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Is climate change-centrism an optimal policy making strategy to set national electricity mixes?

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HIGHLIGHTS

- The impact of climate-centric policies on other environmental impacts is uncertain.
- Analysis of changing electricity grids of Peru and Spain in the period 1989–2013.
- Life Cycle Assessment was the selected sustainability method to conduct the study.
- Policies targeting GHG reductions also reduce air pollution and toxicity.
- Resource usage, especially water, does not show the same trends as GHG emissions.

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ABSTRACT

In order to combat the threat of climate change, countries have begun to implement policies which restrict GHG emissions in the electricity sector. However, the development of national electricity mixes should also be sensitive to resource availability, geo-political forces, human health impacts, and social equity concerns. Policy focused on GHG goals could potentially lead to adverse consequences in other areas. To explore the impact of "climate-centric" policy making on long-term electricity mix changes, we develop two cases for Peru and Spain analyzing their changing electricity grids in the period 1989–2013. We perform a Life Cycle Assessment of annual electricity production to catalogue the improvements in GHG emissions relative to other environmental impacts. We conclude that policies targeting GHG reductions might have the co-benefit of also reducing air pollution and toxicity at the expense of other important environmental performance indicators such as water depletion. Moreover, as of 2013, both countries generate approximately equal GHG emissions per kWh, and relatively low emission rates of other pollutants compared to nations of similar development levels. Although climate-centric policy can lead to some positive environmental outcomes in certain areas, energy policy-making should be holistic and include other aspects of sustainability and vulnerability.

1. Introduction

Climate change constitutes a major threat to the stability and existence of both anthropogenic and ecological systems, and necessarily, countries have shaped a wide range of policies focused on reducing greenhouse gas (GHG) emissions [1,2]. Beyond GHG emissions, however, there are many other significant goals that should not be ignored in energy decision-making. Foremost of these is human health and safety concerns, such as exposure to pollutants during energy production [3]. Other important concerns include environmental degradation, negative social impacts, energy security, and economic stability. Laurent and colleagues discuss the limitations of carbon footprint as an indicator for decision-making since decreasing GHG emissions could lead to negative consequences in other important areas such as impacts related to toxic emissions [4]. On the other hand, reductions in GHG emissions have been shown to have environmental co-benefits [5,6], such as reducing ocean acidification [7], and may even increase energy security [8]. A central question to be explored in this article is whether these "climate-centric" policy decisions in the energy sector lead to adverse outcomes in other realms, or whether there are substantial co-benefits.

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GHG emissions are closely linked to the production and use of energy, and changing primary sources of energy will be critical to the decarbonization of modern economies [9]. Energy consumption worldwide is a leading driver of climate change through heavy reliance on fossil fuels. The energy sector contributed over 31 million tonnes of CO_2 in 2011 alone, with 18% of total world energy being used to produce electricity [10]. Therefore, electricity decarbonization has been cited as being a major key to stabilizing GHG emissions [11,12]. As part of this, most countries will need extensive modifications to their existing electricity mixes. Multiple studies have explored decarbonization of the electricity sector as a potential path toward climate change mitigation with varying conclusions on the feasibility and cost. Studies in California and Germany show that electricity decarbonization will have to occur if policy goals of 80% reduction below 1990 GHG emission levels are to be met [10,13,14]. From an energy return on investment (EROI) standpoint, renewable energy sources fall much lower than traditional petroleum-based sources. For example, corn ethanol hovers around an EROI of 1:1 or potentially even negative (indicating energy loss from using this source) [15]. EROI is a fundamental metric for evaluating the feasibility of renewable energy sources, as sources with lower EROI consume a higher percentage of energy in the production phase. Investing in these sources could mean potentially increasing GHG emissions or other negative environmental impacts above alternate source scenarios, especially given that energy policy decisions have far-reaching and long-term impacts. A minimum EROI of 3:1 for sustainable development has even been suggested [16]. Some policies have already began to subsidize renewable technologies, such as wind and solar power, which show higher mean EROI values than other renewable sources of energy [15,17]. Nevertheless, countries such as New Zealand, which plan to expand their electricity system by 100% in 2050 using renewables exclusively, plan a reduction in EROI of nearly 45% [18].

National electricity mixes obtain unique characteristics in response to resource availability, geo-political conditions, and long-term resiliency of the supply within each country-context. The specific definition of energy security has many interpretations [19], but generally it can be thought of as retaining or quickly restoring essential system functionality during perturbations such as disruptions in primary energy supply. As part of this, previous studies have stressed the importance of system diversity, both in origin and type of supply [12,20,21]. Japan presents an interesting case study of energy system resiliency, given its extreme scarcity of natural resources and dependence on foreign imports [22]. This has led to a high reliance on nuclear power as well as government incentives to invest in solar power [23]. Across the world, concerns have been raised about the long-term availability of petroleum supply [24], and there is speculation as to whether oil production has "peaked" [25]. These supply concerns have also led countries to diversify electricity production beyond conventional fossil fuel sources. Much of the world's oil supply comes from regions that are politically unstable, creating vulnerability for countries that use petroleum from these areas as the majority of their supply. Diversifying countries of origin is one strategy for mitigating the impact of prospective political disruptions to oil supply. Becoming self-sufficient in energy production is an alternate route toward energy stability [26].

The primary goal of this study is to analyze the evolution of national electricity mixes in response to resource availability, renewable energy goals, and other political considerations, with the secondary goal of cataloguing improvements (or digressions) in GHG emissions compared to other environmental impacts, such as human respiratory impacts, typically ignored in policy-making. We do this via two case studies with differing levels of resource abundance, commitment to renewable energy, as well as unique energy resiliency strategies. We study the changes in electricity mixes of Spain and Peru between 1989 and 2013 in order to quantify mix sensitivity to policy and market pressures as well as to look at the environmental consequences of mix changes from a life-cycle perspective. While previous studies have included time-series environmental analyses of electricity production, most lack a holistic perspective by focusing on a limited number of environmental dimensions. A series of studies by Greening et al. in the late 1990s analyzed long-term electricity mix trends with a focus on the carbon-intensity of the manufacturing sector [27]. Additionally, Steenhof & Fulton [28] investigate the drivers of electricity mix change in the provinces of the People's Republic of China, lining up changes with political and economic conditions, with a focus on developing future scenarios. There are multiple reasons that our chosen case studies provide a unique prospective to climate policy and electricity mix change. Peru and Spain, in many ways are stark contrasts, providing diverse examples of system complexity, timing of economic development, resource availability, energy independence, and Kyoto compliance stipulations. The two countries also have distinct energy development goals and policies which reflect their unique circumstances. Altogether, this allows us to cover an important knowledge gap when it comes to understanding the evolution of electricity production in these two countries from an environmental perspective, as well as draw extrapolate recommendations for a wide-range of countries under varying conditions.

2. Materials and methods

2.1. Methodology and scope

A life cycle perspective was selected in this study to monitor the inter-annual change in the environmental profile of the electricity sector at a national level. Therefore, Life Cycle Assessment (LCA), an internationally standardized environmental assessment methodology was selected to study the changes in the environmental performance of the electricity grids in Peru and Spain [29,30]. The functional unit (FU), which is the mathematical quantification of the service delivered by the production system [29], was fixed as 1 kWh produced in one year of operation based on the electricity mix of the specific year under analysis.

The system boundaries for both case studies include the production and delivery of high voltage electricity to the grid, including the extraction of fuels and raw materials, the processing and transportation of these fuels/materials, the operation of power plants and wind/solar farms, the construction/decommissioning of power plants and supporting infrastructure, and waste disposal. In addition, it is important to recognize that the energy production technologies and fuels varied considerably in the analyzed period, so some technologies have been newly implemented through time while others have been phased out.

2.2. Selection of case studies

Peru and Spain were selected as case studies based on criteria which make them sufficiently distinct for a comparative environmental and policy assessment. First, Peru and Spain have had similar economic growth patterns, but occurring nearly two decades apart (see Fig. S1 in the Supplementary Material – SM). For instance, Spain's economic expansion and corresponding demand for electricity occurred in two stages, first during the 1980s when it entered the European Union, and second in the period 1996–2008, ending with the World Financial Crisis (WFC) which plunged Spain into a deep recession that is still on-going. Peru experienced a similar economic expansion at the turn of the millennia, and the