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Sustainable development goal interactions for a just transition: multi-scalar solar energy rollout in Portugal

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ABSTRACT

Solar energy rollout has environmental and socio-economic impacts vital for just low-carbon energy transitions. The modular characteristics of solar photovoltaics enable multi-scalar deployment. How do environmental and socio-economic impacts vary across scales? This understudied relationship impacts the socio-spatiality of solar rollout, who benefits, and how this is enabled. Our study in Portugal during 2017–2020 examines how solar energy went from subsidies to record-setting competitiveness. Most new solar capacity was large scale, with barriers for community energy that weakened in 2020. We draw on interviews with 80 experts and a small-scale questionnaire survey with solar energy cooperative members. Findings show large-scale solar rollout primarily yielded environmental benefits, whereas small scale yielded socio-economic benefits. We argue that near-future joined-up solar energy policies can facilitate synergistic interactions across three United Nations Sustainable Development Goals by integrating environmental and socio-economic impacts. This main contribution can inform Portuguese and wider energy policies for sectoral development toward sustainability.

KEYWORDS

Multi-scalar solar PV; energy transitions; SDG interactions; community energy; Portugal; SDG7

1. Introduction: Solar energy, scale and the sustainable development goals

Societal debates over energy transitions include environmental and socio-economic dimensions and, more recently, feature a notable spatial emphasis (Bridge 2018). Whereas a shift from fossil fuels to renewable energy sources at traditionally large scales has made rapid headway (Liu 2018), a growing movement calls for more transformative transitions that change the ownership and scales of energy production (Moss, Becker, and Naumann 2015). The latter movement argues for wider participation in energy production and ownership by installing more socio-spatially distributed renewable energy technologies, as decentralization would challenge oligopolies and the power inequities entrenched in energy markets and energy regulation (Späth and Rohracher 2014). Scalar contestation has become possible due to the cost competitiveness of technologies that offer new modular options for spatial diffusion (Kaygusuz 2007), solar photovoltaics (PV) being the most prominent example (Liu 2017). Modular characteristics of solar PV have invigorated multi-scalar analyses in energy social science research, to address interdependencies between energy production and consumption, spatio-temporal availability, and pricing (Sovacool et al. 2017). Systemic interdependencies demand a socio-spatial approach to energy transitions (Bridge 2018) that enables cross-scalar analysis to transcend a producer-consumer binary (Silvast et al. 2018) and identify prospects for energy democracy (Szulecki 2018).

Solar power illustrates the need for multi-scalar analyses because scalar changes in energy supply logics translate into new roles for consumers. Solar PV technologies comprise the fastest growing

source of electricity in the world. At end-2016, global installed solar capacity stood at 307 gigawatts (GW), with 77 GW installed in 2016 alone (Solar Power Europe 2017). By 2019, annual solar capacity installation had grown to 97 GW, or 55% of all renewable energy capacity added that year; the more recent cumulative figure of 580 GW of solar constitutes 23% of the 2,537 GW total renewable energy capacity installed globally (IRENA 2020). Table 1 shows this increase in global installed solar capacity by almost 89% in four years. Yet most of this increase has come from utility-scale solar PV plants that represent a low-carbon energy transition but not the transformation that energy democracy proponents envision with lower-scale diffusion. Without economies of scale to trade on wholesale electricity markets, adoption at lower scales by retail electricity users requires supportive energy policies and legislation, e.g., for net metering and energy communities (Inderberg, Tews, and Turner 2018), even in high solar irradiation contexts where payback periods are in a low range such as 5–10 years (Camilo et al. 2017). Such energy policies must address sustainable energy transitions as both socio-technical and energy justice concerns that produce multi-dimensional societal benefits at multiple scales (Sareen and Haarstad 2018, 2020). This manuscript aims to advance such multi-scalar analysis for a country case, and examines both environmental and socio-economic dimensions of solar energy rollout.

The modularity and affordability of solar PV means that entrants like individuals, communities and energy cooperatives can participate in energy ownership, production and distribution within enabling regulatory frameworks. Greater participation in renewable energy transitions and more equitable distribution of benefits and costs represent central tenets of energy justice (Wood and Roelich 2020). This democratizing potential of solar PV positions it as a promising technology to realize synergies between the United Nations (UN) Sustainable Development Goals (SDGs). An SDG-centric approach pivots from a focus on primarily environmental effects to a systemic approach that includes socio-economic considerations in multi-scalar clean energy transitions, often referred to as ‘just transitions’ (Healy and Barry 2017). Three SDGs target these benefits directly: SDG7 (universal clean affordable energy access), SDG10 (reduced inequalities), and SDG13 (climate action). SDG7 has five targets that aim to ensure access to affordable, reliable, sustainable and modern energy; SDG10 has ten targets that aim to reduce inequality within and among countries, while SDG13 has five targets that aim to take urgent action to combat climate change and its impacts.¹ A recent review that examined the most directly implicated SDG7 in terms of its interactions with other SDGs stated:

“Synergies and trade-offs exist in three key domains, where decisions about SDG7 affect humanity’s ability to: realize aspirations of greater welfare and well-being; build physical and social infrastructures for sustainable development; and achieve sustainable management of the natural environment. There is an urgent need to better organize, connect and extend this evidence” (Nerini et al. 2018, 10).

These synergies suggest a more prominent role is needed for energy users to achieve sustainability as outlined by the UN. We contribute by identifying these synergies specific to a prominent case of multi-scalar solar energy rollout in Portugal.

The study addressed in Nerini et al. (2018) identified synergies between SDG7 and 7/10 of the SDG10 targets and all 5/5 of the SDG13 targets, indicating their intertwined nature. By contrast, few trade-offs were reported between SDG7 and each of the other SDGs. One notable trade-off is with Target 10.1 (prioritized income growth of the bottom 40% of the population) as this progressive economic effect constrains the speed of decarbonization. Other notable trade-offs are with Target 13.1 (strengthening resilience and adaptive capacity to climate-related hazards) as these considerations limit the feasibility of some technological deployment, and with Target 13.2 (integrating climate

Table 1. Global installed solar capacity in 2016 and 2020.

Year	2016	2020
Global installed solar capacity	307 GW	580 GW

Sources: Solar Power Europe (2017), IRENA (2020).

¹For official details, see <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>.

change measures into policies) as this can place conditions such as environmental impact standards on low-carbon energy technologies. The relationship between SDG10 and SDG13 has also been studied in general terms and features large overlaps (Nerini et al. 2019) but needs to be specified for solar PV rollout and situated in the context of specific national energy policies. Our manuscript uses this multi-scalar case to visualize the relationship between these three SDGs in a novel manner.

In this manuscript, we focus on the Portuguese case of solar PV rollout during the 2017–2020 period when it experienced a rapid U-turn in this sector. Subsequently, Portugal went from being a solar power laggard to a globally celebrated example of large-scale solar PV diffusion. Methodologically, we combine multi-sited and multi-scalar fieldwork featuring expert interviews, field observations and a small-scale survey with members of Portugal's first solar energy cooperative. Data analysis brings out three trends: large-scale solar PV is directly aiding rapid low-carbon energy transitions, but less so socio-economic ones; small-scale solar PV rollout has faced legal and economic barriers due to energy policies that favor large-scale incumbent interests; and recently enabled community-scale solar PV rollout offers scope for wider transformative participation. We offer a synthesis framework of multi-dimensional SDG–SDG interactions to theorize the rich multi-scalar insights from this national energy transition.

2. The Portuguese case study of multi-scalar approaches during solar energy transitions

The case of solar energy transitions in Portugal during 2017–2020 offers a highly relevant setting to study implications of multi-scalar approaches to energy. As a European Union (EU) member state, Portugal is part of a region with globally high climate ambition. Solar PV is slated to play a large role in reaching its EU-mandated goal of achieving carbon-neutrality by 2050; Portugal's National Energy and Climate Plan 2030 mentions a target of 9 gigawatts (GW) by 2027 (European Commission 2019). The country has been one of the leaders on renewable energy, building hydropower and then wind power (Fernandes and Ferreira 2014). Despite financial constraints during and after the 2008–2015 economic crisis, Portugal launched a Carbon Neutrality Roadmap 2050 stating its commitment to renewable energy goals in 2019 (Silva and Sareen 2020).²

As Table 2 shows, total solar PV in Portugal grew steadily from 174 megawatts (MW) in 2011 to 673 MW in 2018, with a jump to 1030 MW in 2020 (DGEG (Directorate General for Energy and Geology) 2020). Since 2014, major addition to installed solar PV capacity came from large-scale projects. In 2014, Portugal had 419 MW of solar PV, of which 163 MW was small scale. Mini and micro projects below 250 kilowatts (kW) that injected power to the grid came under a 'small production units' or UPP regime that stagnated between 163 and 171 MW during 2014–2019. In June 2019, a new law simplified registration, certification and integration procedures, and community energy projects are likely to appear following its enactment in 2020. A 'self-consumption units' or UPAC regime came into force from 2015 onward, and has been relatively successful, recording 216 MW worth of small projects by 2019, with increasing year-on-year growth. Not all self-consumption projects are registered, hence total small-scale solar capacity is probably higher. This increase in small-scale solar, in the absence of enabling policies such as subsidies, represents a significant desire on the part of consumers to take an active role in their energy, since these projects are usually elective in nature. Thus, as of 2019, registered small scale (171 MW UPP and 216 MW

Table 2. Installed solar PV capacity in Portugal by year during 2011–2020.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MW	174	218	299	419	454	520	585	673	907	1030

Source: Directorate General for Energy and Geology, DGEG (Directorate General for Energy and Geology) (2020).

²Details available online: <https://descarbonizar2050.apambiente.pt/en/>

UPAC) projects constituted 387 MW while utility-scale solar plants made up 527 MW of the 907 MW total installed capacity (DGEG (Directorate General for Energy and Geology) 2020). The approximately 2 GW auctioned during 2019 and 2020 was all large scale, which, if installed by 2021–2022, will multiply this segment rapidly.

During the study period of 2017–2020, Portugal showed remarkable energy regulatory evolution. Until 2017, feed-in-tariffs subsidized limited large-scale solar PV rollout. During 2018, queuing solar developers had to navigate bureaucratic requirements to compete for limited grid capacity that caused delays, confusion and mistrust. In October 2018, a new Ministry of Environment and Energy Transition was formed. It phased in a market-based mechanism to auction grid capacity at specific nodes for solar PV capacity. These solar auctions set world records in July 2019 and August 2020, averaging below 40% of annual average wholesale electricity market prices for a total of approximately 2 GW of awarded projects across 36 lots (Silva and Sareen 2020). When installed by 2021–2022, these will more than triple installed solar capacity in Portugal.

During this period, Portugal became a poster child for large-scale solar PV. In January 2020, energy legislation eased to enable collective self-consumption schemes. Moreover, with Lisbon being the European Green Capital 2020, urban-scaled solar projects, rooftop solar support schemes, energy flexibility measures, and energy poverty mitigation featured in public debates. These notable achievements in a financially constrained country with significant energy poverty merit attention.

The Portuguese context also represents the shifting role of the consumer, as many Portuguese citizens choose to take on a more involved role than as simply end users of utility-scale energy. Empowered by the scalability and affordability of solar, these energy citizens have begun to actively choose to engage with energy production and distribution in individual capacities. In addition to the eased legislation mentioned above, community schemes such as those led by Coopérnico,³ Portugal's first energy cooperative, have emerged and boast an increasing member base. This renewable energy cooperative rents roof space for its PV panels from socially minded institutions, and provides affordable virtual solar power to members via an electricity retailer. Such expressions of energy citizenship draw additional motivation from the history of high-energy prices in Portugal, which were 9–14% higher than the European average between 2015 and 2018 (PORDATA 2020). Energy poverty is increasingly recognized as a significant problem in Portugal (Gouveia, Seixas, and Long 2018), and the emergence of low-cost, accessible and modular solar PV inspires ideas about a serendipitous pairing.

Shifting scales of energy systems, egalitarian socio-economic conditions, brand-new community energy legislation, and its growing identity as a renewable energy leader converge to make Portugal a highly relevant case study. Our contribution examines the role of energy governance and energy citizens in this context. We aim to generate broadly applicable insights on energy governance and the changing role of consumers during rapid solar energy rollout that can inform energy policies. To ensure transferability to other contexts, we visualize these insights in terms of the relationship between three SDGs, which many countries worldwide have committed to implement.

3. Data and methods

Commitment to multi-scalar analysis demands a mixed methods approach. Our methods featured multi-sited ethnography, with 80 semi-structured expert interviews conducted during six months of fieldwork between 2017 and 2019 in the capital Lisbon, and the Alentejo and Algarve regions of Portugal where solar PV rollout is concentrated. Respondents included regulators, energy companies, solar developers, energy scholars, energy associations and consultants, investors, energy cooperative and environmental organization members, and energy ministry representatives, resulting in over 90,000 words of interview notes. Notable sectoral stakeholders in Lisbon whose representatives we interviewed include institutions such as the Ministry of Environment and Energy Transition,

³For details about Coopérnico, see <https://www.coopernico.org>

municipal energy agency Lisboa E-Nova, national regulator Energy Services Regulatory Authority, national executive agency Directorate General for Energy and Geology, Portuguese Renewable Energy Association and the Secretary of State for Energy office; research institutions such as the University of Lisbon, NOVA University of Lisbon and the National Laboratory of Energy and Geology, small-scale actors such as PROSEU (European prosumer project), GoParity (impact investment start-up) and Coopérnico, and larger energy companies such as the incumbent Energias de Portugal (EDP), Infraventus and Hyperion. [Figure 1](#) provides an overview of the number of respondents interviewed per stakeholder category. In this short article, we draw briefly on this material by quoting the most relevant insights for our multi-dimensional SDG interactions, a common methodological approach in case study analysis ([Flyvbjerg 2006](#); [Lund 2014](#); [Yin 1981](#)). We use institutional attribution to maintain the anonymity of expert interviewees throughout this study, and make extensive use of direct quotes from situated institutional actors to provide rich comprehensive insights into complex sectoral dynamics ([Kendall 2008](#); [Kvale 1994](#)).

We conducted participant observation during public energy-sector meetings (e.g., the launch of the Carbon Neutrality Roadmap 2050, workshops on community energy models and energy poverty, and an International Energy Agency event at the National Laboratory for Energy and Geology), site visits to solar PV plants, and academic seminars. This experience informs our thinking tacitly and enriches the rigor and relevance of the analysis.

During October–November 2018, the first author designed and fielded an online questionnaire survey through the mailing list of the solar energy cooperative Coopérnico, which returned 47 responses, including 43 from their members. We report key results from this survey below (using our own translation to English). These empirical methods were complemented by desk study of peer-reviewed articles and gray literature (industry reports, media articles, ministry documents) throughout 2017–2020.

We include a map to orientate the reader on solar energy transitions in Portugal. It shows most sites of large-scale solar projects and other renewable energy projects in Portugal, drawn from a 2019 renewable energy association report ([Figure 2](#)). A similar map for small-scale solar PV is not available as there are thousands of such installations, of which many small ones need not be registered.

In the next section, we report findings and discuss them, focusing on large-scale and small-scale solar PV projects. As community energy legislation came into force in January 2020, there were no such projects active during data collection for this study, but respondents for small-scale solar referred

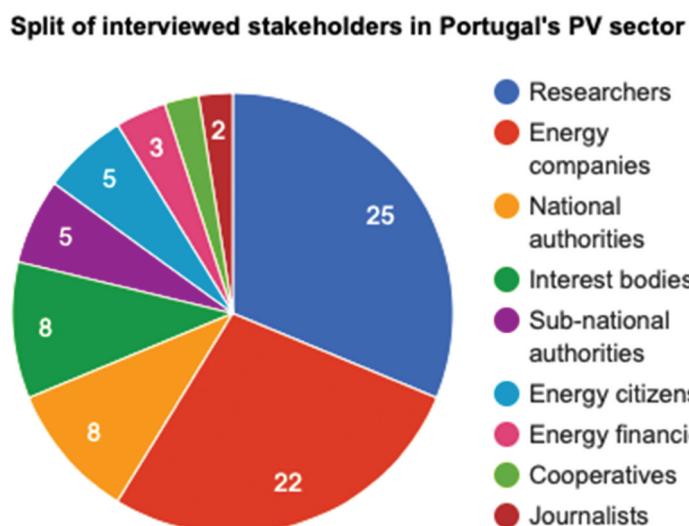


Figure 1. Stakeholders interviewed per sectoral category during 2017–2019 (n = 80).

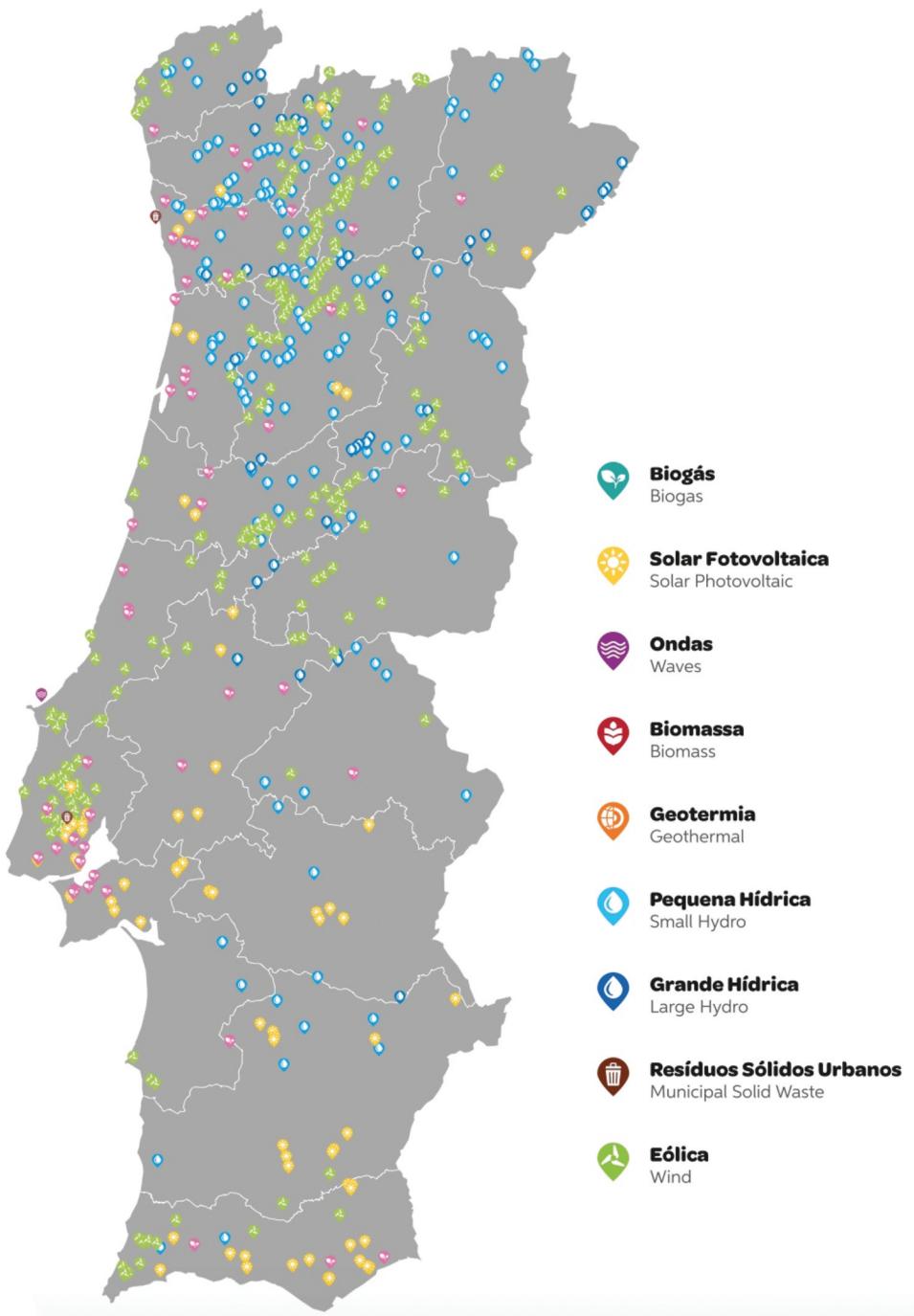


Figure 2. Renewables map with large solar projects (Source: APREN (Portuguese Renewable Energy Association) 2019).

to this future development. The pandemic circumstances prevented further fieldwork in 2020, which limits our insight into this.

4. Results and analysis

Our study can explain the slow progress of small-scale solar in Portugal, as well as the jump in large-scale solar PV after 2018, and suggests that traditional approaches to environmental governance prioritize carbon mitigation over social equity. In other words, this case study illustrates the lack of an integrated approach to the governance of energy transitions for sustainability. After Portugal exited the economic recession of 2008–2015, it phased out subsidized feed-in-tariffs for utility-scale solar plants by 2017 (Sareen and Haarstad 2018). An earlier rollback of similarly attractive small-scale solar feed-in-tariffs led to the stagnation of the UPP regime and shifted new solar adoption away from prosumenting to self-consumption by 2015, due to new tariffs for prosumenting being kept too low. A former employee of the national electricity regulator stated that:

“My criticism is that decentralized solar should be promoted instead of being stopped by the government, it is particularly strange for a central-left government. It should be supportive for local communities to manage their energy resources. Portugal is one of the few countries in Europe where you cannot do anything as an energy community even if you want. Even if you build your own micro-grid infrastructure, each household has to pay the full cost of energy. The politicians and regulator are afraid that allowing this would lead to an increase in the distribution tariff, and anything that leads to even a small tariff increase makes the government panic. The politicians have instructed the regulator to act in the same way. This is very sad because the residual issues can be addressed in simple ways. The government is blocking all kinds of innovation” (interview dated 14.08.2018).

In late 2017, a Secretary of State for Energy office representative estimated that

“In the future, solar projects may find it harder to get grid access, only 500 MW has been installed and 2.7 GW is in the pipeline, with 500 MW of it having paid a deposit. So, grid access will determine how much of it will be installed, maybe 1.5 GW in total by 2020” (interview dated 03.10.2017).

This illustrative quote underscores the uncertainty associated with even large-scale solar at the time. Indeed, during 2017–2018, the former energy ministry failed to offer a transparent large-scale solar licensing regime. At the time, one solar developer said that “Our approach contrasts with speculative finance in the Portuguese solar sector, where government friends get contracts” (interview dated 22.08.2018). Another solar developer explained “We have good connections with EDP [large incumbent energy company] and DGEG, so we can just get a meeting and sit down, which takes others lots of time and effort” (interview dated 23.10.2018). Thus, weak and limited grid capacity in solar-rich southern regions created competition and bureaucratic bottlenecks for large-scale solar. However, in July 2018, the European Commission agreed to finance €578 million or about a third of the cost to increase electric grid interconnections between the Iberian Peninsula and France, creating more capacity for solar projects (Sareen 2020). Plans to strengthen the Portuguese grid were accordingly firmed up.

Things continued to look up for large-scale solar prospects later that year. A cabinet reshuffle a year prior to the national elections of 2019 created a new Ministry of Environment and Energy Transition in October 2018. This notable merger of energy and environment portfolios (energy formerly having come under the finance ministry) represented a shift in values and enabled visionary national plans. A solar energy cooperative (Coopérnico) representative opined that “The political handling of the current ministry has been great, they have taken the opportunity to make a difference in the energy sector, give a brand” (interview dated 25.07.2019). By January 2019, Portugal had launched, in coordination with the EU mandates, an ambitious National Energy and Climate Plan 2030 complemented by a Carbon Neutrality Roadmap 2050. These foresaw energy transitions based on rapid electrification of sectors and expansion and decarbonization of electricity, with a large role for solar PV rollout – up to 9.9 GW by 2027. According to a ministry representative in early 2019:

“Right now, one installation can feed a single consumer. With community energy, all households in condominiums, all service buildings, can share with other consumers with complementary consumption patterns. We have to be very assertive on what we want to do in this regard over the next four months, critical timing with [October 2019] elections. We cannot directly intervene in legislation of

course, but need to push with energy policy. Pushing on solar auctions is very hard. That has needed several legislative adjustments. Earlier projects failed ... at [the] bottleneck of grid capacity constraints. So we want to avoid that, and then ensure that they deliver once they have been allocated capacity. The market will decide on what scale capacity is split. That is one innovative aspect. If 50% of people want to go the PPA [power purchase agreement] way and 50% want to go with FiT [feed-in-tariffs] for financing, or 80–20 split, we will go with that. ... There are legal obstacles on small-scale, so on that we are trying to strike those down to open up options. Meanwhile [we will] move aggressively on large-scale solar" (interview dated 07.03.2019).

This was a pragmatic course, that sought to achieve success with rapid large-scale solar PV rollout, and simultaneously legislate to enable rollout at smaller scales including community energy. After the solar auctions in July 2019 set a world record with the lowest lot closing below €15 per MWh, a solar developer explained:

"We had lower IRR [internal rate of return] requirements than our partner, so after losing the first auctions we took part independently so that we could compete more, went down to €26 per MWh, but even that did not work. So we struck a revised deal with the partner, did due diligence over the weekend. They took all the risk so we could even go down to €17 but when it went lower than that it was just crazy" (interview dated 30.07.2019).

By 'crazy', the solar developer indicates an unanticipated market development, possibly an irrational one, or one explained by bidders overvaluing the 15-year lot in order to gain access to scarce transmission grid capacity. These views are echoed by some market experts.⁴ This sums up how quickly large-scale solar PV took off with a policy framework in place.

A similar, more recent development concerns a policy framework that was activated in January 2020 and legislatively enabled solar PV projects at the community scale. The proliferation of micro- and mini-scale solar projects prior to this development suggests that such a supportive policy framework may lead to a similar rapid uptake of new, small-scale solar PV. A DGEG representative stated that they are "currently embracing self-consumption and energetic communities" (interview dated 26.6.2019). Despite increasing scholarly interest in community energy (Koirala et al. 2016), little thematic research exists on Portugal (cf. Sareen, Baillie, and Kleinwächter 2018), which offers promising prospects (Brito et al. 2012). Our findings can contribute new and timely insights in this respect, by reporting on responses by small-scale solar energy enthusiasts in Portugal to a questionnaire survey. Table 3 shows and analyses key quantitative findings, while Table 4 presents a categorized comparison of qualitative ones.

Table 3 showcases our interpretation of findings for analytical insights on indicators of energy poverty, knowledge about electricity costs, dissatisfaction with electricity costs, and motivation for involvement in a solar energy cooperative. Table 4 categorizes and compares motivation for and barriers to investing in small-scale solar energy projects for individuals in Portugal. Figure 3–5 provide a visual overview of some of the key findings. 16/37 (34%) of the respondents reported that they did not satisfy their energy needs. These further responded to the question of what they would use more energy for. Figure 3 presents these clustered aspirations for more energy use (some respondents specified multiple energy uses), with space heating/cooling being the most frequent need. From the same subset of respondents, Figure 4 shows that most reported that they were able to specify most or all of the components of their electricity bill. Figure 5 shows that among all 47 respondents, the components of the electricity bill that users found most frustrating to pay were the media tax and other taxes and fees, as well as value-added taxes at a relatively high rate.

We also queried respondents on their motivation for involvement in a solar energy cooperative. 43/47 reported they were members of Coopérnico: 20/47 for socio-economic and environmental reasons, 13/47 solely out of environmental concern, and 10/47 because they were supportive of Coopérnico. Based on complementary descriptive statistics collected per individual, the surveyed solar energy

⁴See industry coverage in this regard: <https://www.pv-magazine.com/2020/08/27/portuguese-government-confirms-world-record-solar-price-of-0-01316-kwh/> (accessed 25.01.2021).

Table 3. Electricity use, needs and motivation for engagement with energy cooperative (Coopérnico).

Question -> targeted information	Notable response characteristics	Analytical insights generated
Do you satisfy your electricity needs, if not what would you use more for? -> <i>Indicators of energy poverty</i>	Yes: 31/47 Clustered aspirations for more use: 1. Space heating/cooling: 9 2. Charge electric vehicle: 4 3. More electronics use: 3 4. Substitute gas: 2 5. More low-tariff time use: 1 6. Luxury (heat pool): 1	The most common under-use of electricity for domestic needs is for space heating and cooling. Some small-scale solar enthusiasts link greater electricity use with vehicle charging. A few see increased use as a substitute for other fuels and as enhancing energy flexibility.
What are the components of your electricity bill that you can name? -> <i>Knowledge about electricity costs</i>	All: 15/47; Most: 26/47; Few: 6/47 Most commonly mentioned: 1. Variable & fixed charges: all except a few unclear/indirect responses 2. Media tax: 14 3. Value added tax (VAT): 11	Most respondents, given their interest in an energy cooperative, knew basic information, but many did not state specific components under a generic 'taxes' category.
Which of these components are you frustrated to pay as part of your electricity bill? -> <i>Dissatisfaction with electricity costs</i>	Media tax: 22/47 High VAT @23% rate: 10/47 Other taxes/fees to service sectoral debt and operating costs: 20/47 Fixed charges: 3/47	Respondents protested that the media tax should not be on the electricity bill, wanted VAT lowered to its earlier 6% rate, and were frustrated with numerous taxes.
If you are a member of Coopérnico, why did you decide to become one? -> <i>Motivation for involvement in a solar energy cooperative</i>	Environmental concern: 13/47 Supportive of Coopérnico: 10/47 Socio-economic and environmental concerns together: 20/47 Not a member yet: 4/47	Of the 43 members, almost half mentioned multi-dimensional concerns, and between a third and a quarter were motivated by cooperativism or climate action.

enthusiasts tend to be middle-class to upper middle-class (30/47 have housing >100 square meters (sqm), 10/47 between 70 and 100 sqm, and only 7/10 < 40 sqm, for 1–5 person households). Only 8/47 households report a monthly electricity bill of over €100, with most in the €30-70 range; notably, some have installed rooftop solar self-consumption or prosuming projects.

5. Discussion: Implications for energy citizenship in multi-scalar solar rollout

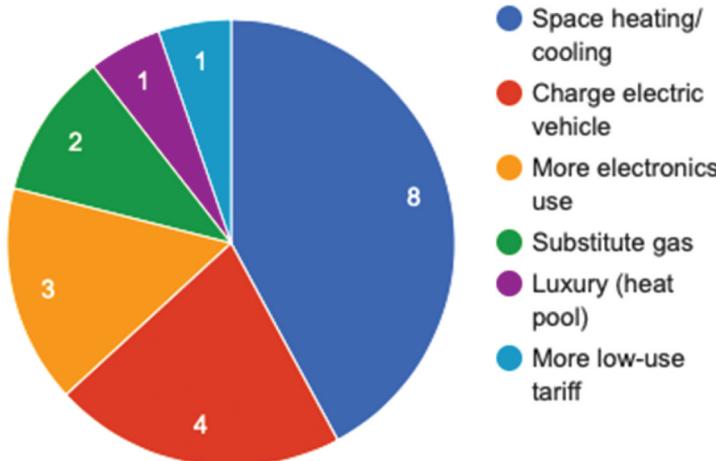
The findings and analysis yield three specific insights on how multi-scalar solar PV transitions affect policy implementation and the role of the user:

Insight 1 is that large-scale solar PV rollout is directly linked with rapid low-carbon energy transitions and thus environmental dimensions, but less so with socio-economic ones. We see this in the Portugal case through the energy regulator's relative inattention to the policies limiting small-scale solar PV. It is also evident in the way people recognize the limitations of large-scale iterations of energy, and their innovative responses; for example, the formation of Coopérnico and its engaged members. Large-scale solar rollout combines climate action and achievement of universal clean affordable energy access by rapidly expanding installed solar capacity on the electric grid. In the absence of new financing and ownership models, however, this transition remains limited to environmental effects, without moving existing socio-economic effects of the energy sector to greater equity and justice. This may seem obvious, but it is in stark contrast to the ambitions espoused in the National Energy and Climate Plan 2030 (European Commission 2019), and hence indicates a gap

Table 4. Motivation for and barriers to small-scale solar PV investment.

Responses to: "Have you invested in a project by Coopérnico, and if so why?" Targeted information -> <i>Motivation for solar PV investment</i>	Responses to: "If not, what would make you invest in a project by Coopérnico?" Targeted information -> <i>Barriers to solar PV investment</i>
Category 1: Solidarity/ethical investment "To help a cooperative that fights for consumers in this area." "Yes, because solar energy is underutilized in this country." "Yes, I believe in solar energy, acceptable yield." "Yes, because the projects are important and [were financially accessible]." "Yes. To support the implementation of new [solar PV] projects." "Yes. Helping Coopérnico [and receiving] remuneration."	Category 1: Willing but financially constrained "Without a doubt, we would invest more if the family budget allowed it!" "I have already invested in 2 [projects] and tried 2 others but I didn't [invest] in time" [indicating limited availability of investment options]. "[Will invest] when there are funds to invest." "[Need] greater investment/liquidity capacity."
Category 2: Socio-economic and environmental grounds "To help boost [renewable energy] production and [personal] financial return." "I believe in the need to increase renewable energy sources in the energy mix + good interest rates." "Yes. [Coopérnico is a] safe investment [and has] impact on energy and environmental sustainability." "Yes several. Because it is a way to profit from ... investments in projects with economic, social and, not least, environmental value." "Yes. To ... contribute to [sustainable] change." "Yes, attractive remuneration for the [investment] amounts, be part of the democratization of solar energy." "Investment in useful projects for all (user, investor, society and environment)." "Helping a [solar PV] project, the environment [and] society." "Yes. Profitability and environmental protection." "Yes. In addition to having a return on investment, it allows [supporting] the production of renewable energy." "Yes. Investment in real, sustainable, social, participatory and profitable economy."	Category 2: Dissatisfied with available options "Something that was disruptive in the market" [indicating Coopérnico model was not impactful enough]. "What would make me invest more would be shorter terms for repayment of capital and higher interest rates, similar to the first support projects." "Increase the interest rate. It does not make sense for the installation cost/kw to be increasingly cheaper and the interest rate to decrease." [Lack of renumeration] "Guarantees." [Bad] "Investment timing." [Want more] "Investment appeal, simplicity in the description of the contract and security in the financial return of the amounts invested." "I would rather invest the same rate, but for more years, like [the] 25 years duration of the panels." [Lack of] "Belief in the goal and profitability."
Category 3: Reasonable economic option (or not) [Yes.] "For profitability." "No, because there are better financial investments."	Category 3: Contribute in other ways "I prefer to invest in my work and intelligence than to participate in capitalist investments."

Clustered aspirations for more use

**Figure 3..** 'No' answers – energy use aspirations.

What are the components of your electricity bill that you can name? -> Knowledge about electricity costs

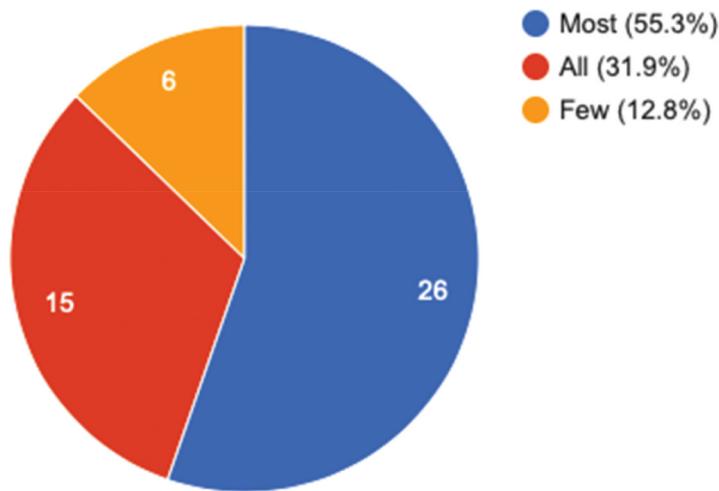


Figure 4. Electricity bill knowledge.

Which of these components are you frustrated to pay as part of your electricity bill? -> Dissatisfaction with electricity costs

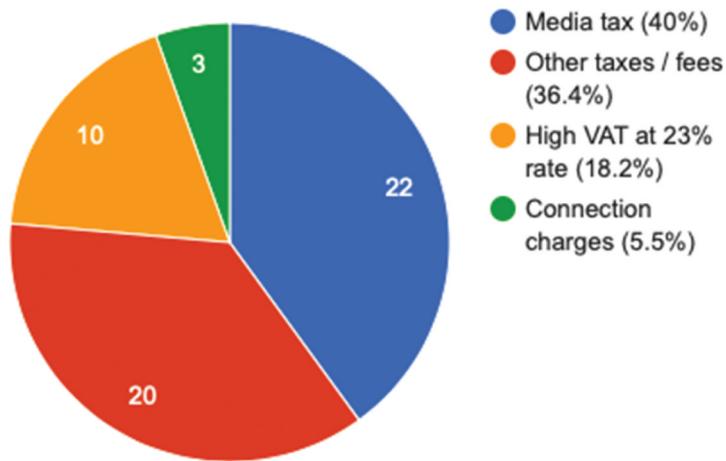


Figure 5. Dissatisfaction with electricity bill components.

between national policy and the mode of implementing solar PV rollout. As we argue below, addressing this gap is vital for generating multi-dimensional (both environmental and socio-economic) benefits from the energy transition (Moss, Becker, and Naumann 2015) and robustly interlinking three key SDGs. An emphasis on large-scale solar plants mimics the logic of the fossil fuel regime, in which a narrow, top-down point of control matches the nature of the fuel (Szulecki 2018). However, the modularity of solar PV makes control, participation and energy operations scalable to current needs of society (Kaygusuz 2007; Liu 2017), and energy policy must recognize

and enable this. In this sense, the rollout of large-scale solar is lacking in distributional justice as the benefits have been historically concentrated with incumbent and/or large-scale energy companies.

Insight 2 is that small-scale solar PV rollout has faced legal and economic barriers due to energy policies that favor large-scale incumbent interests. Knowledge on these barriers and dynamics is advancing in other European country contexts as well, such as Greece (Nikas et al. 2018). In the Portuguese case, the absence of a legal path to self-consumption schemes prior to 2020 has limited environmental and socio-economic benefits for energy citizens to a potentially significant degree. Those with the means to do so, such as the Coopérnico members interviewed for this study, are creating their own socio-economic benefits that simultaneously contribute to wider renewable energy rollout. This slow growth in small-scale solar due to regulatory barriers and incumbent interests has limited solar PV's overall environmental benefits; moreover, both the socio-economic impact of both small-scale and large-scale solar PV seems slanted toward middle-class and richer households. Community energy models such as the 'Solar for All' scheme of the New York State Energy Research & Development Authority can obviate the need for any upfront costs and enable targeted involvement of energy poor households as beneficiaries of small-scale solar rollout.⁵ Indeed, the municipality of Almada neighboring Lisbon is piloting a similar scheme from 2021 onwards as part of a new 'Sun4All' Horizon 2020 project, which combined with more enabling Portuguese legislation on community energy projects, bodes well for more inclusive sectoral development. Small-scale solar rollout can combine achievement of reduced inequalities with universal clean affordable energy access through energy policies that give households meaningful options for such investment. Self-consumption policy is a limited form of this; solar prosumption needs net metering and fair remuneration for its contribution, including virtual solar electricity supply for tenant households and those without access to their own rooftop space for solar panels. Without progressive policy frameworks, small-scale solar makes limited contributions on all dimensions, with limited socio-economic benefits to poor households.

Insight 3 is that community-scale solar PV rollout offers scope for wider participation in energy transitions in a transformative sense. Most mobilized stakeholders in our case state a multi-dimensional motivation to contribute to both environmental and socio-economic change in line with SDG7, SDG10 and SDG13. For example, our respondents who chose to invest with Coopérnico overwhelmingly reported a serendipitous interaction between socio-economic and environmental benefits as the central motivator. Community-scale solar rollout has scope to reduce inequalities and enable wider participation in climate action, as evident in our triangulated analysis of the key insights from many sectoral experts. Such a virtuous interaction between SDG10 (reduced inequality) and SDG13 (climate action) can also promote SDG7 (universal clean energy access), and combine environmental and socio-economic dimensions to motivate public engagement. Solar energy cooperatives and their membership show explicit commitment and action toward such goals, as evident from our findings above. Yet, as Campos et al. (2020) point out, while new legislation defines renewable energy communities and collective self-consumption, and provides a basis for an energy cooperative, it is not yet backed by a specific legal framework. Its provision for direct exchange between multiple prosumers enables "the development of micro-grids and various collective self-consumption business models (including peer-to-peer schemes)" and remuneration to prosumers "that reflects the market value of that electricity and which can be commercialised by an independent aggregator or utility company" (Campos et al. 2020, 7). However, as in highly liberalized electricity markets such as the UK where the regulator has navigated uncertainties of a regime in transition through experimentation (Bolton & Foxon, 2015), there is likely to be a period of pilot schemes before potential upscaling for sectoral transformation, and thus near-future developments may well be characterized by an element of relative inertia. The legislation, Decree-Law 162/2019, requires DGEG to conduct an assessment in 2021 and follow up biannually thereafter to inform regulatory

⁵For scheme details, see <https://www.nyserda.ny.gov/All%20Programs/Programs/NY%20Sun/Solar%20for%20Your%20Home/Community%20Solar/Solar%20for%20All> (accessed 25.01.2021).

evolution and operationalize socially inclusive renewable energy communities. Campos et al. (2020, 7) foresee the current legislation as offering “a legal basis for aggregators and the use of Guarantees of Origin (producers and energy suppliers may use this mechanism), allowing the setting up of new business models and new networks and social innovations” as a relatively stable pathway to citizen energy communities.

Figure 6 visualizes key interactions between the three SDGs in terms of the environmental and socio-economic dimensions of solar energy transitions. The figure shows that multi-scalar solar PV rollout offers real potential to increase equality through participation of energy poor households and improve access to reliable clean energy across various socio-economic backgrounds. It can be scaled up for rapid, sizable climate action, an area of keen research and policy interest (Rodrigues et al. 2016) with positive experiences emerging in country cases such as Brazil (Rigo et al. 2019) and Australia (Best, Burke, and Nishitateno 2019). The arrows highlight key anticipated features of each SDG–SDG relationship. Thus, we argue that adjustments to the nature of multi-scalar solar rollout can help address the trade-offs between SDGs and enable synergies through the policy prioritization of inclusive small-scale solar PV rollout options. Pragmatic mobilization of socio-economic dimensions in conjunction with environmental dimensions is critical for energy policies to gain public and political support within complex socio-political contexts and institutions. This contribution from our study can inform practice in a manner that leads to societal benefits and just energy transitions beyond the specific case of Portuguese solar rollout, notably in line with the European Union’s prominent commitment to a vision of a citizen-centric European Green Deal.

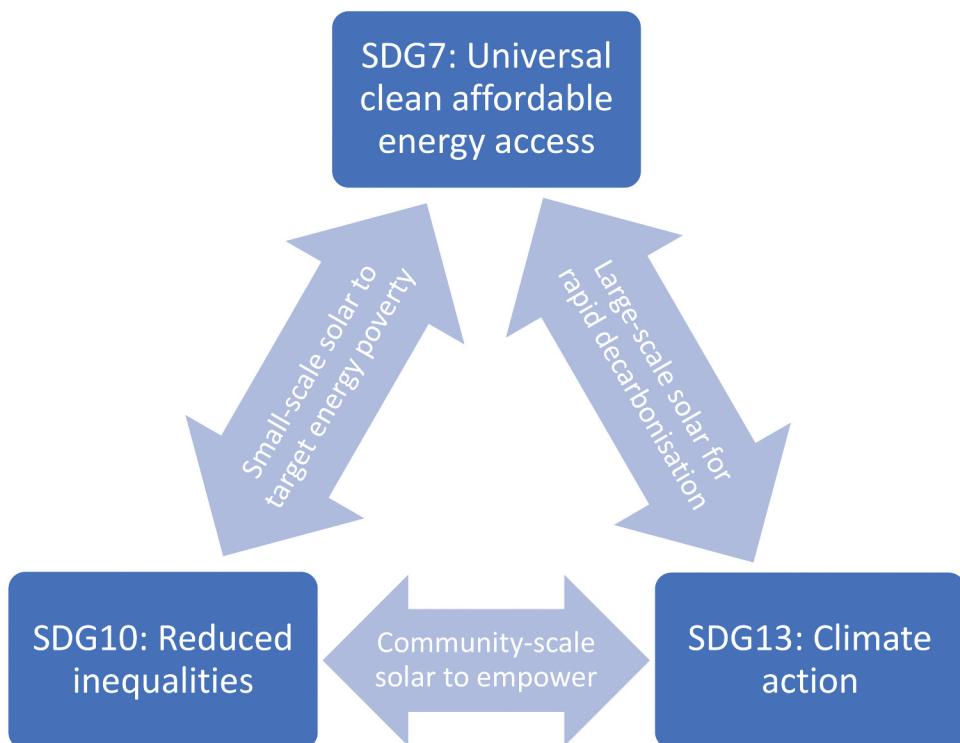


Figure 6. Multi-dimensional SDG7 interactions with SDG10 and SDG13 for solar PV.



5.1. Conclusion

Interest for small-scale solar uptake is growing among both regulators and users, with legislative barriers being removed and functional examples becoming available in various parts of the world. This development suggests a context ripe for multi-dimensional approaches to small-scale solar uptake. The insights from our study constitute an evidence-based push for energy policies to consider multi-dimensional SDG interactions and develop supportive frameworks for multi-scalar solar rollout. Our Portugal case study illustrates pitfalls of not having joined-up policy frameworks (stagnated small-scale grid injection projects, delayed large-scale solar projects), as well as pragmatic policy pathways to enable virtuous interactions (ambitious national vision documents backed by mechanisms such as solar auctions and legislative action to enable community energy projects). Our case study further illustrates collective anticipation for the community energy legislation now in effect, namely Decree-Law 162/2019 (Government of Portugal 2019), and suggests that this will elicit an uptick in small-scale solar uptake by catalyzing the activities of emerging stakeholders such as solar energy cooperatives. The case further suggests that, although this policy benefits stakeholders beyond large energy sector players, these benefits tend to accrue to middle- and high-income groups without an integrated policy approach that would simultaneously ensure the inclusion of energy poor households. Hence, the development of progressive schemes that emulate successful examples (such as ‘solar for all’ in New York) in socially situated ways must be an energy policy priority.

While most of these insights are becoming established in energy social science research, rich multi-scalar evidence from a national energy transition case remains rare (this is beginning to change, see Nikas et al. 2018). The Portugal case shows us how multi-scalar solar PV transitions affect energy governance and the role of the user. Governance in Portugal has primarily favored large-scale solar rollout, which in itself is a creditable achievement and advances environmental goals. But it has unnecessarily come at the cost of small scale, community and individual solar rollout. Indeed, a study by Rodrigues et al. (2016, 84) showed that in Portugal “The grid injection tariff is four times lower than the consumption tariff, therefore forcing the solar producers to self-consume and not inject any solar power into the grid since the grid injection extends the payback time.” Their analysis placed Portugal in an unfavorable eighth place out of 13 countries in a global comparison of the profitability index for a small-scale solar PV plant of 5 kW. Despite this, a self-selected group of consumers has transformed their role from end-users into energy citizens through the voluntary uptake of, or investment in, small-scale solar, illustrating growing, keen public interest. There is a policy window of opportunity for the incumbent national government, which was reelected in 2019 with a progressive policy platform that mainframes energy transitions, to make solar rollout a more inclusive phenomenon, and indeed the latest legislative changes to enable community energy options are encouraging signs that must be backed by action.

Notably, we offer some early insights on motivation and mobilization by small-scale solar enthusiasts in a financially constrained economic context. Our analysis demonstrates that citizens engaged in solar energy adoption during an energy transition explicitly recognize the multi-dimensional nature of the transformative change required to realize broader sustainability goals, such as those of the SDGs, particularly interlinked aspects of SDG7, SDG10 and SDG13. Such popular aspirations and agency must be backed up by granular energy policies to integrate socio-economic and environmental dimensions at multiple scales. Joined-up multi-scalar policy can guide energy sector development toward sustainability in practice.

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