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Short communication

How organizational and global factors condition the effects of energy efficiency on CO_2 emission rebounds among the world's power plants

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HIGHLIGHTS

- Skeptics charge that energy efficiency may actually cause CO_2 emissions to rise.
- Few have examined whether such rebound effects occur among power plants.
- Little also known about whether plants' organizational and global characteristics condition rebounds.
- Conduct first analysis of rebound effects among the world's power plants.
- Rebounds found to depend on plants' age, size, and location in international economic and normative systems.

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ABSTRACT

The United Nations Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA), and several nations suggest that energy efficiency is an effective strategy for reducing energy consumption and associated greenhouse gas emissions. Skeptics contend that because efficiency lowers the price of energy and energy services, it may actually increase demand for them, causing total emissions to rise. While both sides of this debate have researched the magnitude of these so-called rebound effects among end-use consumers, researchers have paid less attention to the conditions under which direct rebounds cause CO_2 emissions to rise among industrial producers. In particular, researchers have yet to explore how organizational and global factors might condition the effects of efficiency on emissions among power plants, the world's most concentrated sources of anthropogenic greenhouse gases. Here we use a unique dataset containing nearly every fossil-fuel power plant in the world to determine whether the impact of efficiency on emissions varies by plants' age, size, and location in global economic and normative systems. Findings reveal that each of these factors has a significant interaction with efficiency and thus shapes environmentally destructive rebound effects.

1. Introduction

Because recent improvements in the amount of energy needed to create a single unit of production (E/GDP) have helped to drive down the carbonization *rate* of economies (C/GDP), several policy experts and consulting firms have suggested that gains in energy efficiency can also reduce the *level* of carbon emitted into the atmosphere (IEA, 2013, 2015; EPA, 2009). Groups like the Rocky Mountain Institute and McKinsey and Company estimate that efficiency measures, by themselves, can meet America's 2020 greenhouse gas emissions reduction goals and cut global emissions by one-third within the next 15 years (Lovins, 2005; McKinsey and Company, 2009). The IEA recently cited improvements in energy efficiency as a primary step toward producing a peak in global energy-related CO_2 emissions by 2020 (IEA, 2015; IPCC, 2007).

These and other estimates are based on the assumption that aggregate gains in energy efficiency have a direct effect on greenhouse gas emissions. However, researchers have challenged this assumption, arguing it ignores the potential increases in energy consumption known to result from below-cost efficiency improvements (Brookes, 1979; Khazzoom, 1980; 1982; Jevons, 1865). This effect, commonly referred to as a “rebound,” can cause CO_2 emissions to rise as the cost of consuming energy decreases.

Subsequent research has sought to determine the size of rebound effects, with some studies suggesting the actual resource

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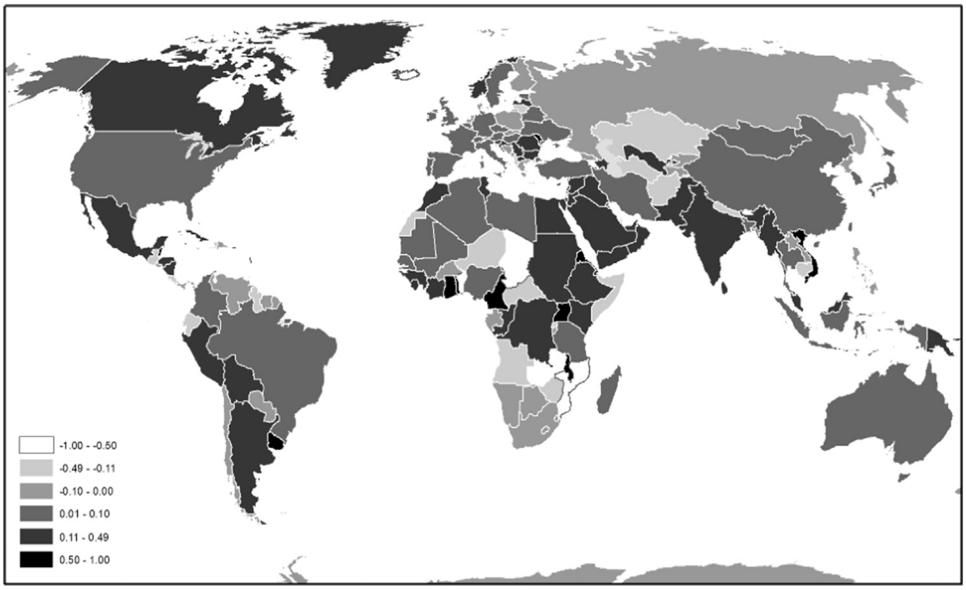

Fig. 1. Correlation between plant-level CO_2 emissions and thermal efficiency by country (2009).[1,1]Shadings reflect different correlation values.

savings are higher than expected (a negative rebound), others claiming it is less than expected but still between 0% and 100%, and still others asserting it is greater than 100% of projected energy savings (a "backfire" effect) (Sorrell, 2009). Researchers have also tried to distinguish direct rebounds (efficiency measures that cause an increased use of an energy input or service) from indirect rebounds (second-order increases induced by energy savings, such as additional consumption of other goods or services). To date, the majority of these studies have focused on direct rebound effects among end-use consumers of energy (Berkhout et al., 2000; Greening et al., 2000). In general, this research finds that direct rebounds for consumer energy services, especially in developed countries, are fairly modest, typically eroding between 10 and 30% of the energy savings (Sorrell, 2009; Greening et al., 2000).

Direct rebounds among commercial and industrial producers have received far less attention, despite the fact that one sector - electric utilities - is the single largest source of anthropogenic CO_2 emissions (IEA, 2015). The few studies done on the subject have compared the scale of direct rebounds of specific producer sectors within a single nation or the combined direct rebounds of producers across nations (Grant et al., 2014a). They find that the electric utilities sector is the most responsive ("elastic") to changes in energy prices and consumer demand as well as the most able to substitute a cheaper energy input for others. Hence, improvements in energy efficiency in this sector are the most likely to generate rebound effects that could cause higher emission levels. Most of these direct rebounds are also the result of utilities relying on cheaper – and more carbon intensive – energy inputs. International comparisons suggest further that utility sectors in developing countries are especially prone to rebound effects because their populations' demand for energy services is still largely unfulfilled (Sorrell, 2007).

Although these studies provide important insights into the electric utilities sector, they have several shortcomings. First, studies that find direct rebound effects often suggest efficiency gains increase CO_2 emission levels but without actually examining the empirical relationship between the two. Consequently, they fail to probe the conditions under which efficiency increases or decreases emissions. Instead, they posit that if rebound effects cause more CO_2 emissions, it is either because rebounds spur the substitution of a now cheaper energy input for other factors of production ("substitution effect") or an increase in economic output to meet rising consumer demand ("output effect").

Second, sectoral analyses overlook how emissions are distributed unevenly across power plants. For instance, in the United States, the top 5% percent of polluting power plants are responsible for 75% of its electricity-related CO_2 emissions but only generate 47% of all electricity. Likewise, in India's electricity sector, the top 5% account for 75% of total CO_2 discharges but just 58% of total electricity produced (Grant et al., 2013). Sectoral analyses overlook such facility-level variations.

Third, because sectoral and national analyses do not address variation in power plants' emissions, they also fail to examine how plants' organizational characteristics might shape the impact of efficiency on emission outcomes. In contrast, other studies report that because older and larger plants are more subject to inertia, they are less likely to improve their efficiency and curb their emissions (Grant et al., 2014b, 2002). It seems likely, therefore, that these organizational properties may also interact with efficiency to temper or enhance its effect on CO_2 discharges.

Fourth, studies that report that the electricity sectors' of developing countries are more prone to direct rebounds do not take into account relationships between countries and their implications for the environmental behavior of power plants. For example, proponents of the world-systems perspective in the social sciences argue that countries are organized into a stratified political-economic interstate system that is largely controlled by a set of wealthy and geopolitically powerful "core" nations (Chase-Dunn and Grimes, 1995). These nations not only dominate trade and financial relationships, but their dependence on basic energy resources like fossil fuels for continued growth locks them into environmentally destructive trajectories (Clark and York, 2005; Jorgenson and Clark, 2012). This suggests that plants in the core zone of the global economy may also have an especially difficult time translating efficiency gains into emission reductions.

Finally, analyses of utility sectors' direct rebounds extract individual plants from the larger normative systems in which they are nested. The sociological literature on organizational embeddedness argues that industrial facilities do not operate in a cultural vacuum. Rather, facilities whose nations are more embedded in the global environmental regime (or world society), as indicated by their participation in environmental international non-governmental organizations (EINGOs), are more likely to adhere to global norms and recognize the importance of environmental