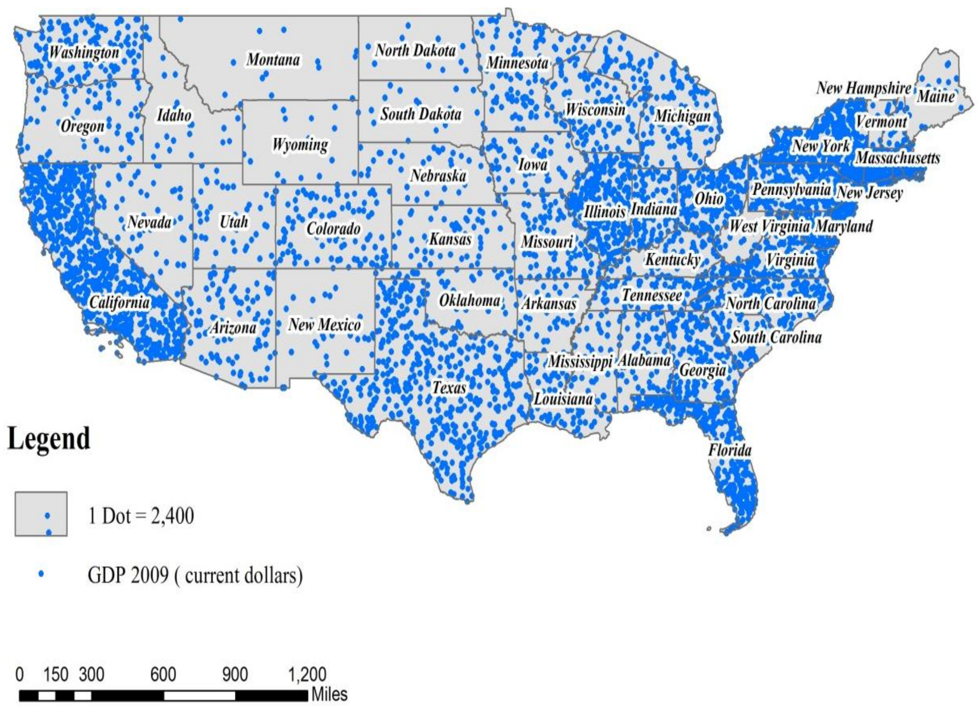
Table 3. Correlation between CO_2 emissions and GDP

Correlations			
		CO2	**GDP**
CO2	Pearson correlation	1	.810**
	Sig. (2-tailed)		.000
	N	50	50
GDP	Pearson correlation	.810**	1
	Sig. (2-tailed)	.000	
	N	50	50

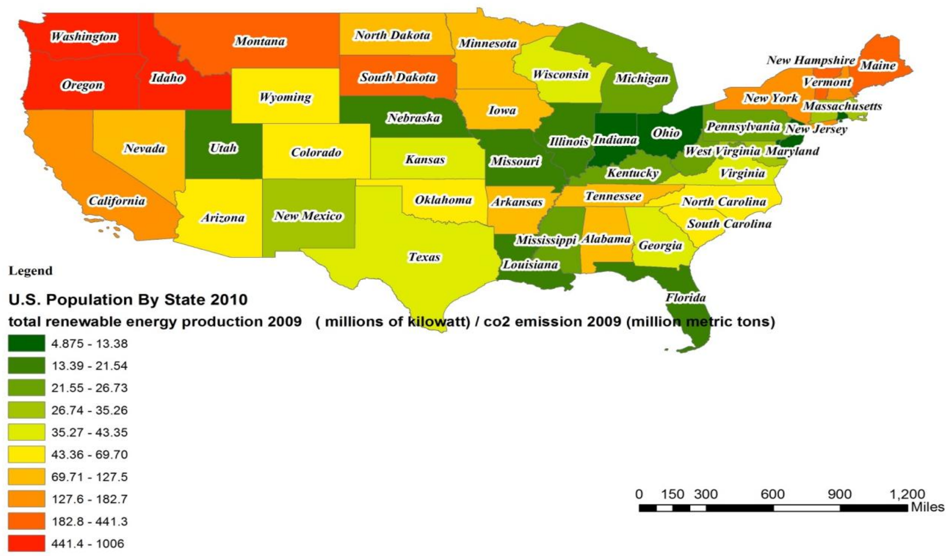
***. Correlation is significant at the 0.01 level (2-tailed)*



Map 3. U.S. total renewable energy production 2009



Map 4. U.S. gross domestic production (GDP) 2009



Map 5. U.S. total renewable energy production / CO_2 emissions 2009

Table 4. Correlation between CO_2 emissions and renewable energy

Correlations			
		CO2	Renergy
CO2	Pearson correlation	1	.282*
	Sig. (2-tailed)		.047
	N	50	50
Renergy	Pearson correlation	.282*	1
	Sig. (2-tailed)	.047	
	N	50	50

**. Correlation is significant at the 0.05 level (2-tailed)*

Table 5. Correlation between CO_2 emissions and renewable energy (Controlling GDP and population)

Correlations				
Control variables			CO2	Renergy
POP & GDP	CO2	Correlation	1.000	-.175
		Significance (2-tailed)	.	.234
		df	0	46
	Renergy	Correlation	-.175	1.000
		Significance (2-tailed)	.234	.
		df	46	0

4. CONCLUSION

The effect of renewable energy production on CO_2 emissions has been the focus of this study. The main findings of the study were as follows:

- Pearson Correlations result between renewable energy production and CO_2 emissions was found to be statistically insignificant. The resulting coefficient is (r = -.18). Conversely, correlations between CO_2 emissions and GDP, and CO_2 emissions and population were all statistically significant (p = .00) with resulting coefficients of (r = .81) and (r = .85) respectively.

These findings means, the more populated the state is the more CO_2 emissions expected; also the higher GDP results and the higher CO_2 emissions are. However, this study could not find any specific pattern between renewable energy and CO_2 emissions. Map 5 shows the proportion of renewable energy production and CO_2 emissions. States such as Washington, Idaho and Oregon have extremely high renewable energy production in comparison with their CO_2 emissions. It follows that there is no positive relationship between CO_2 emissions and renewable energy production in this study. Also, the study could not conclude that if one state has higher production of renewable energy, it follows that there will be less CO_2 emissions, as this for example in the State of California.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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