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Transitions to Future Energy Systems: Learning from a Community Test Field

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Abstract: This article explores the challenges of transitioning towards future energy systems in a solar test field within the eco-community of Tamera, Portugal. We examine what findings can point to wider actionability and how. First, we consider how Tamera's solar test field has addressed energy transition challenges. We unpack the nature of stability and change in achieving 60 percent energy autonomy; trace the linkages to spatiotemporal issues implicated in this sociotechnical process informed by keen commitment to energy justice; and dwell on the test field's socioeconomic considerations at its interface with the Portuguese institutional framework and global connections. Second, we identify which findings can fertilise policy and action across European contexts. Considerations in gradually installing sub-100 kW solar capacity contrast starkly with the current proliferation of grid-scale solar in southern Portugal, raising questions about the actionability of knowledge on sociotechnical transitions. We co-generate ideas on how such contextualised epistemological advances can aid our understanding of societal energy transitions. The article encourages socially informed, integrated policy pathways. It speaks to building epistemological complementarities between applied researchers and practicing agents; problematises linking across scale between a community and institutionalising powers; and calls for actionable efforts that integrate systems thinking and power dynamics towards transformation.

Keywords: community energy; sociotechnical transition; Portugal; solar power; actionable knowledge

1. Introduction: Tamera's Solar Test Field as a Living Laboratory

Transitions to future energy systems are characterised by stability and change across time, space and scale, within institutional structures and through relational processes [1]. They comprise elements of sociotechnical transitions as well as of energy justice that research has only recently begun to address in an integrated manner [2,3]. There is a need to build bridges across analytical perspectives in order to progress in this interdisciplinary field [4,5]. A rewarding step towards accomplishing this in recent times is living laboratories (e.g., [6]).

This article explores the challenges of stability and change in transitioning towards future energy systems in a solar test field in southern Portugal. It is the product of reflexive engagement between three researchers over the course of a year: one a social scientist researching the governance of energy transitions, and two physicists working hands-on to develop sustainable community-scale energy solutions in the Tamera eco-community, primarily through the use of solar thermal systems. The authors draw on a long-running example of a transition to future energy systems in Tamera in the southwestern reaches of the undulating Alentejo region. Tamera is an intentional eco-community

of 160 people working towards a trust-based form of social organisation and communal living since 1995, alongside energy, food and water autonomy. This can serve as a living laboratory for understanding processes of stability and change over time (cf. [7]). Specific to energy transitions, Tamera's decade-old solar test field represents a rare and fruitful coming together of community engagement in sociotechnical change processes (cf. [8]). The solar test field takes the continuing form of 25–30 people living in a cluster within Tamera's 130 hectares of land, moving towards energy autonomy through solar and other renewable energy innovation in conjunction with changes in lifestyle that they collectively determine to be sustainable. The take-home from these experiences for wider actionability responds to two research questions: (i) What learning does the solar test field's experience offer to understand energy transitions? and (ii) How can this knowledge inform energy transition policies in other European contexts?

In keeping with the research questions, the work is two-fold. First, we draw on the extensive experiences of Tamera's solar test field from multiple perspectives in an interdisciplinary manner, to consolidate learning from its manner of having addressed energy transition challenges so far. Methodologically, this has been facilitated by intensive interactions during two in-person visits to Tamera (in September 2017 and August 2018) by the lead author with the two physicists, who are long-running residents of Tamera, as well as correspondence during periods of writing. We unpack the nature of stability and change in the solar test field's efforts in having achieved approximately 60 percent self-estimated energy autonomy; trace the linkages to the wider spatiotemporal issues implicated in this sociotechnical process informed by Tamera's keen commitment to energy justice; and dwell on the test field's navigation of socioeconomic and pragmatic considerations at its interface with the Portuguese institutional framework and broader set of global connections (cf. [9]).

Second, we identify the key learnings that can fertilise policy and action in other European contexts based on the solar test field's experiments, including intangible process-oriented lessons. These are particularly relevant given that the Alentejo and Algarve regions of Portugal are currently being developed on a massive scale (cf. [10]), with large-scale solar parks redefining their landscape for rapid adoption of renewable energy sources in keeping with a general European push [5]. The stark contrast between an eco-community's considerations in installing sub-100 kW solar capacity over years, versus the current proliferation of grid-scale solar energy systems within a two-year span, raises questions of the actionability of knowledge on sociotechnical transitions. On what basis are which types of solar energy technologies promoted, at what scale and by whom, and with what consequences for social and environmental justice (cf. [5])? We co-generate ideas on whether and how such contextualised epistemological advances can aid understandings of an overall societal move towards future energy systems (for analogous work on cities, see [11]). The article thus captures responses to both research questions, and urges future policy pathways to open up to more socially informed, integrated treatment of energy transitions across European contexts (see also [12]).

Our work builds on a lively strand of social innovations scholarship. Two decades ago, Kemp et al. [13] posited the emergence of technologies as modulated by strategic niche management. To them, social innovation involved coupling expectations with the technology, articulating sociotechnical practices linked with its uptake, and forming a network of actors to enable uptake. A decade later, Røpke [14] (p. 2496) emphasised attention to practices in relation to sustainability, noting that "most valued practices are performed with little or marginal concern for the environment." Seyfang and Haxeltine [15] highlight this focus on practice while expanding the arena of attention beyond internal factors to external ones. They point out that social innovations are "often countercultural and self-consciously formed in response to unsustainable regimes: hence, the scope for easy translation of ideas and practices between niche and regime is reduced" [15] (p. 396). They moreover emphasise the role of individual and community identity and purpose in determining social innovations around technology and how linked goals emerge and evolve. How to engage with such variation at the community scale in a manner that supports outscaling and enables truly participatory decision-making in energy transitions remains a pertinent issue [16,17]. Thus, we can

see that scholarship calls for both improved insight into social innovation around technology within communities, as well as reflection on the uptake of such innovation beyond the local scale and its implications for energy transitions.

Informed by the extant academic discussion, the research questions are premised on co-producing knowledge about the following concerns around social innovation under energy transition: to bring about epistemological complementarities between applied researchers and practicing agents; to problematise linking across scale between a community and institutionalising powers; and to develop actionable efforts that integrate complementary foci on systems thinking and power dynamics towards transformation. Rather than explicitly targeted as headlines, these concerns are approached in conversation together as authors who have co-produced this text from different vantage points—either as an applied researcher with expertise on governance and energy transitions or as practice-oriented researchers-cum-members of the solar test field with long-running links within the Tamera eco-community. This collaboration foregrounds key learnings with regard to the materiality of the technology, people's conditioning and social dynamics, access to financial capital and incentives, and how technologies fit together and within the social context.

2. Materials and Methods: The Solar Test Field's Multi-Dimensional Energy Transition

During the first fortnight that the lead author spent in Tamera, he engaged extensively with the solar test field's members and its technology team in particular, in addition to undertaking a curated introduction to Tamera's portfolio of activities, of which energy autonomy is one major thrust. The introductory course brought him in contact with many of Tamera's residents and included multiple daily group sessions over the course of a week. During the second week, he engaged intensively with residents of Tamera's solar test field as part of a 'hands-on week'. During this period, he helped build a compost heating system, and his understanding of the test field's aims and practices is based as much on these hands-on impressions as on lengthy interviews and conversations conducted during this stay, which he prepared for through detailed discussions and consultation of documents for months before the visit. Fifteen interviews were conducted, ranging between 30 and 120 min, each with one or two interviewees; there were 19 interviewees in all from among Tamera's residents.

Interviews focussed on understanding Tamera's energy autonomy efforts and the practices associated with everyday energy use, with a focus on various solar energy forms. Interviewees were selected based on relevance: as a function of their role in Tamera, by snowball sampling based on others' recommendations, or following the advice of resident co-authors. Discussions and correspondence continued during the writing process, supported by a three-day follow-up visit within a year's span for shared reflection during manuscript finalisation. These broad concerns guided the lead author's questions during semi-structured interviews: (i) the informant's everyday engagement with the solar test field, (ii) their views on solar uptake and energy transitions both in Tamera and more widely in Portugal or elsewhere in Europe that they knew about, (iii) their knowledge on specific aspects of Tamera's energy autonomy efforts, spanning social, technical, economic and political issues, (iv) energy-related aspects they wished to discuss in detail (e.g., fundraising and communication around solar and electric transport projects, particulars of cooking with solar energy, energy use to heat public and living spaces such as offices, rooms and caravans, depending on the informant's role and expertise), and (v) other questions the informant wished to explore and other Tamerans they thought could contribute valuable insights for the study.

While Tamera is over two decades old, the solar test field took off in earnest in the mid-2000s, and has evolved incrementally to its present form. Progress may seem to the outside to be slow, due to the depth of inner work required as a consequence of its members seeing themselves as participants in a living laboratory on energy autonomy. Where quick fixes would be inadequate, the community has a preference for weighing the multiple impacts of alternative energy solutions across space and time, then trying some out to see how they work in relation to everyday lives. An additional reason for the gradual pace of change has been the requisite financial resources, which for such projects are usually

raised by donations. Tamera's work on autonomy and cooperation as principles encompasses not only energy autonomy, water retention, food self-sufficiency and natural resource conservation, but also in-depth social experimentation, making for a complex interaction between projects and resource allocation that seeks to takes into account the needs of the whole.

One of Tamera's and the solar test field's oldest members, recounting its early days, discussed how in the initial years after establishing the eco-community on this site, Tamerans lacked even basic power outlets and access to tapped water. With a shrug of the shoulders, he gestured to the impressive workshop apparatus surrounding him, including power tools and multiple computers running in the room, pointing out that much like many other places, the solar test field is quite dependent on technologies that consume significant energy. Yet switching to these has been accompanied by shifts away from sources like wood and reduced dependence on a grid whose electricity is partly produced using fossil fuels. The solar test field uses biogas from biomass produced within Tamera using food waste, as well as concentrating solar power, to cook food for 50 people on a daily basis for most of the year. Not only does the entire site now have abundant water, this has moreover been achieved in a manner such that Tamera's presence contributes positively to replenishing groundwater levels.

The relationship between the solar test field and the wider eco-community of Tamera merits clarification. The test field operates based on its residents' preferences in a manner that is autonomous on a day-to-day basis, but also places itself within the framework of Tamera's overall goals of a comprehensive paradigm shift towards a social structure based on trust. To develop and maintain coherence over the whole project requires communication, which takes place through multiple forums that are adaptive in the spirit of Tamera's social experimentation. For instance, a form that was prevalent in 2017 but has since evolved entailed: (i) weekly meetings where the entire community gathers to listen to one of a set of main speakers, who on occasion focus on this part of Tamera's vision; (ii) discussions within a smaller group of individuals in Tamera who deliberate upon the profound aspects of the eco-community's efforts including ones pertaining to energy autonomy; and (iii) interactions that all Tamera residents have with solar test field residents as well as with those visitors whom the technology team invites in to contribute their competence to the test field's projects during short and often repeat visits. Additionally, special events such as the annual 'defend the sacred' gatherings hosted by Tamera enable enrichment and cross-fertilisation with similar efforts globally. The 2018 edition, which concluded as the authors finalised the manuscript together in Tamera, focussed on solidarity against drilling for oil off the Portuguese coast in defence of water as a sacred resource for life. These political economic developments weighed heavy on the authors' minds in relation to the second research question of how community efforts can enable policy learning in the face of such overwhelming obstacles to energy transition.

Setting priorities for time and financial decisions is a dynamic process involving many different and interconnected groups who aim to find decisions based on humanity's evolutionary path, with an emphasis placed on profound cooperation with nature, with as much awareness as possible given to perceiving and addressing selfish motivations that otherwise remain hidden drivers within discussions and decision-making. The community aims to find and follow the interests of the whole; an energetic line that holds beyond individual opinions. With this overall aim, attention is given in Tamera's various councils to distinguishing between opinions, prejudices and facts, including when this leads to transformational personal processes. For instance, as elaborated in Section 3.2 below, some men were perceived as dominating a conversation rather than contributing based on relevance; recognising this tendency enabled constructive discussion.

The solar test field's social relationships with inventors and innovators have resulted in many experiments and advances. Among these is a Stirling engine that can efficiently convert heat captured using concentrating solar power and stored temporarily in the form of hot oil in insulated containers into electricity. This engine, however, is now unused while the feedback that it was too noisy for users is taken up. A new almost silent engine has been developed since this round of testing and its operationalisation is awaited. An energy-producing greenhouse structure equipped with linear

Fresnel lenses served to capture solar heat for circulation as hot oil while providing plants a cooler environment to thrive in during the arid Portuguese summer functioned in conjunction with the old Stirling engine and now forms part of the 'museum' of solar solutions that solar test field visitors get a tour of. The chief on-site development project from 2015 onwards till 2018 is a lightweight paraboloid mirror that uses transparent and reflective inflatable membranes, creating a precision optical surface using air pressure to achieve high solar concentrations. This concentrating solar power device, in combination with a kiln, both designed in-house, is intended as a decentralised modular power producing element for small-scale industrial processes and cooking. It will hopefully allow the solar test field to manufacture its own lime cement using solar energy and also store solar energy in natural, locally available materials such as specific stones for cooking around the clock. The latter solution is used by the small team working on this project to brew their coffee, and night-time pizza cooking events and aluminium castings are currently only occasional demonstrations. (At the time of concluding manuscript revisions, progress on this project had stalled despite its advanced stage of functionality due to legal disagreements between external partners, which we are unable to address here due to reasons of sensitivity. However, the existence of this problem itself is worth noting, as an example of the challenges inherent in efforts to shift existing paradigms such as our relationship with energy. It evokes questions such as how we can move from a resource ontology to different ways of viewing energy systems in society.)

Such projects have been made possible by grants and donations combined with the free skilled labour of some solar test field residents who comprise the technology team. Using Tamera's wider networks, this small team with a handful of members has repeatedly invited in others with specific competencies to aid in their experiments. The hands-on week the lead author participated in was preceded by a week of planning for future advances in energy autonomy. Two direct outcomes of the hands-on week were: (i) the construction of a shed roof over the biogas plant as shelter for users and in order to mount a photovoltaic panel on it, and (ii) setting up a compost heating system as a prototype for a sustainable solution to heat the houses and caravans in which Tamerans live over the Portuguese winter. Energy poverty is a significant problem in Portugal [18], and finding solutions to keep buildings warm over the winter is a dual priority for the solar test field: to improve Tamerans' quality of life while furthering energy autonomy (the compost heating system uses almost only locally available materials, with the exception of a small pump motor and an insulated pipe, and the side effect is to produce valuable compost material rather than any form of waste), and to demonstrate a more widely useful solution for potential adoption elsewhere. Ontological accounts of such community efforts are hard to find in nascent literature on this subject. Such epistemological complementarities emerged during the collaboration. Tamera's work on water retention landscapes, for instance, has been recognised as salutary and resulted in many invitations for assistance, leading to some Tamerans being in demand as expert consultants.

But when it comes to the uptake of photovoltaic solutions, the solar test field has been selective, deploying such systems in a decentralised manner across Tamera rather than as a large-scale installation to rapidly increase their energy autonomy (Tamera uses hybrid energy sources: biomass, biogas, concentrating solar power, solar photovoltaic, car fuels, electric grid supply, stored heat and biophysical energy. Data availability on each source varies based on its materiality, temporality, and community-level monitoring capabilities. Since our study is not concerned with the historical evolution of energy uptake and also out of respect for the privacy of all Tamerans, we do not provide figures on installed capacity and usage). One reason for this is an ethical concern for the impact that extracting the materials used in the photovoltaic infrastructure (e.g., the metals used in batteries) has on people elsewhere (echoed in [19] and emerging telecoupling scholarship, e.g., [20]). This awareness is highlighted by Tamera's relationship with a Colombian sister community as part of its peace work; this community is in a region with extraction driven conflicts. Another reason for limited uptake of photovoltaic solutions is concern for the environmental externalities involved in their production; the test field did identify producers who prioritise environmentally responsible practices, even though

these entail higher costs, but such producers are hard put to stay alive in the evolving solar market and one identified company did in fact fold, as is typical of the Schumpeterian creative destruction that currently characterises the renewable energy innovation space. As an alternative that does not suffer from these issues, the technology team is working on thermal energy storage solutions using readily available materials. Similar concerns are evident in action research on community wind energy, including in Portugal's Alentejo region.

A third important reason was expressed by a leading technology team member, who emphasised the test field's commitment to doing and testing cutting-edge, innovative solar solutions in a living laboratory setup. He pointed out that while larger research institutions have far better funding and infrastructure to carry out ambitious scientific experiments to design state-of-the-art solar technologies, the solar test field's strength as a research institution is in generating these solutions in and for a community setting and seeing how they can fit within their lived experience. To him, the solar test field's priority was to demonstrate the promise of particular solar energy solutions in a socially-integrated manner, then leave the details to better-equipped laboratories as long as it would eventually be possible to pass on the benefits to a wide range of users (a hybrid take on the internally and externally oriented niches theorised by [21]). The inflatable membrane mirror in particular held much promise in this regard, being scalable so that many similar ones could be added to increase industrial process capacity and produce cement and cook at scale for a larger community.

To date there has been no systematic engagement between the socially innovative eco-community and the policy environment on solar energy solutions in Portugal (which resonates with discussions on strategic niche management and grassroots innovation elsewhere in Europe, cf. [22]). In fact, none of the solar test field members brought this up as a topic they accorded much consideration. One called Tamera and Portugal the 'Wild West of Europe', indicating that regulations had little to do with what happened in practice in remote locations such as Tamera. While national legislation on solar micro- and mini-generation does allow for the installation of the modest solar capacity the solar test field has on an individual basis, there was no strategic push from Tamera towards demanding laws for community solar projects. One reason is the perceived need to demonstrate fully-integrated solutions before such efforts. Portuguese political discourse in recent years having turned strictly against any subsidies for renewable energy including solar sources, there is perhaps less to be gained from such efforts in the short run than by fundraising from other sources for specific projects the test field hopes to realise. In the long run, however, this can limit the contribution of inputs from the test field's efforts to the Portuguese and European solar uptake strategy; even so, the communication of its activities via Tamera's networks and media outreach does reach an international audience. In the next section, we broach the second research question of key learnings that can fertilise policy and action, and whether and how they can constitute actionable knowledge.

3. Results: Using Community Learning for an Integrated Take on Energy Transitions

The solar test field's decade-long experiments with energy autonomy have yielded social innovation learning. This is potentially valuable for both conceptual and policy-oriented understandings of energy transitions, insofar as these should interact with experiential knowledge. Such interactions help arrive at accounts that integrate multiple aspects of stability and change, like sociotechnical and energy-justice-related issues (cf. [23]). Yet epistemological complementarities between energy transitions research and practice rarely pre-exist and must often be cultivated (see [24]). Bridging these knowledge communities introduces practicing agents of change to the academic and policy state-of-the-art on the general predicament they are concerned with, and helps articulate community knowledge within policy debates and academic discussions. In effect, one hopes to conjoin the outward-oriented tendency of a systems thinking approach with the inwardly-directed property of a focus on power and social dynamics to enable actionable efforts for sustainable energy transitions based on enabling social innovation. As co-authors, applied and practice-oriented researchers alike are agents of change in this respect. Particularly during talks with the co-authors, who are test

field members, the relevance of some learnings from this living laboratory for policy and academic debates surfaced clearly. So did some challenges that get in the way of cultivating the epistemological complementarities required for such community knowledge to permeate these debates.

An example serves to illustrate some such challenges. During fieldwork, there was a call from a European Union funded project to contribute research on stability and change to inform European policy on energy transitions. The authors were convinced there was a strong case for them to make, and pulled together a team and proposal that they felt would enable them to make it. Their submission was disqualified on grounds of two co-applicants from the solar test field not being associated with a recognised research institution (despite being physicists conducting research) even though others within the team adequately satisfied affiliation requirements stated in the call, and they were informed that an anarchic context like Tamera was unlikely to yield useful insights for European policy in any case. The initial surprise that test field members had expressed upon hearing that a policy-oriented European Union project might be interested in their knowledge seemed well-founded in hindsight. While the call reviewers doubtless had sufficient objective reasons for their decision, this example illustrates the point that community knowledge is often restricted to fringe status by forms of recognition that preferentially accord legitimacy to certain types of relationships and institutions for knowledge creation. The rest of this section details four key learnings from the test field that could in fact fertilise European policy.

3.1. The Materiality of the Technology

In spending years furthering the solar test field's work, the co-authors have found that, as expected, the social aspects dominate over the technical aspects of technology development and uptake. Getting access to resources in a manner consistent with their aim of sourcing in environmentally and socially responsible ways has been challenging; getting access to technical knowledge for their context, such as which locally abundant materials could be used to store solar heat to cook in the evenings, is time-consuming; the community has to rely on social capital and goodwill for various forms of technical assistance such as during the 'hands-on week' and to be put in contact with reliable companies to procure products; and only a small number of Tamera's inhabitants feel interested in and capable of being part of the technology team, of which the majority are men. Using the solar kitchen and the various solar solutions they have come up with has over time proven to be relatively straightforward, partly because development has been in conjunction with close awareness of the context, including in everyday interaction with female users of the technologies even if few are on the technology team. Thus, one learning is that communities can do with support on simple technical resources, for both knowledge and material procurement as well as installation expertise. Such prosumer perspectives, as noted in [5], constitute key epistemological complementarities to round out sociotechnical scholarship in order to understand sustainable energy transitions holistically.

3.2. People's Conditioning and Social Dynamics

The social aspects have greatly influenced both the technology development and the uptake of the technologies implemented in the test field. One or two enthusiastic and dedicated users have been shown to have a very positive leadership effect in times when the solar test field has focussed attention on using the technologies; conversely, when the overall commitment of the test field residents wanes, so does the willingness to go the extra steps necessary to make a new technical undertaking a success. A leader of the technology team highlighted some social and power dynamics integral to decision-making processes. One is *parental projection*, where two team members replayed patterns of argument until they identified that one unconsciously related with the other as a maternal figure. Once this was acknowledged, it became easier to address, and the patterns of argument were resolved. Another dynamic he pinpointed was *competitive dynamics*, wherein some men spoke up in meetings not in order to state the most relevant thing but to display their knowledge or prowess to others, perhaps semi-consciously. Once this was openly discussed, it became something people could help identify

in a constructive manner, again enabling better discussion and decision-making. The relevance of such dynamics appears to have been relatively silenced so far, not just in community case studies but in energy transitions scholarship overall, perhaps because their observation and specification is challenging, even more so in the high-powered decision-making forums typical of the energy sector. These learnings are pertinent not merely for energy transitions processes, but as a more general principle extending to all decision-making, namely that forums must ensure that content is prioritised over any underlying egoistic drivers, and that this takes real work at considerable depth even in a community context. This role of community efforts as living laboratories to understand dynamics of energy transitions extends well beyond localist discourses around community energy as a substitute for the state, as critiqued by, e.g., [25], and can serve to incorporate public values into navigating the uncertainty associated with decision-making processes around energy futures [26]. Explicating power dynamics is an essential step towards being able to identify strategic opportunities for intervention towards more participatory decision-making in the energy sector across scales, based on improved representation of stakeholders as well as more inclusive deliberative processes within key forums.

3.3. Access to Financial Capital and Incentives

The fundraising strategy adopted by the solar test field is instructive for another key learning. One of the projects the test field took up in 2017 was to raise funds for an electric vehicle, as most vehicles used in Tamera were still powered by fossil fuels. Tamera avoids bank loans, instead accepting interest-free loans from individuals, besides donations. Its chief funding source is money raised by organising courses, which it runs on a regular basis, with approximately 4000 paying visitors spending weeks or months in the eco-community annually. This makes up about two-thirds of its income, and part of it goes to the eco-community's housing budget, of which a portion is allocated to the solar test field; other than this the test field must raise its own funds for any additional expenses. Yet the solar test field has not prioritised funding bodies or donors' wishes in order to expand operations. On the contrary, residents saw in the membrane mirror project that when they resolutely aimed for what they really wanted to do and believed necessary, the requisite funds followed very shortly thereafter. In this sense, a key enabler for a project to come up is finding the requisite internal energy embodied in a resident to take charge of an initiative and thereby create the conditions that engender it. It is nonetheless also true that while they would also like to proceed with more photovoltaic installations as soon as possible, requisite external funds have not yet appeared. Financing significant new photovoltaic capacity would eat into the limited internal budget; meanwhile Tamera is also fundraising to move towards energy autonomy in its transport solutions through the envisaged future purchase of electric vehicles.

Hence the solar test field is concerned with the tension between its wish to contribute to a just regenerative energy policy and the financial constraints it faces. The insight this contributes towards policy-making is that providing incentives for communities to move towards energy autonomy might enable various innovative projects that are appropriate at this scale (see also [27]). Straightforward examples of possible incentives include feed-in tariffs for prosuming solar energy back to the grid, and financial and technical support for localised heating solutions against energy poverty. Communities that develop these proactively may well demonstrate how to tailor them for everyday use, making for a sociotechnically robust system. As a communal system, Tamera's energy generation and usage are both inclusive: energy use including electricity is available to all residents, with an expectation of responsible use supported by a tradition of regular discussions among members on communal matters. So most energy use is communally financed, with some exceptions such as car fuel. While not easily extendable beyond intentional communities with mutual trust and a partly shared economy, such an approach can enable discussions of energy democracy with a balanced focus on production and consumption, and motivate efforts to institute trust-based community energy-sharing systems. Such pluralist representation of energy users is desirable in, e.g., smart grid scholarship, when ideating future sociotechnical systems [28].

3.4. How Technologies Fit Together and within the Social Context

A final learning is that multiple types of solar technologies such as photovoltaic and concentrating solar power, as well as adjacent solutions such as Stirling engines and biogas plants, can be combined in ways that lend themselves to community-scale projects. To illustrate the basis of Tamera's approach towards energy, consider the following excerpt from an essay by their energy mentor Jürgen Kleinwächter on the eco-community's companion website (http://terranovavoice.tamera.org/2018/01/living-in-paradise-without-noticing-it/5799, accessed 24 January 2018):

> "Everything that today constitutes the objects of our dreams and desires was created by the radiation of the sun. Coal, oil, gas, uranium are ultimately almost marginal by-products compared to the incredibly large, steady flow of light on our Earth. We understand more and more that we can technically transform this clean, billions of years long-lasting, completely environmentally neutral light flux directly into all the known utility forms of energy and with many unimagined possibilities in the future.
>
> With a huge difference to today's energy-political situation: sunlight falls freely and evenly distributed, free on our Earth. And even the smallest area receives so much radiant energy that you can only marvel. Who knows that the solar radiation that falls in the course of a year on a one-hundred-square-meter single-family house roof in Germany, a country not really kissed by the sun, is equivalent to the energy of about 10,000 L of heating oil? An equal area in Africa receives about three times this amount. Saudi Arabia's national territory receives an annual amount of radiation that far exceeds the oil supplies dormant under the desert. And today we are technically able to convert this radiant energy elegantly into electricity, power, cold, heat, biomass and much more. Local, producible on site, creating jobs—that's already a reality today."

Kleinwächter goes on to posit that sunlight is a freely given gift of abundance:

> "not accepting it means either being blind or being rude. Using it only partially (for example, only for electricity production) creates monocultures instead of using the very wise principle of diversity. Accepting abundance does not mean to fall victim to the unrestrained, unconsidered craving for consumption; on the contrary, in the presence of abundance, to deal intelligently and rationally with the radiation resources, in harmony with the equally-acting nature. To achieve liberation from the class-creating opposites of today's distribution structures: It means that there is no more need to fight for resources; that the free gift enables the creation of modern, small tribal societies that cooperate peacefully in global networks for mutual benefit."

This cuts close to the heart of what Stirling [29] (p. 54) terms "culturing plural radical progress" when discussing the politics of green transformations. The scope of emerging solar technologies, appropriately harnessed as part of greater emancipatory struggles, can exceed replacing part of people's grid consumption; with modular prototypes that can be easily stacked, solar heat can be used directly for many purposes and stored in creative locally adapted ways rather than necessarily only as electricity. These are the preliminary steps that lead to the development of closed-loop systems that are essential for a transition to clean energy situated within any context, in keeping with the European Commission's push towards a more circular economy based on sustainable consumption and production [30]. Thus, a policy insight is that providing assistance for the energy transition need not be limited to supporting mini-grids and system integration at the community level, but can profitably take a multi-pronged approach, where provisions in suitable contexts must include support for social innovations built around versatile solar heat and light uses and be responsive to local demands. In Tamera, for instance, there is scope for technical assistance, subsidies or incentives for uptake of compost-based heating systems through housing upgrade and energy poverty alleviation

budgets; their social innovation with concentrating solar power has received private financing but public funds could spur other similar efforts at a community scale.

Table 1 provides a summary overview of the four learnings above and their prospective contribution to energy policy in Europe.

Table 1. Key learnings from the solar test field for European energy policy.

Key Learning Focus	Contributions from Learning to Energy Policy in Europe
The materiality of the technology	(i) To support community energy, make simple technical resources available: knowledge of solutions, material procurement details, installation expertise. (ii) Customise resources to social contexts and everyday use: use locally available resources, do not make unrealistic demands of an ordinary person. (iii) Social aspects are challenging but with some inspiration and motivation, communities can self-organise to address these within their own context.
People's conditioning and social dynamics	(i) Individual leadership and process ownership is important for community efforts to work well over time. (ii) Social and power dynamics are integral to decision-making (e.g., parental projection and competitive dynamics) and must be explicitly addressed. (iii) How communities address power dynamics can offer key insights to enable more participatory decision-making in the energy sector across scales.
Access to financial capital and incentives	(i) Adopting different technologies under energy transition usually presents trade-offs, and sometimes synergies, so local priorities require assessment. (ii) Justice considerations, often spatially removed, accompany most technologies: local deliberation on these should precede technology adoption. (iii) Most energy use is hybrid: incentives informed by actual use must be given to encourage communities to undertake a responsible energy transition.
How technologies fit together and within the social context	(i) Multiple technologies in contextualised configurations around versatile solar heat and light uses are appropriate for community energy projects. (ii) Community energy does not have to be limited to self-consumption, but can be deployed for multiple purposes driven by social innovation. (iii) Energy can be stored in creative, locally adapted ways, also as heat, towards building closed-loop systems: e.g., technical and financial support for compost-based heating systems from energy poverty alleviation budgets.

4. Discussion: Integrated Energy Transitions Require Both Stability and Change

Energy transitions are proceeding apace. Whether or not community knowledge informs action, the energy sector will be massively reconfigured in decades, if not years—more likely the latter in relation to solar energy. As noted at the outset, these transitions are characterised by stability and change across time, space and scale, within institutional structures and through relational processes [1]. In southern Portugal and particularly in its Alentejo region where Tamera is located, these changes are poised to happen at a rather more dramatic spatiotemporal magnitude [10]. Over 2 GW of solar capacity is in the pipeline, compared to less than a GW previously installed in the whole of Portugal. Whether and when all of this will be installed is a complex question dependent on a multitude of factors that are likely to be determined as much or more by political economic factors as by technical ones, with attendant implications for energy justice [5]. Yet some of it is already underway, including a solar park exceeding 220 MW, which leads us to the question of what this means for Portugal's energy future and indeed what difference community knowledge can or should make at this key juncture.

The energy future that is at stake at the moment is one that can be driven by massive and rapid photovoltaic installations, accompanied by massive transmission infrastructural growth or by a more gradual phasing out of Portugal's two coal plants and eventual replacement with solar sources in southern Portugal. Alternatively, it can be premised on many smaller community-scale solar installations, with stable mini-grids directed primarily at local consumption while also connected to the national grid, leading to a stable, flexible system without the need to develop massive transmission

infrastructure; instead, one can add some decentralised local infrastructure near small towns and big villages [12]. Going by the scale of proposed solar capacity and the policy framework that favours larger players in terms of the requirements for the procurement of licenses, what we are likely to witness is one of the former scenarios (akin to the gloomy analysis Dóci et al. [21] make vis-à-vis the transition potential of Dutch renewable energy communities). The latter might well be a missed opportunity to transform the logic of our energy system in the Portuguese case—a transition to a cleaner source, without the promise of energy democracy.

Yet the multi-dimensional nature of solar energy uptake in the solar test field as well as the learnings highlighted from it in the preceding sections suggest that we can do better. Or at least that, no matter what happens, there are things to be done at the community level, partly by citizens but mainly through policy incentives (cf. [27]), that can help move the logic of our energy system towards one where technology and its social use are more in sync, where the promise of solar energy is being harnessed in ways that approach sustainability in a manner that integrates sociotechnical and energy justice aspects [5,23]. Ultimately, this can contribute to more efficient systems, harmonised with people's needs [15]. But equally, the trajectory in Tamera points out a truth about energy transition dynamics—that these are contingent on many diverse factors: the materiality of the technology, people's conditioning and social dynamics, access to financial capital and incentives, and how technologies fit together and within the social context. While these considerations are likely to play out differently across contexts, and in ways quite unlike those in an intentional community, they nonetheless need to be understood in a situated manner so that policy support can enable energy transitions through social innovations around technology uptake [16,17]. While not necessarily directly resolvable through science, our empirically identified challenges contribute towards an understanding of how to institutionalise improved, more just decision-making systems.

In sum, while energy transitions involve considerable change, this change is modulated by structures and processes that are as old as the Alentejo hills. Actors with greater access to capital will be able to install more solar capacity more quickly, those well-entrenched in the current fossil fuel dominated energy sector will be able to influence its course more than others in terms of key decisions pertaining to timing, spatial allocation and scalar preference, and cheaper technological forms such as photovoltaic solar will dominate over concentrating solar power uptake unless the latter finds a way to integrate storage cheaply using simple physical processes in an easy-to-use manner. Living laboratories like the solar test field provide a microcosmic insight into how some of these contingencies play out (cf. [14])—others require an understanding of the national or sub-regional political economic dynamics, or even global geopolitics (cf. [1]). Within the solar test field, power dynamics are still ubiquitous: women are under-represented in technological engagement, parental projection and competitive dynamics modulate social deliberation. This study supports the argument that community knowledge has a role to play in improving our integrated understanding of energy transitions as this interplay of stability and change (cf. [22]), given their multi-scalar and multi-dimensional nature, but also signals that it can be challenging for such knowledge to perform this role. That said, channelling such learning into conversations about energy transition is crucial towards stabilising social imaginaries of desirable energy futures driven by social innovation. Community energy is an important part of the solution alongside other energy sector transitions, which must be complemented by similar changes in transport, production, and cognate sectors.

5. Conclusions: Learning from or with a Community Test Field?

In this concluding section, we turn a reflexive gaze upon ourselves and this article. As an output, it is partly an artefact of the first author's role as an applied researcher trying to be a change agent, partly of the many inhabitants of the solar test field and its technology team who gave generously of their time as practice-oriented members trying to be change agents, especially the co-authors from among them as researchers in their own right, and partly of the nature of academic production. What is the afterlife of this artefact once it is made public, and is there a more intangible output that

accompanies its production? Have two purposes been served in its creation: the first the mutual enrichment of its authors' perspectives as we gain insights from the contexts our counterparts are most familiar with, and the second the reflections it triggers in the minds of readers and hopefully the subsequent actions that these partly inform?

Time will tell with regard to the first, but in closing we append our current reflections. We have found this collaborative exercise tremendously generative with regard to the first research question on what learning the solar test field's experience offers for understanding energy transitions. For the social scientist lead author, it has brought the intricacies of community energy initiatives to the fore in full empirical complexity; for the Tameran authors, it has enabled repeated confrontation with the question of their modalities of engagement with systemic change, especially as manifested in the political economic developments of Portugal's energy transition and their stake therein. While the former is an expected, desirable outcome, the latter is an unanticipated, productive conjuncture with potency for future action.

We trust that the answer to the second question is a resounding yes. We have modestly treaded the tortuous terrain of how epistemological complementarities between applied researchers and practicing agents can be brought out, and problematised the scalar links between a community and institutionalising powers only in passing (cf. [24]). Somewhat more directly, we have analysed how actionable efforts that integrate twin foci on systems thinking and power dynamics towards transformation can be developed, and the challenges involved therein (as called for by Geels et al. [4] and furthered by Sareen and Haarstad [5]), drawing upon community knowledge with specific reference to energy transitions. This makes modest headway towards addressing the second research question on how community knowledge through social innovation can inform energy transition policies in other European contexts, but much remains to be done. While Tamera's lack of emphasis on direct engagement with energy policy means that this study cannot comment on any existing external impact from the learnings above, this fact renders our contribution all the more useful as bringing new community energy knowledge to inform systemic transition efforts.

We urge the adoption of future policy pathways that are responsive to more socially-informed, integrated treatment of energy transitions in Portugal and also across contexts worldwide. Opening up to learning from living laboratories such as the solar test field at the community level would certainly be a step along this way (see also [6,26]). Equally, taking proactive measures to understand the needs of communities everywhere, and then identifying and making pertinent knowledge on and resources for energy transitions available in a manner designed with them in mind, will bridge the prevalent knowledge gap and sub-optimal resource prioritisation on the academic and policy state-of-the-art for sustainable energy transitions. Certainly, in a world where a country as blessed by the sun and other renewable sources as Portugal can pursue offshore drilling for oil despite public protests and soaring summer temperatures and wildfires that desecrate its land and life year upon year, there is an urgent need to attend to robust social innovation modes of energy transition. Such recursive efforts are in order if we are to move to learning not only from but also with a community test field.

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