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Democracy, economic development and low-carbon energy: When and why does democratization promote energy transition?

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Abstract

Despite the growing consensus surrounding the need to decarbonize power for meeting the ambitious temperature target set out in the 2015 Paris Agreement, the share of low-carbon energy sources in the overall energy mix varies significantly across countries and over time. We evaluate the influence of democracy on clean energy transition by studying national solar, wind, hydro and nuclear energy shares of total energy use for electricity generation from 1980 to 2020. Using data from the Varieties of Democracy, Freedom House and Polity IV democracy indices, International Energy Agency Extended Energy Balances and Summary Statistics and World Bank World Development Indicators, we conduct a large-N study of the emissions levels of 135 countries. This article develops existing understandings about the relationship between democracy and energy transition by employing a more sophisticated – hierarchical – research design to determine whether: (i) democracy continues to be an important driver of low-carbon energy use once country-level clustering is accounted for, (ii) fluctuations in the democratic attributes of domestic political regimes have uniform effects across countries and (iii), if so, economic development plays a role in shaping the effect of democracy within individual countries. The results suggest that, even after controlling for country-level clustering and other putative drivers of energy portfolios, democracy has a significant effect on the low-carbon energy sources examined here. A second-order regression of country-specific democracy effects estimated by our hierarchical model provides robust evidence that economic development plays an important role in shaping the effect of democracy within individual countries: Strikingly, democratic spells (of increased democratic institutions and processes) in advanced economies tend to inhibit solar, wind and hydro energy, but promote nuclear energy use, while having the opposite effects (promoting solar, wind and hydro and inhibiting nuclear shares) in emerging economies.

Keywords renewable energy; solar; wind; hydro; geothermal; nuclear, energy transition, decarbonization; democracy, electricity generation; energy mix; economic development

JEL Classification N7, O13, P18, P28, P48, Q42, Q43, Q48

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EPRG WORKING PAPER

Democracy, economic development and low-carbon energy: When and why does democratization promote the energy transition?

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Abstract: Despite the growing consensus surrounding the need to decarbonize power for meeting the ambitious temperature target set out in the 2015 Paris Agreement, the share of low-carbon energy sources in the overall energy mix varies significantly across countries and over time. We evaluate the influence of democracy on clean energy transition by studying national solar, wind, hydro and nuclear energy shares of total energy use for electricity generation from 1980 to 2020. Using data from the Varieties of Democracy, Freedom House and Polity IV democracy indices, International Energy Agency Extended Energy Balances and Summary Statistics and World Bank World Development Indicators, we conduct a large-N study of the emissions levels of 135 countries. This article develops existing understandings about the relationship between democracy and energy transition by employing a more sophisticated – hierarchical – research design to determine whether: (i) democracy continues to be an important driver of low-carbon energy use once country-level clustering is accounted for, (ii) fluctuations in the democratic attributes of domestic political regimes have uniform effects across countries and (iii), if so, economic development plays a role in shaping the effect of democracy within individual countries. The results suggest that, even after controlling for country-level clustering and other putative drivers of energy portfolios, democracy has a significant effect on the low-carbon energy sources examined here. A second-order regression of country-specific democracy effects estimated by our hierarchical model provides robust evidence that economic development plays an important role in shaping the effect of democracy within individual countries: Strikingly, democratic spells (of increased democratic institutions and processes) in advanced economies tend to inhibit solar, wind and hydro energy, but promote nuclear energy use, while having the opposite effects (promoting solar, wind and hydro and inhibiting nuclear shares) in emerging economies.

1. Introduction

'In order to solve the climate crisis, we're going to have to pay attention to the democracy crisis' [1] warned former vice president Al Gore at the COP26 United Nations Climate Summit in 2021. This sentiment echoes a longstanding assumption in the environmental politics literature that democracies are better at environmental quality provision than non-democracies [2–5]. Numerous studies investigate the implications of democracy for climate mitigation, usually by analysing fluctuations in national carbon emissions (Böhmelt et al., 2015; Bättig & Bernauer, 2009; Burnell, 2014; Clulow, 2019; Fredriksson & Neumayer, 2013; Povitkina, 2018). More recently, the growing consensus that meeting an ambitious temperature target as set out in the 2015 Paris Agreement necessitates more stringent and rapid action to transition from fossil fuel to low-carbon energy technologies [12] has led an increasing number of scholars to study the influence of democracy on national energy portfolios, [13–18]. As with the broader literature on climate mitigation, studies on the energy mix have largely assumed that democracy would have positive consequences. Some of this bias is because of a (largely implicit) presumption that the influence of domestic democratic political regimes on energy outcomes arises from the same causal processes and pathways that energy democracy scholars associate with democratic forms of energy policy-making: that is, by facilitating a participatory decision-making process, democracy ensures that energy policies generate just, sustainable outcomes that are socially acceptable [19,20]. Indeed, past studies have identified various grounds for expecting democracies to be more embracing of energy transition such as, for example, the higher value that they allegedly place on human life [21], increased opportunities they provide for environmental interests [22,23] and local interests [20,24] to influence policymaking, electoral incentives for elected politicians to deliver sustainable energy policy [25] and democratic commitment devices that incentivize decarbonization [26].

Yet surprisingly little effort has been made to empirically test whether or not democratic political regimes (or processes) do indeed result in more sustainable energy outcomes [19]. Moreover, the empirical evidence on the implications of democratic political regimes for energy transition is quite varied. While a number of studies do find the expected positive effect [17,27–29], some suggest that democracy sometimes inhibits decarbonization [17,29–31]. Indeed, contradictory empirical findings have led some authors to conclude that democracy's effect on transitions might be contingent on certain facilitating conditions or moderating factors such as, for example, a nation's level of trade openness [30], fossil fuel endowment [31], political corruption [9], ideological orientation of political parties [32] and economic development [33,34]. There are also important methodological limitations as most existing empirical studies are anecdotal [13,27] or based on a single country or homogenous group of countries [15,28], raising the risk that claims of significant findings may be the result of confounding factors rather than democracy itself.

Thus we seek to contribute to this literature by addressing a critical question: how do the democratic attributes of domestic political regimes influence national transitions from fossil fuel energy to low carbon electricity generation? In doing so, our core objectives are to determine whether the consequences of democracy for the decarbonization of power: (i) are uniform (i.e. always compatible with or obstructive to transition) across countries and; if not, (ii) divergences in democracy effects are (at least partially) determined by national levels of economic development. Therefore, our findings will have important policy insights for whether democratization initiatives, which are typically concentrated in countries with fragile political systems with weak economies, are likely to promote or obstruct energy transition.

In this article, we investigate the relationship between democracy and the use of four key low-carbon energy sources - hydro, nuclear, wind and solar energy - for electricity generation. The first two sources are large scale, centralized technologies that typically require a significant degree of top-down regulation and number of years to deploy (e.g. to build a new plant). In contrast, the latter two options are small scale, decentralized sources that are often heralded as more democratic technologies that facilitate citizens to become more directly involved in the planning, production, consumption and regulation of energy [20]. By analysing these four options simultaneously, we are able to explore whether the effect of democracy varies across different low-carbon options that vary in terms of level of centralization and scale. Using data from the International Energy Agency World Extended Energy Balances and Summary, V-Dem Correlates of Democracy, Freedom House and Polity IV democracy indices and World Bank Development Indicators, we conduct a large-N investigation of the low-carbon energy portfolios of 135 countries from 1980 to 2020. We go beyond most existing quantitative studies, which rely on ordinary least squares regression by employing a two-level hierarchical model [35,36] consisting of country-years nested in countries that allows us to test whether democracy is an important driver of low-carbon energy shares once country-level clustering is accounted for. We arrive at a more sophisticated understanding of the effect of domestic fluctuation in the level of democratic institutions and processes by building a random coefficient model (RCM) that allows the effect of democracy to vary between countries. We add further nuance by employing RCM with interaction terms and conduct second-order analysis of Bayesian country-specific democracy effects to explicitly test the role of economic development in moderating the democracy effect on low-carbon energy usage.

Our results provide strong evidence that democratization has distinct, and often contradictory, effects on the use of low-carbon energy sources between and the within countries: while democracies tend to employ higher shares of low-carbon energy sources than non-democracies, increasing levels of democracy within the same country are associated with diminishing shares of solar, wind and hydro (but not nuclear) energy. Our findings also suggest that the effect of democracy on small scale low-carbon technologies varies significantly between countries at different levels of economic development: increasing wind and solar energy shares in developing economies but inhibiting them in advanced economies. However, we find that democracy and economic development interact differently in relation to large-scale low-carbon options as democratization appears to promote nuclear use in advanced economies, while inhibiting it in weaker economies. These results hold even when we control for the share of fossil fuel rents of national income as well as other putative drivers of energy portfolios and choice of democracy proxy.

This article consists of four sections. The next section reviews the literature on democracy, the energy mix and economic development to draw out our core hypotheses about the influence of democracy and moderating effect of national income on the transition to low-carbon energy sources. Section two describes the research design by discussing our methodological approach, dataset, and spatial-temporal domain of analysis. The third section presents the empirical results and conducts a second order regression using the Bayesian estimates of the country-specific democracy effects predicted by the RCM to formally test the moderating effect of economic development on the relationships between democracy- and shares solar, wind, hydro and nuclear energy. Finally, we conclude by discussing the conclusions, policy relevance and limitations of the findings.

2. Theoretical Foundations

2.1. Existing Explanations

In understanding the (divergent) paths of energy transition followed by different countries, most existing explanations focus on the role of economic, technical and geographical factors associated with different energy sources. Many experts have studied the economic incentives (and disincentives) facing transition and provided estimations of the capacity of economic policies such as electricity market reforms, price interventions, government subsidies or tax incentives (or a combination thereof) to promote sufficient investment in low-carbon energy [37–40]. Others emphasize the importance of technological innovation. Solomon and Krishna (2011), for example, take a historical approach by assessing the role of earlier technological developments in enabling previous transitions. Given the critical role of new climate technologies involving geological storage of carbon dioxide (such as carbon capture and storage and direct air capture) for meeting an ambitious temperature target, an emerging theme in this literature is the need to innovate carbon storage technologies to reduce the deployment costs of these critical options [42]. Similarly, others foresee a need for improvements in small scale battery storage to facilitate the deployment of local scale low-carbon options such as solar panels and wind turbines [43,44]. Others explore how national geographical conditions shape countries' capacities to utilize different energy technologies. Earlier studies focused on natural resource endowments and access to raw material inputs required for different energy technologies [45], whereas more recent analyses have begun to explore how geographical factors affect vulnerability to the economic repercussions of decarbonization such as changes in electricity prices, property values, land prices and proportion of population in poverty [46]. Undoubtedly, these factors have had an important bearing on efforts to phase out fossil fuels and upscale low-carbon energy sources. Yet, as experts increasingly maintain, even beyond these factors, the national policymaking environment play an important role in making energy policies – and transitions – politically and socially feasible ([17,18,26–28,30,47–50]. For example, several authors concur that political stability [51–54] and low levels of corruption [9,55] are conducive to effective climate policy outcomes and energy transition. Indeed, the dataset we use for this article (described below) appears to corroborate these claims as the correlations between the shares of different low carbon energy sources (solar, wind, hydro and nuclear) used for electricity generation and indicators of market forces (namely: fossil energy prices and shares of fossil fuel rents of national income) were close to zero, suggesting that transition could be influenced by non-economic factors such as political and institutional variables.

Existing treatment of the relationship between democracy and energy systems is limited. Most research focuses on the influence of energy systems on political regimes. A dominant strand of the resource curse scholarship, for example, purports that an abundance of (both fossil fuel and renewable) energy resources is conducive to the emergence of authoritarian political regimes as national energy systems (and economies) that revolve around a narrow range of energy resources tend to concentrate vital energy resources (and associated socio-economic power) in the hands of resource elites with close ties with political rulers [56–58]. Research on the opposite process – whereby democracy influences energy transition - is comparatively limited. The few economic models that do engage with political drivers usually model democracy as a control variable without much theoretical discussion [18,59]. On the other hand, political science studies have offered in-depth explanations about the influence of democracy, but the emphasis here is on policy outputs such as taxes, subsidies and, occasionally, mitigation commitments (Bättig & Bernauer, 2009; Rabe & Borick, 2012; Yahya & Rafiq, 2019). The handful of analyses that do focus on outcomes analyze carbon emissions or indicators of environmental performance more broadly defined [6,8,9,63–65]62] rather than energy portfolios or sources of electricity generation. Existing understandings about the relationship between democracy and energy transition are also limited by various methodological issues. Although some studies do employ large-n datasets that span diverse political and energy systems, almost all of them rely exclusively on cross-sectional comparisons between countries[18,28,60] without exploring how changing democratic conditions within the *same* country might affect the energy mix.[1] This oversight is of enormous empirical importance given the widespread belief that more democratic forms of energy policymaking will result in more sustainable energy outcomes around the world [63].

We attempt to address these gaps in our understanding of the implications of democracy for the decarbonization of power. We develop and test a theoretical framework that brings together the literature on democracy and energy transition with structuralist approaches towards climate politics, which leads us to argue that, to an important extent, the cross-country variation we observe in the relative shares of low-carbon energy sources used for electricity generation is rooted in differences in the democratic attributes of domestic political regimes and levels of economic development. Our two core arguments are that: (i) democracy influences the shares of solar, wind, hydro and nuclear energy in the national energy mix and (ii) the democracy effect is shaped (in part) by a country's level of economic development. We arrive at these arguments by first outlining the core attributes of democratic regimes that promote (and obstruct) transition and then addressing the role of economic development in moderating the effect of democracy on low-carbon energy usage within individual countries.

2.2. *Democracy and energy transition*

There is a longstanding assumption in the international environmental politics literature that democracies are better at environmental goods provision than non-democracies. This assumption is underpinned by a rich collection of empirical studies that find positive effects in a wide range of areas such as, for example, air pollution control [64], afforestation [65], conservation [66] and land degradation [5]. In particular, a number of studies suggest that 'open' political regimes, which possess the core attributes that are typically associated with democracies (such as opportunities for civil society involvement in policymaking, electoral accountability and democratic ideational values), perform better at climate mitigation - both in terms of policy outputs and outcomes - compared to 'closed' regimes (e.g. Bättig & Bernauer, 2009; Burnell, 2014; Fredriksson & Neumayer, 2013; Li & Reuveny, 2006). This literature provides impetus for a nascent but growing effort to investigate the implications of different aspects of democracy for energy transition.

As with the broader environmental politics literature, most of this research assumes that democracy tends to help, rather than hinder, transition from fossil-fuel-based power to low-carbon energy sources. To this end, the scholarship attributes the expected positive relationship to three core attributes of democratic political regimes - namely: (i) participatory decision making, (ii) electoral accountability and (iii)

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[1]To our knowledge, Bayulgen and Ladewig (2017) is the only study that analyses within-country effects of political variables on renewable energy shares of the national energy mix.

ideational values. The most dominant argument, which overlaps with the scholarships on energy democracy [13,20,67] and just transitions [68], is that the participatory decision making process that is associated with democracies facilitates open political regimes to deliver sustainable energy outcomes by ensuring that diverse stakeholders (e.g. public, environmental and local) collaborate in reaching socially acceptable decisions that maximize the benefits for society as a whole [23,24,69,70]. Another thesis, which is also put forward in relation to climate mitigation [11], is that the expectation of regular election cycles creates a strong incentive for elected policymakers to embrace transition as a way of addressing the needs of their publics for a safe climate [25,71]. Third, by placing value on human life and life quality, it has been suggested that democracies have an ideational disposition to accept the kinds of lifestyle changes that are needed to facilitate ambitious climate policy [11] and, by extension, energy transition. Relatedly, some authors argue that state compliance with international decarbonization targets is driven, in part at least, by an ideational respect for the rule of law that is rooted in democratic values [9,21].

Yet the empirical evidence on the extent to which democracy is conducive to energy transition is quite varied. On the one hand, while some mature democracies such as the EU have led the way in promoting the energy transition, others, such as the US, Australia and Canada, have been reluctant to undermine the dominance of fossil fuels in the power sector ([72,73]. Similarly, at the other end of the political spectrum, while some closed political regimes such as Russia and Iran [74,75] have continued expanding fossil energy, others such as various Gulf states have set ambitious targets for upscaling renewable energy [76,77] and other key low-carbon energy technologies such as carbon capture and storage [78,79].

The accumulation of contradictory findings and numerous empirical cases of authoritarian regimes that have successfully upscaled low-carbon energy sources has recently encouraged more critical perspectives towards the relationship between democracy and energy choices [80–82], paving the way for debate over when, how and why the very attributes of democratic regimes that were conventionally believed to promote transition (discussed above) can also obstruct the decarbonization of energy. For example, it is well documented that even in advanced democracies with well-established institutions and processes for participatory decision-making, politicians have often struggled to reach consensus between diverse stakeholders, particularly when competing interests such as fossil fuel lobbies and environmentalists wield significant political influence. Contrary to the conventional democracy thesis, a number of commentators conclude that the democratic process often results in inaction or stalled transition [19,24,83,84]. Similarly, while there are theoretical grounds for expecting electoral accountability to bind elected politicians to meet societal demands such as a safer climate and the avoidance of adverse effects that are expected to materialize if climate change reaches dangerous levels, publics can also demand that policymakers address other priorities that may, temporarily at least, conflict with transitions. This has been observed, for instance, in poor countries where economic development is likely to take precedence over climate mitigation [85–87] or fossil-fuel-rich countries, where economic stability and energy security are perceived as being dependent on the continued dominance of fossil fuels within the power sector [77,88]. More generally, the reluctance of many open political regimes to interfere in individual lifestyles and markets for the sake of climate mitigation (Bättig & Bernauer, 2009) draws attention to an important incompatibility between democracy and energy transition, which is all the more challenging when one considers the sheer scale of regulatory interventions and comprehensive nature of policy changes that are needed to decarbonize most national power sectors [89].

Drawing on these contradictory arguments about the influence of democracy on energy transition, we pose an open-ended set of hypotheses about the effect of democracy on the use of low-carbon energy sources:

Hypothesis 1A: *The share of low-carbon electricity generation in the national energy mix rises as the level of democracy within a country rises, ceteris paribus;*

Hypothesis 1B: *The share of low-carbon electricity generation in the national energy mix declines as the level of democracy within a country rises, ceteris paribus*

2.3. *Economic development and energy transition*

Debate over the implications of democracy for energy transition has prompted many studies investigating whether the consequences of democracy on national energy portfolios are contingent on the existence of certain facilitating conditions or characteristics of the democratic institutions. For example, some authors find that democracy is more conducive to energy transition when the decision-making process is accessible to a broad range of stakeholders rather than limited to narrow elites [24,83]. Others conclude that democracy tends to inhibit decarbonization in fossil-rich countries, while promoting it in fossil-poor countries and subnational regions [90–92]. The avenue of enquiry that has attracted the most attention in this respect, however, is the role of economic development in moderating the democracy effect. Structuralist scholars have long argued that unequal access to technology, know-how, financial capital and capacity in the global South obstructs climate mitigation in developing economies [85,93]. According to this view, mitigation performance is not just a question of capacity, but fundamentally, societal values and needs as developing countries are forced to prioritize basic needs relating to survival and material well-being while advanced economies have the 'luxury' of being able to focus on climate protection [93]. As attested to by the institutionalization of the principle of Common But Differentiated Responsibilities in the Kyoto Protocol to the UNFCCC [94], which confines binding carbon emission reduction targets to advanced economies, this position has come be widely accepted. To the extent that democratic institutions and processes make politicians more receptive to public and civil society demands, democratization should tend to harmonize climate and energy policy in line with public interests, which, to an important degree, are likely to be shaped by prevailing national economic conditions. Accordingly, in developing economies, lower living standards and greater energy poverty make it likely that democratization would be associated with greater public focus on economic development, even if this comes at the expense of climate protection, in contrast to advanced economies, where better living standards should arguably facilitate prioritizing climate vis-à-vis economic activity. This is supported empirically, for example, by Lagreid and Povitkina's (2018) study, which shows that economic development is associated with smaller increases in CO2 emissions in democratic countries with strong civil society activity [55]. Similarly, Bento's (2022) recent analysis finds that democratic institutions have a stronger CO2 emissions-reducing effect in developed economies compared to industrializing countries [95].

It is not difficult to see how these arguments might apply to energy transition. Most financial capital in low-carbon energy technologies is invested in North America, Europe and China, with developing countries (excluding China) receiving a mere 12% of the total global investment in modern renewable energy [96,97]. This is further compounded by unequal access to technology, know-how, and the difficulty of integrating low-carbon technologies with pre-existing energy systems while powering rapid economic development in industrializing or newly emerging economies [86]. Thus, in developing economic contexts, key stakeholders such as publics, private and public sector are likely to be opposed to transition due to legitimate concerns over reliability, energy security and, at least in the short-term, the perceived incompatibility between decarbonization of power and socio-economic development. To the extent that democracies provide more opportunities for public interest and civil society to influence policymaking, in poor economies, we expect that an increase in democratic institutions and process to obstruct transition from conventional to low-carbon energy sources. By contrast, advanced economies are likely to have higher capacity to compensate domestic losers from the transition by creating viable alternative income streams, making it easier for elected policymakers in these countries to reach agreement with opposing interests [15,98], while eliciting broader support for decarbonization from more climate-aware and, typically, climate-concerned publics in developed economies [99]. In keeping with this rationale, as with climate mitigation, a number of experts propose extending the principle of CBDR to include respective capabilities for transition so that high-income countries take the lead in providing the initial investments for low-carbon energy technologies and transfer additional finances until mechanisms develop that enable developing countries to make a progressively increasing contribution to decarbonization without infringing on their development rights. [100,101]

Quantitative research generally supports the proposed – positive – effect of economic development on energy transition. Most economic models find a significant positive relationship between economic development and renewable energy utilization [17,18,102]. In particular, a recent strand of the environmental Kuznets literature [103], which claims that the relationship between economic development and adverse environmental impacts follows an inverted 'U' shape, suggests that in weak economies, economic growth is initially associated with rising fossil-based energy generation, before eventually being associated with declining fossil and rising low-carbon energy in advanced economies [34,104,105]. [34,104,105]

We therefore expect democracy to become increasingly compatible with the decarbonization of energy as economic development rises, ceteris paribus.

Hypothesis 2*: As the level of economic development rises, the relationship between democracy and low-carbon electricity generation in the national energy mix becomes increasingly positive, ceteris paribus.*

3. Materials and Methods

3.1. Temporal-spatial domain

We use cross-sectional time series data to analyse the shares of solar, wind, hydro and nuclear energy used by 135 countries for electricity generation over 1980 to 2020. This time period spans many important developments in energy transition (both nationally and globally) as well as key milestones in the international political of climate change. By the 1980s, several industrialized economies had begun phasing out fossil fuel energy and upscaling low-carbon technologies such as hydro and nuclear power. Modern renewable energy sources (solar and wind) took relatively longer to take off – only accounting for a negligible share of power until the 1990s, but have continued to become increasingly important sources of electricity thereafter. The emergence of climate change on the international agenda in 1990, as well as subsequent institutionalization of mitigation commitments in the Kyoto Protocol in 1997 no doubt increased impetus for energy transition, at least in industrialized economies, which were assigned binding mitigation targets over the first commitment period (from 2005 - 2012). The adoption of the Paris Agreement in 2015 ushered in a period of more ambitious climate action and political debate over distributing responsibility for energy transition as most countries – including multiple key emerging economies – have committed to net zero and decarbonization targets.

The spatial domain was kept as wide as possible to ensure the inclusion of diverse countries that vary widely in terms of the dependent variables (the shares of low-carbon energy sources of the energy mix), key independent variables (democratic political regime characteristics and level of economic development) and other putative drivers of energy transition (discussed below). An observation is the percentage share of solar, wind, hydro or nuclear energy of the total energy used by a country for electricity generation in a given year, bringing the total number of (possible) observations to 5,535.[2]

3.2. Data sources

Table 1 summarizes the variables and data sources. We focus on the relative shares of four key low-carbon energy sources – solar, wind, hydro and nuclear. The first two sources are relatively modern renewable energy options, which, due to the small-scale of deployment (e.g. as solar panels on homes), are frequently heralded as key technologies for facilitating decentralized, participatory energy systems that are consistent with the emerging concept of energy democracy [17,20] but are challenging to integrate at scale into the electricity because of their variable nature. By contrast, in some respect, hydro and nuclear energy resemble conventional energy sources because their usage entails large-scale projects (e.g. building new power plants) that requires some degree of top-down centralized regulation and which provide relatively consistent 'baseload' power that is not sensitive to the time of day or other conditions. Therefore, focusing on four energy sources allows us to evaluate whether the influence of democracy varies across different scales of low-carbon energy source. Our dependent variables are thus

[2] After omitting observations with missing data, the total number of observations was equal to 3,759.

the percentage share of solar, wind, hydro and nuclear energy of the total energy mix used for electricity generation in a given country-year. Energy share data are available for the entire dataset and come from the 2022 International Energy Agency World Extended Energy Balances and Summary database.

Variable	Definition	Source
$SHARE(x)_{ij}$	Percentage share of low-carbon energy source X (solar, wind, hydro or nuclear) of total energy used for electricity generation in a given country-year.	International Energy Agency World Extended Energy Balances and Summary
DEM_{ij}	Level of democracy in a country-year.	V-Dem polyarchy index. Scores range from 0 (very undemocratic) to 100 (very democratic). Additional democracy proxies (P2 and FH) used for robustness tests are described in the appendix.
$FRENT_{ij}$	Percentage share of rents from fossil fuels of total GDP in a given country-year	International Energy Agency World Extended Energy Balances and Summary
GDP_{ij}	Per capita GDP (in US$) in a given country-year	World Bank Development Indicators
$GDPGROWTH_{ij}$	Percentage growth in GDP since the previous year	World Bank Development Indicators
$lnLAGX_{ij,(i-1)}$	One-year lagged percentage share of low-carbon energy source (X) of the total energy used for electricity generation	International Energy Agency World Extended Energy Balances and Summary
$TOTAL_{ij}$	Growth in total energy generation as a percentage change from the previous year.	International Energy Agency World Extended Energy Balances and Summary
POP_{ij}	Population growth as a percentage change from the previous year.	World Bank Development Indicators
$MANU_{ij}$	Percentage share of manufacturing sector of total GDP	World Bank Development Indicators
$SERVICES_{ij}$	Percentage share of services of total GDP	World Bank Development Indicators

Table 1: Variables and data sources.

We measure democracy by drawing on three leading databases that are used for operationalising democracy in political science – namely, the Varieties of Democracy polyarchy index (V-DEM), a combined score consisting of the Freedom House (FH) political rights and civil liberties indices and Polity II (P2) index of the Polity IV Project. The V-DEM results, which are reported in the main text, reflects the fulfilment of the electoral ideal of democracy based on aggregate performance across a range of core democratic dimensions (i.e., freedom of association, clean elections, freedom of expression, elected executive and suffrage) in a country-year.[3] FH and P2 data are used to test robustness of proxy choice. All data are normalized from 0 (very undemocratic) to 100 (very democratic).

GDP and per capita GDP are significantly associated with our dependent variables, warranting their inclusion as separate variables. Since the latter provides an insight into socio-economic level of development and general living standards, we use per capita GDP to analyse how democracy schedules may vary as a function of economic development. GDP data are obtained from the World Bank Development Indicators.

We include additional variables to control for potential confounding effects from other putative drivers of low-carbon energy use that are identified in the literature. Previous research suggests that countries that rely on fossil fuel rents as a major income source tend to be reluctant to phase out fossil-based energy, providing grounds for expecting an inverse relationship with low-carbon energy use [88,106]. Therefore, we control for fossil rents as a share of national income using data from the World Bank Development Indicators. We expect that a country's existing energy portfolio and infrastructure create biases in favour of further expansion of dominant energy sources [107]. We therefore control for pre-existing levels of low-carbon energy sources by (separately) including the level of (in TWh)solar, wind, hydro and nuclear energy sources used for electricity generation in the previous country-year using data from the IEA WEEBS database.[4] Population growth and growth in total energy generation are likely to increase electricity demand, and are therefore modelled using World Bank Development Indicators (WBDI) data.[5] Preliminary tests on our dataset showed that low-carbon energy shares are significantly associated with key sectors of the economy – manufacturing and services. Drawing on past research [108], we expect the former to be inversely related and the latter positively related with low-carbon energy shares. Therefore, we use WBDI data to control for the percentage shares of each industry of GDP. Descriptive statistics for all variables are shown in Supplementary Table 1.

3.3. *Approach*

Most existing quantitative work employs ordinary least squares (OLS) regression to study energy portfolios [18,59,109,110]. Yet, consistent with a minority of other studies that address the issue of clustering in energy portfolios [17,99] and other indicators of transition (most prominently CO2 emissions) [6,111,112], we find that our dataset violates the critical independence assumption of OLS analysis: that is, observations of low-carbon energy shares of energy portfolios used for electricity generation are more likely to be similar if they are from the same country compared to observations from different countries. Table 2 shows the statistical proof behind this claim by reporting the share of variation in solar, wind, hydro and nuclear energy usage shares at the country and country-year levels in the null models (excluding any controls) of the dataset. For all four energy sources, a significant portion of total variance occurs between, rather than within, different countries. For the small-scale variable renewables (solar and wind), between-country variance accounts for 11 and 27 percent of total variance respectively, which, according to established diagnostic criteria for multilevel regression [35], warrants the use of a hierarchical approach. Strikingly, for the centralized energy technologies (hydro and nuclear), country-level clustering accounts for the vast majority of all variation (around 90 percent). Crucially, failure to account for country-level clustering in low-carbon energy shares is likely to assume that parameters are fixed [112] and significantly underestimate the standard errors [111], resulting in erroneous inferences about the drivers of energy transition. The LR test results, which compare the goodness of fit of the two-level models with the equivalent single level regression are highly significant ($p<0.0001$), further justifying the use of the proposed hierarchical model.

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[3] Interested readers are referred to the V-Dem codebook for a detailed discussion of the index methodology: Coppedge, M, et al (2021) 2021. "V-Dem Codebook v11.1" Varieties of Democracy (V-Dem) Project. https://www.v-dem.net/static/website/img/refs/codebookv111.pdf.

[4] IEA WEEBS is accessible at: https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances.

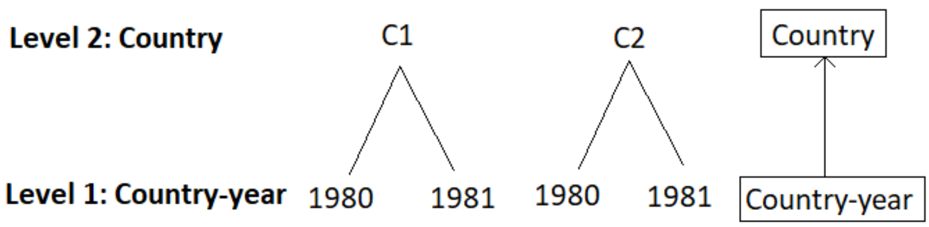
[5] WBDI can be accessed at: https://databank.worldbank.org/source/world-development-indicators.

Parameter	Solar	Wind	Hydro	Nuclear
Country variance	0.10*** (11.23)	2.98*** (27.09)	1013.83*** (91.50)	174.67*** (90.00)
Country-year variance	0.79*** (88.77)	8.02*** (72.91)	93.72*** (8.50)	18.92*** (10.00)
LR test	382.27***	1322.07***	12139.14***	11401.31***

Table 2: Null model results showing variance in low-carbon energy shares at the country and country-year levels. Entries are maximum likelihood estimates with percentage variance shares in parentheses. * denotes Significant at 5% ($p < 0.05$), **Significant at 1% ($p < 0.01$), *** Significant at 0.01% ($p < 0.001$).

We therefore employ a two-level model consisting of country-years nested in countries alongside a 'flat' OLS specification for reference. The proposed hierarchical data structure is shown in Figure 1.

Figure 1: Unit and classification diagram showing the proposed two-level data structure.



We employ a series of four models to explore the drivers behind the shares of solar, wind, hydro and nuclear energy used for electricity generation. The first model is an OLS regression that includes the full set of control variables from Table 3. Model 2 is a random intercept model that introduces the hierarchical data structure by distinguishing between observations (energy shares) based on their country, providing an insight into typical democracy effects within countries. The third, random coefficient model adds further nuance by allowing the democracy schedule to vary across countries. We use the country-specific democracy effects estimated by this model to conduct detailed analysis of variation in effect sizes, directions and significance levels across countries and setup a second regression to formally evaluate the influence of economic development (and other putative moderating factors) in shaping the democracy effect on low-carbon energy usage. The fourth model uses an interaction term (between per capita GDP and democracy) to conduct an alternative test of the moderating role of economic development over country-specific democracy effects on low-carbon energy shares.

Our econometric specification with interaction effects (model 4) is:

$$SHARE_{(X)ij} = \beta_0 + \beta_1 DEM_{ij} + \beta_2 lnLAGX_{ij,(i-1)} + \beta_3 POP_{ij} + \beta_4 GDP_{ij} + \beta_5 GDPGROWTH_{ij} + \beta_6 XRENT_{ij} + \beta_7 MANU_{ij} + \beta_8 SERV_{ij} + \beta_9 TOTAL_{ij} + \beta_{10} ANNEX_{ij} + \beta_{11} DEM_{ij} \, X \, GDP_{ij} + u_{1j} DEM_{ij} + u_j + e_{ij}$$

where $SHARE(X)_{ij}$ is the percentage share of fossil energy source X of total energy used for electricity generation in country-year i (i = 1,…,3,759) in country j (j = 1,…,135) and u_j and e_{ij} denote country and country-year residual error respectively. The variable names are those defined in Table 3 above.

4. Results

Tables 3-4 summarize the empirical results of the first three models we use to analyse the relationship between democracy and low-carbon energy shares. Model 1 displays the estimates of the OLS regression, which represents the predominant quantitative approach in the field. It is noteworthy that while the democracy coefficient is not statistically significant in the solar and wind regressions, it is highly significant in the hydro and nuclear models (at the $P<0.001$ level). If the analysis were to end here, we would conclude that while small-scale renewable energy shares appear to be autonomous of democracy, the democracy effect on large-scale low-carbon sources is in accordance with the conventional – positive – thesis (Hypothesis 1A): even a small (one-point) increase in the V-Dem index (which ranges from 0 to 100) is associated with a 0.13 percent increase in the share of hydro and 0.04 percent increase in nuclear energy used for electricity generation. The apparent positive association between democracy and deployment of large-scale low carbon energy would be consistent with the conventional thesis that democracy promotes energy transition and climate policy [8,20,23,24].

Parameter	Solar				Wind			
Model	1	2	3	4	1	2	3	4
Fixed effects								
Democracy	-3.81E-4	-0.01T	-0.02*	-0.04**	0.01T	-0.01**	-0.01**	-0.03***
Lagged deployment	8.28E-4***	7.75E-6***	7.05E-5***	7.58E-5***	9.20E-5***	6.78E-5***	6.62E-5***	5.90E-5***
Pop growth	-0.02T	-0.03	-0.04*	-0.03T	-0.35***	-0.26***	-0.27***	-0.24***
GDP per cap	1.39E-6***	2.32E-5***	2.38E-4***	7.06E-7	6.97E-6***	1.37E-4***	1.37E-4***	-1.10E-4***
GDP growth	-0.01	0.01	8.68E-4	-7.50E-5	0.01	0.01	0.03	-4.19E-4
Resource rent	0.03	0.02	2.03E-3	-0.01	0.01T	3.11E-4	-0.02	-0.03*
Manuf. share	-0.01***	-0.02***	-0.01***	-0.01**	-0.03***	-0.02	-0.03*	0.01
Services	0.01***	0.01***	0.01***	0.01***	0.01	0.03***	0.03**	0.03***
Total elec. gen.	-4.31E-7***	-5.97E-7***	-5.64E-7***	-5.13E-7***	-2.15E-6***	-2.02E-6***	-1.90E-6***	-1.37E-6***
Random effects								
Country dem. var.	-	-	2.56E-4***	3.20E-5***	-	-	9.64E-3***	0.01***
Country variance	-	0.17***	0.07***	0.03***	-	6.26***	2.43***	0.58
Country-year var.	-	0.78***	0.78***	0.78***	-	7.37***	7.27***	6.94***
LR test	-	355.24***	379.24***	373.17***	-	1286.78***	1332.78***	1436.57***
R2 (or equiv.)	0.22	0.23	0.24	0.25	0.23	0.24	0.26	0.25
N	3759	3759	3759	3759	3759	3759	3759	3759

Table 3: Effects of democracy and potentially confounding factors in solar and wind energy shares (1980 to 2020).

Entries are maximum likelihood estimates with percentage variance shares in parentheses. * denotes Significant at 5% ($p < 0.05$), **Significant at 1% ($p < 0.01$) and *** Significant at 0.01% ($p < 0.001$).

Parameter	Hydro				Nuclear			
Model	1	2	3	4	1	2	3	4
Fixed effects								
Democracy	0.13***	-0.16***	-0.19***	-0.18***	0.04***	0.01*	0.01	0.02T
Lagged deployment	2.29E-4***	2.79E-5*	1.77E-5	1.56E-5	6.91e-5***	9.69E-5***	9.61E-5***	9.60E-5***
Pop growth	2.79***	1.22***	1.19***	1.26***	-2.12***	-0.07	-0.06	-0.05
GDP per cap	-9.18E-5*	-1.77E-4***	-1.72E-4***	-2.80E-4*	1.19E-4***	-2.61E-6***	-2.78E-6***	6.06E-6T
GDP growth	-0.09	0.01	002	0.02	-0.09**	0.01	0.04	0.01
Resource rent	0.04	0.01	0.04	0.07	-0.12***	-0.01	-0.01	0.01
Manuf. share	-1.02***	-0.27***	-0.23***	-0.22***	0.12***	-0.02	0.02T	0.02
Services	-1.05***	-0.24***	-0.24***	-0.24***	-0.08***	0.02	0.01	0.01
Total elec. gen.	-3.03E-5***	-4.83E-6*	-3.24E-6	-2.68E-6	-5.70E-6***	-2.56E-6***	-2.51E-6***	-2.62E-6***
Random effects								
Country dem. var.	-	-	0.17***	0.01***	-	-	0.01***	0.01***
Country variance	-	974.46***	1286.87***	0.58	-	131.04***	115.78***	115.25***
Country-year var.	-	78.64***	67.20***	6.94***	-	7.45***	7.10***	7.07***
LR test	-	8418.53***	8744.97***	1436.57***	-	8672.92***	8765.88***	8625.44***
R2 (or equiv.)	0.23	0.25	0.28	0.25	0.27	0.28	0.30	0.56
N	3759	3759	3759	3759	3759	3759	3759	3759

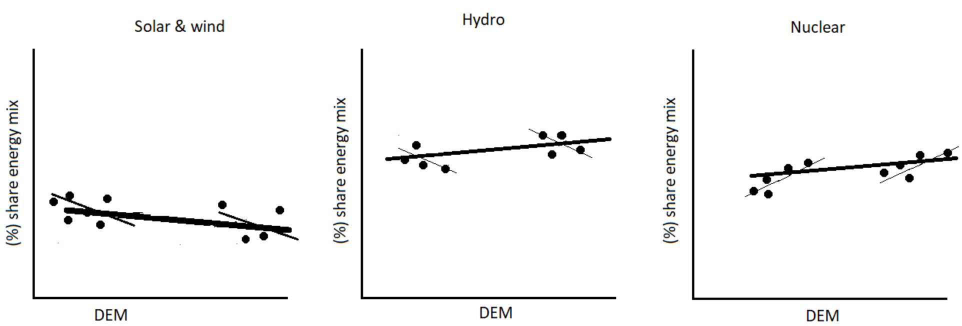
Table 4: Effects of democracy and potentially confounding factors in hydro and nuclear energy shares (1980 to 2020).

Entries are maximum likelihood estimates with percentage variance shares in parentheses. * denotes Significant at 5% ($p < 0.05$), **Significant at 1% ($p < 0.01$) and *** Significant at 0.01% ($p < 0.001$).

Yet the results change significantly once we begin modelling the hierarchical structure of the dataset. By distinguishing between observations based on country of origin, model 2 (the RIM) offers a stronger test of the democracy thesis since it evaluates whether the democracy estimates obtained in the flat regression are still valid once country-level clustering is accounted for. Strikingly, the democracy coefficient is negative and approaches significance (P=0.090) in the solar model, while being negative and highly significant (P<0.001) in the wind and hydro regressions. Collectively, these results provide strong evidence that increases in the level of democracy within countries, which we refer to as democratization, are associated with declining shares of three key low-carbon energy sources. While, for solar and wind; a one-point increase in the democracy score is associated with a 0.01 percent decline in the relative energy share, the magnitude is rather striking in the case of hydro as the same increase in democracy is associated with a 0.16 percent decline in the share of the energy mix. In this respect, the nuclear RIM results stand out from the other energy sources as the negative democracy coefficient indicates that increases in democracy both between and within countries are always associated with increasing nuclear shares. How do the RIM results fit with previous research? Since most existing quantitative analyses of democracy and energy portfolios focus on cross-sectional, rather than within-country, differences in democracy, they are comparable with the results of our first – OLS - model (discussed above). An important exception to this is Bayulgen and Ladewig's (2016) study, which employs a RIM to investigate the drivers of hydro and non-hydro renewable energy shares [17]. Contrary to our results, they find that democracy is positively associated with hydro electricity generation while not being significantly associated with non-hydro renewable energy. Notably, however, their analysis spans an earlier time frame (from 1974 – 2012), which, given the rapid increase in hydro and particularly, solar and wind energy deployment since 2010, could account for the apparent non-significance of democracy for non-hydro renewables and inverse hydro relationship in their model.

Comparing the democracy coefficients across the OLS and RIM models reveals important differences in the relationship between democracy and low-carbon energy sources between and within countries. While the OLS results suggest that moving from less to more democratic countries is associated with an increase in the share of hydro and nuclear energy (without any significant change in the shares of solar and wind), the RIM results suggest that increases in democracy within the same country are inhibitory to solar, wind and hydro usage, while being (weakly) conducive to nuclear energy. Figure 2 depicts the divergence between interstate and intrastate democracy effects. Crucially, accounting for country-level clustering suggests that more critical assessments about the inhibitory implications of democracy for energy transition are valid for most low-carbon energy sources longitudinally, if not cross-sectionally. Similar divergences between country-specific and inter-state democracy effects have been reported by previous research about the relationship between democracy and other climate policy outcomes (most notably CO2 emissions) [6,9].

Figure 2: Cluster confounding in between versus within country effects of democracy on low-carbon energy sources implies by the OLS and RIM regressions (models 1 and 2, Tables 3-4).



Note: Each point represents country-years, thin lines within country and thick lines between country effects.

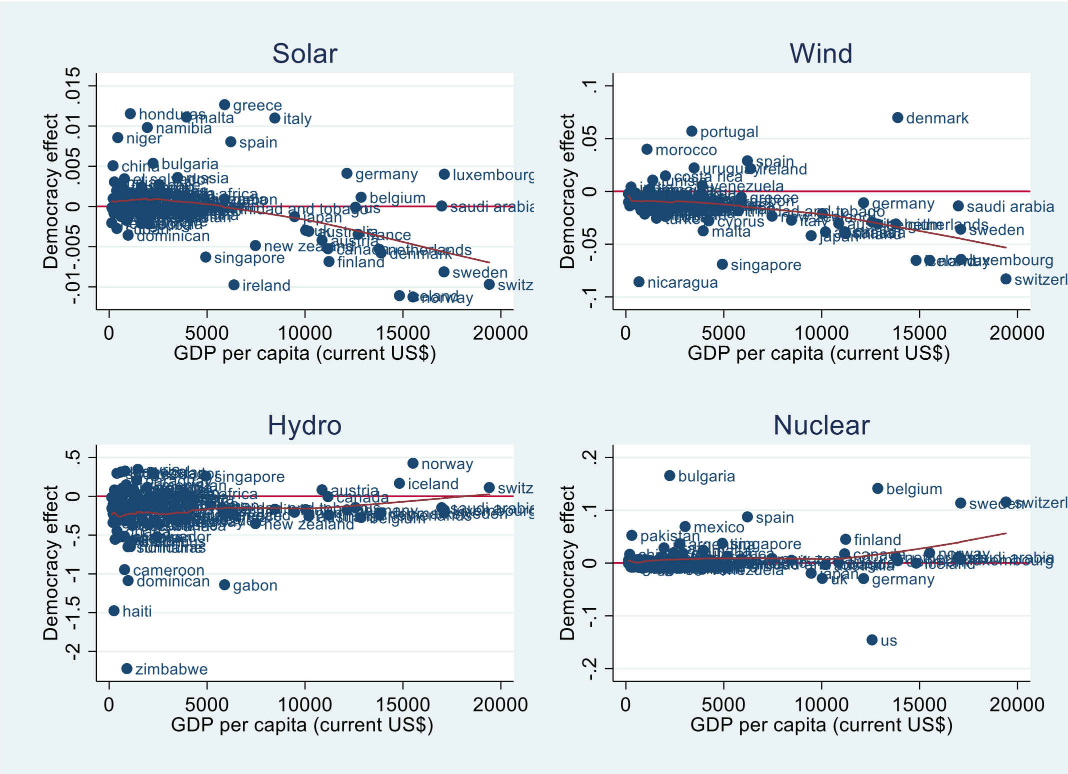
We now move on to ascertaining whether democratization (i.e, increases in the level of democracy within the same country) has uniform effects across countries. In other words, does democratization always inhibit solar, wind and hydro and promote nuclear energy usage and, if not, are these effects contingent on certain conditions? Models 3 and 4 go some way towards answering these questions. The random coefficient model (RCM) estimates a separate democracy schedule for each country. The fixed democracy effect is significant and negative for solar, wind and hydro energy, indicating that democratization tends to inhibit the use of these energy sources. By contrast, the fixed democracy estimate does not attain significance in the nuclear RCM. Crucially, this does not mean that democracy is not an important driver of nuclear energy shares. On the contrary, the random democracy effect is highly significant for all low-carbon energy sources, which is a strong indication that, although democratization tends to be inhibitory for solar, wind and hydro, and indeterminate for nuclear energy, its effect varies significantly across different countries, warranting closer examination of the implications of democracy on decarbonization on a country-by-country basis. Crucially, the random democracy coefficient continues to be significant at the $P<0.001$ level when democracy is coded using FH and P2 data (Supplementary Tables 2-3). The high significance of the LR test statistic ($P<0.001$), which compares the RCM with the equivalent single-level regression and increase in the R2 equivalent on moving from the RIM to the RCM provide further evidence that the democracy- energy schedules vary significantly between different countries.

These findings are not directly comparable to existing research since, to our knowledge, no previous studies of energy portfolios employ random effects models to investigate the relationship with democracy. Nonetheless, from a methodological perspective, it is possible to compare our RCM results with other studies that employ random effects models to investigate the influence of democracy on CO2 emissions, which may be regarded as a distinct, but relevant, indicator of energy transition. Crucially, despite important differences in the time periods and constellations of countries included in other datasets, the results of previous random effects analyses of democracy on climate outcomes cohere with our core finding that the relationship between democracy and low-carbon electricity generation varies significantly between different countries [9,28,111].

Is it possible to say anything more general about how and why the effect of democratization varies across countries? Figure 3 plots the estimated country-specific democracy effects predicted by our third model (the RCM without interaction effects) for each energy source as a function of economic development (measured as country-mean per capita GDP). The distribution of democracy effects across the y-axis shows the variation in the sign and magnitude of the effects across the different countries. Strikingly, democratization promotes low-carbon energy usage in countries that are located above the y-axis, while inhibiting usage in countries that fall below it. The nonparametric lowess (locally weighted scatterplot smoothers) curves, which estimate moving averages across the scatterplot to generate a smooth trendline, suggest a negative relationship between economic development and democratization effects on small-scale low-carbon energy sources: for solar and wind, democratization tends to have increasingly inhibitory effects on solar and wind energy shares as we move from less to more developed economies on the right of the x-axis. These results contradict previous research on the relationship between economic development and small-scale renewable electricity generation (e.g. [17,18,102]), which provided the rationale for our second hypothesis that democracy is more compatible with energy transition in advanced economies. On the contrary, the apparent adverse relationship between national income and solar and wind electricity generation suggests the very opposite scenario; that democratization becomes increasingly inhibitory with economic development. A possible justification for this unexpected finding is that, compared to centralized large-scale energy technologies (including fossil fuel, hydro and nuclear plants) small-scale low-carbon energy technologies provide a more accessible and, therefore, viable option for developing economies to meet a key regional priority of improving energy access [87], thereby counteracting the expected negative influence of economic development on democracy. In contrast, the upward sloping nuclear lowess curve suggests a mild positive association between democratization and per capita GDP, which supports our second hypothesis and previous findings that economic development increases the positive effect of democratization on low-carbon energy utilization by increasing mitigative capacity and public demand for climate mitigation [15,99]. The flat slope of the hydro lowess, on the other hand, suggests an indeterminate relationship between economic development and democracy effects on hydro energy shares. While the absence of random effects studies on democracy, economic development and energy portfolios makes it difficult to compare the country-specific democracy effects predicted by our RCM with previous research, the hydro lowess curve depicted in Figure 3 coheres with other quantitative studies that model democratic and economic drivers of renewable electricity generation, which also find that hydro energy usage is not significantly associated with economic development [17,113].

Supplementary Figure 1 shows the predicted country-specific democracy effects as a function of country mean democracy levels from 1980 to 2020, which capture a country's accumulated level of democratic stock over the time period under investigation. Both sets of lowess curves follow similar paths, although, compared to the per capita GDP curves, the country mean lowess curves are noticeably flatter suggesting a weaker relationship between a country's mean democracy level and the effect of democratization on low-carbon energy usage.

Figure 3: Random country effects of democratization on low-carbon energy shares as a function of per capita GDP.



Note: Points represent country-specific democracy effects of a one-point increase in a country's V-Dem score on the percentage share of the energy source used for electricity generation (as a fraction of total energy). Estimates are from model 3 in Tables 3-4.

Drawing on established approaches for evaluating random effects predicted by hierarchical (random coefficient) modelling [114], we also conduct a more formal test of the influence of economic development on the effect of democratization on low-carbon energy sources by utilizing the predicted within-country democracy effects estimated by the RCMs as dependent variables to determine whether their differences can be explained by countries' levels of economic development, fossil fuel rents and pre-existing democracy level. Table 5 provides the results of an OLS regression that regresses the predicted random democracy effects depicted in figure 3 with (country mean) per capita GDP, fossil fuel rents as a percentage share of national income and democracy (as measured by a country's V-DEM score).

Parameter	Solar	Wind	Hydro	Nuclear
Mean per capita GDP	-1.43E-7***	-1.01E-6***	3.60E-6	5.83E-7*
Mean fossil rents	2.50E-5	1.61E-4	0.01	-1.44E-4
Mean democracy	2.64E-5	2.40E-4*	5.06E-5	-6.20E-6
Adj. R2	0.15	0.24	0.00	0.06
n	108	106	106	105

Table 5: The influence of (country mean) economic development, fossil rents and democracy over country-specific democracy effects on low-carbon energy shares.
* denotes Significant at 5% ($p < 0.05$), **Significant at 1% ($p < 0.01$) and *** Significant at 0.01% ($p < 0.001$).

The results cohere with the inferences we drew from Figure 3. That is, economic development plays a significant role in moderating the effect of democratization on the energy shares of solar, wind and nuclear, but not hydro. Contrary to Hypothesis 2, we find an inverse relationship between per capita GDP and democracy effects on the small-scale technologies, which indicates that democracy has an increasingly inhibitory effect on solar and wind energy shares. In contrast, the positive sign of the per capita GDP coefficient in the nuclear model coheres with the expected – positive – moderating effect that democratization becomes increasingly compatible on nuclear energy utilization in tandem with economic development. In contrast the carbon curse scholarship [88,90], which suggests that democracy effects on energy portfolios should be contingent on fossil fuel endowments, we found that the share of fossil fuel rents of national income has no significant moderating effect on country-specific democracy effects. A country's mean level of democracy over the time period of investigation (1980 – 2020) was positively associated with the effect of democratization on wind energy shares ($P<0.05$). Negative stepwise tests indicated that economic development explains 10% of the variance of democracy on solar, 14% on wind and three percent on nuclear energy shares. These findings demonstrate that democracy becomes increasingly inhibitory on the use of small-scale low-carbon technologies with rising economic development. By contrast, democratization increasingly promotes nuclear energy usage as national income increases.

As an alternative approach, we introduce an interaction term to model the moderating effect of economic development on democracy in our core specification. Model 4 in Tables 3-4 presents the results of a RCM with an interaction term that models the potential moderating effect of economic development on democracy. Consistent with the previous results, the interaction term is highly significant ($P<0.001$) in the solar, wind and nuclear, but not hydro, regressions. The interaction between economic development and democracy continues to be statistically significant at the $P<0.001$ level for all iterations of the solar, wind and nuclear models when we replace the V-Dem additive polity index with FH and P2 data (reported in Supplementary Tables 2-3). It is also worth noting that the interaction term is significant for hydro energy shares when democracy is operationalized using FH, but not V-Dem or P2, data, suggesting that hydro utilization is more sensitive to prevailing individual rights and liberties, which are given more weight in FH coding compared to V-Dem and P2, compared to other energy sources.

5. Conclusions

As proponents of just transition and energy democracy contend [13,20], it is generally assumed that democracy is conducive to energy transition. This article speaks to rising calls to interrogate this assumption empirically [19,63,83]. By employing a novel large-N dataset spanning most countries from 1980 to 2020, we substantiate the claim that democracy is indeed an influential driver of the decarbonization of power. Even when country-level clustering is accounted for, our results show that fluctuations in the level of democracy within the same country significantly affect the use of four key low-carbon energy sources – solar, wind, hydro and nuclear energy – for electricity generation. This continues to be true irrespective of which democracy proxy one chooses.

However, the results also show that democracy has different – often contradictory – effects between and within countries. While democracies tend to use higher shares of hydro and nuclear energy compared to non-democracies, we observe no significant cross-sectional differences between closed and open political regimes in relation to solar or wind energy. Yet the implications of democracy change markedly when we model within-country effects – bouts of democratization within the same country are associated with falling shares of most low-carbon energy sources (solar, wind and hydro). In this respect, the democracy-nuclear energy schedule differs from the schedules that we find for the other energy sources as nuclear energy shares tend to rise in tandem with more democratic conditions. The positive association between democracy and large-scale (hydro and nuclear) energy shares that we find between-countries and the positive within-country effects of democratization on nuclear energy cohere with the conventional thesis that democracy promotes energy transition [17,18,21,24–26]. By contrast, the negative within-country effects of democratization on solar, wind and hydro energy within countries appear to justify more critical assessments of the implications of democracy for energy transition [29,31,38].

Our results provide robust evidence that comparable increases in democratic conditions and processes can have very different outcomes on low-carbon energy shares depending on the country of analysis. That is, within the same country, bouts of democratization sometimes strongly inhibit, but in other countries, promote the use of low-carbon energy. From a methodological perspective, these finding make a compelling case for employing random effect modelling to study the influence of democracy on energy transition.

These findings also help develop theoretical discussions on the linkage between democracy and energy transition by depicting a more heterogenous and nuanced relationship that varies across different low-carbon energy sources. In addition, we also contribute to understandings of the source of divergent democracy effects by empirically evaluating whether (at least some of) the variation stems from a nation's level of economic. The posterior estimates of country-specific democracy effects predicted by the RCMs and second-order regressions between random democracy effects and economic development provide consistent evidence that economic development does indeed play an important role in moderating the democracy effect solar, wind and nuclear, but not hydro, energy utilization. However, contrary to widespread expectations in the literature [34,104,105], we found that economic development tends to increase the inhibitory effect of democratization on small scale energy sources, while having the predicted positive effect on democracy-nuclear energy schedules. Drawing on the sustainable energy transitions literature, we argued that these unexpected negative moderating effects might reflect important advantages of small-scale energy technologies over centralized (high- and low-carbon) energy sources for weak economies. That is, by bypassing the need for a strong state apparatus to plan, implement and finance large-scale energy projects, solar and wind energy might facilitate developing countries overcoming energy poverty [87] and meet future rising energy demand [115] at lower cost than conventional, large-scale options.

What are the policy implications of these findings? On the one hand, the positive relationship between democratization and use of solar and wind energy in developing economies, which happen to be the main focus of most democratization initiatives, provides new grounds for optimism that the global South could go on to assume an important role in global mitigation and decarbonization efforts. Yet an alternative reading of these results is that it may be more difficult to upscale small scale low-carbon technologies in advanced economies, which, given increasing efforts to democratize energy decision-making through initiatives such as citizens juries and avenues of public consultation, appears to substantiate structuralist claims that the global North is better suited to hosting large-scale centralized energy technologies that require higher start-up investments and stronger governance capacities [85,86,97].

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