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The Paradoxical Relationship between Renewable Energy and Economic Growth:

A Cross-National Panel Study, 1990-2013

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Abstract

This cross-national study employs a time-series cross-sectional Prais-Winsten regression model with panel-corrected standard errors to examine the relationship between renewable energy consumption and economic growth, and its impact on total carbon dioxide emissions and carbon dioxide emissions per unit of GDP. Findings indicate that renewable energy consumption has its largest negative effect on total carbon emissions and carbon emissions per unit of GDP in low-income countries. Contrary to conventional wisdom, renewable energy has little influence on total carbon dioxide emissions or carbon dioxide emissions per unit of GDP at high levels of GDP per capita. The findings of this study indicate the presence of a "renewable energy paradox," where economic growth becomes increasingly coupled with carbon emissions at high levels of renewable energy, and the negative effect of economic growth on carbon emissions per unit of GDP lessens as renewable energy increases. These findings suggest that public policy should be directed at deploying renewable energy in developing countries, while focusing on non-or-de-growth strategies accompanied with renewable energy in developed nations.

Keywords: Climate Change; Economic Growth; Renewable Energy Consumption; Renewable Energy Paradox; World Economic System

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Driven primarily by anthropogenic causes, the concentration of carbon dioxide (CO_2) in the atmosphere is at levels not observed for at least the past 800,000 years, if not longer (IPCC 2014a: 4). The concentration of greenhouse gases (GHG), particularly CO_2, will continue to alter the climate system, placing a disproportionate amount of stress on the poor and marginalized (IPCC 2014a:13). Fossil fuel combustion and industrial production are the largest contributors, leading many analysts to place a prodigious emphasis on decarbonizing the electricity and energy sector (IPCC 2014:28; Obama 2017; World Bank 2010:14). The ecological contradictions of fossil fuel use and production processes have been closely tied to a global, capitalist system that is based on exponential growth and profit accumulation (Foster, Clark, and York 2010). However, many policymakers and institutions have been reluctant to acknowledge or address the underpinnings and social relations of the macro-economic system on national and cross-national levels (see Obama 2017; OECD, World Bank, and United Nations 2012). In some quarters, promoting the deployment of renewable energy sources is a key strategy to mitigate carbon emissions (IPCC 2014b). However, scant attention has been given to macro-economic investigation of renewable energy and its relationship to various processes within the global economic system.

Myriad studies—including contributions in this issue of *JWSR*—have demonstrated the presence of asymmetric power relations and inequalities between countries, their position in the world system, and resulting environmental outcomes (Bunker 1984; Rice 2007; Roberts and Parks 2007; Jorgenson and Clark 2012; Jorgenson and Dietz 2015; Jorgenson 2016). Within this framework, this study investigates how the effect of renewable energy consumption on carbon emissions varies by country position within the world economic system. More specifically, this cross-national study examines the relationship between renewable energy consumption and economic growth, and its impact on total CO_2 emissions and carbon efficiency (CO_2 per unit of GDP).

Background

A host of international institutions (OECD 2011; World Bank 1992; World Bank 2010) and scholars (Lovins and Lovins 2000; Mol 2002) have argued, directly or indirectly, that a "green" capitalism or "green" growth is possible and sustainable. Proponents of the green growth paradigm argue that a decoupling between the environment and economic growth can occur, i.e., the economy can be transformed so economic growth lessens its negative impact on the environment.[1]

[1] There are two types of decoupling; relative and absolute. Relative decoupling occurs when the negative impact of economic growth on an environmental indicator becomes less intense but still results in environmental degradation. Absolute decoupling would occur if economic growth had no effect on the environmental indicator or actually improved environmental conditions (OECD 2002).

These arguments arise from two related theories. The ecological modernization theory posits that the economy and environment can decouple from one another through a transformation of ideas and processes that incorporate ecological considerations into the economy and social institutions (Mol 2002:93).[2] Similarly, the Environmental Kuznets Curve (EKC) school proclaims that even though economic growth may initially cause environmental degradation, it will eventually lead to cleaner production processes and sustainable practices (Grossman and Krueger 1995:370). In contrast, scholars working within theoretical schools such as the treadmill of production and metabolic rift theory assert that economic growth and improvements in global environmental conditions are incompatible goals (Foster 1999; Gould, Pellow, and Schnaiberg 2004). For example, the treadmill of production posits that increasing capital investments lead to increasing rates of resource extraction (Gould, Pellow, and Schaniberg 2004:297). Because the global economic system is built on profit accumulation and increasing production, efficiency improvements and technological advancements often lead to greater resource use and environmental degradation, i.e., the Jevons Paradox (Foster, Clark, and York 2010:179). Similarly, utilizing metabolic rift theory, Clark and Foster (2009) argue that the ever-expanding processes of capital accumulation creates a "rift" between human and natural systems, leading to social and environmental inequalities and contradictions (314).

Regardless of the evidence, global environmental policy has been closely aligned with the ecological modernization and EKC schools of thought. This is not surprising given these theories are less critical of the unequal power relations that exist in the current world economic system. Thus, the response to climate change has primarily focused on transforming the energy sector and promoting carbon efficiency. A common, but largely hidden assumption among policy makers and governmental bodies, is that fossil fuels will be displaced by merely increasing renewable energy production and consumption (York 2012). For example, 29 U.S. states and a number of countries have adopted Renewable Portfolio Standards (RPS) or similar mechanisms (National Conference of State Legislators 2016). These standards often set a future date by which a certain percentage of energy is to come from renewables, but they do not address the use of fossil fuels, implicitly assuming renewable energy will displace them. However, as York (2012) observed, renewable energy has only a modest effect in supplanting fossil fuels. Therefore, simply establishing percentage targets are likely to be an ineffective strategy for mitigating carbon emissions, especially without simultaneously reducing fossil fuel use.

Several previous studies have examined the relationships between the economy, carbon dioxide emissions, and renewable energy. Ben Aissa et al. (2014) found that renewable energy

[2] See Ewing (2017) and Salleh (2012) for critiques of "green capitalism" from a world-systems perspective. Ewing (2017) specifically critiques ecological modernization theory and outlines the salient role that world-systems research should play in environmental sociology.

consumption and trade openness had a positive, long run impact on GDP in their sample of 11 African countries. However, other studies have shown that economic growth is a main contributor of carbon dioxide emissions (Dietz, Rosa, and York 2007; Jorgenson, and Clark 2012; Rosa, York, and, Dietz 2004), suggesting that the negative effect of reneawble energy on carbon dioxide emissions may be offset by interactions with other economic processes. Assessing the relationship between GDP and renewable energy consumption, Apergis and Payne (2010) observed a bidirectional, causal relationship between the two in a panel study of OECD countries. Shafiei and Salim (2014), also examining OECD countries, found that renewable energy consumption negatively affected carbon dioxide emissions. These studies suggest that although renewable energy could decrease carbon dioxide emissions, the effect may be mitigated by renewable energy's positive feedback on economic growth.

A host of sociological studies have also examined economic/environmental decoupling across various ranges of time, space, and environmental indicators. Using per capita ecological footprints as their dependent variable, Jorgenson and Clark (2011) found that economic growth became more resource intensive over time for both developed and less-developed countries. Jorgenson, Clark, and Giedraitis (2012) explored the relationship between economic growth and carbon dioxide emissions in Central and Eastern Europe. They used three measures of CO_2 emissions (total carbon emissions, carbon emissions per capita, and carbon emissions per unit of GDP) and found an intensification occurred between each carbon measure and economic growth from 1992-2005 (Jorgenson, Clark, and Giedraitis 2012). Extending their analysis to the global economy and employing the same three measures of carbon dioxide emissions, Jorgenson and Clark (2012) found that a slight decoupling occurred between economic growth and total carbon emissions for the global economy and for developed countries from 1960-2005 (Jorgenson and Clark 2012: 21). However, they found an intensification occurred between economic growth and carbon emissions per capita on a global scale and for less-developed countries (Jorgenson and Clark 2012: 22). Their results also indicated that a decoupling between economic growth and carbon emissions per GDP occurred in developed countries, but the magnitude of the coefficient was near zero (Jorgenson and Clark 2012: 23). In an assessment of the relationship between the electricity sector and GDP per capita, York and McGee (2017) found that increases in renewable electricity had a larger negative impact on carbon emissions in poorer nations, and that economic growth had a larger positive impact on emissions in countries with a high degree of renewable electricity.

With the exception of York and McGee (2017), the aforementioned economic/environmental decoupling studies did not incorporate any measure of renewable energy into their models, which suggests that further investigation into the linkage between renewable energy, economic growth and carbon emissions is warranted. As renewable energy continues to be deployed, could economic growth become decoupled from carbon emissions? Could adoption of renewable energy in other sectors besides electricity (e.g., transportation, industry, residential, commercial) further decoupling? Lastly, how does renewable energy affect carbon efficiency? In the cross-national analyses below, these considerations are tested by classifying countries as to their income position in the world economic system. By examining the effect of renewable energy in this way, the study seeks to provide insights into how renewable energy may impact carbon emissions across disparate economies and within country classification groups (e.g., high income, upper-middle income, lower-middle income, and low income).

Data and Methods

This study uses panel data from 1990-2013. There are 129 total countries used in the analysis. Countries were separated into four groups: high income, upper-middle income, lower-middle, and low income. The four categories were based on the World Bank's (2017a) classification of economies from 2013. The breakdown of countries into these groups allow for meaningful insight into how a country's income position in the world economy may impact how renewable energy influences CO_2 emissions.[3] Table 1 lists the countries by economic position.

The present study relied on an unbalanced panel. Most countries included in the panel had relatively complete data, but there were some missing data for former Soviet nations in the early 1990s. Also, a number of countries did not have full data for industry as a percentage of GDP. Additionally, only countries with a population over 1 million people were included in the analysis. Data were collected for every year from 1990-2013, which totalled 2,832 observations.[4]

Dependent Variables

This study employs two measures of CO_2 emissions as dependent variables: total CO_2 emissions and CO_2 per unit of GDP. Total CO_2 emissions are the most important measure for sustainability purposes, as they are the prime driver of climate change (IPCC 2014a:4). Total CO_2 emissions data were obtained from the World Resource Institute (WRI, CAIT 2017). WRI provides public climate data through their Climate Analysis Indicator Tool (CAIT). CAIT obtains most of their emission data from the International Energy Agency (IEA) (WRI, CAIT n.d.). The CO_2 emissions data excludes emissions from land use changes and forestry.

To measure how renewable energy consumption affects carbon efficiency, CO_2 per unit of GDP were also employed. Such an indicator is a common measure of efficiency (Jorgenson and Clark 2012; Roberts, Grimes, and Manale 2003; York, Rosa, and Dietz 2009). To obtain CO_2 per

[3] Though classifying countries by GDP per capita isn't exactly the same as world-system position, the two are highly correlated (Roberts, Grimes, and Manale 2003)

[4] The descriptive statistics are in Table A1 in the Appendix.

unit of GDP, the carbon emissions data gleaned from WRI was divided by GDP. GDP is measured in constant 2010 U.S. dollars and obtained from the World Bank (2017b).

Table 1. Countries included in the Study by Income Level

High	Upper Middle	Lower Middle	Low
Australia	Albania	Armenia	Bangladesh
Austria	Algeria	Bolivia	Benin
Belgium	Argentina	Cameroon	Burkina Faso
Canada	Azerbaijan	Congo, Rep	Burundi
Chile	Belarus	Egypt	Central African Republic
Croatia	Bosnia and Herzegovina	El Salvador	Chad
Cyprus	Botswana	Georgia	Congo, Dem Rep
Czech Republic	Brazil	Ghana	Ethiopia
Denmark	Bulgaria	Guatemala	The Gambia
Estonia	China	Honduras	Guinea
Finland	Colombia	India	Guinea-Bissau
France	Costa Rica	Indonesia	Kenya
Germany	Cuba	Kyrgyz Republic	Liberia
Greece	Dominican Rep	Lao PDR	Madagascar
Ireland	Ecuador	Mauritania	Malawi
Italy	Gabon	Moldova	Mali
Japan	Hungary	Mongolia	Mozambique
Latvia	Iran	Morocco	Nepal
Lithuania	Jamaica	Myanmar	Rwanda
Netherlands	Jordan	Nicaragua	Sierra Leone
New Zealand	Kazakhstan	Nigeria	Tajikistan
Norway	Lebanon	Pakistan	Tanzania
Poland	Macedonia	Paraguay	Togo
Portugal	Malaysia	Philippines	Uganda
Russia	Mauritius	Senegal	Zimbabwe
Saudi Arabia	Mexico	Sri Lanka	
Singapore	Panama	Sudan	
Slovak Republic	Peru	Swaziland	
Slovenia	Romania	Ukraine	
Spain	Serbia	Uzbekistan	
Sweden	South Africa	Vietnam	
Switzerland	Thailand	Zambia	
South Korea	Tunisia		
Trinidad and Tobago	Turkey		
United Kingdom	Venezuela		
United States			
Uruguay			

Independent Variables

The key drivers of CO_2 emissions included in the model are GDP per capita, total population, urbanization, trade openness (international trade as a percentage of GDP), and the percentage of GDP from industrial processes. These data were obtained from the World Bank (2017b). GDP per capita is a measure of economic growth and affluence (Dietz, Rosa, and York 2007; Jorgenson and Clark 2012; Rosa, York, and Dietz 2004). GDP per capita is in constant 2010 U.S. dollars for each country. Urbanization was also controlled for, which has commonly been included in carbon emission models (Jorgenson and Clark 2012; Jorgenson, Rice, and Clark 2010; Lankao, Nychka, and Tribbia 2008; York 2008; York, Rosa, and Dietz 2003). Urbanization was measured as the percentage of people living in urban areas in a particular country. To control for a country's integration into the global economy, international trade (imports and exports) as a percentage of GDP was included. International trade has been demonstrated to have a positive influence on CO_2 emissions (Dietz, Rosa, and York 2010; Frey 2003; Roberts and Park 2007). Another key driver, total population, was included in the model as well (Dietz, Rosa, and York 2007; Jorgenson and Clark 2012; Rosa, York, Dietz 2004; York, Rosa, and Dietz 2003). To capture a holistic measure of the role manufacturing and resource extractive industries play in a country's economy, industry as a percentage of GDP was included in the model. Industry includes the mining, manufacturing, electricity, water, and gas sectors (World Bank 2017c). Lastly, the main variable of concern, the percentage of total final energy consumption from renewable energy, was included to measure the effect that renewables have on CO_2 emissions. This measure includes energy consumption from a variety of renewable sources (hydroelectric, solar, wind, geothermal, biofuels, etc.). Total final energy consumption measures how energy is employed in its end use. It includes not only electricity, but energy use from other sectors including industry, transportation, residential, commercial, and agriculture. Thus, using renewable energy consumption rather than a similar measure like renewable electricity output, provides a holistic measure of energy use across various sectors. All variables were logged to correct for skewness.

Model Estimation Technique

The present study utilized Prais-Winsten regression models with panel-corrected standard errors. Prais-Winsten corrects for first-order serial correlation (Baum 2006:159). Because the study used time-series cross-sectional data, panel corrected standard errors were employed in the analyses. Panel-corrected standard errors are more accurate than the alternative feasible generalized least squares (Beck and Katz 1995:634). Disturbances across panels were assumed to be heteroskedastic and contemporaneously correlated with panel corrected standard errors (Beck and Katz 1995:636). Two models were estimated for the entire sample and separately for high income, upper-middle income, and lower-middle and low income countries, as follows:

Model 1: Total Carbon Emissions or Carbon Emissions per Unit of $\text{GDP}_{it} = \beta_1$ Renewable $\text{Energy}_{it} + \beta_2$ GDP per $\text{capita}_{it} + \beta_3\ \text{Population}_{it} + \beta_4\ \text{Urbanization}_{it} + \beta_5\ \text{Trade}_{it} + \beta_6\ \text{Industry}_{it} + \beta_7$ year $1990_t + \ldots + \beta_{30}$ year $2013_t + u_i + e_{it}$

Model 2: Total Carbon Emissions or Carbon Emissions per Unit of GDP_{it} = β_1 Renewable $Energy_{it}$ + β_2 Renewable $Energy_{it}$ * GDP per $capita_{it}$ + β_3 GDP per $capita_{it}$ + β_4 $Population_{it}$ + β_5 Urban $Population_{it}$ + β_6 $Trade_{it}$ + β_7 $Industry_{it}$ + β_8 year 1990_t + … + β_{31} year 2013_t + u_i + e_{it}

In Model 1, β_1 (% of Renewable Energy) is the coefficient of primary interest. An interaction term (Renewable Energy * GDP per capita) is added to Model 2. This interaction term captures the relationship between the effect of renewable energy and GDP per capita as each variable changes. Subscript *i* indexed each country, and subscript *t* indexed each time-period. The models are considered two-way fixed effects models (Baum 2006:224). Dummy variables were constructed for u_i and w_t. The former controls for time-invariant, unobserved heterogenity within countries, such as geography, and the latter controls for time-invariant, unobserved heterogeneity within each time-period, such as global economic changes that impact all countries (Baum 2006:221). e_{it} was the disturbance term for each country at each time-period. The study sample accounted for 95% of the World's population.[5]

Though the model employed in the study was relatively robust, not all time-variant controls were included. State or local factors and policies that change over time could impact CO_2 emissions, such as regulatory policies or environmental treaties between countries. Controlling for these factors are beyond the scope of this study. However, several studies have demonstrated that military expenditures and size have a positive effect on CO_2 emissions (Clark, Jorgenson, and Kentor 2010; Jorgenson, Clark, and Kentor 2010) Therefore, military expenditures per soldier are controlled for in the sensitivity analysis, but the results remain nearly identical to the findings below.[6]

Results and Discussion

Table 2 reports the results for total CO_2 emissions and their relationship to the share of renewable energy as a percentage of total final energy consumption for the entire sample and subsamples by country types. Model 1 reports the linear effects of renewable energy consumption, GDP per capita, population, urbanization, trade openness, and industry as a percentage of GDP. Model 2 presents the results of the interaction term (Renewable Energy * GDP per capita). As a reminder, the independent and dependent variables were all logged.

[5] This calculation was derived from The World Bank Indicators Database (2017b).

[6] Military expenditures were obtained from the SIPRI Military Expenditure Database (2017), and the total number of armed forces per country were obtained from the World Bank (2017b). Military expenditures are in constant 2014 US$. The sensitivity analysis is available upon request.

Table 2. Unstandardized Coefficients for the Regression of Total Carbon Dioxide Emissions, 1990-2013: PW Regression Model Estimates with PCSE and an AR (1) Correction

	World		**High**		**Upper-Middle**		**Lower-Middle**		**Low**	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
% Renewable Energy of Total Final Energy Consumption	-0.291*** (27.32)	-1.430*** (16.65)	-0.124*** (9.10)	-0.233 (1.09)	-0.281*** (14.20)	-1.478*** (7.56)	-0.602*** (15.92)	-0.253 (0.99)	-2.327*** (23.71)	-11.821*** (10.79)
% Renewable Energy * GDP per capita		0.128*** (12.80)		0.011 (0.52)		0.146*** (6.22)		-0.048 (1.34)		1.404*** (8.67)
GDP per Capita	0.578*** (21.38)	0.175*** (4.01)	0.563*** (8.77)	0.550*** (9.66)	0.538*** (8.86)	0.186* (2.23)	0.310*** (3.86)	0.437*** (3.88)	0.438*** (11.79)	-5.708*** (8.10)
Population	1.504*** (18.13)	1.418*** (20.18)	1.355*** (16.32)	1.381*** (12.93)	1.231*** (9.96)	1.407*** (11.19)	1.369*** (7.86)	1.361*** (8.43)	1.546*** (7.44)	1.470*** (7.77)
% Urban	0.666*** (9.63)	0.458*** (6.23)	0.469* (1.98)	0.460 (1.93)	0.424*** (3.90)	0.160 (1.39)	0.883*** (7.62)	0.969*** (6.94)	0.198 (1.17)	0.449*** (4.08)
Trade Openness	0.055*** (4.41)	0.044*** (3.19)	0.065* (2.38)	0.067* (2.48)	0.022 (0.88)	0.017 (0.69)	0.053*** (3.32)	0.057** (2.68)	0.045 (1.82)	0.044* (2.05)
% Industry	0.077*** (3.54)	0.089*** (4.38)	0.026 (0.37)	0.026 (0.37)	0.029 (0.65)	0.045 (1.13)	0.101** (2.75)	0.099** (2.68)	0.057* (2.53)	0.044 (1.94)
R^2	.981	.982	.994	.994	.984	.985	.964	.966	.938	.953
N	2,832	2,832	799	799	801	801	693	693	539	539
Estimated Coefficients	158	159	66	67	64	65	61	62	54	55

Absolute values of *z*-ratios are in parentheses; unit-specific and period-specific intercepts are unreported.
* $P < .05$
** $P < .01$
*** $P < .001$

The results of Model 1 for the entire sample indicate that all the key drivers of CO_2 emissions were statistically significant. For all country types, total population and GDP per capita were statistically significant. The coefficient for urbanization was statistically significant for the entire sample and all country types excluding low income countries. Furthermore, trade openness was statistically significant for the entire sample and for high income and upper-middle income countries. The industrialization coefficient was also statistically significant for the entire sample and for lower-middle and low income countries, but not for upper-middle and high income countries. These findings suggest there are substantial differences in the organization of production and types of processes that drive CO_2 emissions across country positions in the world economic system.

The main coefficient of interest in Model 1, the percentage of renewable energy as a share of total energy consumption, indicated a negative and statistically significant effect for the entire sample. For the entire globe, the coefficient was -0.291. Thus, holding other factors constant, a 1% increase in the percentage of renewable energy consumption is associated with a 0.291% decrease in CO_2 emissions. Therefore, consuming a larger percentage of renewable energy, relative to all energy sources, does result in a decrease in total carbon emissions, holding other factors constant.

Examining countries by their position in the global economy indicates that renewable energy consumption has a different effect relative to economic position. The largest impact was in low income countries (-2.327), whereas the slope coefficient was -0.602 in lower-middle income countries and -0.281 in upper-middle income countries. Renewable energy consumption had the smallest effect in high income countries (-0.124). These findings suggest that the development level of countries and their position in the world economic system affects the responsiveness of their national carbon emissions to renewable energy.

Model 2 of the results incorporates an interaction term, allowing for a closer examination of the relationship between GDP per capita and renewable energy consumption. The linear coefficients in Model 2 are conditional, indicating these coefficients are the effect when all other variables are at zero (Jaccard, Wan, and Turrisi 1990: 469). The interaction term between two continuous variables (renewable energy * GDP per capita) is to be interpreted as the effect of GDP per capita on CO_2 emissions, given a one percent increase in the percentage of renewable energy (Jaccard, Wan, and Turrisi, 1990: 469). Conversely, the coefficient can also be interpreted as the effect of renewable energy given a one percent increase in GDP per capita.

On the global level, the coefficient was positive (0.128) and statistically significant. Thus, the effects of the two are linked and differ depending on the position of the country in terms of income and the amount of renewable energy they consume. The coefficient indicates that growth in renewable energy consumption in less developed countries reduces CO_2 emissions more than in high income countries. Furthermore, the result indicates that economic growth has a greater effect on emissions in high renewable energy consuming countries than in countries with low levels of renewable energy. York and Mcgee (2017) found a similar relationship between renewable electricity production and carbon emissions per capita.

In regard to the subsamples, the coefficient is zero for high income countries. This result indicates that the effect of both GDP per capita and renewable energy consumption is constant across high income countries, i.e., the slope of each measure does not change as the other variable changes. However, in upper-middle income countries, the coefficient is positive (0.146) and statistically significant. Thus, the slopes of renewable energy and economic growth change relative to the value of the other variable. This result indicates that renewable energy has a greater suppressing effect on carbon emissions in poorer countries in the group (Jordan and Tunisia) than in the wealthier countries in the group (Hungary and Venezuela). For lower-middle income countries, the coefficient for the interaction between GDP per capita and renewable energy consumption is zero, signifying that the effect of both measures is constant across the country group. Lastly, the continuous interaction term for low-income countries is the largest of all country groups (1.404). This finding indicates that increases in renewable energy consumption has its greatest impact on emissions in the least developed countries.

These results by country group are interesting in that they indicate that not only does renewable energy have an unequal affect across developed countries and less developed countries, but the effect also differs within country groups. For example, the slope of GDP per capita and renewable energy consumption remains constant across high income countries even though there is a wide distribution of income in this cohort. The effect is also constant across lower-middle income countries, which is less surprising because most of the countries have a similar GDP per capita, roughly between $1,000 and $3,500. However, the largest unequal effect occurs in the low income group, suggesting that the negative impact of renewable energy on CO_2 emissions is significantly greater for the poorest low income countries compared to the slightly wealthier low income countries.

Table 3. Slope Coefficients of GDP per Capita and Renewable Energy Consumption

Share of Energy Consumption from Renewables	Slope of GDP per Capita	GDP per Capita	Slope of Renewable Energy Consumption
0.29%	0.016 (0.055)	$208	-0.745*** (0.033)
8.33%	0.447*** (0.028)	$976	-0.547*** (0.019)
28.19%	0.603*** (0.023)	$3,585	-0.380*** (0.010)
64.52%	0.709*** (0.023)	$11,322	-0.233*** (0.013)
96.96%	0.762*** (0.024)	$67,829	-0.003 (0.028)

Panel Corrected Standard Errors are in parentheses.

* *P* < .05

** *P* < .01.

*** *P* < .001.

Table 3 presents an alternative way to interpret the continuous interaction between renewable energy and GDP per capita.[7] The table provides the slope coefficients for GDP per capita at the 1st, 25th, 50th, 75th, and 99th percentiles of renewable energy consumption, and the slope coefficients for renewable energy consumption at the 1st, 25th, 50th, 75th, and 99th percentiles of GDP per capita. The slope coefficients indicate that the effect of GDP per capita intensifies as renewable energy consumption increases, and the negative effect of renewable energy consumption lessens as GDP

[7] These slope coefficients were derived using the *Margins* command in STATA.

per capita increases. The GDP per capita slope coefficients suggest that growth becomes increasingly coupled with total CO_2 emissions at high levels of renewable energy consumption. Similarly, renewable energy consumption relatively couples with total carbon emissions at high levels of GDP per capita, i.e., the effect of renewable energy becomes less negative and approaches zero.

Table 4. Nation's Carbon Emissions Expected at 2st, 25th, 50th, 75th, and 99th Percentile Using World Sample

	Average Nation's Carbon Dioxide Emissions at 1st, 25th, 50th, 75th, and 99th Percentiles				
	Share of Energy Consumption from Renewables				
GDP Per Capita	0.29%	8.33%	28.19%	64.52%	96.96%
\$208	111.3 $MtCO_2$	9.1 $MtCO_2$	3.7 $MtCO_2$	2.0 $MtCO_2$	1.5 $MtCO_2$
\$976	114.2 $MtCO_2$	18.2 $MtCO_2$	9.3 $MtCO_2$	5.9 $MtCO_2$	4.7 $MtCO_2$
\$3,585	116.6 $MtCO_2$	32.5 $MtCO_2$	20.5 $MtCO_2$	14.9 $MtCO_2$	12.8 $MtCO_2$
\$11,322	118.8 $MtCO_2$	54.4 $MtCO_2$	40.9 $MtCO_2$	33.8 $MtCO_2$	30.7 $MtCO_2$
\$67,829	122.3 $MtCO_2$	121 $MtCO_2$	120.5 $MtCO_2$	120.2 $MtCO_2$	120.1 $MtCO_2$

Note: Carbon emissions are measured in Million Metric Tons of CO_2. None of the predicted values for \$67,829 are statistically different from each other. The standard errors of each estimate and the pairwise comparisons of estimates are available upon request.

Table 4 presents the expected CO2 emissions of a nation at the 1st, 25th, 50th, 75th, and 99th percentiles for the percentage of renewable energy consumption and GDP per capita.[8] In this sample, the 1st percentile for renewable energy consumption is 0.29%, the 25th is 8.33%, the 50th is 28.19%, the 75th is 64.52%, and the 99th is 96.96%. The 1st percentile for GDP per capita is \$208, the 25th is \$976, the 50th is \$3,585, the 75th is \$12,322, and the 99th is \$67,829. The table is a cross-tabulation in which reading across a row provides the expected value of total carbon emissions for that income level at various renewable energy consumption levels. In contrast, reading down a column provides the expected value for a fixed renewable energy level varying by income. The other variables included in the model are held constant at population averages. The table illustrates that renewable energy has a substantial effect on developing countries, but it does not decouple economic growth from carbon emissions at high levels of GDP per capita. In fact,

[8] These expected values were also calculated using the *Margins* command in STATA. *Margins* calculates the average value of the dependent variable and assumes all the countries in the sample had that specific level of renewable energy consumption or GDP per capita (STATA, n.d.)

none of the expected carbon emission values for a country with a GDP per capita of $67,414 are statistically different from one another, reaffirming the results from Table 3.

Table 5. Unstandardized Coefficients for the Regression of Carbon Dioxide Emissions per unit of GDP, 1990-2013: PW Regression Model Estimates with PCSE and an AR (1) Correction

	World		**High**		**Upper-Middle**		**Lower-Middle**		**Low**	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
% Renewable Energy of Total Final Energy Consumption	-0.291*** (28.32)	-1.432*** (17.27)	-0.123*** (8.95)	-0.228 (1.06)	-0.281*** (14.20)	-1.478*** (7.56)	-0.598*** (15.86)	-0.298 (1.12)	-2.327*** (23.71)	-11.821*** (10.79)
% Renewable Energy * GDP per capita		0.129*** (13.26)		0.010 (0.49)		0.146*** (6.22)		-0.041 (1.11)		1.404*** (8.67)
GDP per Capita	-0.416*** (14.91)	-0.820*** (18.16)	-0.436*** (6.81)	-0.448*** (9.66)	-0.462*** (7.61)	-0.814*** (9.76)	-0.664*** (8.12)	-0.553*** (5.04)	-0.562*** (15.12)	-6.708*** (9.52)
Population	0.521*** (6.86)	0.435*** (6.71)	0.363*** (4.36)	0.388*** (3.62)	0.231 (1.87)	0.407*** (3.24)	0.426** (2.66)	0.417** (2.81)	0.546** (2.63)	0.470* (2.42)
% Urban	0.660*** (10.38)	0.452*** (6.71)	0.470* (1.97)	0.461 (1.92)	0.424*** (3.90)	0.160 (1.39)	0.874*** (6.76)	0.947*** (5.98)	0.198 (1.17)	0.449*** (4.08)
Trade Openness	0.055*** (4.26)	0.044** (3.11)	0.065* (2.38)	0.067* (2.47)	0.022 (0.88)	0.017 (0.69)	0.053*** (3.29)	0.057*** (3.50)	0.045 (1.82)	0.044* (2.05)
% Industry	0.066*** (3.20)	0.077*** (4.08)	0.029 (0.41)	0.028 (0.41)	0.029 (0.65)	0.045 (1.13)	0.068 (1.72)	0.066 (1.11)	0.057* (2.53)	0.044 (1.94)
R^2	.997	.997	.999	.999	.998	.998	.995	.995	.997	.998
N	2,832	2,832	799	799	801	801	693	693	539	539
Estimated Coefficients	158	159	66	67	64	65	61	62	54	55

Absolute values of *z*-ratios are in parentheses; unit-specific and period-specific intercepts are unreported.
* $P < .05$
** $P < .01$
*** $P < .001$

Table 5 reports the results for CO_2 emissions per unit of GDP (carbon efficiency), and their relationship to the share of renewable energy as a percentage of total final energy consumption for the entire sample and subsamples by country types. Several of the measures included (% urban, trade openness, and % industry) have similar coefficients to the results from total carbon dioxide emissions (Table 2). The renewable energy consumption coefficient also remained nearly identical to the results found in Table 2, suggesting that the effect of renewable energy is similar on total CO_2 emissions and CO_2 emissions per unit of GDP. The most significant difference between the results of the two is the effect of GDP per capita. Unlike for total CO_2 emissions, the effect of GDP per capita is negative and statistically significant for carbon efficiency. This finding indicates that economic growth does result in carbon efficiency improvements, which is consistent with previous studies (Jorgenson and Clark 2012; Roberts, Grimes, and Manale 2003).

In Model 2, the interaction term (% renewable energy consumption * GDP per capita) coefficients are nearly indistinguishable from those found for total CO_2 emissions. However, the interpretation of the term changes because the coefficients for GDP per capita are negative. Thus, the negative effect of GDP per capita on CO_2 emissions per unit of GDP trends toward zero as the level of renewable energy consumption increases, i.e., a relative coupling occurs between GDP per capita and total CO_2 emissions per unit of GDP as renewable energy increases. Similar to the results for total CO_2 emissions, these findings indicate that increases in renewable energy consumption in poorer countries leads to larger improvements in carbon efficiency than in high income countries.

The same unequal effects of GDP per capita and renewable energy persist within country groups for carbon emissions per unit of GDP. The slopes of both variables are constant for high income and lower-middle income countries, whereas the slopes change relative to each other in upper-middle and low income countries. In upper-middle and low income countries, the poorest countries in each group gain the greatest improvements in carbon efficiency from increases in renewable energy.

Similar to Table 3 for total CO_2 emissions, Table 6 provides an alternative way to interpret the coefficient slopes for CO_2 emissions per unit of GDP.

Table 6: Slope Coefficients of GDP per Capita and Renewable Energy Consumption

Share of Energy Consumption from Renewables	Slope of GDP per Capita	GDP per Capita	Slope of Renewable Energy Consumption
0.29%	-0.979*** (0.056)	$208	-0.746*** (0.032)
8.33%	-0.547*** (0.030)	$976	-0.547*** (0.018)
28.19%	-0.391*** (0.024)	$3,585	-0.380*** (0.010)
64.52%	-0.284*** (0.024)	$11,322	-0.232*** (0.013)
96.96%	-0.232*** (0.024)	$67,829	-0.002 (0.027)

Panel Corrected Standard Errors are in parentheses.
* $P < .05$
** $P < .01$.
*** $P < .001$.

The slope of GDP per capita trends closer to zero as renewable energy consumption increases, and the slope of renewable energy also trends toward zero as GDP per capita increases. Thus, both variables become relatively coupled with CO_2 per unit of GDP as the other increases.

Presenting the expected carbon efficiencies for countries as was conducted in Table 6 for total CO_2 emissions would be useful for visualization purposes, but the numbers are too small to be expressed in readable form. For a country with a GDP per capita of $208 with 0.29% of their energy coming from renewables, their expected hundred metric tons of CO_2 per unit of GDP would be 0.00004, whereas at 96.96% renewable energy consumption, the same country would increase its efficiency to 0.0000005 hundred metric tons of CO_2 per unit of GDP.[9] Thus, moving from 0.29% to 96.96% renewable energy results in a 98.75% ((0.0000005-0.00004)/0.00004)) increase in carbon efficiency. For a country with a GDP per capita of $67,829 with 0.29% of their energy coming from renewables, their expected hundred metric tons of CO_2 per unit of GDP would be 0.0000001, indicating that wealthier countries are more efficient than low-income countries at the same level of renewable energy. However, this efficiency remains constant at 96.96% renewable energy, indicating no improvement in efficiency for high income countries as renewable energy is deployed. Thus, at high levels of renewable energy, less developed and developed country's carbon efficiencies would converge due to increases in efficiencies in less developed countries and efficiency stagnation in developed countries.

Policy Implications

The results of this study indicate that renewable energy has an asymmetric effect on total CO_2 emissions and carbon efficiency varying by economic position of a country in the global economy. These findings suggest that climate and energy policy should differ depending on the development level of a country. Specifically, developed countries should replace all fossil fuels with renewable energy, but deployment of renewables must be tied to additional non- to de-growth strategies. In contrast, deploying renewable energy, accompanied with low-carbon intensive growth that provides individuals with a sufficient standard of living should be the focus of climate change and development policy in less-developed countries. However, what specific policy options could developed and less-developed countries pursue? The following section offers several policies to consider for both types of countries.

1) Implement high carbon and income taxes. Developed countries need to take the lead on implementing a high carbon tax to mitigate CO_2 emissions. However, there is considerable uncertainty about measuring the social cost of carbon. For example, Ackerman and Stanton (2012) found that the social cost of carbon could be as high as $900/t$CO_2$. In contrast, the Environmental

[9] Million metric tons were converted to hundreds to make the numbers larger and easier to read and comprehend.

Protection Agency (EPA) assumes the social cost of carbon to be between $11 and $105 (EPA 2017). Given the drastic need to curtail carbon dioxide emissions, countries should err on the side of implementing a tax that is too high rather than too low.

Rather than using accrued tax revenue to fund governmental programs in general, the revenue could be distributed back to the public, which is also known as “tax and dividend.” A carbon tax and dividend approach could be a way to attract individuals to the pro-environmental movement by linking economic well-being of the working class and climate change together (Schor 2015: 533). Re-distributing the tax revenue on a need basis could provide individuals with additional income, reduce inequality, and galvanize support for climate change and de-growth policies. Along with carbon taxes, income and investment income taxes (e.g. capital gains) could be significantly increased to curb capital accumulation and conspicuous consumption, simultaneously providing another mechanism to re-distribute income. A substantial re-distribution program could provide citizens, particularly the poor and most marginalized, a basic income that could allow them to reduce their working hours, which could lead to further reductions in carbon dioxide emissions (Knight, Rosa, and Schor 2013). Reducing growth while simultaneously redistributing wealth could tie economic and environmental concerns together, and make the transition to a steady state or de-growth economy easier.

2) Create, subsidize, and provide special privileges to national, regional and local programs and initiatives for new collective forms of production and living. Along with attempts to decarbonize economies and re-distribute incomes, new forms and measures of prosperity and development need to be advanced in developed and less-developed countries alike. New forms of organization will need to be collective in nature. For example, worker-owned cooperatives, or what economist Richard Wolff refers to as worker self-directed enterprises, will need to be an essential aspect of any macro de-growth, steady state, or low carbon growth policy. Wolff (2012) argues that worker self-directed enterprises would place ownership of the workplace at the site of production, i.e., the workers own the means of production, which contrasts with the traditional top-down hierarchy of the private or state capitalist firm (Wolff 2012: 134). If workers live where they work and own and operate the firms in which they work, environmental considerations could increase in production processes. However, this is assumption is contingent upon workers living in close proximity to their workplace, and given the processes of urban sprawl, gentrification and dispossession that is common place in the developed and developing world, new forms of housing and spatial relations will need to be created as well. Creating collective housing programs like housing cooperatives and developing well-designed public transit systems, will lessen the effect that urbanization and growth have on carbon emissions, while concurrently building community and connections between spaces.

3) Supplant GDP as a measure of progress with new indicators that measure well-being, equity, and sustainability. GDP should be replaced by new economic and ecological measures that concentrate on maximizing human development and the preservation of environmental resources. Several alternatives to GDP have been proposed in the past. One example is the Index of Sustainable Economic Welfare (ISEW). As presented in Daly and Cobb (1989: 418-419), the equation is as follows:

> +Household labor + consumer durables + streets and highways + Public expenditures on health and education – expenditures on consumer durables – private expenditures on health and education – private expenditures on advertising – costs of commuting – cost of urbanization – cost of auto accidents – costs of water, air and noise pollution – loss of wetlands – loss of farmland – depletion of non-renewable resources – long term environmental damage + net capital growth + change in net intergenerational position.

Using a measure like ISEW would provide a useful starting point for developing new national accounting systems that addressed both human and environmental well-being and sustainability. Countries could also incorporate a planetary boundaries approach into their national accounting systems (Rockström et al. 2009). This measure would indicate how well a country was living within their environmental "budget," providing a means for countries to track and adjust their economic and environmental policies as needed to meet sustainability goals. For climate change specifically, a "greenhouse gas budget" would need to be created. Such a budget could be developed on multiple scales, from municipally to globally. Budgeting could be a way for countries to globally plan and facilitate climate change policy in cohesion.

4) New forms of currency and finance. New mediums of exchange like time banking have been proposed as alternatives to market-based exchanges. Time banking uses hours as currency, earning "time" as one provides services and expending them to receive services (Dubois, Schor, and Carfagna 2014). Exchange mechanisms like time banks are inherently egalitarian because each person's time is assumed to be equal in value (Dubois, Schor, and Carfagna 2014). Furthermore, the localized nature of time banks can help build local, sustainable economies, keeping production and consumption local (Kallis, Kerschner, and Martinez-Alier 2012).

Substantial changes to the organization of current financial systems can also lead to more equitable and sustainable economies. For example, socializing the financial sector could help smoothen the transition to a de-growth economy. Public banking would shift the financial sector from being profit-driven to public interest oriented. It would help facilitate investment from carbon intensive production and consumption into collective economic activities like recreation and education. Additionally, it could enable development in less-developed countries built on renewable energy deployment and collective forms of living. Given the negative economic and environmental consequences associated with foreign investment dependence and the transnational organization of production (Chase-Dunn 1975; Jorgenson 2006; Jorgenson 2009; Kentor and Grimes 2006), a democratized, public-oriented financial sector would help shift the economic and political power of core countries and corporations to local democratic processes.

Conclusion

Two study limitations should be kept in mind when interpreting the findings presented here. First, the temporal range of the study extends back only to 1990. Thus, the pattern of associations identified here cannot be presumed to exist before that time. Second, this study did not attempt to calculate the effect of individual renewable energies, i.e., the slope coefficients for wind, solar, geothermal, etc. It is possible that solar or wind energies have a different interaction with economic growth than do other energies like biofuels. Future research should examine this possibility. However, most countries will likely have an amalgam of renewable energies going forward.

Overall, this paper makes two significant contributions to the literature: First, the study results suggest the existence of a "renewable energy paradox." Second, the findings indicate that the development level of countries and their position in the world economic system affects the responsiveness of their national carbon emissions to renewable energy. The renewable energy paradox is two-fold. First, though renewable energy is widely perceived to decouple economic growth from carbon emissions, it does the opposite. Economic growth becomes increasingly *coupled* with carbon emissions at high levels of renewable energy, i.e. economic growth has a larger, positive effect on carbon emissions at high levels of renewable energy compared to low levels. Second, the negative effect of economic growth on carbon efficiency diminishes as renewable energy increases. This results in a situation where economic growth has its largest, positive effect on total carbon emissions in high income countries, while simultaneously having its weakest, negative effect on carbon efficiency in these same countries. Thus, climate policy focused primarily on renewable energy deployment may lead to a convergence of carbon efficiencies between less developed and developed countries, but it may also result in a *divergence* of total carbon emissions between these countries.

The second contribution of this paper is that the effect of renewable energy is asymmetric across and within country types, which is likely tied to the paradoxical relationship found between renewable energy and economic growth for several reasons. First, production processes and energy use tend to be dirtier and less efficient in less-developed countries (Jorgenson 2006). Thus, the large negative effect that renewable energy consumption has on carbon emissions, particularly in lower-middle and low income countries, may be due to renewable energy emitting less CO_2 than fossil fuels, but also renewable energy technologies being more eco-efficient and up-to-date compared to the common technologies employed in these countries. There may be less of a negative effect in high income countries because they tend to already be more eco-efficient than less-developed countries, and the potential mitigating effect of renewable energy is neutralized by further increases in affluence. Therefore, the large negative effect of renewable energy may be primarily tied to efficiency increases, but as efficiency diminishes with increases in income, growth outpaces any decrease in carbon emissions made by deploying renewable energy.

This paradox has significant ramifications regarding climate justice. Extensive renewable energy deployment would not significantly impact carbon emissions in high income countries, even though they are historically responsible for the majority of carbon emissions and developed by burning fossil fuels. In contrast, less developed countries who are responsible for an inconsequential amount of emissions, would disproportionately bear the mitigation of carbon emissions. Low income countries would significantly reduce their emissions with renewable energy in a relative sense, whereas a substantial deployment of renewables in high income countries would keep their emission levels seemingly constant if their economies continued to grow; leading to an increase in the inequality of total carbon emissions between developed and less-developed countries.

The findings of this study and the development of the renewable energy paradox contribute to the growing body of economic/environmental decoupling literature. It seems increasingly unlikely that economic growth and affluence will lead to a decoupling between growth and carbon emissions as posited by the ecological modernization and environmental Kuznets curve theories. Furthermore, the results of this study support assertions made by proponents of the treadmill of production that posit that economic growth leads to increases in environmental degradation. Particularly in high income countries, renewable energy appears to have little influence on negating the treadmill. Instead, growth becomes coupled with carbon emissions at high levels of renewable energy. Renewable energy does seem to be able to mitigate emissions associated with growth in less-developed countries. However, Table 4 shows that CO_2 emissions still grow as affluence increases.

The results also indicate that examining the effect of the global organization of production on environmental outcomes from a world-systems or quasi-world systems perspective is a useful tool for investigating the differences between country types in the world economic system. Technologies like renewable energies are often assumed to have the same effect across all economies, but the findings here suggest that their mitigation potential is associated with larger macro-power structures tied to the world system. Overall, this study finds that purely technical solutions will likely be insufficient to appropriately mitigate climate change. A larger restructuring of power relations from the individual firm to the world-system will have to be undertaken, and new forms of prosperity that challenge the axiom of economic growth are critical to overcoming the perpetual environmental degradation associated with global capitalism.

About Author

Ryan Thombs is a Ph.D. student in the Department of Sociology at Boston College. His research interests include political economy, environmental sociology, urban sociology, human ecology, and class analysis.

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Any conflicts of interest are reported in the acknowledge section of the article's text. Otherwise, author has indicated that she has no conflict of interests upon submission of the article to the journal.

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Appendix A

Table A1: Descriptive Statistics for All Countries, High Income, Upper-Middle Income, and Lower-Middle and Low Income Countries

	All *N* **= 3,096**		**High** *N* **= 888**		**Upper- Middle** *N* **= 840**		**Lower-Middle N = 768**		**Low N = 600**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total CO_2	3.02	2.23	4.54	1.62	3.76	1.68	2.60	1.81	0.27	1.33
CO_2 per GDP	-21.57	0.82	-21.85	0.69	-21.17	0.66	-21.28	0.85	-22.10	0.73
GDP per Capita	8.20	1.56	10.13	0.67	8.53	0.51	7.29	0.55	6.13	0.41
Total Population	16.37	1.42	16.27	1.41	16.39	1.50	16.57	1.54	16.24	1.12
Urban Population %	3.88	0.52	4.25	0.37	4.12	0.25	3.73	0.34	3.22	0.47
Trade as % of GDP	4.18	0.61	4.30	0.54	4.23	0.53	4.15	0.82	3.98	0.42
% Industry	3.33	0.38	3.40	0.24	3.50	0.28	3.40	0.32	2.92	0.42
% Renewable Energy	2.94	1.53	1.93	1.65	2.48	1.20	3.46	1.17	4.41	0.19

All variables are logged.