



Does Renewable Energy Development Decouple Economic Growth from CO₂ Emissions?

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Abstract

We assess how renewable electricity production interacts with GDP per capita to influence CO₂ emissions per capita, analyzing cross-national data from 1960 to 2012. We find an interaction effect between the quantity of renewables and GDP per capita, where, counterintuitively, economic growth is more closely tied to emissions in nations with a large share of their electricity from renewable sources and growth of renewable electricity has a smaller suppressive effect on emissions in more affluent nations. Additional analyses suggest that this relationship emerges because renewable energy sources tend to suppress nuclear energy in affluent nations, thereby unintentionally perpetuating reliance on fossil fuels.

Keywords

environmental reform, renewable energy, decoupling, CO₂ emissions

Introduction

Global climate change is one of the most serious threats facing the world, and it is primarily driven by anthropogenic greenhouse gas emissions (Intergovernmental Panel on Climate Change [IPCC] 2014). Of these greenhouse gases, CO₂ is the largest contributor to climate change, and the largest share of anthropogenic CO₂ comes from the combustion of fossil fuels (IPCC 2014). Recognizing this fact, a growing number of sociologists analyze the social forces that affect fossil fuel use and CO₂ emissions (Dunlap and Brulle 2015). Sociologists tend to agree that in order to curtail the effects of climate change, nations must substantially reduce their reliance on fossil fuels. However, a long-standing debate still persists over the effectiveness of mechanisms intended to reduce the amount of CO₂ emitted from fossil fuel use. One question of special importance in this debate is whether the development of “green” technologies, such as renewable energy generation, can allow societies to effectively address climate change and other environmental problems while they also expand economic production (Rosa et al. 2015; York, Rosa, and Dietz 2010). Some scholars argue that economic growth in modern societies is fundamentally at odds with environmental conservation since growth typically necessitates expanding consumption of energy and other resources (Schnaiberg and Gould 1994). In contrast, other scholars

suggest that rational management and technological innovations can allow societies to continue to grow without expanding resource consumption or pollution emissions (Sonnenfeld, Spaargaren, and Mol 2009).

Empirical work addressing this issue commonly uses cross-national time-series data to assess how tightly linked economic growth is with CO₂ emissions (Rosa et al. 2015). This body of research also seeks to determine whether there are processes that are leading to a decoupling of emissions from economic growth, where economies grow but emissions do not. The most prominent sociological study addressing this specific issue found that in nations around the world since 1960, the connection between the economy and emissions has generally weakened, but economic growth still tends to be associated with growth in emissions (Jorgenson and Clark 2012). The question still remaining to be answered is: What factors influence the coupling/decoupling of growth in economic production and CO₂ emissions?

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There is a common assumption in environmental science and policy analyses that the development of renewable energy sources will contribute to the decoupling of economic development from CO₂ emissions (Fischer-Kowalski 2011; OECD 2011; von Weizsäcker et al. 2014). On the surface, it seems that renewable energy production could take the place of fossil fuels and thereby allow for a reduction in CO₂ emissions even in the face of expanding economic production. However, one of the most prominent observations in sociology is that technological developments and social actions frequently have a variety of unanticipated consequences (Merton 1936). In this vein, empirical analyses have shown that the development of “green” technologies, such as renewable energy generation, often does not lead to the anticipated environmental benefits due to complex interactions in political and economic systems (McGee 2014; Sellen and Harper 2002; York 2012).

Analysts commonly assume that renewables will lead to decoupling economic growth from CO₂ emissions (e.g., Jackson et al. 2016). The International Energy Agency ([IEA] 2015:1) states explicitly that: “In OECD economies, recent efforts to promote more sustainable growth—including greater energy efficiency and more renewable energy—are producing the desired effect of decoupling economic growth from greenhouse gas emissions.” Some researchers have observed that global CO₂ emissions have flattened in the two most recent years for which there are estimates available, and in this period, the global economy and renewable energy production grew (IEA 2016; Jackson et al. 2016). However, these analyses do not rigorously assess whether renewable energy was an important reason behind the stabilization of emissions. Here we analyze the pattern over a much longer period of time since short-term patterns are less likely to reflect general tendencies. Whether the development of renewable energy sources actually leads to the decoupling of economic growth and emissions is an empirical question; one that we address here.

The term *decoupling* can have several different meanings, and different versions of decoupling need to be assessed in different ways. The claim that renewable energy sources lead to decoupling can be used to mean that renewable energy sources have a countereffect on emissions so that despite a positive effect on emissions from economic growth, emissions could stabilize or decline due to increases in renewable energy production. By analogy, a factory could reduce its total expenses even if its labor costs increase if its raw material costs decrease—namely, rising labor costs are not associated with growth in total expense even though they add to expenses because the decline in the cost of raw materials counters this upward pressure on expenses. We believe it is inaccurate to characterize a simple countereffect as decoupling. This can be more accurately described as a multicausal process where various factors affect emissions, with economic growth still spurring emissions while other factors suppress emissions (e.g., economic growth pushes emission

up, while growth in renewable energy production pushes emissions down, potentially leading to stable or declining emissions). Empirical analyses of whether renewable energy has a countereffect on emissions have had mixed findings (Apergis et al. 2010; Shafiei and Salim 2014), and they have not established whether the effect of economic growth on emissions is changed in character. The fact that in two recent years global CO₂ emissions approximately stood still while GDP grew, as the IEA (2015, 2016) observes, could be explained by counterforces to emissions rather than by a fundamental change in the relationship between the economy and emissions. In an obvious and uninteresting sense, one could say that the economy and emissions from fossil fuels are decoupled if fossil fuel use is entirely replaced by non-fossil energy sources. This, however, is not especially meaningful since if fossil fuel use is eliminated, ipso facto every conceivable factor, not only economic development, will have no effect on fossil fuel emissions.

We think that decoupling most correctly refers to the claim that the nature of the relationship between economic growth and emissions is transformed by the rise of renewable energy sources. To characterize this empirically, we employ an approach that has become standard in environmental sociology but with an important nuance. Specifically, we assess how renewable energy production and GDP are connected with CO₂ emissions using an elasticity model, which estimates the percentage change in CO₂ emissions for a 1 percent change in each of the independent variables (see York et al. 2003). However, for the added nuance, we assess how GDP and renewable energy production interact with one another, thereby changing how each one affects CO₂ emissions. If renewable energy production leads to a decoupling between GDP and CO₂ emissions, the elasticity coefficient (the percentage change in CO₂ emissions for a 1 percent change GDP) will decline as renewable energy production increases. This would indicate a weakening effect of economic growth on emissions as renewable energy production grows, which is distinct from renewables serving as an independent counterforce. While not the same as defining decoupling as a weakening of the correlation between GDP and emissions, there is a clear connection between a declining elasticity coefficient and a declining correlation coefficient in that if the elasticity coefficient reaches zero, the correlation coefficient will also be zero. Our conceptualization of decoupling is the standard one in the sociological literature, being consistent with that used by Jorgenson and Clark (2012) in their assessment of whether there is a temporally mediated decoupling of emissions and economic growth.

Here we assess in nations around the world whether changes in the proportion of electricity generated from renewable energy sources (which include hydro, wind, and solar power; geothermal and tidal energy; and combustible biomass and wastes) change the elasticity of the relationship between GDP per capita and CO₂ emissions per capita from the electrical sector. If the development of renewable energy

sources leads to decoupling of GDP from emissions, then in a model of emissions, the elasticity coefficient for GDP should be low in nations with a high percentage of their electricity from renewables and high in nations with a low percentage of their electricity from renewables. It is important to recognize that renewable energy sources as measured here include all sources that are not fossil fuels or nuclear power.

The common expectation that the development of renewables will tend to decouple economic growth from CO₂ emissions is based on the assumption that renewables will primarily compete with fossil fuels. However, since the development of renewables may affect (1) total energy consumption, (2) the types of fossil fuels used, and/or (3) the use of nuclear power, which may in turn influence dependence on fossil fuels, the assumption of a simple and direct link between renewables and fossil fuel use, and thereby CO₂ emissions, is not necessarily valid, a point we return to in the following. We present analyses that examine these three possibilities.

Methods

Our models examine national CO₂ emissions (metric tons) per capita from the electrical sector. All data are from the World Bank (2015). There are 128 nations for which sufficient data are available, listed in Table S1 in the Supplementary Material. These nations include the vast majority of the world's population, emissions, and economic output. The data cover the period 1960 to 2012. Some years are missing for some nations, particularly early in the period examined. We use fixed effects panel regression models with robust standard errors adjusted for clustering of residuals by nation. The models include dummy variables for each year to control for period effects. This modeling approach controls for factors that vary across nations but do not change over time, such as major geographic features (e.g., the physical potential a nation has for hydropower, wind power, or solar power; whether a nation is landlocked or mountainous; the latitude of each nation). It also controls for factors that change over time but do not differ across nations, such as international energy prices.

Our primary aim is to determine whether there is an interaction effect between GDP per capita (constant 2005 US\$) and the percentage of electricity from renewable sources. In Models 1 and 2, we control for the percentage of the population living in urban areas, percentage of the GDP coming from the manufacturing sector, and age dependency ratio (the ratio of people under 15 years of age and over 64 to those 15 to 64), key factors commonly found to be connected with emissions (Jorgenson and Clark 2012; Rosa et al. 2015; York 2012). In Models 3 and 4, we additionally control for electricity production per capita to assess whether the effects of GDP and renewables on emissions go beyond their effects on the scale of electricity production. Models 1 and 3 show the effects of GDP per capita and

renewables on emissions without taking into account any interaction effect. Models 2 and 4 assess whether there is a significant interaction effect, where the interaction term is the multiplicative product of GDP per capita and percentage of electricity from renewables.

All variables (except period dummy variables) are in natural logarithmic form, which makes these elasticity models. We added 1 to renewable electricity to eliminate 0s, since the log of 0 is undefined. If we do not do this, all nation-years with no renewables cannot be included in the models, which would bias our analysis. In initial models, we included a quadratic of the log of GDP per capita to assess whether there is a nonlinear relationship with emissions, such as an environmental Kuznets curve (Stern 2004). The quadratic was not significant in any of these initial models, suggesting that the log-linear specification for GDP per capita is appropriate. A variety of checks, which we present in Note S1 in the Supplementary Material, suggest the findings we present in the following are robust.

Results

The results of our analyses are presented in Table 1. Model 1 shows that GDP per capita has a positive effect on emissions per capita, where emissions grow approximately .50 percent for each 1 percent growth in GDP per capita. The percentage of electricity from renewable sources has a suppressive effect on emissions, as would be expected. There is a similar finding for Model 3, although the effect of GDP per capita is nonsignificant. This is not surprising since the model controls for electricity production per capita, which is the primary route through which the economy influences emissions from the electrical sector. In Models 2 and 4, the interaction between GDP per capita and renewables is positive and significant. This indicates that the effects of these two factors are intertwined, requiring a subtle interpretation since the effect of GDP per capita on emissions varies based on the level of renewables and the effect of renewables varies based on GDP per capita. In nontechnical terms, this finding means that in affluent nations, growth in renewable electricity production reduces emissions less than it does in poorer nations. Also, it indicates that in nations with high levels of renewable electricity, economic growth increases emissions more than it does in nations with low levels of renewable electricity.

To help interpret this finding in more precise terms, in Figure 1, we present the estimated effect of GDP per capita on emissions for various levels of renewables and in Figure 2, the estimated effect of renewables on emissions for various levels of GDP per capita based on the results of the analyses reported in Table 1. As can be seen in Figure 1, the elasticity coefficient for GDP per capita is higher in nation-years when a large share of electricity comes from renewable sources, based on results from both Models 2 and 4. This indicates that a rising share of electricity from renewables leads to a tighter

Table 1. Fixed Effects Panel Regression Models of the Influences on CO₂ Emissions Per Capita from Electricity Production across Nations, 1960–2012.

	Model 1 Coefficient (SE)	Model 2 Coefficient (SE)	Model 3 Coefficient (SE)	Model 4 Coefficient (SE)
GDP per capita	.500** (.157)	.194 (.192)	.211 (.154)	-.126 (.172)
Renewable electricity sources (percentage)	-.365*** (.084)	-.465*** (.112)	-.340*** (.081)	-.447*** (.106)
Interaction: GDP per capita × renewable sources		.112* (.052)		.121** (.044)
Urbanization (percentage of population)	.574 (.501)	.530 (.487)	.297 (.504)	.242 (.494)
Manufacturing (percentage of GDP)	.511** (.169)	.514** (.182)	.282* (.131)	.280* (.141)
Age dependency ratio	-.642 (.344)	-.739* (.340)	-.501 (.351)	-.601 (.344)
Electricity production, per capita			.489** (.167)	.502** (.170)
R ² (within)	.593	.604	.624	.637
N (total/nations)	3,509/128	3,509/128	3,509/128	3,509/128

Note. All variables are in natural logarithmic form. All models include year dummy variables (not shown) to control for period effects. The standard errors are robust, accounting for clustering by nation.

* $p < .05$. ** $p < .01$. *** $p < .001$ (two-tailed tests).

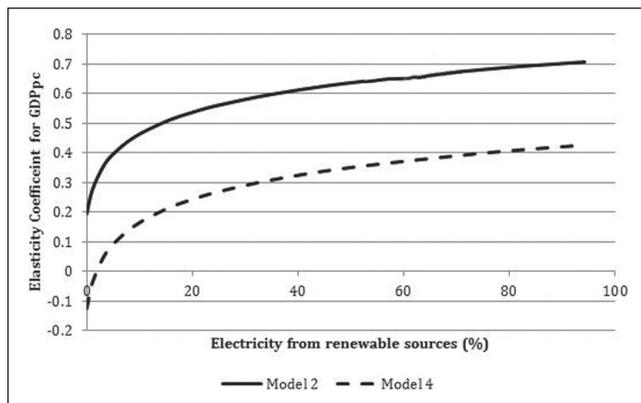


Figure 1. Elasticity coefficient for the effect of GDP per capita on CO₂ emissions for different values of electricity from renewable sources (percentage). The values are calculated from the results from Models 2 and 4 (Table 1) as electricity from renewable sources ranges from the 10th to the 90th percentile of observed values.

coupling between GDP and emissions. For example, based on the results in Model 2, for a nation with the median (50th percentile) level of renewables (25.112 percent of electricity production), a 1 percent increase in GDP leads to a .561 percent increase in emissions. However, for a nation at the 75th percentile of renewables (67.324 percent of electricity), a 1 percent increase in GDP per capita leads to a .669 percent increase in emissions. Model 4 indicates that when renewables are very low, economic growth has a negative effect on emissions, although this effect becomes positive when renewables exceed 2 percent of electricity production.

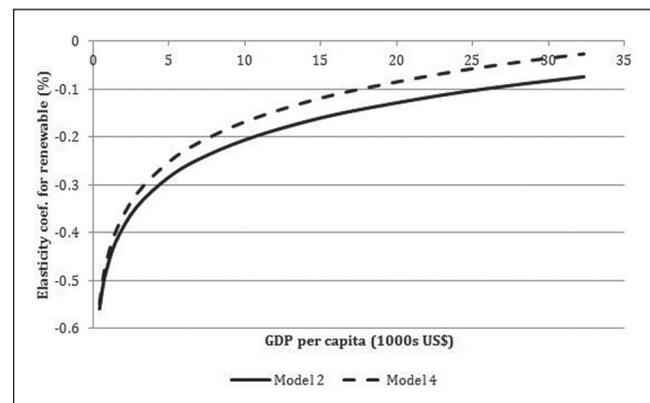


Figure 2. Elasticity coefficient for the effect of electricity from renewable sources (percentage) on CO₂ emissions for different values of GDP per capita (1,000s US\$). The values are calculated from the results from Models 2 and 4 (Table 1) as GDP per capita ranges from the 10th to the 90th percentile of observed values.

Figure 2 shows how the effect of renewables varies across levels of GDP per capita. As can be seen in the figure, for nations with low GDP per capita, renewables have a substantial negative effect on emissions, but for nations with a high GDP per capita, the effect of increasing the share of electricity from renewables approaches zero. For example, based on the results from Model 2, for a nation at the median GDP per capita (\$2,870), a 1 percent increase in the percentage of electricity from renewables corresponds with a decline of .347 percent in CO₂ emissions. However, for a nation at the 90th percentile of GDP per capita (\$32,335), a 1 percent

increase in the percentage of electricity from renewables leads to only a .074 percent decline in emissions. In fact, the estimated effect becomes positive when GDP per capita is much above \$62,000 (based on Model 2) or \$40,000 (based on Model 4). However, these values of GDP per capita are much higher than most observed values, and therefore, the estimated effect at this extreme is less reliable than the estimated effect when GDP per capita is closer to the median.

Although these results may appear paradoxical, there are three potential routes, mentioned previously, by which growth in renewable electricity sources can be connected with tightening the coupling between GDP per capita and emissions. First, growth in renewables may spur electricity consumption synergistically with GDP per capita so that affluent nations with more renewables consume more electricity from all sources. In fact, previous research has established that non-fossil fuel sources of electricity to some degree add on top of fossil fuel sources rather than substituting for them (York 2012). However, since we find the same type of relationship when we control for electricity production per capita (Model 4) as when we do not (Model 2), it appears that this is not the singular reason for our findings. Second, the interaction between renewables and the economy could be connected with shifts in the types of fossil fuels that are used from less to more carbon-intensive fuels. In other models (see Table S2 in the Supplementary Material), we substitute the amount of electricity generated from fossil fuel sources per capita (KWh) for emissions as our dependent variable and get the same substantive results as in the models we present here. This suggests that the finding goes beyond changes in the composition of fossil fuel sources.

Third, the interaction between renewables and GDP per capita may mean that in affluent nations with high levels of renewables, fossil fuels and renewables tend to squeeze out nuclear power (the electricity source that is not captured by renewables or fossil fuels). In this case, high levels of renewables make economic growth dependent on fossil fuels in place of nuclear power, and conversely, in affluent nations with nuclear power, growth in renewables tends to substitute more for nuclear power than for fossil fuels. To illustrate what this connection may look like, we examine trends in electricity production by source in Germany after its reunification in 1990 (see Figure 3). Germany provides an informative case since it is affluent and it recently substantially expanded electricity production from renewable sources. As can be seen in Figure 3, nuclear power production per capita declined noticeably as production from renewables grew while production from fossil fuels remained roughly stable. These trends in Germany are consistent with what we would expect if in affluent nations renewables have a tendency to take the place of nuclear power, not fossil fuels.

We performed additional analyses that suggest this is the primary explanation for our results, where the interaction effect between GDP per capita and renewables is even more pronounced when we limit the sample to only nation-years

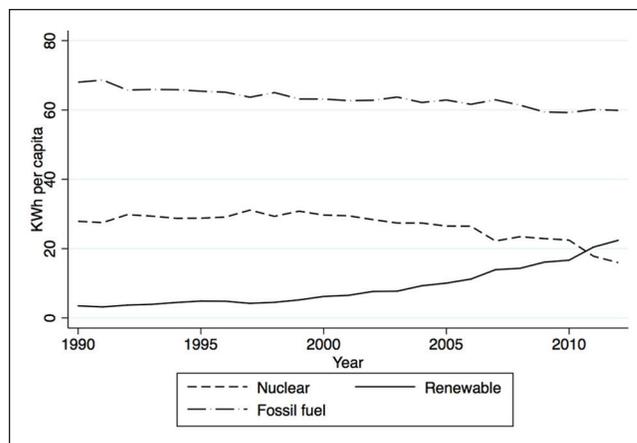


Figure 3. Electricity production (KWh) per capita in Germany by source, 1990–2012.

with nuclear power (see Supplementary Material, Table S3), whereas the interaction effect is smaller and not statistically significant when examining only nation-years without nuclear power (see Supplementary Material, Table S4). Of course, a combination of the three routes explained previously could operate differently across nations.

Conclusion

Our findings indicate that, as is commonly expected, nations with more electricity from renewable sources typically have lower carbon dioxide emissions per capita, controlling for other factors, than nations with less production of renewable energy. However, there is an interaction effect between GDP per capita and the percentage of renewable electricity production that makes it so that the generation of electricity from renewable sources has less of a suppressive effect on emissions in affluent nations than it does in poorer nations and conversely, economic growth is more tightly coupled with emissions in nations with a high level of renewable energy production. This counterintuitive result appears to happen because the production of electricity from renewable sources is prone to suppressing the production of nuclear power instead of fossil fuel use in affluent nations. Perhaps the most practical implication of our findings is that if the patterns we identify here continue into the future, adding renewable sources of electricity will be most effective at suppressing CO₂ emissions in less affluent nations, especially those without nuclear power, and will be less effective at doing so in affluent nations, where renewables may be more likely to take the place of nuclear power than of fossil fuels. This suggests that working to deploy renewable energy sources in developing nations may be a particularly important part of mitigating climate change, while trying to reduce overall electricity consumption in affluent nations is needed. Additionally, our results suggest that

decoupling CO₂ emissions from economic growth is not likely to easily happen if non-fossil energy sources are developed alone without parallel changes to political-economic structures that affect fossil fuel use.

Authors' Note

Data can be accessed online at the World Development Indicators Database: <http://data.worldbank.org/data-catalog/world-development-indicators>. The authors will also provide the data set upon request (rfyork@uoregon.edu).

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