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Renewable energy injustice: The socio-environmental implications of renewable energy consumption

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ABSTRACT

We explore how national income inequality moderates the relationship between renewable energy consumption and CO_2 emissions per capita for a sample of 175 nations from 1990 to 2014. We find that, independent of income inequality and other drivers of emissions, increases in renewable energy consumption reduce emissions. However, when national income inequality is considered, we find that as inequality increases renewable energy consumption is associated with a much larger decrease in emissions. We also find that when fossil fuel energy is controlled for, inequality does not significantly moderate the association between renewable energy and emissions. These results suggest that fossil fuel consumption is the main vector through which inequality moderates the relationship between renewable energy and emissions. Drawing on previous work from energy poverty scholars, we theorize that national inequality influences the way renewables are deployed. Specifically, our findings suggest that renewable energy displaces more fossil fuel energy sources when inequality is increasing, while– conversely– fewer existing fossil fuel energy sources are displaced when inequality is decreasing. In additional analyses, we find that as the top 20 percent of income earners' share of income grows, the association between renewable energy consumption and emissions decreases in magnitude. We conclude by arguing that efforts aimed at increasing renewable energy consumption should adopt policies that ensure the effective displacement of fossil fuels and reduce inequality.

1. Introduction

Alleviating CO_2 emissions is an important part of climate mitigation strategies [1]. Although research has found that increasing the proportion of renewable energy produced in nations decreases CO_2 emissions [2–4], a number of studies have demonstrated that the ability of renewable sources to reduce emissions is contingent on the size of national economies [5,6]. Further, the association between economic development and emissions has been found to vary as national levels of income inequality change [7]. The present study seeks to further understand the mechanisms through which inequality affects climate by assessing how national income inequality changes the relationship between renewable energy consumption and emissions.

There are a number of theoretical arguments that suggest that energy consumption contributes to, and is a product of, social inequality [8–11]. For instance, energy poverty studies, which explore the points at which energy consumption becomes insufficient for populations to meet certain basic needs [12], have found that subsidies and various other incentives for carbon mitigation technologies disproportionately increase the percentage of household income spent on energy by marginalized groups (Boardman 2013, [13–16]). Such findings indicate that carbon mitigation strategies potentially exacerbate issues of injustice. On the other hand, energy poverty scholars have found that renewable energy production can increase access to electricity in impoverished areas, and reduce energy poverty overall [17,18].

Environmental justice scholars have long contended that environmental privilege is a cause of environmental injustice. For instance, it is argued that coveted environmental amenities, such as commodities associated with environmental awareness, are often acquired at the expense of others who are burdened with environmentally tenuous conditions, such as energy poverty and exposure to hazards [19]. The environmental outcomes of renewable energy consumption are largely contingent on the subsidies and policies implemented by national governments, as well as geographic and infrastructural conditions. Such circumstances are indelibly linked to conditions of equality and injustice both within and across nations. As a result, it is likely that the deployment of renewable energy infrastructure has an impact on inequality as it develops in scale. The hypothesis proposed here contends

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that renewable energy consumption works synergistically with income inequality, such that renewable energy consumption reduces emissions more effectively when it occurs in a context of increasing inequality, and reduces emissions to a lesser degree when occurring in a context of decreasing inequality. Our hypothesis is supported by research conducted by energy poverty scholars who have theorized the ways in which renewable energy consumption expands energy poverty [20,21], as well as the ways in which it can serve to alleviate such poverty [17,18,22].

2. Background

Energy is often considered "the cornerstone of economic growth" [23]. The industrialization of nations around the world and the continued growth of the global economy are dependent upon the abundance of natural resources that can be used as energy sources to power machinery, heat homes, and supply billions of individuals with electricity. While widespread energy use has reduced global poverty by increasing the living standards of billions of people, the acquisition and production of energy has also historically contributed to mass displacement and unequal socioeconomic development. Further, the acquisition of lands for energy use continues to disproportionately affect marginalized peoples. For example, in Canada over 12,000 indigenous peoples have been displaced for the expansion of oil tar sands production in Alberta [24]. Likewise, the building of hydroelectric dams is the single largest contributor to annual involuntary displacement [25].

Energy poverty refers to individuals with a lack of access to modern energy services, especially the provision of electricity or cleaner forms of cooking [26].[1] It is estimated that close to four billion people live under energy impoverished conditions [23]. Individuals living in energy poverty exist in a unique intersection of social and environmental injustice. Access to energy is essential for satisfying basic human needs of warmth and sanitation, making energy poverty a social injustice that deprives individuals of basic needs. Individuals living in energy poverty also typically live under environmentally tenuous conditions, such as low-quality housing, making them more vulnerable to environmental harms and less capable of investing in living improvements[2] [27]. Moreover, the inability to access modern fuels in the home forces households to rely on open fires for cooking, which leads to high levels of indoor air pollution. This injustice is compounded by intersections of age and gender as women and children are more likely to be exposed to pollution produced from open flames, particulate matter from stoves, and are more likely to die from such exposure [28]. People living in energy poverty are also more susceptible to price fluctuations in the cost of energy and spend a higher proportion of their incomes on energy consumption. For example, in the UK individuals with poor credit ratings have been routinely put onto pre-payment meters by energy suppliers, where the cost per unit has historically been higher than if paid for by other means [29].

While there have been a multitude of attempts to address issues of energy poverty at the national level in both wealthy and poor nations, this section will emphasize attempts to address energy poverty using renewable energy, as well as the consequences of renewable energy consumption as it relates to energy poverty (for a more comprehensive assessment see [26]). Globally, renewable sources of energy have been invested in as an alternative to fossil fuel sources of energy [30]. The continued use of fossil fuels for electrical power generation poses numerous social, economic, and environmental problems that can be alleviated by transitioning to renewable electricity. Perhaps the most pressing issue derived from continued use of fossil fuels is their contribution to climate change through the emission of CO_2 into the atmosphere. As carbon-neutral sources of electrical power generation, renewables have the potential to mitigate CO_2 emissions by displacing fossil fuels. However, the ability of renewable sources of electricity to displace fossil fuels since the 1960s has been fairly limited [31]. Specifically, while renewables generally reduce fossil fuel consumption, on average throughout most nations, there has not been a unit-to-unit displacement of fossil fuels by renewable sources of energy. This is partly because renewable sources of energy may expand energy consumption rather than displacing fossil fuels. As York notes, "The failure of non-fossil energy sources to displace fossil ones is probably in part attributable to the established energy system where there is a lock-in to using fossil fuels as the base energy source because of their long-standing prevalence and existing infrastructure and to the political and economic power of the fossil-fuel industry" (2012: 442). Further, it has been found that decreasing the carbon intensity of the overall energy supply, which includes increasing the share of energy derived from renewables, is associated with greater energy consumption [32]. While these findings do not suggest that increasing renewable energy consumption inevitably results in increased total energy consumption, they do provide evidence for this potential outcome. Thus, an important question raised by renewable energy expansion is whether renewables effectively supplement existing infrastructure based upon fossil fuel use.

Energy poverty scholars have suggested that many of the mechanisms through which renewable sources of electricity are introduced into electrical grids also affect their ability to alleviate energy poverty. For example, a number of studies have explored the environmental and social implications of using renewable sources of electricity to electrify rural areas in Southeast Asia and sub-Saharan Africa [17,33,18,22,34]. The consensus of these studies is that supplying renewable sources of electricity to rural energy impoverished areas would alleviate poverty and reduce potential increases in fossil fuel consumption.

Alternatively, in countries such as the United States, increasing renewable electricity consumption through the installation of privately funded, and distributed energy generation systems raises rates and bills for customers not financially capable of investing in renewable energy privately, such as low-income households. Oppenheim [13] argues that the use of government incentives, such as subsidies, to induce consumer substitution of fossil fuels for renewables does serve to reduce energy costs for owners of renewable electricity generation systems. However, the additional cost to the utility is often added to the rates paid by all customers who continue to be provided electricity by centralized fossil fuel electricity producers. Put differently, renewable sources of energy may "disrupt the balance of the regulatory compact by shifting consumption, and its associated revenue, from regulated utilities to other unregulated entities without commensurate reduction in utility costs" ([13]: 105). An example of such tradeoffs can be seen in Germany, where the "German Renewable Energy Sources Act" has led the way toward the development of a low-carbon renewable energy-based economy, but has done so at the cost of implementing surcharges to finance the transition, surcharges that disproportionately affect low-income households [35]. In these scenarios, there is clear substitution of fossil fuel energy for renewable energy, but one which comes at the cost of increased inequality. In such cases, we note that inequality manifests itself in the form of energy poverty by increasing the percentage of individual/household income spent on basic needs, such as heating, cooking, and refrigeration.

3. Modeling approach

Based on the research discussed above, we hypothesize that

[1] Similar to energy poverty, fuel poverty can be defined as the inability of households to ensure adequate heating in living spaces [50]. In this study, the term energy poverty is used synonymously with the term fuel poverty (see [50,21]). Thus, it might be noted that while referring to energy poverty we also cite studies that engage with the term fuel poverty. The term energy poverty often captures the broader inequities associated with lack of energy services, particularly for individuals living in the global south. As a result, we elect to use the term energy poverty but acknowledge its similarity to the term fuel poverty.

[2] This claim is not intended to suggest that all individuals living in energy poverty live under environmentally tenuous conditions.

renewable energy consumption and income inequality are interconnected, such that inequality moderates the association between renewable energy consumption and emissions. Across our data on income inequality, there are almost an equal number of nation-years where inequality increases and decreases (see Appendix Table A3), as a result, we identify two outcomes that correspond with the findings of energy poverty scholars (discussed above). Specifically, we hypothesize that as inequality increases within nations, renewable energy consumption is more likely to displace fossil fuels through economic incentives that consequently increase the energy burdens of those living in energy poverty. We expect that in nations where inequality is increasing there will be a stronger negative correlation between renewable energy consumption and emissions. These results would be consistent with the findings of Oppenheim [13] as well as Bouzarovski and Tirado [35]. Since our modeling approach assumes a symmetrical association between all of our variables[3] (see [36,37]), the association of decreases in inequality should be understood as the inverse of the association of increases in inequality. Following this logic, we expand our hypothesis to note that as inequality decreases, the association between renewable energy and emissions becomes gradually smaller. We hypothesize that this is (at least in part) because renewable energy that is associated with reduced inequality is being used to expand overall access to energy in order to alleviate poverty. This hypothesis is in line with the findings of energy poverty scholars (see [17,33,18,22,34]), who have found that renewable energy can be used to electrify impoverished areas. To be clear, our model does not directly measure energy poverty as we are not measuring people living in energy poverty; instead, we explore energy poverty as a potential explanation for the relationship between income inequality and renewable energy use.

The logic of our modeling approach assesses the extent to which renewable energy consumption and income inequality correlate to emissions. We subsequently assess how it is that these factors of energy systems affect each other's association to emissions. Our modeling technique is in line with previous research that has explored used interaction effects to explore decoupling of socioeconomic factors, such as economic growth, and emissions[4] [6,7]. Similar to these studies, we control for factors that are known to be associated with emissions, such as GDP per capita, age structure of the population, and urbanization (see [38,39]), and assess the degree to which particular covariates moderate each other's association to emissions by analyzing the magnitude and statistical significance of their interactions. Assuming that inequality was not a factor in the association between renewable energy consumption and emissions, and vice versa, our model would indicate that the interaction of renewable energy consumption and inequality is not significantly different from zero. However, if we find that the interaction of renewable energy consumption and inequality is significantly different from zero, then our model indicates that the correlation of one variable to emissions is moderated by the other variable.

4. Data and methods

To address our hypothesis, we constructed fixed-effects panel regression models with robust standard errors that account for clustering in 174 nations from 1990 to 2014 using the nation as the unit of analysis, and including dummy variables for each year to control for general period effects. This approach controls for any effects that are constant over the span of time examined for each nation, such as geographical and geological characteristics, and any effects that are constant across nations for a given point in time, such as international energy prices. All reports of statistical significance or non-significance are based on an α level of .05 with a two-tailed test.

All variables included in the models, with the exception of the Gini coefficient for income inequality, are from the World Bank's World Bank (2018) World Development Indicators. The dependent variable in all of our models is national CO_2 emissions (metric tons) per capita from the burning of fossil fuels and the manufacture of cement.

The data for national-level Gini coefficient measures income inequality from household disposable income (after tax and after transfer), using a range of 0 (equal distribution of wealth across a population) to 100 (one person having all the wealth across a population). This data was taken from Solt's [40] SWIID database, which uses a custom missing-data multiple-imputation algorithm to standardize observations collected from the United Nations University's World Income Inequality Database (version 2.0c), the Organisation for Economic Cooperation and Development Income Distribution Database, the Socioeconomic Database for Latin America and the Caribbean generated by the Center for Distributive, Labor and Social Studies and the World Bank, Eurostat, the World Bank's PovcalNet, the United Nations Economic Commission for Latin America and the Caribbean, the World Top Incomes Database, national statistical offices around the world, and many other sources.

The data for income share held by the lowest and highest 20 percent of income earners reflect the share of income or consumption accruing to a portion of the population which is ranked by income or consumption levels. The data derive from nationally representative household surveys. The national survey data are used to directly calculate the income or consumption shares by quintile. The data are also adjusted for household size.

We use five control variables in our models: percent urban population, percent population age 15–64, GDP per capita (in 2010 constant US dollars), total energy consumption per capita (kg of oil equivalent), and percent of energy consumption from fossil fuel sources. Our control variables are intended to account for the annual variation in the percentage of individuals residing in urban areas, the annual variation in the percentage of individuals that are of productive age, annual changes of the size of national economies relative to population, annual changes in total energy use per person, and annual changes in the proportion of energy consumption from sources that contribute directly to CO_2 emissions– such as oil, coal, and natural gas. The independent variable percent renewable energy consumption measures the share of renewable energy in total final energy consumption. Sources of renewable energy include hydroelectric (the largest share of renewables), wind, and solar. Descriptive statistics for all of our variables can be found in Table 1.

All variables are in natural log form (except period dummy variables). Thus, the regression models estimate elasticity coefficients, where the coefficient for an independent variable is the estimated net percentage change in the dependent variable associated with a 1 percent increase in the independent variable. Since the data for percent renewable energy consumption includes 0 s and the natural log of 0 is undefined, we changed all of our 0 s to .01 before logging the variable. We also performed a number of sensitivity test on this variable to make sure that such a change does not bias our results. In additional models that are not shown here we left the 0 s as undefined and our results stayed substantively the same. Additionally, we added 1 to all 0 s and the results also stayed substantively the same. As a result, we believe the findings displayed here are robust and not influenced by our handling of 0 s.

In additional models not displayed below, we limited the number of nations to high income nations, upper-middle income nations, lower-middle income nations, and lower income nations in four separate models. We also limited our analysis to developed and less developed nations. In each of these models, the effect of the interaction of percent renewable energy consumption and income inequality was not

[3] We tested for the existence of an asymmetrical association in our models and found that the association between our main indicator variables and emissions are symmetrical.

[4] It should be noted that the analytical approach to decoupling we draw upon is one of many approaches, which includes the Environmental Kuznets Curve (see Dinda, [56], [51,52]) and others (see [53–55])

Table 1
Descriptive Statistics (N = 2803).

	Mean	SD	Median	Min.	Max.
Renewable Energy Consumption	29.03	27.07	20.07	.00	97.88
Gini Coefficient	38.00	8.62	37.70	19.00	60.50
GDP per capita (constant 2010 US$)	14026.53	18693.17	5262.10	182.71	111968.40
Population ages 15-64 (% of total)	62.94	6.24	64.72	45.91	85.87
Urban Population (% of total)	59.33	21.55	61.03	8.53	100.00
Energy use (kg of oil equivalent per capita)	2178.62	2412.10	1368.53	9.58	21959.44
Fossil fuel energy consumption (% of total)	65.69	28.67	74.53	.00	100.00
Top 20% of income earners share of income (% of total)	44.55	10.75	42.90	.00	71.00
Bottom 20 % of income earners share of income (% of total)	6.26	2.45	6.60	.00	13.40

significantly different from 0, indicating that our finding is not specific to any subset of nations or that the sampled subsets are too small to have predictive power. We also estimated models not displayed below that account for a potential non-linear association between GDP per capita and emissions as well as urbanization and emissions. In each of these models, the quadratic term was not found to be significantly different from 0. Finally, we also estimated models that assess the effect of foreign direct investment as well as exports as a percentage of GDP (each of these variables were obtained from the World Bank) on emissions. In these models, our results did not significantly change, however, due to the limited data available for each of these variables, we did not include them in the models displayed below.[5]

5. Results

Results from our analysis can be found in Table 2. We estimated the variance inflation factor (VIF) of each of our independent variables and found no issue of multicollinearity. Specifically, non of our VIFs are higher than 10, which means that the estimates in each of our models are not meaningfully affected by a collinear relationship between our independent variables [41,42]. Model 1 shows that our population variables (age structure and urbanization) are not significantly correlated with emissions. While this conflicts with previous findings [38], it may be a result of the limited time frame of our analysis (1990–2014). Model 1 also shows that GDP per capita is positively associated with emissions, which is consistent with previous research. Finally, in Model 1 renewable energy consumption and Gini are found to be negatively correlated with emissions. While the finding for renewable energy consumption is consistent with previous research [2–4,6], we note that our finding for Gini conflicts with results from previous studies [43,44] (albeit that our modeling techniques are different from those put forward in these studies). In light of recent research (see [45]) and additional analyses and sensitivity tests performed here, we caution readers against placing too much weight on the Gini estimate put forth in model 1. Further, we are not confident in the robustness of this particular finding, as the inclusion of additional control variables (mentioned above) alter the significance of Gini's direct correlation with emission.

Model 2 in Table 2 includes the interaction of renewable energy consumption and Gini, which is found to be negative and significant. This finding suggests that the association between renewable energy consumption and emissions is interconnected with income inequality. In the most direct interpretation this finding indicates that the association between renewable energy consumption and emissions becomes increasingly negative as income inequality grows. Model 3 builds upon Model 2 by exploring the nature of the moderation of the relationship between renewable energy consumption and CO_2 emissions per capita

Table 2
Fixed effect models of the relationship between renewables, Gini coefficient, and emissions.

	Model 1	Model 2	Model 3	Model 4
Renewable energy consumption	−0.163**	0.858	0.453	0.301
	(.060)	(.458)	(.274)	(.313)
Gini coefficient	−0.456*	0.455	0.048	0.010
	(.228)	(.394)	(.235)	(.269)
GDP per capita	0.568***	0.559***	0.338***	0.475***
	(.072)	(.072)	(.081)	(.057)
Age ratio	0.659	0.782	0.143	0.333
	(.405)	(.412)	(.267)	(.333)
Urban population	0.492	0.509	0.757***	0.780***
	(.296)	(.267)	(.203)	(.138)
Total energy use	–	–	0.683***	–
			(.088)	
Renewables*Gini	–	−0.297*	−0.155*	−0.129
		(.128)	(.078)	(.089)
Fossil fuel energy consumption	–	–	–	0.602***
				(.110)
Observations	3,379	3,379	2,803	2,772
R^2	.43	.45	.65	.65

Note: all variables are natural log transformed. The result of this procedure is that the coefficients presented here represent the expected percent change in emissions per capita associated with a 1 percent change in the corresponding covariate. In order to avoid transforming 0 into missing values, all 0 values were converted to .001 prior to transformation. In order to test for robustness, in separate analyses 0 values were converted to .01 and 1 prior to log transformations. In all cases the results remained consistent with those presented here. Alternate models are available upon request.

by income inequality, while also controlling for total energy use. Inclusion of the total energy use control allows us to disentangle the relationship between renewable energy consumption and emissions, and changes in the scale of the relevant energy infrastructure. Taken together, Model 3 findings concerning the direct relationship between energy use and emissions are consistent with previous research which suggests that increases in energy and electricity use tends to drive rates of emissions [6]. Controlling for total energy use in Model 3 does reduce the magnitude of the interaction between renewable energy consumption and income inequality. However, as with Model 2, Model 3 suggests that the interaction between renewable energy consumption and income inequality is negative, and statistically significant. Considering that Model 3 includes a control for total energy use, and that it provides the best estimated model fit of the present analyses, we focus the rest of the discussion of this analysis on Model 3 results. Interpretation of two-way continuous interactions can be complex. As a result, we turn to Fig. 1 and Table 3 in order to facilitate this discussion.

Fig. 1 displays the slope estimates for the association of renewable energy consumption and emissions at various levels of Gini. Such a display demonstrates that when income inequality is higher, the

[5] Alternate models can be found in the Appendix A.

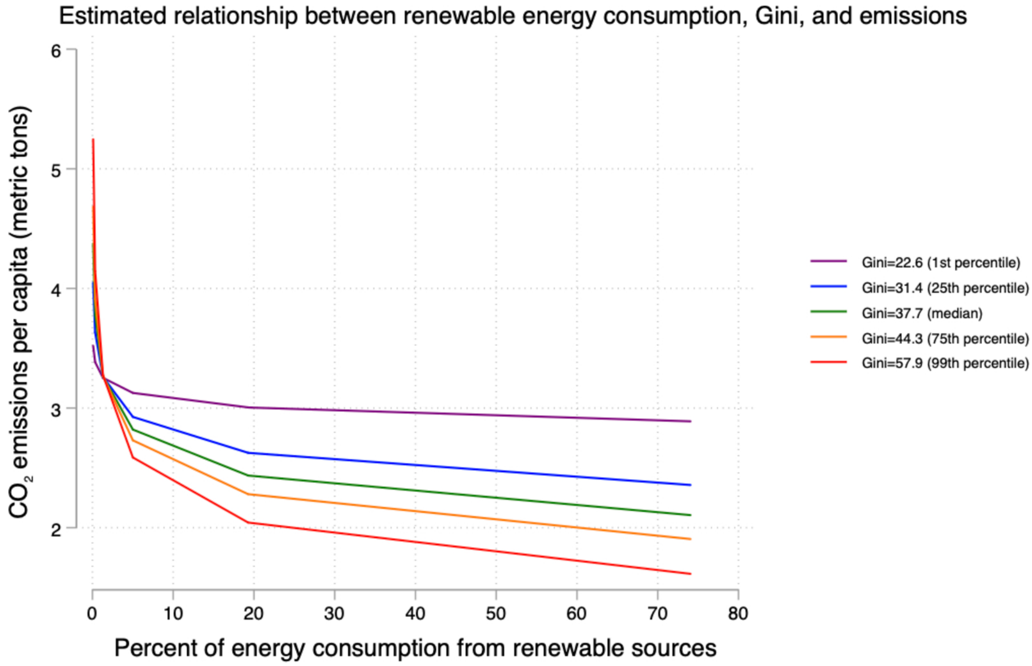

Fig. 1. Estimated relationship between percent renewable energy consumption and emissions per capita at various levels of Gini coefficient held constant.

Table 3
Estimated Table 2, Model 3 slope coefficients for renewable energy consumption and Gini coefficient.

Gini Values	Renewables slope coefficient	Percent renewable Values	Gini slope coefficient
1st Percentile	−0.029	1st Percentile	0.424
(Gini = 22.6)	(0.043)	(0.09%)	(0.383)
25th Percentile	−0.080**	25th Percentile	−0.228
(Gini = 31.4)	(0.031)	(6%)	(0.183)
Median	−0.109***	Median	−0.416*
(Gini = 37.7)	(0.033)	(20.1%)	(0.202)
75th Percentile	−0.134***	75th Percentile	−0.548*
(Gini = 44.3)	(0.039)	(47.1%)	(0.238)
99th Percentile	−0.175***	99th Percentile	−0.656*
(Gini = 57.9)	(0.054)	(94.6%)	(0.276)

$p < .001$***; $p < .01$**; $p < .05$* (two-tailed tests with 0 as null hypothesis); standard errors in parentheses.

relationship between percent of energy consumption from renewable sources and CO_2 emissions per capita is more intensely negative. Table 3 allows for a more in-depth interpretation of this general relationship. While examination of the main effect for renewable energy consumption in Model 3 of Table 2 indicates that there is no significant relationship between renewables and CO_2 emissions, Table 3 indicates that following the 25th percentile of income inequality, the association between percentage of energy consumption from renewables and emissions is increasingly negative, and statistically significant. Thus, as is demonstrated in Table 3, at the 25th percentile of income inequality (Gini = 22.6) the association between energy consumption from renewables and emissions is estimated to be -0.080, while at the 99th percentile of income inequality (Gini = 57.9) the magnitude of the association is notably more negative (-0.175). What these coefficients suggest is that in nations with a Gini coefficient of 31.4, we should expect that increasing the percent of energy consumption from renewable sources by 1 percentage point will be associated with a reduction in CO_2 emissions per capita of .08 percent, but in nations with a Gini coefficient of 57.9 a 1 percent increase in the percentage of energy consumption from renewables will have an associated reduction in emission of .175 percent.

We note that, overall, the findings presented in Fig. 1 and Table 3 suggest that there is a complex relationship between renewable energy consumption and inequality, such that renewables seem to most effectively reduce CO_2 emissions in nations with substantial amounts of income inequality. Based on the above literature, we note that the results presented here may be a function of nations' interest in reducing energy poverty, and forms of inequality more broadly, by using newly implemented renewable infrastructures to expand to populations previously unserved by existing energy infrastructures– while nations less interested in pursuing the reduction of inequalities likely encourage the displacement of fossil fuel energy consumption through the implementation of privately installed, and distributed renewable energy production technologies. In order to begin to explore this possibility, we incorporate the percentage of energy consumption from fossil fuel sources as a control in Model 4 of Table 2. Model 4 indicates that, when percent of energy consumption from fossil fuel sources is included, the interaction between consumption from renewable energy sources and inequality is no longer significant. This broadly suggests that the complex nature of the effect of the interaction between renewables and income inequality is likely indicative of changes in the extent of fossil fuel-based energy consumption.[6] It also suggests that, in turn, fossil fuels are the main vector through which inequality moderates the relationship between renewable energy consumption and CO_2 emissions.

To explore the implications of Model 4 further, we examine trends in income inequality, renewable energy consumption, and fossil fuel consumption, in Namibia and Slovak Republic. We examine trends in these nations because they represent nations with the highest and lowest Gini coefficients across our samples. Fig. 2 illustrates how Gini coefficients have changed over time in both Namibia (the country with the highest Gini coefficient) and Slovakia (the country with the lowest Gini coefficient). Although Namibia as a nation has one of the highest Gini coefficients, from 1990 through 2014 its Gini coefficient decreased. Conversely, although Slovakia has one of the lowest Gini coefficients, from 1990 through 2014 its Gini coefficient increased.

[6] In a separate model, the same relationships were explored while also controlling for total energy use. The results remained consistent with those presented in model 4. These results are available upon request.

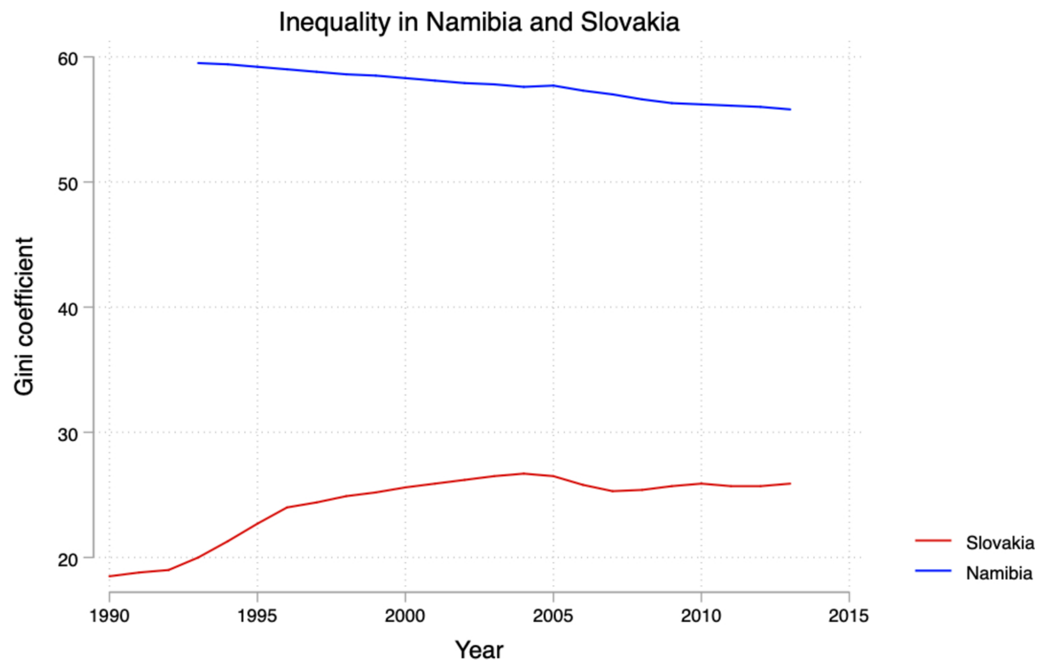

Fig. 2. Change in Gini coefficient in Namibia and Slovakia from 1990-2014.

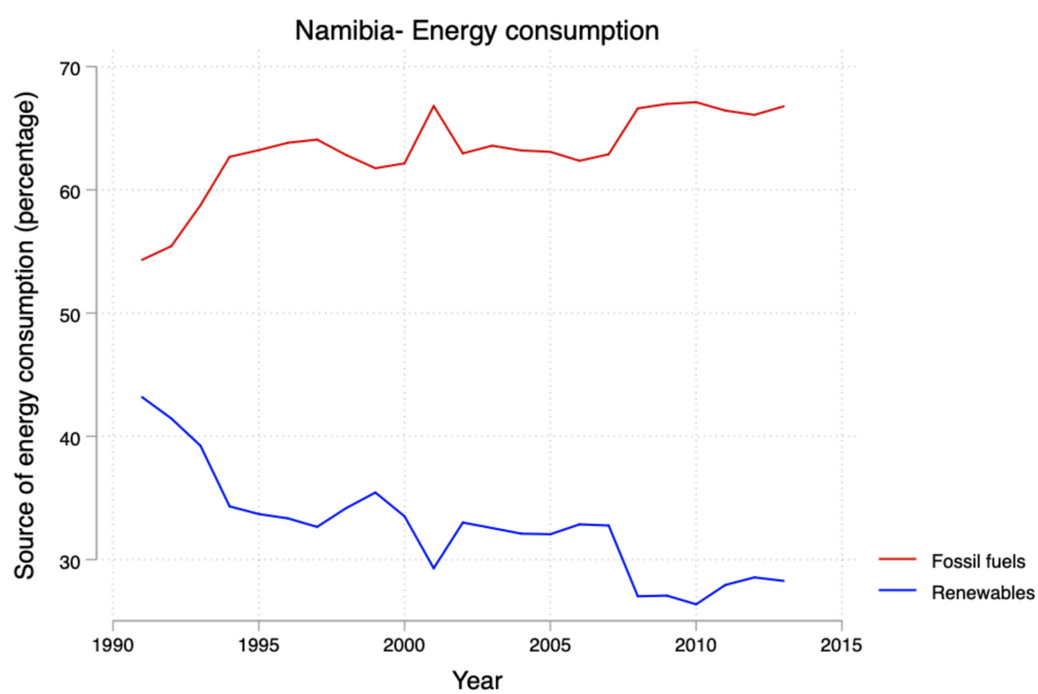

Fig. 3. Change in percent fossil fuel and percent renewable energy consumption in Namibia from 1990-2014.

Figs. 3 and 4 also help to elucidate the implications of Model 4. Fig. 3 demonstrates that in Namibia[7] from 1990 through 2014 the percentage of energy from fossil fuels increased while the percentage of energy from renewable sources decreased, indicating that fossil fuels were displacing renewable sources of energy as income inequality declined. Meanwhile, Fig. 4 demonstrates that in Slovakia[8] from 1990 through 2014 the percentage of energy from fossil fuels decreased while the percentage of energy from renewable sources increased, indicating that renewables displaced fossil fuels as income inequality rose. These figures provide further evidence in support of the claims made by researchers who argue that renewable energy consumption may be indirectly driving energy poverty. Specifically, they demonstrate that even in nations with relatively low inequality, increases in the percentage of energy from renewable sources is reducing the percentage of energy from fossil fuels– while, simultaneously, inequality began to rise. Conversely, these figures show that even in nations with high levels of inequality, which is decreasing over time, renewables are not displacing fossil fuels but, rather, are expanding the overall reach of the nation's energy infrastructure.

[7] In addition to Namibia we also explored South Africa based on a reviewer suggestion and found that South Africa follows the same pattern.

[8] For a robustness check we also explored Germany and found that Germany follows the same pattern.

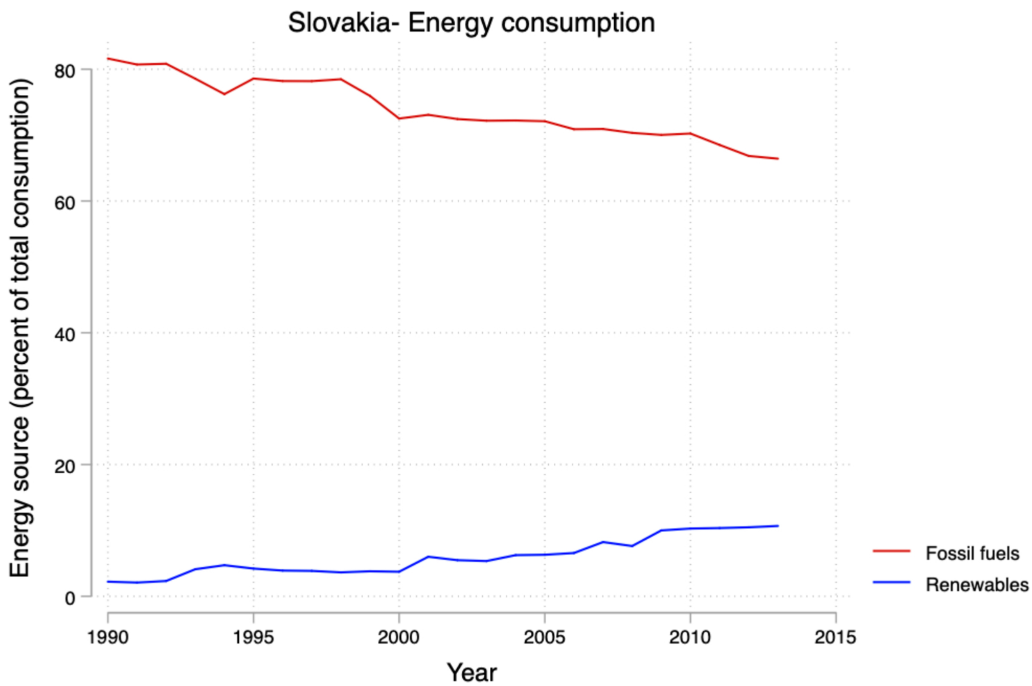

Fig. 4. Change in percent fossil fuel and percent renewable energy consumption in Slovakia from 1990-2014.

Table 4
Fixed effect models of the relationship between renewables, top and bottom twenty percent of income earners share of national income, and emissions.

	Model 1	Model 2	Model 3
Renewable energy consumption	−0.246***	0.530	−0.357***
	(.047)	(.368)	(.076)
Top 20% of income earners share of income	−0.219	0.384	−0.279
	(.186)	(.308)	(.185)
Bottom 20% of income earners share of income	−0.107	−0.129*	−0.322*
	(.066)	(.064)	(.146)
GDP per capita	0.595***	0.616***	0.613***
	(.085)	(.084)	(.084)
Age ratio	0.772*	0.875*	0.838*
	(.374)	(.382)	(.378)
Urban population	0.671	0.649***	0.664***
	(.169)	(.167)	(.168)
Renewables*Top 20%	-	−0.207*	-
		(.093)	
Renewables*Bottom 20%	-	-	0.057
			(.037)
Observations	1,196	1,196	2,803
R^2	.61	.62	.65

Note: all variables are natural log transformed. The result of this procedure is that the coefficients presented here represent the expected percent change in emissions per capita associated with a 1 percent change in the corresponding covariate. In order to avoid transforming 0 into missing values, all 0 values were converted to .001 prior to transformation. In order to test for robustness, in separate analyses 0 values were converted to .01 and 1 prior to log transformations. In all cases the results remained consistent with those presented here. Alternate models are available upon request.

To assess the robustness of our findings, we also explore how specific changes in the top 20 and bottom 20 percent of income earners moderates the relationship between renewable energy and emissions. Findings are presented in Tables 4 and 5, and Fig. 5. As is true of the findings presented in Table 2, findings presented in Table 4 suggest that growth in renewable energy consumption does serve to reduce CO_2 emissions per capita, but the magnitude of the estimated reduction is dependent on the degree of income inequality within the nation being examined. For instance, findings from Model 2 of Table 4, indicate that as the proportion of national income held by the top 20% of income earners grows renewable energy consumption becomes a more effective means of reducing emissions. Examination of change in the coefficient for renewable energy consumption at different levels income share held by the top 20% of earners– which is displayed in Table 5– demonstrates that when the top 20% of earners account for 37.4% of national income a 1% increase in renewable energy consumption is expected to reduce emissions by .205%, while when the top 20% of earners account for 64.9% of national income an identical increase in renewable energy consumption is estimated to reduce emissions by .335%.

Interestingly, results from Model 2 of Table 4 also indicate that, while change in the proportion of national income held by the top 20% of earners does not have a direct effect on emissions until roughly three fourths of all energy consumption is drawn from renewable sources, increasing the share of income held by the bottom 20% of earners appears to reduce emissions regardless of renewable energy consumption status (see Table 5). In order to examine this result further, in Model 3 of Table 4 we interact the share of national income held by the bottom 20% of earners with renewable energy consumption. Findings of Model 3 suggest that, though there is no significant interaction between renewable energy consumption and change in the share of income held by the bottom 20% of earners, increasing the share of income of the bottom 20% of earners has a significant negative effect on CO_2 emissions that is of a notable magnitude. Specifically, we find that growing the share of total energy consumption from renewable sources by 1% is estimated to reduce CO_2 emissions per capita by .357%, while increasing the proportion of national income that is earned by the bottom 20% of earners decreases CO^2 emissions per capita by .322%.

6. Discussion

The findings from the analyses presented above provide support, generally speaking, for the hypotheses presented here. The finding that income inequality serves to moderate the relationship between the percent of energy from renewables and CO_2 emissions confirms the proposition that, on average, income inequality and the implementation and use of energy infrastructures are deeply linked to one another. We argue that this finding has two major implications.

First, the finding that change in income inequality serves to augment the association between renewable energy consumption and

Table 5
Estimated Table 4, Model 2, slope coefficients for renewable energy consumption and Gini coefficient.

Top 20% of earners income share	Renewables slope coefficient	Percent renewable values	Top 20% slope coefficient
1st Percentile	−0.205***	1st Percentile	0.888
(Top 20% share = 34.7%)	(0.053)	(0.09%)	(0.510)
25th Percentile	−0.233***	25th Percentile	0.013
(Top 20% share = 39.7%)	(0.045)	(6%)	(0.197)
Median	−0.255***	Median	−0.238
(Top 20% share = 44.1%)	(0.041)	(20.1%)	(0.180)
75th Percentile	−0.289***	75th Percentile	−0.415*
(Top 20% share = 51.9%)	(0.039)	(47.1%)	(0.238)
99th Percentile	−0.335***	99th Percentile	−0.559*
(Top 20% share = 64.9%)	(0.045)	(94.6%)	(0.247)

$p < .001$***; $p < .01$**; $p < .05$* (two-tailed tests with 0 as null hypothesis); standard errors in parentheses.

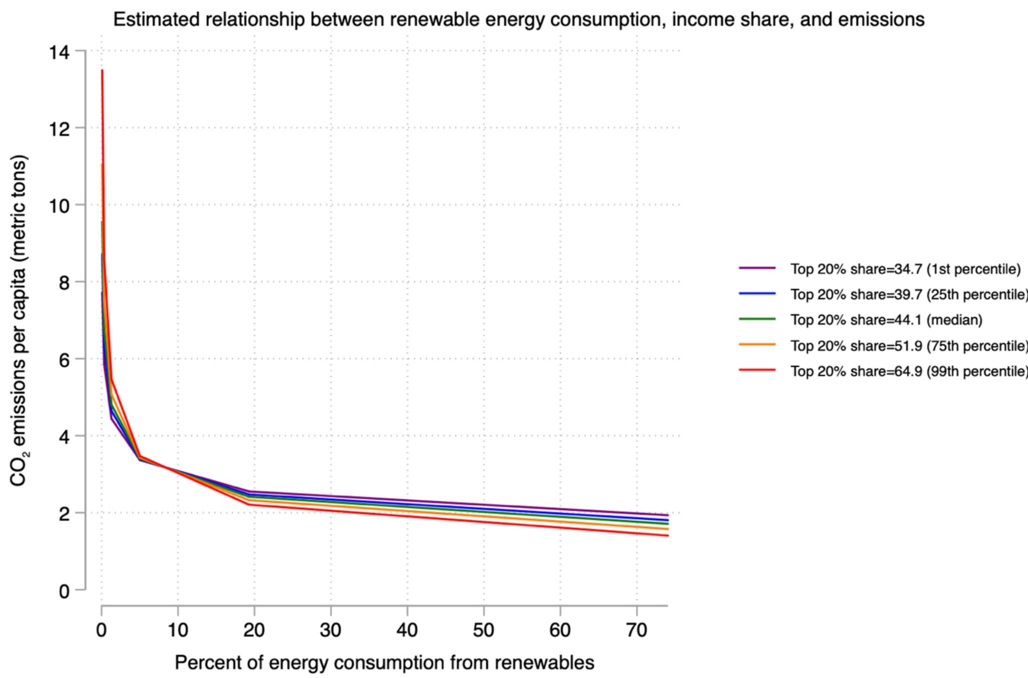

Fig. 5. Estimated relationship between percent renewable energy consumption and emissions per capita at various levels of the top 20% of income earners share of income held constant.

emissions in the ways discussed above suggests that nations which are best addressing income inequality and energy poverty are most likely doing so by utilizing new renewable energy generation systems in order to expand the reach of the nation’s energy infrastructure in total. The result of such an expansion is a reduction in energy poverty, but also a failure to displace established fossil fuel systems with renewables ones. Thus, in such nations, though more energy is provided to a greater number of people, CO_2 emissions from the fossil fuel energy sector continue unabated. Though, it should be noted that in such a scenario we should expect to see a decoupling of total energy use and emissions, since a growing share of kWh will be drawn from renewable sources.

Second, and conversely, the negative interaction between renewable consumption and income inequality, as measured by Gini coefficient, indicates that those nations that are effectively using renewable consumption in order to displace fossil fuel consumption, and thereby reducing higher levels of emissions, are also failing to confront the various sources of income inequality that spring from energy infrastructures at the national level. We argue that in such a situation there is a reliance on, and encouragement of, the installation of dispersed, individual level, renewable energy production systems. Such an approach to the expansion of renewable energy consumption would effectively displace consumption from fossil fuels. However, the individualist strategy employed in such scenarios would also greatly limit the number of potential renewable energy consumers to those financially capable of investing in such a capital-intensive resource. Additionally, reductions in the total number of kWh drawn from fossil fuel sources among those privileged enough to access individually maintained renewable systems could serve to drive up the prices of fossil fuel sourced energy as utility companies seek to recapture losses. Ultimately, such changes may exacerbate previously existing inequalities by leading to those populations who are unable to afford renewable installations paying more per kWh of energy than their wealthier counterparts [13].

Finally, we note that an important part of our hypotheses is that the interaction between income inequality and the percent of energy consumption drawn from renewables, in many ways, acts as a proxy for the extent to which renewable energy infrastructures are displacing fossil fuel infrastructures, or are being used in order to reduce inequalities. The fact that the interaction between inequality and renewables is not statistically different than 0 once fossil fuel energy consumption is controlled for supports these hypotheses, suggesting that– in this case– using renewables to reduce emissions or using them to reduce inequalities may be obverse sides of the same coin. This point is also supported by specific assessments of Namibia and Slovakia. In Namibia, inequality is decreasing, and although renewable energy consumption is relatively high, it has not successfully displaced fossil fuels through the period examined in this study. Nonetheless, rural electrification, which is supported by the state, has successfully installed numerous solar home systems, which reduce inequality and increase Namibia's overall renewable energy consumption. In Slovakia, inequality has increased over the past several decades. However, in Slovakia renewable energy is also successfully reducing fossil fuel consumption. Unlike Namibia, in Slovakia renewable energy consumption is supported by subsidies for solar and wind power operators, and tax exemptions [46], which are aimed at reducing emissions by increasing renewable energy consumption. However, these policies lack an explicit effort to simultaneously reduce poverty through a just transition. The energy and income equity trends in these nations demonstrate the need for a just transition that is aimed at decreasing fossil fuel consumption and reducing income inequality. As Sovacool et al. write "Energy resources ought to be depleted with consideration for savings, community development, and precaution, and we must recognize the equitable distribution of energy services (and costs) among current and future generations, and acknowledge that all people have a right to fairly access energy services" (2017; 47). In the final analysis, what may be indicated by these findings is that without targeted intervention by policy makers, reducing emissions from energy consumption and alleviating energy related inequalities might be elusive, if not impossible.

However, we argue that it is critical to acknowledge that there is nothing inherent in the energy production process that makes the choice between inequality and climate change mitigation necessary or inevitable. Rather, the difficult choice that our findings indicate stems from the fact that energy production, in most nations is distributed unevenly. As a result, energy use can constitute a form of injustice, in that access to energy is, itself, based on wealth accumulation and processes of dispossession. Attempting to correct such an injustice by supplying renewable energy to historically marginalized communities may alleviate poverty and reduce *potential growth* in CO_2 emissions, but it does little to reduce to contributions of energy use to contemporary CO_2 emissions. Moreover, attempting to reduce fossil fuel consumption by financially incentivizing renewable energy use for private consumers and producers alone builds on existing forms of inequality and has unforeseen consequences to those living in energy poverty. Considering this, policy makers should consider implementing policy tools that are aimed at both reducing inequality, and reducing emissions stemming from energy use. Such policies would both incentivize the implementation of renewable energy resources, while also protecting the populations that are most exposed, financially and geographically, to the dangers of energy poverty. Though the causal mechanism behind our findings cannot be confirmed through the analysis at hand, we highlight that our research supports previous arguments regarding the implications of renewable energy use and energy poverty and we draw attention to the importance of considering such relationships.

Conflict of interest

The authors declare no conflict of interest related to this study.

Appendix A

See Fig. A1, Tables A1 and A2.

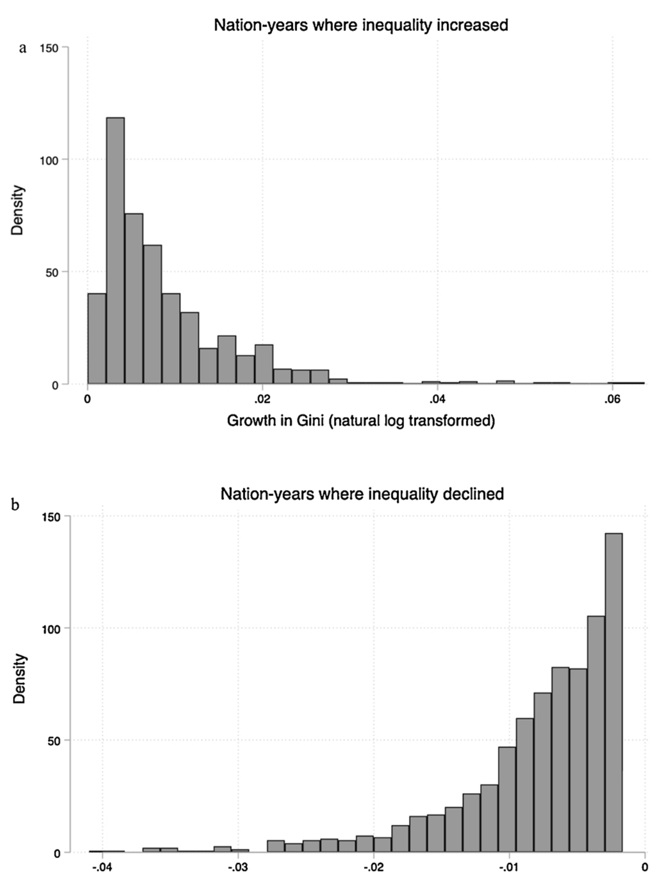

Fig. A1. Frequency and level of change of Gini coefficient for nation years (logged).

Table A1
Fixed effect models of the relationship between renewables, income inequality, and emissions for more developed and less developed nations.

	Less Developed	More Developed
Renewable energy consumption	0.664	0.496
	(.658)	(.368)
Gini coefficient	0.713	−0.220
	(.599)	(.381)
GDP per capita	0.574***	0.364**
	(.083)	(.135)
Age ratio	0.445	0.793
	(.574)	(.702)
Urban population	0.339	0.105*
	(.267)	(.438)
Renewables*Gini	−0.272	−0.165
	(.176)	(.113)
Observations	2,337	1,042
R^2	.50	.32

Note: all variables are natural log transformed. The result of this procedure is that the coefficients presented here represent the expected percent change in emissions per capita associated with a 1 percent change in the corresponding covariate.

Table A2
Fixed effect models of the relationship between renewables, income inequality, and emissions for more high, upper-middle, lower-middle, and low-income nations.

	High	Upper-middle	Lower-middle	Low
Renewable energy consumption	0.496	0.429	1.342	5.732
	(.368)	(.629)	(.958)	(6.426)
Gini coefficient	−0.220	−0.059	1.701	9.216
	(.381)	(.561)	(.945)	(7.867)
GDP per capita	0.364**	0.420***	0.651***	0.572***
	(.135)	(.110)	(.128)	(.139)
Age ratio	0.793	0.553	0.354	−2.385
	(.702)	(.657)	(.717)	(1.637)
Urban population	0.105*	0.549*	0.813**	−0.038
	(.438)	(.230)	(.268)	(.296)
Renewables*Gini	−0.165	−0.167	−0.518	−1.984
	(.113)	(.168)	(.281)	(1.784)
Observations	1,042	962	944	461
R^2	.32	.57	.61	.59

Note: all variables are natural log transformed. The result of this procedure is that the coefficients presented here represent the expected percent change in emissions per capita associated with a 1 percent change in the corresponding covariate.

Table A3
Count of nation-years with growth/decline in inequality.

Nation-years where Gini coefficient increased	Nation-years where Gini coefficient decreased
1,180	1,136

Note: Increases and declines in Gini coefficient are displayed graphically in Fig. 1a and b.

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