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Drivers of Scalar Biases: Environmental Justice and the Portuguese Solar Photovoltaic Rollout

Siddharth Sareen[i]

ABSTRACT

Studying the dynamics of solar photovoltaic (PV) rollout can generate insights on how policies enable and constrain energy transitions. This energy source has low carbon emissions, and has rapidly become economically competitive. This combination makes it one of the fastest growing energy technologies globally. Yet its rollout is spatially uneven, and slowed down by drivers other than cost and environmental impact, namely energy infrastructure, regulatory inertia, and political dynamics. These drivers of scalar biases make the rollout of solar energy along environmentally just lines challenging. This article analyzes the solar PV rollout in solar-rich Portugal during 2017–2020 to illustrate these drivers. The way solar PV layers on top of existing electric grid infrastructure determines the geography of its rollout. The path dependence of sectoral regulations modulates which actors are able to drive this technological diffusion. The particular political moment, unfolding contestation, and orchestrated consensus are decisive for both the rate and manner of growth of solar PV energy. The three drivers promote large-scale solar PV, whereas small-scale projects for households and communities remain limited. Empirical study of these drivers and how they combine in a specific context are key to understand the scalar environmental justice effects of policies for energy transitions.

Keywords: regulatory inertia, energy infrastructure, political dynamics, energy transitions, Portugal, scalar bias

DEFINING THE SCALAR PROBLEM OF SOLAR PHOTOVOLTAIC ROLLOUT

An energy transition is a shift in energy systems. These systems include energy sources, technologies, infrastructure, markets, and social use. Solar photovoltaic (PV) energy is one of the fastest growing parts of energy transitions globally.[1] It has rapidly become a highly affordable low-carbon technology. In countries such as Portugal with abundant sunshine, this renewable energy source has gone below grid parity prices,[2] and can compete at wholesale electricity market prices. This grid parity is a radical development, unanticipated in industry outlooks a decade ago. It coincides with high climate mitigation ambitions in countries such as the European Union member states,[3] in response to global anthropogenic climate change. Owing to these new climate targets, countries are trying to increase the proportion of solar energy in electricity supply.

Dr. Siddharth Sareen is an associate professor at Department of Media and Social Sciences, University of Stavanger, Stavanger, Norway.
[i]ORCID ID (https://orcid.org/0000-0002-0826-7311).

[1]Felix Creutzig, Peter Agoston, Jan Christoph Goldschmidt, Gunnar Luderer, Gregory Nemet, and Robert C. Pietzcker. ‘‘The Underestimated Potential of Solar Energy to Mitigate Climate Change.’’ *Nature Energy* 2 (2017): 1–9.

[2]Fernando M. Camilo, Rui Castro, M.E. Almeida, and V. Fernão Pires. ‘‘Economic Assessment of Residential PV Systems with Self-Consumption and Storage in Portugal.’’ *Solar Energy* 150 (2017): 353–362.

[3]Kacper Szulecki, Severin Fischer, Anne Therese Gullberg, and Oliver Sartor. ‘‘Shaping the ‘Energy Union’: Between National Positions and Governance Innovation in EU Energy and Climate Policy.’’ *Climate Policy* 16 (2016): 548–567.

Solar PV has a temporally variable production profile,[4] only generating energy during certain times of day and with variance during annual cycles. As the proportion of solar energy in electricity supply grows, energy markets, therefore, begin to value energy flexibility—the ability to balance energy supply and demand. Regulations for the electric grid begin to allow two-way flows of electricity, both consumption and prosumption—the latter refers to users producing solar energy and selling it back through the electric grid. The need for, and use of, infrastructure for electricity transmission and distribution also changes with these changing spatial patterns of energy production,[5] offering rich scope for more distributed resilient energy systems and ownership models rather than traditional top-down centralized control. Distributed solar rollout can reconfigure energy systems that are historically exploitative, unjust, and even vulnerable to climate change, in favor of just, propeople, resilient energy generation, distribution, and consumption.[6]

But what happens as these dynamics unfold, in terms of environmental justice across scales? The need to achieve national targets combines with existing barriers to spatially distributed energy generation. This drives scalar biases in solar energy rollout,[7] rather than boosting community resilience. The drivers that determine these biases—and hence justice outcomes–in the Portuguese case are the subject of this article. Large-scale spatially concentrated solar energy projects have appeared. Meanwhile, households, small businesses, and communities have lacked attractive options to contribute to and benefit from distributed small-scale solar PV rollout.[8] Since energy transitions entail large shifts in infrastructure and the functioning of energy systems, it is important to identify the drivers of such scalar biases, so that they are addressed in energy policies. Policies that are blind to such drivers may promote energy transitions that exacerbate inequity, benefit a narrow group of actors, and fail to channel the full range of options in democratic ways and consequently lack long-term political support.

This article uses key empirical data from a multiscalar study of solar PV rollout in Portugal during 2017–2020, to show how three drivers of scalar biases can impact environmental justice outcomes during an energy transition. These drivers are energy infrastructure, regulatory inertia, and political dynamics. Environmental justice outcomes are specified at multiple scales (cf. Hendriks[9]). They range from changes in national policy to auctions for solar PV, and from investment in transmission infrastructure to rules for energy communities (communities that produce, trade, and manage their energy). The article provides an understanding of how scalar biases and their underlying drivers can be barriers to just solar energy transitions, building on the growing intersection of scholarship on just energy transitions and environmental justice.[10] Policies for energy transitions must address these drivers. Portugal is an appropriate context to study these drivers during 2017–2020, as this period precedes an announcement by its incumbent energy company Energias de Portugal (EDP) in 2020 regarding closure of Portugal's two remaining coal power plants in 2021. This signifies the country's increasing reliance on renewable energy sources, and the importance of ensuring a just transition.

The Three Drivers of Scalar Biases: Energy Infrastructure, Regulatory Inertia, and Political Dynamics section presents the three drivers and anchors them in relevant streams within energy social science research, especially energy geographies and political economy. The Background, Case Selection, and Methodology: The Solar PV Rollout in Portugal Before 2017 section introduces the solar PV rollout case in Portugal and provides background details, with emphasis on key developments up to 2017, around when solar PV reached grid parity in Portugal. It includes details on case selection and methodology. The Scalar Biases in Solar PV Rollout in Portugal During 2017–2020 section addresses the study period of rapid sectoral evolution during 2017–2020. It analyzes key scalar biases supported by evidence for the Portuguese rollout, including 80 expert interviews during 5 months of data collection. The Discussion and Conclusion: The Drivers of Scalar Biases and Energy Transition Policies section discusses the drivers underlying scalar biases in terms of the broader implications for energy transition policies and environmental justice

[4] Elias Sanz-Casado, Maria Luisa Lascurain-Sánchez, Antonio Eleazar Serrano-Lopez, Birger Larsen, and Peter Ingwersen. ''Production, Consumption and Research on Solar Energy: The Spanish and German Case.'' *Renewable Energy* 68 (2014): 733–744.

[5] Gavin Bridge, Stefan Bouzarovski, Michael Bradshaw, and Nick Eyre. ''Geographies of Energy Transition: Space, Place and the Low-Carbon Economy.'' *Energy Policy* 53 (2013): 331–340.

[6] Karl S. Zimmerer. ''New Geographies of Energy: Introduction to the Special Issue.'' *Annals of the Association of American Geographers* 101 (2011): 705–711; Jonathan Rutherford and Olivier Coutard. ''Urban Energy Transitions: Places, Processes and Politics of Socio-Technical Change.'' Urban Studies 51 (2014): 1353–1377; J.A.M. Hufen and J.F.M. Koppenjan. ''Local Renewable Energy Cooperatives: Revolution in Disguise?.'' *Energy, Sustainability and Society* 5 (2015): 1–14; Jenny Rinkinen, Elizabeth Shove, and Jacopo Torriti (eds). *Energy fables: Challenging ideas in the energy sector*. (London: Routledge, 2019). Siddharth Sareen and Håvard Haarstad. ''Decision-Making and Scalar Biases in Solar Photovoltaics Roll-Out.'' *Current Opinion in Environmental Sustainability* 51 (2021): 24–29.

[7] Siddharth Sareen and Sunila S. Kale. ''Solar 'Power': Socio-Political Dynamics of Infrastructural Development in Two Western Indian States.'' *Energy Research & Social Science* 41 (2018): 270–278.

[8] Siddharth Sareen and Håvard Haarstad. ''Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions.'' *Applied Energy* 228 (2018): 624–632.

[9] Carolyn M. Hendriks. ''Policy Design Without Democracy? Making Democratic Sense of Transition Management.'' *Policy Sciences* 42 (2009): 341–368.

[10] Darren McCauley and Raphael Heffron. ''Just Transition: Integrating Climate, Energy and Environmental Justice.'' *Energy Policy* 119 (2018): 1–7; Noel Healy and John Barry. ''Politicizing Energy Justice and Energy System Transitions: Fossil Fuel Divestment and a ''Just Transition.'''' *Energy Policy* 108 (2017): 451–459.

scholarship. Although these insights are based on solar PV rollout in Portugal, the drivers of scalar biases are broadly applicable. As the conclusion argues, policies must address these drivers to advance just solar energy transitions.

THREE DRIVERS OF SCALAR BIASES: ENERGY INFRASTRUCTURE, REGULATORY INERTIA, AND POLITICAL DYNAMICS

As renewable energy sources, most notably solar PV, have reached and gone beyond electric grid parity in terms of cost competitiveness during the 2010s,[11] energy social science research has rapidly proliferated in fields such as energy geographies[12] and political economy.[13] Whereas energy transitions are often discussed in terms of transitions from fossil fuels to low-carbon renewable energy sources, the dynamics within the renewable energy sector merit distinct attention.[14] The emergence of these sources at particular scales is reciprocally related with energy geographies. On one hand, energy geographies define the spatial concentration (horizontal scales) and the multilevel decision making (vertical scales) that give shape to new energy infrastructures. On the other hand, as these new infrastructures emerge, they reconfigure the electricity sector and territorially remake energy geographies. The entry of these sources interacts with power differentials in energy sectors that have traditionally been rather top-down, with a political economy that often favors powerful incumbents.[15] These strong and complementary research streams offer numerous insights that overlap with and draw from research on infrastructure and change in other fields, such as science and technology studies, environmental justice, and sustainability transitions.

Table 1 situates three drivers of scalar biases, inductively derived from the empirical study presented subsequently, into this relevant suite of scholarship. Their light theorization aims at versatile operationalization into a broad range of energy transitions. This treatment is explicitly intended to be comprehensible to scholars outside the social sciences as well as policymakers and practitioners, as key target groups to enable policies for environmental justice.

Having established the three drivers of scalar biases during energy transitions, the next section offers contextual background on the specific energy transition case of solar PV rollout in Portugal. It provides a brief overview of historical developments up to 2017, around when solar PV reached grid parity in the country, to contextualize subsequent sectoral dynamics. The section includes details of the data collection carried out during the study period of 2017–2020, which witnessed not only intense contestation but also rapid changes. Subsequent sections analyze and discuss empirical developments during 2017–2020 in terms of observed scalar biases and their underlying drivers.

BACKGROUND, CASE SELECTION, AND METHODOLOGY: THE SOLAR PV ROLLOUT IN PORTUGAL BEFORE 2017

The story of solar PV before 2017 in Portugal, told at two distinct scales (small and large solar PV), reveals stark differences in their timelines. Large-scale PV began in 2008 with what was briefly the largest solar plant in the world, Amareleja, built with an aim to install 46 MW of solar PV capacity. At the time, it was subsidized through governmental offers of an attractive feed-in tariff running 15 years into the future (€300 per MW hour, or MWh) that recognized the emerging nature of the technology. Even as technological costs continued to decline drastically during the early 2010s, the modest national limits for subsidized solar energy capacity defined the speed of rollout of large solar PV. When large solar PV reached grid parity on costs, around 2017, it did not see a sudden rise in installed capacity in Portugal. Instead, solar developers faced new challenges, as the Scalar Biases in Solar PV Rollout in Portugal During 2017–2020 section explains.

Until 2012, EDP had a monopoly over electricity supply in Portugal. In 2013, supplier status was opened up to companies who could pay grid access charges. EDP remained a dominant incumbent in Portugal's energy sector: a multibillion-Euro multinational energy company with a strong presence as an electricity generator, distributor, and supplier. While investing in solar PV abroad, EDP had not made any major commitments in Portuguese solar till 2017.

Small solar PV had a strong start a decade ago, with similarly attractive initial feed-in tariffs as large-scale plants. From 35 MW in 2010,[16] Portugal built out distributed small solar PV capacity of over 100 MW quite rapidly. Shortly thereafter, the attractive tariffs were reduced, then renewed on a year-by-year basis from 2013 onward. Rollout slowed down at $\sim$170 MW once the early adopters and quick payoff options that drove early

[11]Felix Creutzig, Peter Agoston, Jan Christoph Goldschmidt, Gunnar Luderer, Gregory Nemet, and Robert C. Pietzcker. ''The Underestimated Potential of Solar Energy to Mitigate Climate Change.''

[12]Gavin Bridge, Stewart Barr, Stefan Bouzarovski, Michael Bradshaw, Ed Brown, Harriet Bulkeley, and Gordon Walker. *Energy and Society: A Critical Perspective*. (London: Routledge, 2018).

[13]Siddharth Sareen and Sunila S. Kale. ''Solar 'Power': Socio-Political Dynamics of Infrastructural Development in Two Western Indian States.''

[14]Karl S. Zimmerer. ''New Geographies of Energy: Introduction to the Special Issue.''

[15]Tor Håkon Jackson Inderberg, Kerstin Tews, and Britta Turner. ''Is There a Prosumer Pathway? Exploring Household Solar Energy Development in Germany, Norway, and the United Kingdom.'' *Energy Research & Social Science* 42 (2018): 258–269; Benjamin K. Sovacool. ''Reviewing, Reforming, and Rethinking Global Energy Subsidies: Towards a Political Economy Research Agenda.'' *Ecological Economics* 135 (2017): 150–163.

[16]DGEG. *Renováveis. Estatísticas Rápidas, No. 158*. (Lisbon: DGEG, 2018).

Table 1. Drivers of Scalar Biases

Drivers	*Description and basis in scholarship*
Energy infrastructure	Scalar aspects pertain to the infrastructure itself, hence this research foregrounds the sociomateriality of the electricity sector. The generation, transmission, and distribution of electricity are clearly a technical and material concern, with deeply entrenched spatial logics that must be reconfigured as an integral part of energy transitions.[43] It is moreover social, as it affects the everyday lives of people who use electricity in various forms for diverse purposes.[44] The way that electricity is embodied and made available through energy infrastructure defines the scope of its use, in terms of physical access, affordability, monitoring, and measurement by and for a variety of actors.[45] New interventions layer on top of existing infrastructure, and their manner of integration into the energy sector is conditioned by existing logics.[46]
Regulatory inertia	The supply- and demand-side functioning of this sector, as well as the supply–demand interface, are characterized by innovation and regulation.[47] These continuously engage with and act on each other to bring about sectoral change.[48] These activities pertain to legal and financial aspects, bureaucratic and technocratic requirements, and the general codification and institutionalization of the electricity sector. There is inevitably path dependence in these trajectories, which sets up the need for adaptive regulation. Path dependence can exhibit in terms of which scales decision is made at and implemented at, often for historical reasons rather than optimal performance.[49] Moreover, the pace of innovation and emergence of new actors and technological niches can lead to regulatory lag and low policy visibility as sociotechnical systems evolve.[50]
Political dynamics	During sectoral change, the field of actors is by definition also subject to change. New entrants emerge and incumbents adapt their activities to retain relevance across scales.[51] These change dynamics are fraught, contingent, and determined through relational processes.[52] Actors interact to contest and modulate changes in ways that best serve their self-interest and reduce their exposure to risk from uncertainty. Owing to existing power differentials in typically top-down energy sectors, in the absence of explicit mechanisms aimed at ensuring equity, processes tend to favor powerful incumbents despite the emergence of economically competitive technological alternatives.[53] These processes transcend the electricity sector into broader political and economic entanglements through which the sector is governed. In the balance is the allocation of benefits and burdens from energy infrastructure transitions.[54]

[43]Gavin Bridge. ‘‘The Map Is not the Territory: A Sympathetic Critique of Energy Research’s Spatial Turn.’’ *Energy Research & Social Science* 36 (2018): 11–20.

[44]Jenny Rinkinen, Elizabeth Shove, and Jacopo Torriti, eds. *Energy Fables: Challenging Ideas in the Energy Sector*.

[45]Siddharth Sareen and Kjetil Rommetveit. ‘‘Smart Gridlock? Challenging Hegemonic Framings of Mitigation Solutions and Scalability.’’ *Environmental Research Letters* 14 (2019): 075004.

[46]Antti Silvast, Robin Williams, Sampsa Hyysalo, Kjetil Rommetveit, and Charles Raab. ‘‘Who ‘Uses’ Smart Grids? The Evolving Nature of User Representations in Layered Infrastructures.’’ *Sustainability* 10 (2018): 3738.

[47]Valeria Costantini and Francesco Crespi. ‘‘Public Policies for a Sustainable Energy Sector: Regulation, Diversity and Fostering of Innovation.’’ *Journal of Evolutionary Economics* 23 (2013): 401–429.

[48]Martino Maggetti. ‘‘The Politics of Network Governance in Europe: The Case of Energy Regulation.’’ *West European Politics* 37 (2014): 497–514.

[49]Adrian Smith. ‘‘Emerging in Between: The Multi-Level Governance of Renewable Energy in the English Regions.’’ *Energy Policy* 35 (2007): 6266–6280.

[50]Kevin Marechal and Nathalie Lazaric. ‘‘Overcoming Inertia: Insights from Evolutionary Economics into Improved Energy and Climate Policies.’’ *Climate Policy* 10 (2010): 103–119.

[51]Adrian Smith and Andy Stirling. ‘‘The Politics of Social-Ecological Resilience and Sustainable Socio-Technical Transitions.’’ *Ecology and Society* 15 (2010): 11.

[52]Teis Hansen and Lars Coenen. ‘‘The Geography of Sustainability Transitions: Review, Synthesis and Reflections on an Emergent Research Field.’’ *Environmental Innovation and Societal Transitions* 17 (2015): 92–109.

[53]Jonathan Rutherford and Olivier Coutard. ‘‘Urban Energy Transitions: Places, Processes and Politics of Socio-Technical Change.’’

[54]Darren McCauley and Raphael Heffron. ‘‘Just Transition: Integrating Climate, Energy and Environmental Justice.’’; Noel Healy and John Barry. ‘‘Politicizing Energy Justice and Energy System Transitions: Fossil Fuel Divestment and a ‘‘Just Transition.’’’’

growth had been exhausted. Although continued cost declines, horizontal diffusion, and wider availability led to gradual increases in installed capacity, small-scale solar installations stood at 313 MW of total solar PV capacity by end 2018.[17] A self-consumption law imposed the limitation that the electricity generated had to either be consumed by a single user entity or injected to the electric grid in exchange for a nominal tariff set far lower than the purchasing price any consumer was subjected to. This meant that small solar PV was not particularly attractive for those whose electricity consumption profiles did not match the production profile of solar PV,[18] which peaks during the day and is unavailable during the evening, night, and early morning. Adding energy storage in the form of batteries, while becoming cheaper, was not yet a cost-effective option at the household scale.[19]

The option of setting up economies of scale by installing batteries at higher scales, such as at the secondary substation, remained off-limits as regulations did not permit community energy until January 2020. Thus, small solar PV owners could not sell their electricity to other users beyond the household. Small enterprises such as businesses and public buildings could not use generation during long periods like summer holidays when they did not have much daytime consumption. In short, small entities could only invest in solar PV to sell a lot of electricity at very low rates to the electric grid, while making savings on the part they self-consumed by reducing their electricity bills accordingly.

This narrative becomes more complex and contoured, and more revealing of the underlying dynamics, when political and regulatory trends for this period are added. Portugal went through an economic recession during 2009–2015, the time when solar PV began to be economically viable with subsidies in the form of feed-in tariffs. Owing to some poorly designed wind energy contracts during the 2000s,[20] the political opposition mobilized against the incumbent political party as part of the strategy that brought it into power in 2011.[21] This Social Democrats government was politically opposed to renewable energy during 2011–2015. They profiled it as a burden to taxpayers, while imposing austerity politics across economic sectors. When the Socialist Party, which had heavily supported the development of renewable energy sources with a view to create a renewable energy industrial and technological cluster, returned to power after the 2015 elections, it did not perceive renewable energy subsidies as politically viable. Moreover, fiscal room was very squeezed as Portugal sought to retain its financial credibility and exit both the economic recession and deeply unpopular austerity measures. Hence, financial incentives to solar PV remained largely dry.

A former member of the office of the Secretary of State for Energy during the 2011–2015 government retrospectively explained these temporal shifts: ''Energy associations saw the government going from all-in to all-out to all-in again with renewable energy. … in reality this was not really what happened, rather these changes had a time and reason. The things we had to do with regard to political measures during 2012–13—if we were to be in office today, we would probably be doing something similar to what is being done by the current government. … Back then our annual deficit was €1.2 billion in a €7 billion system and you cannot have that. … Even developers understand the logic even though it entailed a lot of pain and suffering on the professional side. No problem to enjoy the current solar moment. It is here.''[22]

This clearly indicates how Portugal's fiscal constraints and political decision making impinged upon the evolution of its energy sector during a critical period for solar PV rollout. Adding the concurrent technological trends completes this picture. With continuing global innovation and the rise of solar PV modular manufacturing in China, solar PV became competitive without subsidies. This led to an adjustment period during which Portuguese authorities tried to come to terms with emerging technoeconomic possibilities. Starting in 2017, they brought in new regulations and financial options, as presented and analyzed in the Scalar Biases in Solar PV Rollout in Portugal During 2017–2020 section. The period addressed in this empirical section, 2017–2020, is characterized by intense contestation and change in the sector. It thus constitutes a suitable case study to understand both the dynamics and drivers of scalar biases during rapid energy transitions.

The empirical analysis is informed by 80 expert interviews conducted over 5 months of fieldwork, and field visits to >10 large- and small-scale solar PV plant sites and various pertinent energy sector sites and events during this period, complemented by desk research focused on solar energy policy debates in peer-reviewed and gray literature, including official reports and media coverage. Fieldwork was conducted in accordance with the applicable institutional guidelines, consistent with national guidelines. Informants were located at multiple scales—community, urban, regional, national, and European—and included regulators, government officials, solar developers, energy companies, energy consultants, regional

[17]DGEG. *Renováveis. Estatísticas Rápidas, No. 176*. (Lisbon: DGEG, 2019).

[18]Cristina Herce Villar, Diana Neves, and Carlos A. Silva. ''Solar PV Self-Consumption: An Analysis of Influencing Indicators in the Portuguese Context.'' *Energy Strategy Reviews* 18 (2017): 224–234.

[19]Fernando M. Camilo, Rui Castro, M.E. Almeida, and V. Fernão Pires. ''Economic Assessment of Residential PV Systems with Self-Consumption and Storage in Portugal.''

[20]Joao Carlos Marques Silva and José Azevedo Pereira. ''EDP–Portugal's Main Energy Producer That Everyone Loved to Hate.'' *The CASE Journal* 15 (2019): 545–574.

[21]Ana Delicado, Elisabete Figueiredo, and Luís Silva. ''Community Perceptions of Renewable Energies in Portugal: Impacts on Environment, Landscape and Local Development.'' *Energy Research & Social Science* 13 (2016): 84–93; Siddharth Sareen and Håvard Haarstad. ''Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions.''

[22]Interview on July 25, 2019, with former member of the office of the Secretary of State for Energy during the 2011–2015 government.

Table 2. Interviewed Stakeholders During 2017–2019 ($N=80$)

Stakeholders interviewed by category	*Number*
Solar energy researchers	25
Energy companies	22
National authorities	8
Interest bodies	8
Subnational authorities	5
Energy citizens	5
Energy financiers	3
Energy cooperatives	2
Energy journalists	2

researchers, civil society groups, energy associations, and citizens. See Table 2 for an overview. Interviews were conducted on an institutional attribution basis due to the tightly networked nature of the energy sector and the focus on evolving issues, hence only organizational or domain-level affiliation is provided in footnotes with interview dates. Running notes were taken during interviews and typed up subsequently; these exceeded 80,000 words. These were analyzed with attention to scalar and justice issues, triangulated with ethnographic insights.

SCALAR BIASES IN SOLAR PV ROLLOUT IN PORTUGAL DURING 2017–2020

During 2017, licenses for solar projects were only available through a time-taking process, while subsidies were faded out. Solar developers had to deal with the uncertainties of clearing bureaucratic hurdles of license acquisition from the sectoral executive agency, the Directorate General for Energy and Geology (DGEG). DGEG operated a license application window every 4 months, where developers handed in expressions of interest. The industry faced a new barrier: limited capacity on the electric grid in the locations with the highest solar irradiation, the southern Portuguese regions of Alentejo and Algarve (cf. Sareen and Haarstad[23]). Applications for licenses quickly exceeded 2.2 GW, of which DGEG commissioned about one-third with a 2-year deadline, in line with achieving 1000 MW installed solar PV nationally by 2019. But 1-year extensions were granted several times.

Sectoral stakeholders had very critical views of the developments during 2017–2018. An energy association representative called for ‘‘a pre-qualification component based on technical and financial expertise to avoid speculative accrual of licenses. I know of one case, I am not going to name it, where the same company has been sitting on a license since 2012, using first the two year period then the one year prolongation based on not being responsible for the unavoidable delay, every year, including 2018.’’[24] Even developers who had previously successfully acquired licenses were frustrated: ‘‘The problem is the mechanism to obtain the production license. The process at DGEG is supposed to last less than four months, because applications can be submitted on a four-monthly basis three times a year. In every such window, we should know if power is sanctioned, but we wait. 500 MW or 1 GW in solar projects is waiting for license from the SSE office. More than *[a large amount, redacted for anonymity]* of this is ours and we have been waiting for 6 months.’’[25] A researcher suggested that the dithering approach favored the incumbent: ‘‘People have different perspectives about how licenses are allocated, based off of what—grid capacity or what EDP wants?’’[26]

Solar developers worried about the emergence of a speculative tendency due to the translucent process of license allocation. In 2018, one stated: ‘‘Our approach contrasts with speculative finance in the Portuguese solar sector, where government friends get contracts. … We will build 100 MW as a minimum, with long-term ownership commitment. Other companies are mostly speculating with their investments in solar. Will license prices go up or down, who really knows? That’s a question that can make or save a lot of money.’’[27] This developer, like several others at the time, expected power purchase agreements to be the popular future route, as it would allow solar developers to access requisite capital despite feed-in tariffs having been removed. A foreign investor eyeing the solar PV market in Portugal differed: ‘‘PPA versus premium tariffs, right now it does not matter very much to us. With low production costs like 2–3 €-cents we know we will always be able to sell at 5–6 €-cents *[per kWh on the wholesale market]*. What helped us decide to invest is that project financing is available with banks. … We are trying to buy plants at a stage when they are ready to go and just waiting for a production license, at which time you have 8–9% returns on equity with very low risk.’’[28]

Despite the problems characterizing this period, a few large-scale solar plants did come up during 2017–2018, and nationally installed solar PV capacity surpassed 650 MW, of which large-scale solar PV comprised ~500 MW. In October 2018, the energy portfolio was moved to the environment ministry, representing an unprecedented change in how energy policies were recognized within the state apparatus as closely intertwined with environmental governance, a year before the 2019 election. When I interviewed its representatives in early 2019, one explained their strategy: ‘‘Stated intent in solar has been 5 GW, but this has translated into not even 10%, maybe 500 MW. Grid constraints, financial constraints, investor speculation on licenses have emerged. So to achieve 47% renewable energy by 2030, compared to 31% by 2020, which is a big jump, *[we plan]* two procedures. First, to attract foreign investors to come to

[23]Siddharth Sareen and Håvard Haarstad.‘‘Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions.’’

[24]Interview on August 7, 2018, with an energy association representative.

[25]Interview on October 12, 2017, with a solar developer.

[26]Interview on March 8, 2019, with a regional energy researcher.

[27]Interview on August 22, 2018, with a solar developer.

[28]Interview on February 25, 2019, with a foreign investor in Portuguese solar PV energy.

Portugal, which is a challenging thing, but also something where we are well positioned and have experience with renewable energy, although not with solar. We do not have the solar debt that Spain has had to deal with. The feed-in tariffs we gave were small enough in scale that they did not have a major economic impact. *[Then]* we want to close the cycle of those who have the licenses and the capacity. So we can clear the backlog *[and]* have a clear overview after the work we are doing now in order to proceed with auctions. The auctioned capacity will only be available in 2020–21. They did not construct, so they lose the licenses.''[29]

Having assessed grid availability and demarcated 24 lots, the ministry conducted a solar auction for 1350 MW in July 2019. The auctions fetched an average price of marginally >€20 per MWh. This was far lower than the annual average price on the wholesale electricity market, which was >€55 per MWh the previous year. The lowest bid attracted set a new world record, going <€15 per MWh. Shortly thereafter, a large gas supplier took over 200 MW of further solar PV capacity in Spain to supply the Portuguese market. A further 700 MW of solar PV capacity was successfully auctioned in 2020. Thus, large solar PV capacity in Portugal is set to exceed 2000 MW in 2021, triple or quadruple the total solar PV energy capacity installed in Portugal by 2019, in line with Portugal's National Energy and Climate Plan 2030 and Carbon Neutrality Roadmap 2050, which target >9000 MW by 2027.

Although small-scale solar PV did not witness similar changes during 2017–2019, the Socialist Party government re-elected in October 2019 brought in legislative changes to define community energy in January 2020. This may enable new shifts in the sector, and could change the prospects for small-scale solar PV energy. An understanding of the drivers of scalar biases can help interpret the potential of such ongoing energy transitions. The main growth in small-scale solar PV during 2017–2020 was due to those upper middle-class households and businesses who invested in self-consumption, some with storage. A small-scale solar PV systems installer I interviewed in the Algarve region in late 2017 explained: ''If you pay infrastructure and metering and license costs, it makes better sense to approach it as zero-feed self-consumption with storage, a pirate system *[meaning unregistered]*. Only foreigners come to ask me about these type of systems, but storage is getting cheaper and enabling people to do what they want to do. So we are moving from grid-feed-tariff being only about making or saving money, to changing their relationship with their system, a lifestyle choice about energy production. … Despite legislation, solar is about operating in the blank space at the end of the page.''[30] This suggests an anarchist or energy autonomy orientation among energy users with adequate financial ability.

One exceptional actor did demonstrate small-scale solar PV growth, Portugal's first solar energy cooperative: Coopérnico. In 2018, a representative had both happy and sad news to share: ''When we won an award from the Gulbenkian Foundation in 2018, we finally had the €100,000 we required in order to apply for electric supplier status.'' The representative was referring to the total amount in grid access charges that the transmission service operator (TSO—Redes Energeticas Nacionais) and the distribution service operator (DSO—EDP distribution) required. Now the representative followed up with the bad news: ''But then, the TSO and DSO cited a case of a supplier in Spain going bankrupt to double the charges to €200,000 to enhance network security, and the regulator agreed, so now we are still excluded.''[31]

Coopérnico's portfolio of just >1 MW at the time constituted >€1 million in investment, impressive for a cooperative with a crowd-funding strategy. But this was tiny compared with a large company such as EDP. With peak demand ~8000 MW, Portugal's electricity market had 3 large suppliers with >100,000 consumers each, and ~10 smaller suppliers.[32] For all of them, €100,000 or €200,000 was a negligible part of their turnover, not a barrier to entry. Thus, Coopérnico's experience, while disappointing, was hardly surprising. The cooperative was trying to enter a sector that had historically been restricted to relatively large players who operated in the many millions or even billions of Euros.[33]

The electricity regulator in Portugal is the Energy Services Regulatory Authority (ERSE). During an interview in 2019, representatives mentioned an explicit interest in ''dynamic regulation,'' which responds to changing needs of evolving systems.[34] They pointed out that this is a key emphasis from the Council of European Energy Regulators, of which ERSE is a member. They explained that regulations tended to lag in the rapidly evolving energy sector: ''We are in a transition period, don't want to make too strict a rule, don't want to create unnecessary doors and barriers.''[35] Historically, Portugal used an energy model in which fossil fuel plants provided baseload (a stable quantity of ''always in demand'' electricity) through coal, and flexibility through gas. An increasing proportion of renewable energy on the grid meant a greater need to manage variable supply through

[29]Interview on March 7, 2019, with a representative of the Ministry for Environment and Energy Transition (later renamed the Ministry of Environment and Climate Change).

[30]Interview on October 4, 2017, with a small-scale solar PV systems installer in the Algarve region.

[31]Interview on August 20, 2018, with representative of solar energy cooperative Coopérnico.

[32]Guillermo Ivan Pereira, Jan Martin Specht, Patrícia Pereira Silva, and Reinhard Madlener. ''Technology, Business Model, and Market Design Adaptation Toward Smart Electricity Distribution: Insights for Policy Making.'' *Energy Policy* 121 (2018): 426–440.

[33]J.A.M. Hufen and J.F.M. Koppenjan. ''Local Renewable Energy Cooperatives: Revolution in Disguise?.''

[34]Kerstin Tews. ''Europeanization of Energy and Climate Policy: The Struggle Between Competing Ideas of Coordinating Energy Transitions.'' *The Journal of Environment & Development* 24 (2015): 267–291.

[35]Interview on July 22, 2019, with representatives of ERSE.

demand response: managing demand to match supply to balance the grid.[36] Thus, changing grid flexibility logics became an increasingly important issue needing legislative and regulatory updates. During 2018–2019, ERSE removed long-standing reserve capacity payments of €20 million to gas plants. This made the aggregation of flexibility on the electric grid not only technically crucial but also a potentially good source of revenue, which made gaining supplier status important for Coopérnico. An energy association representative mused: ''Once you start using renewable energy, you are going to have a system based in flexibility, with all sorts of pricing questions.''[37]

Thus, various scalar biases are evident. Although the share of solar energy on Portugal's electric grid grew from 0.4% in 2015 after the economic recession to 1.5% by 2018 and passed the target of 1.9% by 2020, the drivers of scalar biases can help assess the effects of this energy transition on justice and resilience at lower scales.[38] The conclusion discusses these scalar biases using the three drivers, and draws lessons for just transitions.

DISCUSSION AND CONCLUSION: THE DRIVERS OF SCALAR BIASES AND ENERGY TRANSITION POLICIES

This article argues that Portugal's electricity sector has been dominated by and geared toward big players (also see Sareen[39]). Unlike some European countries (cf. Inderberg et al.[40]), this has come at the cost of disincentivizing participation by small-scale solar players. Actors may construct potentially reasonable arguments for such a scalar bias: a small number of large players are easier to monitor and regulate, can harness economies of scale for competition, and coordinate efficiently internally and with other actors in a sector highly connected through massive grid infrastructure. But as a recent review of scholarship on scalar biases in solar PV rollout shows, there is increasing concern about justice effects at multiple scales, justice impacts in related sectors such as land and finance, and the slow progress of small-scale solar plants.[41] This study of a concrete case suggests that scalar bias has downsides: a small number of players in control can oligopolistically drive up electricity prices; they may ignore new technologies and scales of deployment that are socioecologically desirable but threaten their profits; they may have large-scale adverse impacts on landscapes and local communities while out-competing locally beneficial economic activities such as agriculture; and they might exploit regulatory lags to abuse their control of electricity infrastructure and services and exclude smaller players from benefit sharing. These dynamics have important justice implications and merit further attention in research and policy, in terms of both procedurally just mechanisms and distributively just outcomes, as well as with a view to recognizing the full range of impacted stakeholders. Table 3 interprets the case using the drivers.

Thus, studying the drivers of scalar biases can provide vital policy insights into the scalar environmental justice effects of a given energy transition. The Portuguese government launched vision documents for energy transition in January 2019: a National Energy and Climate Plan 2030 and a Carbon Neutrality Roadmap 2050. These specify ambitious targets for Portugal to grow its share of renewable energy in electricity and other sectors, including systematic electrification of sectors such as transport and manufacturing, with rapid growth envisaged in solar PV to 9000 MW by 2027. These ambitious targets, clear industrial strategies, and market-based mechanisms give solar PV the fillip of being backed by political will, and make it bankable for solar developers who need capital. This combination can drive rapid large PV growth. Although the context-specific effects of some drivers may be less pronounced elsewhere, compared with their importance for solar PV rollout in Portugal, applying the drivers foregrounds key levers and actor configurations that modulate the distribution of costs and benefits across actors and thus determine environmental justice outcomes.

There is clear evidence that during 2017–2020, Portuguese energy policy moved in the direction of enabling rapid solar PV growth, without adequate democratic room for small-scale actors to participate, thus risking that the unfolding renewable energy future fails to also build resilient communities. This is a wider concern as the ''green deal'' and ''net zero'' targets gain policy traction in many global regions, notably including the United States and the European Union, thus driving rapid changes in energy infrastructure with environmental impacts across multiple scales, sectors, and communities. Although there were signs of a shift toward community energy in 2020 and 2021 in this case study, its scalar biases highlight that national energy policies must explicitly address sectoral power differentials to include a wider range of actors in distributed solar PV rollout and thereby advance environmental justice. Energy

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[36]Cherrelle Eid, Paul Codani, Yurong Chen, Yannick Perez, and Rudi Hakvoort. ''Aggregation of Demand Side Flexibility in a Smart Grid: A Review for European Market Design.'' In *2015 12th International Conference on the European Energy Market (EEM)*. (IEEE, 2015), 1–5.

[37]Interview on July 23, 2019, with a representative of an energy association.

[38]Stefan Bouzarovski and Neil Simcock. ''Spatializing Energy Justice.'' *Energy Policy* 107 (2017): 640–648; Siddharth Sareen and Håvard Haarstad. ''Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions.''

[39]Siddharth Sareen. ''Reframing Energy Transitions as Resolving Accountability Crises.'' In *Enabling Sustainable Energy Transitions*. (Cham: Palgrave Pivot, 2020), 3–14.

[40]Tor Håkon Jackson Inderberg, Kerstin Tews, and Britta Turner. ''Is There a Prosumer Pathway? Exploring Household Solar Energy Development in Germany, Norway, and the United Kingdom.''

[41]Siddharth Sareen and Håvard Haarstad. ''Decision-Making and Scalar Biases in Solar Photovoltaics Roll-Out.''

Table 3. Interpretation of Solar Photovoltaic Rollout in Portugal Using Drivers of Scalar Biases

Drivers	*Interpretation of solar PV rollout in Portugal*
Energy infrastructure	The main driver was global cost reduction in technology. This happened at a global scale. Modularity made PV relevant at both large and small scales, unlike fossil fuels that require transport infrastructure and strong supply chains for reliable generation.[55] This property meant that main costs of PV are up-front; then the fuel source is free and maintenance costs are low. Rather, grid access is at a premium; hence, location and legacy infrastructure matter. Thus, although there are clearly economies of scale, there is no firm infrastructural reason that makes small solar PV plants undesirable. Supply chains are evolving where intermediaries procure PV modules in bulk and bundle sales to small players. The social appetite for small PV in Portugal has been limited by regulations on solar prosuming.[56] Limited grid infrastructure in southern Portugal has limited how much solar PV can be installed and grid connection access.
Regulatory inertia	Large solar PV took off due to subsidies. This created the initial conditions for actors to organize and grow such investment. Yet regulations varied, sending mixed signals (cf. Costantini and Crespi[57]), creating messy processes for solar licenses and lack of clarity on grid access. Small players showed interest but incentives dried up quickly, limiting scope to develop resilient involvement and energy citizenship. A short policy horizon penalized large actors who had to invest in greenfield development without later getting a license, and faced high interest rates on capital. Small actors were excluded from fair benefit sharing in PV. This only left open options to prosume at low prices, or self-consume in daytime hours that excluded most small households and businesses without steady demand. This lack of calibration stopped small PV after initial rapid growth, delaying the opportunity to develop resilient small solar PV energy citizens.
Political dynamics	Scalar biases in cross-sectoral energy–finance effects are explained by political dynamics. Politics modulated decisions on solar PV. In the early 2010s, it suffered a legitimacy crisis in public perception, as political rhetoric cited past mistakes to portray it as a taxpayer burden.[58] This combined with austerity politics to squeeze room for solar PV subsidies. A tendency for information to flow to better educated people more quickly, and the greater ability of wealthier households to invest in nonessential infrastructure, meant that early subsidies for small PV accrued to relatively affluent adopters. Community energy legislation in January 2020, another artifact of political will, provides a basis for the small PV segment to lift its trajectory in the near future. Large plants received limited subsidies until the mid-2010s. Since 2019, the solar auction mechanism has insulated solar PV from national politics, with a trajectory defined on a technoeconomic basis.

PV, photovoltaic.

[55]Gavin Bridge, Stefan Bouzarovski, Michael Bradshaw, and Nick Eyre. ‘‘Geographies of Energy Transition: Space, Place and the Low-carbon Economy.’’

[56]Fernando M. Camilo, Rui Castro, M.E. Almeida, and V. Fernão Pires. ‘‘Economic Assessment of Residential PV Systems with Self-Consumption and Storage in Portugal.’’

[57]Valeria Costantini and Francesco Crespi. ‘‘Public Policies for a Sustainable Energy Sector: Regulation, Diversity and Fostering of Innovation.’’

[58]Ana Delicado, Elisabete Figueiredo, and Luís Silva. ‘‘Community Perceptions of Renewable Energies in Portugal: Impacts on Environment, Landscape and Local Development.’’ Siddharth Sareen. ‘‘Reframing Energy Transitions as Resolving Accountability Crises.’’

transitions constitute a historical opportunity—but also a risk—for community resilience as societies build renewable energy systems for low-carbon futures (also see McCauley and Heffron[42]). If scalar biases are not addressed, historical injustices of the energy sector may be reproduced, with benefits limited to a few large-scale actors who exercise centralized control. However, a just approach to energy transitions such as solar PV rollout can enable community ownership, propeople models for distributed energy infrastructure, and positive environmental outcomes with widely shared benefits.

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S.S. researched and wrote this article in full as sole author.

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Address correspondence to:
Siddharth Sareen
Department of Media and Social Sciences
University of Stavanger
Kjell Arholms Gate 23
Stavanger 4021
Norway

E-mail: siddharth.sareen@uis.no

[42]Darren McCauley and Raphael Heffron. ''Just Transition: Integrating Climate, Energy and Environmental Justice.''; Noel Healy and John Barry. ''Politicizing Energy Justice and Energy System Transitions: Fossil Fuel Divestment and a ''Just Transition.''''