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Does site selection need to be democratised? A case study of grid-tied microgrids in Australia

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Highlights (policy implications)

- Authoritative actors (regulatory and industry sectors) should see site selection as a *socio-technical process* embedded in a complex set of (socio-economic, environmental and technical) values, which can cause tensions and conflicts if not treated as all equally important.
- Site selection processes should explicitly aim to further *democratize* technology deployment by including all affected interests, especially the most vulnerable (who are also often the most marginalized), promoting social cohesion and socio-environmental justice, and resulting from well-informed deliberative tools and processes.
- Site selection processes should follow a *clear method* built around the definition of objectives, a process for defining relevant criteria, the establishment of a clear matrix of criteria, and the building of consensus on the sites selected on the basis of this matrix.
- Each stage of site selection must be based on a *participatory and transparent dialogue* with all affected interests, so that each stage is discussed, documented and accessible to all participants.
- Beyond feasibility issues, special attention must be paid to all forms of socio-technical *energy vulnerabilities* and the potential negative, positive, and neutral impacts of grid integration technologies on these vulnerabilities.
- Rather than trying to apply systematic methods to all cases, a *transdisciplinary and place-based approach* with a plurality of local actors should be established.

Abstract

The choice of suitable sites for microgrids is not only a techno-economic process. Many aspects are important in understanding community support (or lack thereof) for the planning and deployment of grid integration. Alongside usual techno-economic considerations, the site selection process *itself* must be responsive to the local socio-political context and concerns (e.g., multiple values, needs and expectations of energy infrastructure or perceived fairness of technology deployment). In our project, we developed, in close collaboration with our local partners, an integrated site selection method to address these multiple imperatives. To this end, in addition to socio-technical considerations, our method seeks to (further) democratise network integration technology and its deployment so that it takes into account energy vulnerabilities and inequalities and fully integrates the views of the most affected (especially the most vulnerable) stakeholders into well-informed, place-based deliberative processes. With the support of the method we detail in this paper, we suggest that researchers and practitioners invest time and resources in developing more democratic and place-based site selection methods for microgrids.

Keywords: microgrid, grid-tied microgrid, Australia, site selection, energy democracy, energy justice

1 Introduction

Microgrids are gaining attention as a potential element of a more resilient and sustainable energy future. The main reason for this is that they can operate independently as power islands with sufficient local energy generation and storage resources and control capabilities. A defining characteristic of microgrids is their discrete and bounded nature, which strengthens the connection between each microgrid and its local context. Contextual influences extend from microgrid design through to operations, and include engineering, economic and governance aspects. This connection between microgrids and their location makes site selection a crucial consideration in establishing sustainable microgrids.

Historically, microgrids have mostly been deployed in isolated locations (e.g., mining sites, military bases and remote and/or island communities) where site selection was highly constrained, and the values and aspirations of energy users were largely ignored (Soshinskaya et al., 2014). Consequently, microgrid research, development, and deployment has focussed on the engineering challenges of sustaining a secure small power system. With the increasing intensity of extreme weather events as well as general trends in the energy sector (i.e., decarbonisation, digitalisation, decentralised generation/storage, and potential democratisation), there is a growing interest in the deployment of microgrids to increase energy resilience in various low-resilience contexts (Carpintero-Rentería et al., 2019). In these contexts, microgrids remain connected (or tied) to a larger grid so that they only occasionally operate as independent islands.

Alongside usual techno-economic complexities, the introduction of microgrids into grid-tied contexts raises new socio-political considerations, which demand greater scrutiny of the process by which sites are selected. Indeed, in an increasingly decentralised energy system, while microgrids are expected to provide a robust and flexible energy system capable of maximising performance and minimising costs and environmental impacts, they can also offer significant additional benefits through increased community control over

energy production and demand, planning, design, implementation and governance (AUTHOR Reference, withheld for anonymity). However, such benefits are not inevitable or inextricably embedded within the technology, but rather reflective of institutional contexts and business model design (Wilkinson et al., 2020). If rolled out naïve to social context, microgrids could (further) damage social cohesion by distributing benefits from project, funding, or research programs inequitably within and across communities, especially as microgrid technology remains expensive. Microgrid deployment could also further disadvantage existing groups who have experienced acute disadvantage in carbon-based energy systems (e.g., older people, people on low incomes, isolated communities) (Biswas et al., 2022). Ensuring positive social impacts is not only an ethical imperative for the responsible implementation of new energy technologies; it is also a key dimension of success for local initiatives such as micro-grids in maintaining social acceptance and sustainable community participation.

In response to these largely neglected issues, the literature on energy democracy and justice are an important reference. Both these research communities raise important ethical questions about the legitimacy of these technologies, the (equitable) distribution of costs and benefits, and their impacts on the most vulnerable populations. Drawing largely on normative guidance from the literature on energy democracy and justice, this paper explores the question of microgrid site selection and reports on our own experience in the context of a feasibility study for microgrids in a bushfire impacted area in south-east Australia, the Eurobodalla shire.

The feasibility project was funded by a Federally administered Regional and Remote Communities Reliability Fund which was established to fund studies that focused on how microgrids could improve regional reliability. This focus is driven by several contextual factors including that Australia already experiences regular natural hazards (bushfires, heatwaves and flooding) and has the world's longest interconnected power system. A local community group approached us as researchers to develop a project exploring feasibility

for grid-tied microgrids in a coastal region that was devastated by bushfires in 2019-20. We formed a research partnership with the community group as well as inviting another partner – the State-owned distribution company that has responsibility for that region. Deciding which sites to choose for the feasibility work was the first substantive task of the research collaboration.

Our overarching argument is that researchers and practitioners (engineers but also policy makers and engagement specialists) should work together and invest time and resources in developing a site selection method that seeks to (further) democratise grid integration technology and its deployment. In addition to the technical requirement, such a method must address energy vulnerabilities and inequities, and fully integrate the views of the most affected (especially the most vulnerable) stakeholders into well-informed, place-based deliberative processes. We recommend that such a method should include (1) defining *objectives* shared by all stakeholders and (2) a clear *process* for determining criteria and associated data based on these objectives. These would then lead to (3) specific *outputs* (e.g., a matrix of relevant criteria) and (4) *outcomes* (i.e., well-founded site selection). It is important that the purpose of the microgrid is explicitly considered, which is a matter for reflection and deliberation.

The paper starts with a brief review of the literature on microgrids and how site selection is considered. We then provide a reflection on our own process of site selection, while drawing on a range of literatures to explain and articulate our approach. We also discuss the limitations of our own process and experience. Finally, we conclude with suggestions for future research and practice.

2 Literature review

Our work draws on three bodies of literature: (1) studies of the impacts of location on microgrid development and operations, (2) the role of community in microgrid deployment, and (3) conceptual literature on energy democracy and energy justice.

2.1 The impacts of location on microgrids

In the past, locations for microgrids have often been determined without regard for energy concerns, but rather triggered by the location of mineral deposits or military bases. However, there is an established body of engineering work assessing the impacts of environmental factors and location on the operation of microgrids. These studies often examine the availability – over extended periods – of renewable energy sources such as solar irradiance and wind levels and the influence of these on the amount of energy storage required for reliable and secure operation of the microgrid (Akram et al., 2018; Baghaee et al., 2016; Bahramirad et al., 2012; Chen et al., 2012; Eriksson and Gray, 2017; Fossati et al., 2015; Hafez and Bhattacharya, 2012; Hajiaghasi et al., 2019; Ramli et al., 2018; Yang et al., 2018; Zhao and Pendlebury, 2014).

More recently, microgrids have been envisioned as a platform for opportunities and challenges of an imagined smart grid future (Farhangi, 2010), in which we see reflected trends of decarbonization, digitization, and decentralization. Microgrids as a microcosm in which to imagine, design and experiment with larger energy trends on a smaller scale fall into two broad categories:

1. technical studies of new devices and systems, which focus on automated control for providing energy security and reliability (Guerrero et al., 2011, 2007; Katiraei et al., 2005; Mohamed and El-Saadany, 2008; Olivares et al., 2014; Pogaku et al., 2007; Rocabert et al., 2012; Wang et al., 2015), and

2. techno-economic studies of alternative ways for people to participate in the energy system. These studies have tended to create local energy markets for financial transactions and energy dispatch through more direct participation from users (as customers or prosumers) in energy trading, including direct peer-to-peer trading (Long et al., 2018; Mengelkamp et al., 2018; Zhang et al., 2018), trading between microgrids (Gregoratti and Matamoros, 2015; Wang and Huang, 2018), and markets and device automation based on game theory models (Paudel et al., 2019).

As microgrids are now thought of as being tied to the grid, they are increasingly described as grid-connected communities. This evolution, together with the general shifts in energy systems (e.g., distributed energy resources, prosumer models, customer centric design, etc), puts more emphasis on the social dimensions of microgrids. These dimensions have not been entirely ignored in the literature on microgrids. For example, some researchers look to develop a mathematical algorithm that considers, among other things, social factors (Akinyele et al., 2018). Others compare the economic performance of microgrids in different countries, including Australia, using a broad set of indicators and including social and environmental sustainability (Wang et al., 2020). However, while it is laudable that engineering scholars such as Akinyele et al. and Wang et al. consider social factors in their site selection or evaluation methodologies, this scholarship remains largely disconnected from a large body of energy social science research into user experiences of emerging technologies and their social impacts (Ransan-Cooper et al., 2020; Strengers, 2013).

2.2 The role of community in microgrid deployment

In the Australian context, it is well established that the energy sector – including both industry and government – have been captured by a techno-economic imaginary that largely sees the public as consumers and passive recipients of efficient smart technologies (Dahlgren et al., 2020; Sadowski and Levenda, 2020; Strengers, 2013; Strengers and Nicholls, 2017). This lack of engagement with people as affected publics interested in a sustainable energy future is part of why trust in the energy sector's ability to deliver public

benefits in the energy transition is low (Temby and Ransan-Cooper, 2021). Despite this, research in Australia suggests that local renewable technologies have, in principle, received broad public support (The Australia Institute, 2022). In Australia, as in many other parts of the world, the regulatory and industry sectors are not strongly connected with public needs and expectations. It is thus unsurprising that Farrelly and Tawfik (2020) identify the major barriers to microgrid feasibility as being related to the socio-institutional context of microgrid deployment, notably risk aversion and lack of industry acceptance.

Even while the social dimensions of microgrid or off-grid technologies are under-researched, there are several studies that provide key insights into social issues. Communities' ability to engage with the technology is an especially important consideration in deployment of microgrid and other new energy infrastructure, particularly whether the community was involved early in planning and design (Boudet, 2019; Valencia et al., 2021). Another key aspect is a recognition that energy users have plural values and expectations of new energy technologies. For instance, contrary to general assumptions that households going off-grid make their decisions primarily on the basis of energy infrastructure price and operating costs, Lovell and Watson (2019) found that they are in fact motivated by a complex mix of reasons that go beyond financial aspects to also include social and environmental values.

Communities' ability to engage with new energy technology or infrastructure is intimately linked to the process of selecting a site in the first place. Alongside usual techno-economic considerations, the site selection process *itself* must be responsive to people's values, needs and expectations of energy infrastructure and their perception of how fair and equitable the deployment of a technology is (Valencia et al., 2021). Without this, we risk further reducing trust in the energy transition process, and further exacerbating inequalities and tensions (Chilvers et al., 2018). Site selection is thus a socio-technical process that requires care and thoughtful attention.

Given a long history of new energy technologies' negative impacts on the most vulnerable groups in society (see Sovacool et al. (2017) on smart meter transition for instance), it is also imperative that, beyond mere 'community acceptance', the development of microgrids takes full account of the issue of energy vulnerabilities (particularly in terms of potential impact on the most vulnerable). The literature on energy vulnerabilities identifies key elements contributing to energy vulnerability as network, geography and environment related. These include remoteness (access to remote areas that the main grid cannot reach), low voltage, accessibility/cost of energy (including the difference between off-peak and peak demand) (Day et al., 2016), frequent short and long power outages (Liévanos and Horne, 2017), and extreme weather events (Winzer, 2012). Some authors also rightly insist on socio-demographic factors that make certain groups more likely to be disinterested in or unable to afford enabling technologies, to be vulnerable to energy market reforms, or to use technologies in unplanned ways (Nicholls et al., 2017). These groups can include the elderly, the ill, the less educated, those in social housing, and/or those in rural and remote areas (Nicholls et al., 2017; Sovacool et al., 2017). A vulnerabilities approach provides a framework that is appropriate for microgrids for two major reasons. First, the nature of a microgrid is to be discrete and bounded so defining technological impacts (whether negative or positive) requires great caution. Second, there are people who might be included in it but who may not understand it or be able or willing to engage with it. Thus, a particularly inclusive framework is needed to accommodate their circumstances (Valencia et al., 2021).

2.3 Towards energy democracy and justice

Since concepts such as "community acceptance" or "engagement" often fail to capture socio-political diversity within and between communities and often neglect energy vulnerabilities, we opt for the more specific concept of energy democracy (or democratisation). Energy democracy implies, in addition to the process, certain elements of content and (expected) outcomes. Energy democracy is best defined as:

- a process and social movement which (through dispersed grassroots initiatives and transnational networks) injects new values such as justice into energy system design,
- institutionalisation of new forms of participative governance in energy systems design collectives as central agents of change
- an overall outcome (decarbonization of energy systems), that situates collectives as central agents of change, and
- a goal (an ideal to aspire to an – often unspecified – decarbonized future) (Szulecki and Overland, 2020; Wahlund and Palm, 2022)

Some researchers such as Droubi et al. (2022) argue that energy democracy should draw on the more developed, coherent, and comprehensive framework of energy justice. However, other scholars rightly argue instead that energy democracy and energy justice are complementary (rather than competitive) concepts as they help explore different avenues for driving socio-technical change (Burke and Stephens, 2017). Energy democracy's focus on collective ownership and management of decentralised energy system lends itself to our study focus.

The energy democracy literature supports the development of inclusive strategies in the deployment of energy technologies to: understand who the 'community' is and what 'public or collective ownership' means from the perspective of local people (Szulecki and Overland, 2020); more comprehensively define who the actors that are impacted/affected by decisions are (Chilvers and Longhurst, 2016); determine what underlying structures promote or limit socio-technical change (Chilvers et al., 2018); and provide bottom-up and place-based (rather than top-down and abstract) pathways to decarbonisation (Devine-Wright, 2022). In this paper, we use energy democracy as an approach whereby the selection of sites for microgrid deployment relies on processes that promote *inclusiveness*, *justice* and *well-informed deliberation* as detailed below:

- 1) *Inclusiveness*: involvement of all affected groups, especially the most vulnerable ones, in decision-making processes to protect them from arbitrary power and facilitate transmission of their perspectives and concerns.
- 2) *Justice*: promotion of social cohesion, socio-environmental justice and the local culture of participation.
- 3) *Well-informed deliberation*: support for processes that improve the quality of communication to achieve better, more informed, locally grounded decisions (Brisbois, 2020; Burton et al., 2019; Devine-Wright, 2022; Fazey et al., 2018; Fouché and Brent, 2020; Hicks, 2021).

To pursue such an agenda in our project, it was crucial to implement a (socio-technical) transdisciplinary approach, both within the research group and with the project partners (Cooper, 2017). In the context of energy studies, transdisciplinary research is not only about understanding issues from different perspectives (i.e., different disciplines and knowledges); it is a comprehensive approach to learning about "what exists" from the perspective of different disciplines (empirical research), "what we are able to do" (pragmatic research), "what is desirable" (normative research) and "how it should be done" (ethical research) (Spreng, 2014). Moreover, a transdisciplinary approach requires that each of these research types draw on and integrate both diverse academic disciplines and non-academic knowledge (e.g. policy, industry, practitioner, community, place-based and indigenous knowledges) (Wickson et al., 2006) (Roux et al., 2017). Transdisciplinarity is not without complexity and uncertainty, especially in institutional contexts that are not designed for it (Sovacool et al., 2015). Given the many unknowns of the four types of research (empirical, pragmatic, normative and ethical) and the lack of standards in site selection practices when dealing with grid-tied microgrids and similar integration technologies that are sensitive to local contexts, site selection is a particularly relevant topic to test transdisciplinary research.

3 Methodology

Our method takes a transdisciplinary approach. In addition to existing empirical and pragmatic research (what are grid-tied microgrids and what can be done with them?), we pursued normative and ethical objectives in line with energy democracy to consider all relevant people and interests in the design process and the practical outcomes for them (who is the microgrid for and for what purpose/s?).

The method we followed for site selection, outlined in the figure below, involved four steps: defining *objectives*, establishing a *process* to determine relevant criteria, developing a generalisable *output* (i.e., matrix of criteria) and delivering a project-specific *outcome* (i.e., site selection).

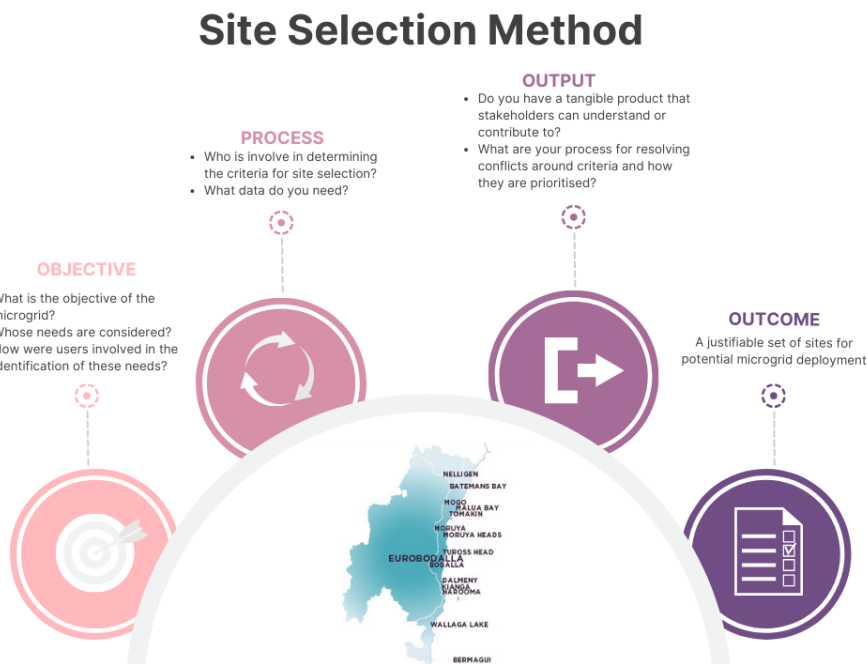


Figure 1: Elements that should be considered in a transdisciplinary method for site selection

3.1 Objectives

The first step in our site selection was to state the normative *objectives* (step 1) by answering key questions: what is the objective of the microgrid(s)? Whose needs are considered? How are people (users) involved in the identification of those needs?

Bearing in mind the imperatives of energy democracy and justice, two key objectives guided our site selection process:

1. To understand the energy vulnerabilities and opportunities for energy resilience and decarbonisation in the Eurobodalla region, which aligns with one of the main reasons for our research project, the total or partial failure of the energy system that occurred during the bushfires of the Black Summer 2019-20.
2. To incorporate much of the socio-technical diversity of the Eurobodalla region so as to generate outputs and outcomes that are generalisable to other rural areas in the region, and Australia.

As a research project, our project does not intend to set up a microgrid in the immediate term, but rather exploring the range of factors feeding into feasibility. The objectives were thus about informing future implementation for decision-makers and communities considering whether or how grid-tied microgrids could be a possible solution. Site selection also preceded further engagement with communities by the paper authors as well as the community group partner to consider diverse needs and their implications. All project partners were integrally involved in the site-selection process as detailed below.

3.2 Process

Having defined the objectives, we decided to establish a *process* for selecting the sites (step 2) which addressed two questions: who is involved in determining the criteria for site selection? And what data do we need?

This process started with a review of the literature (summarised above) to identify the essential aspects and criteria to consider in site selection. This literature review allowed us to generate a list of criteria aligned with our two objectives.

We then identified the data associated with each criterion and where to find it. The data we used to assess the social and technical vulnerability of the sites combines the most recent socio-demographic information on each site provided by the Australian Bureau of Statistics (ABS) and technical data on the network characteristics for each site provided by our project partner and local network operator.

3.3 Output

The *output* (step 3) of this second step was the development of a matrix combining all the criteria. This matrix served as the basis for a comparative assessment of vulnerabilities and feasibility (quantitative) and socio-technical diversity (qualitative) of the potential sites.

Quantifiable and comparable criteria to assess vulnerabilities and feasibility fell into four categories. The criteria for each category are presented in the table below.

Table 1: Criteria for quantitative assessment of vulnerability and feasibility

Category	Criteria
Social vulnerabilities	<ul style="list-style-type: none"> • Percentage of elderly (more than 75 years old) • Percentage of young people (less than 15 years old) • Percentage of people with disabilities • Percentage of low-income household (less than 650 Australian dollar per householder weekly) • Number of life support premises • Critical energy supply (critical load premises, critical infrastructure) • Dwelling and tenure (home occupancy rate)
Infrastructure vulnerability	<ul style="list-style-type: none"> • Premises per kilometre of network • Major event outage days (bushfire included) • Average outage duration per premise
Social feasibility	<ul style="list-style-type: none"> • Distributed energy resource penetration (as percentage of total users)
Infrastructure feasibility	<ul style="list-style-type: none"> • Distributed energy resources capacity (as percentage load on network) • Average daily consumption per premise

These categories emerged and were adapted from the literature in discussion with all project partners. For example, in the category of social vulnerabilities, we characterised communities according to their socio-demographic characteristics. So, in combination with other criteria (e.g., the percentage of low-income households), the occupancy rate of the dwellings is, for example, in a tourist area such as the Eurobodalla region, a relevant indicator of the relative wealth of the population, as there are many second homes. The higher the occupancy rate, the more vulnerable the community, since these households cannot simply return to their other dwelling during a prolonged outage.

In addition to the quantitative criteria of socio-technical vulnerability and feasibility, we have also established a series of 'qualitative' criteria that aim to provide a diversity of socio-technical options representative of Eurobodalla and other rural areas in Australia. These qualitative criteria are of two types: those that are difficult to quantify or those that are quantifiable but have no direct implication for vulnerability or feasibility. These qualitative criteria are listed in the following table.

Table 2: Criteria for qualitative assessment of socio-technical diversity

<ul style="list-style-type: none">• Population size• Percentage of households who speak other than English at home⁴• Presence of shared residential or industrial estates• Network topology based on geographical size (large, medium, small)• Density (high, medium, low)• Type of grid (spur/meshed)• Technical ease (easy, medium, or hard)• Level of early interest in grid-tied microgrids as identified by the community energy group partner

For both socio-technical vulnerability and feasibility, there are other important dimensions that we are exploring in the other phases of the project. For example, social feasibility also

⁴ The literature does not establish a direct link between foreign language speakers and increased vulnerability or feasibility. We therefore considered this dimension as a criterion for diversity.

relates to governance and participation dimensions, which we have not adequately captured in the criteria.

3.4 Outcome(s)

The main *outcome* (step 4) of our method was the actual selection of 8 sites⁵ based on a systematic comparison of 18 sites in the Eurobodalla region (Australia's southeast coast) available for our study according to the quantitative and qualitative sets of criteria (the matrix of criteria) described previously. The 18 sites were: Bodalla, Broulee, Central Tilba, Congo, Meringo, Mogo, Moruya Heads, Mossy Point, Mystery Bay, Nelligen, Nerrigundah, Potato Point, Rosedale, South Durras, Tilba Tilba, Tomakin, Turlinjah, and Tuross Head. The 18 sites are represented in the map below.

⁵ The number specified in our funding agreement (*whether it's 'limited' is relative and not informative here*).



Figure 2: Map of the 18 sites in the Eurobodalla region. Map data from OpenStreetMap (openstreetmap.org/copyright).

In the quantitative assessment, the vastly different nature of the variables in the criteria (some demographic, distances, etc) were compared by normalising each criterion on a relative scale of 0 to 5. Scores of 5 represent the highest level of vulnerability or feasibility present across all sites, while scores of 0 were the lowest. The exception was the criterion of home occupancy rate which we considered to be so fundamental, we gave it twice the weighting with a score out of 10.

To combine the criteria together we devised two methods. The first simply summed up the scores for all 15 criteria, which produces a final result that was biased towards social

vulnerability. The second method meanwhile enforced an equal weighting between social and infrastructure factors by taking the average of the criteria under the four categories (the permutations of social, infrastructure, and vulnerability and feasibility). Table 3 summarizes the weightings that each method placed on the four categories.

Table 3: Two methods of quantitative scoring

	Sum of criteria	Adjusted to equally weigh social and infrastructure
Social vulnerability	60%	40%
Infrastructure vulnerability	20%	40%
Social feasibility	7%	10%
Infrastructure feasibility	13%	10%

As a final step, the qualitative criteria of socio-technical diversity were considered in order to reduce the risk that the quantitative assessment might select relatively homogeneous sites, with a lack of socio-technical diversity that would constrain the translation of our work to other rural localities. Where multiple sites were deemed to be of similar typology, according to the qualitative criteria, all but the highest-ranking site was eliminated from consideration.

If the main outcome of our method was the actual selection of sites, another outcome lies in having tested a proposed method for site selection, as suggested in the first three steps detailed above. This tested method involves the ‘fixed’ elements of the method identified based on the literature - the overarching framework - and more ‘project-specific’ elements, which involved contextual changes to the basic framework.

4 Results

The results of this study consist of a matrix of criteria for selecting sites, which we consider an output, and the actual selection of sites, which we consider the outcome. The matrix of

criteria provides a comprehensive framework for comparing the socio-technical vulnerabilities and feasibilities (quantitative) and the socio-demographic and socio-technical diversity (qualitative) of sites. The matrix in the **Appendices** provides a summary of the quantitative and qualitative assessment for the 18 sites.

The matrix of criteria allowed a collective decision with the project partners and a consultation with local government on which sites to select, taking into account socio-technical vulnerabilities, feasibility and diversity. Table 4 indicates the sites we selected.

Table 4: Selection of sites based on quantitative and qualitative assessment

(Sub)Locality	Site selected
Bodalla	Yes
Broulee	Yes
Central Tilba	Yes (with Tilba Tilba)
Congo	Yes
Meringo	No
Mogo	No
Moruya Heads	No
Mossy Point	No
Mystery Bay	Yes
Nelligen	Yes
Nerrigundah	No
Potato Point	No
Rosedale	No
South Durras	Yes
Tilba Tilba	Yes (with Central Tilba)
Tomakin	No
Turlinjah	No
Tuross Head	Yes

The justification for the site selection involves both the quantitative scoring on vulnerability and feasibility and the assessment based on socio-technical diversity.

4.1 Socio-technical vulnerability and feasibility scoring (quantitative)

In general, the 8 selected sites scored high in terms of vulnerability (e.g., high occupancy rates, lots of elderly, people with disability, numerous critical loads) as well as feasibility (e.g., high rates of solar installs). One further site, Tomakin, scored similarly to the bottom ranked selected sites. It was not selected because we were limited to 8 sites, and analysis of the power network showed that any microgrid in Tomakin would be difficult, due to the meshed nature of the grid and its integration with the rest of the network. Table 5 provides the overall score across vulnerabilities and feasibility according to the two types of scoring outlined in the method section.

Table 5: Overall score on vulnerabilities and feasibility (quantitative)

Indicator (Sub)Locality	Final score - Adjusted to equally weigh social and infrastructure	Final score - Sum of criteria (weighing social more heavily)
Weighting points	N/A	75
Bodalla	7	44
Broulee	3	43
Central Tilba	8	42
Congo	5	38
Meringo	7	38
Mogo	12	45
Moruya Heads	4	35
Mossy Point	2	31
Mystery Bay	5	33
Nelligen	7	36
Nerrigundah	5	35
Potato Point	3	28
Rosedale	5	32
South Durras	3	27
Tilba Tilba	9	40
Tomakin	4	41
Turlinjah	7	37
Tuross Head	4	41

The following two tables provide more detail on this quantitative scoring: Table 6 on the assessment of socio-technical vulnerabilities and Table 7 on socio-technical feasibility.

Table 6: Quantitative assessment of socio-technical vulnerabilities

Indicator (Sub)Locality	Social vulnerabilities									Infrastructure vulnerability			
	Dwellings occupation	Elderly	Young people	People with disabilities	Life support premises	Low-income household	Critical Load Premises	Critical infrastructure	Average social vulnerabilities	Premises per km of network (low is good)	Major event outage days (bushfire included)	Avg outage duration per premise	Average infrastructure vulnerability
Weighting points	10	5	5	5	5	5	5	5	45	5	5	5	15
Bodalla	9	1	4	5		5		4	4	Removed for privacy			2
Broulee	6	5	4	3		4		5	4				0
Central Tilba	9	2	3	5		5		4	3				2
Congo	9	2	5	4		5		0	3				1
Meringo	7	2	5	4		5		0	3				2
Mogo	10	1	5	2		4		1	3				4
Moruya Heads	8	2	4	3		4		3	3				1
Mossy Point	6	2	4	5		4		0	3				1
Mystery Bay	7	2	3	4		5		0	3				1
Nelligen	8	2	3	3		4		0	3				2
Nerrigundah	9	2	1	4		4		0	3				2
Potato Point	5	4	1	4		4		0	2				1
Rosedale	4	3	4	3		4		0	2				2
South Durras	4	2	4	1		4		1	2				1
Tilba Tilba	9	2	3	4		4		0	3				3
Tomakin	7	3	3	5		4		3	4				1
Turlinjah	9	2	3	4		3		0	3				3
Tuross Head	7	4	3	5		5		1	4				1

Table 7: Quantitative assessment of socio-technical feasibility

Indicator (Sub)Locality	Social feasibility		Infrastructure feasibility		
	Distributed energy resource penetration (% users)	Average social feasibility	Distributed energy resource capacity (% load on network)	Average daily consumption per premise	Average infrastructure feasibility
Weighting points	5	5	5	5	10
Bodalla	4	4	4	1	2
Broulee	3	3	3	2	2
Central Tilba	4	4	2	3	2
Congo	3	3	3	2	3
Meringo	4	4	2	3	3
Mogo	2	2	2	3	2
Moruya Heads	3	3	3	1	2
Mossy Point	2	2	2	2	2
Mystery Bay	4	4	4	1	3
Nelligen	4	4	2	3	2
Nerrigundah	5	5	2	3	2
Potato Point	3	3	3	1	2
Rosedale	2	2	1	4	2
South Durras	3	3	2	3	2
Tilba Tilba	3	3	2	3	2
Tomakin	3	3	2	2	2
Turlinjah	3	3	2	1	2
Tuross Head	3	3	5	0	3

4.2 Socio-technical diversity (qualitative)

In addition to the quantitative scoring, the assessment based on diversity criteria provided us with a broad range of examples that represent the plurality of the Eurobodalla as well as other Australian rural areas. Among the selected sites, we have small (190 person), medium (300-600 person) and large (1500-2500 person) communities. The selected sites range

from small, low-density inland communities in the north of the line grid array such as Nelligen to relatively large and dense coastal communities in the south of the region such as Tuross Head.

They all have at least one option for a relatively tractable microgrid design (in how the site, or major constituent of the site, connects to the upstream grid). Many of these sites also have several clearly identifiable microgrid design options. These options present a richness for technical studies, as well as vital social enquiries into which parts of the community receive access to a microgrid – for instance in Bodalla, the petrol station, police station, and bowling club would each require their own microgrid due to the network configuration. Table 8 provides details on all the diversity criteria for the 18 sites.

Table 8: Qualitative assessment of socio-technical diversity

Indicator (Sub)Locality	Population (Australian Bureau of Statistics 2016)	Percentage of households who speak other than English at home (Australian Bureau of Statistics 2016)	Presence of shared residential or industrial estates	Network topology (options): geographical size (large, medium, small), density (high, medium, low), grid (spur/meshed)	Technical ease (easy, medium, hard)
Bodalla	739	3%	Single storey - Agriculture, industry, retail	(1) medium/low/meshed (2) medium/medium/meshed (3) large/medium/meshed	All options medium
Broulee	1717	3%	Free standing - Retail	Two options, both medium/high/meshed	Two options medium
Central Tilba	288	10%	Timber construction - Agriculture, industry, retail	(1) medium/medium/ spur (2) large/medium/meshed	(1) easy, (2) hard
Congo	245	17%	Single dwelling - Limited economic activity	Small/low/Spur	(1) easy
Meringo	322	12%	Single dwelling - Limited economic activity	(1) medium/medium/spur (2) large/low/meshed	(1) easy, (2) medium
Mogo	322	12%	Small businesses, touristic sites	Small/medium/meshed	Medium
Moruya Heads	976	12%	Mixed housing types - Marine economic activities	Medium/low/spur	Easy
Mossy Point	569	8%	Free standing - Retail	(1) large/medium/meshed (2) large/high/meshed	Both options medium
Mystery Bay	191	6%	Agriculture, pumping station, retail, tourism	Small/low/spur	Easy
Nelligen	332	11%	Single dwellings - Cafe, caravan park	(1) large/medium/meshed (2) large/ medium/meshed (3) small/low/spur	(1) hard (2) medium (3) easy

Nerrigundah	25	10%	Nil	(1) medium/low/spur (2) medium/low/spur (3) small/medium/spur	(1) easy (2) easy (3) easy
Potato Point	135	10%	Single storey - Agriculture, industry, retail	(1) medium/low/spur (2) small/high/spur	(1) easy (2) easy
Rosedale	221	15%	Single or double storey - Agriculture	No data	No data
South Durras	341	17%	Large holiday lets and 3 RV parks - Agriculture, tourism	(1) small/high/spur (2) large/medium/ meshed	(1) easy (2) hard
Tilba Tilba	95	10%	Timber construction - Agriculture, industry, retail	(1) large/low/meshed (2) small/high/spur (3) large/low/meshed	(1) med (2) easy (3) hard
Tomakin	1001	12%	Large homes - limited economic activity	(1) medium/high/meshed (2) medium/high/ meshed (3) large/low/meshed	(1) hard (2) hard (3) hard
Turlinjah	157	6%	Nil	(1) small/medium/spur (2) large/low/meshed (3) large/low/meshed	(1) easy (2) hard (3) hard
Tuross Head	2241	8%	Two storey (low energy efficiency) - Golf and bowling club	(1) large/medium/spur (2) medium/high/spur (3) small/high/spur	(1) easy (2) easy (3) easy

5 Discussion

The site selection process and its results raised many questions. Among the most crucial issues (and lessons learned) are those related to energy democracy, and those related to replicability and contextual adaptation.

5.1 Energy democracy

As already mentioned, energy democracy was the key normative conceptual framework for our study. Our initial lack of empirical data forced us to move forward in a piecemeal fashion to give shape to key normative recommendations, namely (1) to involve all relevant interests (especially those most affected), (2) to promote social justice and cohesion in an institutionalised manner, and (3) to achieve more informed and legitimate decisions.

On the first aspect, inclusiveness, we have tried to be as inclusive as possible within the time and resource constraints to which scientific projects are subject. We were unable to develop a proper deliberative process (e.g., by drawing lots of individuals to participate in the decision-making process) but established a very dense deliberative framework with the project partners – which include a local network provider and a local community energy organisation – with whom we collaborated closely at every stage of the decision-making process. Each step of the site selection process relied indeed on multiple deliberative meetings among the project partners and sustainability professionals inside the local government office to ensure that our expectations were aligned. These meetings used participatory and deliberative methods of engagement such as the use of a professional facilitator, a relative balance of speaking time, and varied discussion modalities to incorporate all points of view in the definition of the initial steps of the research project.

On the second aspect, social justice and cohesion, our focus on energy vulnerabilities from a socio-technical point of view provided us with a comprehensive framework to take into

account the multiple forms of inequalities, including socio-economic, gender, age, and ethnic inequalities, to which a microgrid could contribute, for better or for worse. At another scale, the standardised measures we used cannot sufficiently capture in detail specific local inequalities. These structures, whether social (e.g., a local culture of solidarity or processes of capture of economic, social or cultural capital by specific groups) or political (e.g., the perception that local interests are often ignored in decision-making), will be revealed more precisely by the ethnographic research to be conducted in the second phase of the project.

On the third and last aspect, well-informed deliberation, decisions were clearly reinforced by the multiplicity of social and technical criteria that we integrated in the matrix, which we used as a comprehensive information tool for decision making. This matrix is not a final product but rather a means of anticipating issues or problems in the initial phases of the project. Later in the project, this tool can be used to take into account the socio-political complexity that underpins any deployment of network integration technology and thus avoid the adverse effects of top-down processes, favouring instead paths based on detailed local knowledge (Devine-Wright, 2022).

Common to all three aspects, the issue of transdisciplinarity played a central role in the production and sharing of knowledge tools and a common vocabulary among the project partners, despite coming from different fields. Indeed, the method we have detailed can be seen as a structured set of tools that aims to integrate all perspectives into a common framework at each stage, thus overcoming institutional and disciplinary (industry, science and community) communication barriers.

5.2 Replication and adaptability to context and various imperatives

Although our study focusses on (grid-tied) microgrids, the method we used for site selection, which includes defining objectives, a dedicated process for determining the key criteria and data that meet the objectives, the creation of a matrix of criteria and the informed and

justified selection of sites, is to some extent adaptable to various socio-political contexts and socio-technical objects. For example, the deployment of other energy technologies such as electric vehicle charging stations, which are equally sensitive to the local context, could be based on such a site selection method. However, we suggest that it should be adapted both to the context (e.g., by redefining the essential and socially accepted criteria) and to the object (e.g., by identifying technology-specific risks and opportunities). The definition of objectives is an appropriate step to discuss the goals and requirements of the project and thus adapt the method we suggest to the project context.

Understanding of context is key. Knowledge of the local community and institutional context helps to anticipate problems occurring on the way and suggest solutions that are more locally adapted (Devine-Wright, 2022). For example, in our project, knowledge of the recent dramatic impact of 2019-20 bushfires and subsequent flooding – including exploring submissions from Eurobodalla individuals to the 2019-20 Bushfire Royal Commission (“Royal Commission into National Natural Disaster Arrangements,” 2020) and talking to local project partners (local grid provider, local council and community energy group) – was essential to understanding that some particularly affected communities are tired of being involved in various government, industry or research programmes (consultation fatigue).

6 Conclusions and policy implications

The selection of a site, even for a research project, for a grid-integrating technology can have socio-political implications, including increasing local inequalities, exacerbating tensions and deepening institutional distrust or, on the contrary, strengthening social cohesion and contributing to greater trust between communities and between communities and government institutions. Site selection should therefore not be treated lightly or as a mere technical issue, but rather requires a thoughtful and considered process. Based on the method we developed, we now provide some recommendations for various

stakeholders involved in project, funding, or research programs on grid integration technology and other energy technology development or deployment.

First, in Australia, as in many other parts of the world, the regulatory and industry sectors remain disconnected from public needs and expectations with regards to how grid integration technology is deployed. We argue that these authoritative actors should see site selection as a *socio-technical process* embedded in a complex set of values, which can cause tensions and conflicts if not treated equally. Socio-economic, environmental and technical aspects must therefore receive equal attention from decision-makers and – in line with energy democracy concerns – be institutionalised I.e., not seen as accidental, or reliant on good-faith proponents. Aligning site selected with community interests and goals should not be reliant on researchers like us who believe this to be an important part of feasibility. Indeed, ideally, such a process should be initiated by a well resourced, actor like a distribution company or state government that would undertake such a process over a larger spatial scale to determine which locations would be best suited to a feasibility site.

Second, the outcome of site selection should explicitly aim to further *democratize* technology deployment by including all affected interests, especially the most vulnerable (who are also often the most marginalized), promoting social cohesion and socio-environmental justice, and resulting from well-informed deliberative tools and processes.

Third, a democratized site selection process could take the form of a *clear method* built around the definition of objectives, a process for defining relevant criteria, the establishment of a clear matrix of criteria, and the building of consensus on the sites selected on the basis of this matrix. While our project did not directly involve representatives from the community itself, such an approach would be an important future direction to ensure that the criteria aligns with public concerns.

Fourth, each stage of site selection must be based on a *participatory and transparent dialogue* with all affected interests, so that each stage is discussed, documented and

accessible to all participants. This is vital to (re)building trust in the intent and actions of funders, regulators, researchers and project proponents.

Fifth, beyond feasibility issues, special attention must be paid to all forms of socio-technical *energy vulnerabilities* and the potential negative, positive, and neutral impacts of grid integration technologies on these vulnerabilities.

Sixth and finally, while our proposed method for site selection has some generalizable elements (such as its structural process), each project is different and contextual information is vital in determining what to do. We therefore suggest that great caution be exercised in attempting to apply systematic methods to all cases and instead establish a *transdisciplinary and place-based expertise* with a plurality of local actors.

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7 References

- Akinyele, D., Belikov, J., Levron, Y., 2018. Challenges of Microgrids in Remote Communities: A STEEP Model Application. *Energies* 11, 432. <https://doi.org/10.3390/en11020432>
- Akram, U., Khalid, M., Shafiq, S., 2018. Optimal sizing of a wind/solar/battery hybrid grid-connected microgrid system. *IET Renew. Power Gener.* 12, 72–80. <https://doi.org/10.1049/iet-rpg.2017.0010>
- Baghaee, H.R., Mirsalim, M., Gharehpetian, G.B., Talebi, H.A., 2016. Reliability/cost-based multi-objective Pareto optimal design of stand-alone wind/PV/FC generation microgrid system. *Energy* 115, 1022–1041. <https://doi.org/10.1016/j.energy.2016.09.007>
- Bahramirad, S., Reder, W., Khodaei, A., 2012. Reliability-Constrained Optimal Sizing of Energy Storage System in a Microgrid. *IEEE Trans. Smart Grid* 3, 2056–2062. <https://doi.org/10.1109/TSG.2012.2217991>
- Biswas, S., Echevarria, A., Irshad, N., Rivera-Matos, Y., Richter, J., Chhetri, N., Parmentier, M.J., Miller, C.A., 2022. Ending the Energy-Poverty Nexus: An Ethical Imperative for Just Transitions. *Sci. Eng. Ethics* 28.
- Boudet, H.S., 2019. Public perceptions of and responses to new energy technologies. *Nat. Energy* 4, 446–455. <https://doi.org/10.1038/s41560-019-0399-x>
- Brisbois, M.C., 2020. Decentralised energy, decentralised accountability? Lessons on how to govern decentralised electricity transitions from multi-level natural resource governance. *Glob. Transit.* 2, 16–25. <https://doi.org/10.1016/j.glt.2020.01.001>
- Burke, M.J., Stephens, J.C., 2017. Energy democracy: Goals and policy instruments for sociotechnical transitions. *Energy Res. Soc. Sci., Policy mixes for energy transitions* 33, 35–48. <https://doi.org/10.1016/j.erss.2017.09.024>
- Burton, C.A., Ryan, C., Rismanchi, B., Candy, S., 2019. Urban shared energy systems and behaviour change – simulating a common pooled resource problem. *Smart Sustain. Built Environ.* 9, 17–26. <https://doi.org/10.1108/SASBE-01-2019-0013>
- Carpintero-Rentería, M., Santos-Martín, D., Guerrero, J.M., 2019. Microgrids Literature Review through a Layers Structure. *Energies* 12. <https://doi.org/10.3390/en12224381>
- Chen, S.X., Gooi, H.B., Wang, M.Q., 2012. Sizing of Energy Storage for Microgrids. *IEEE Trans. Smart Grid* 3, 142–151. <https://doi.org/10.1109/TSG.2011.2160745>
- Chilvers, J., Longhurst, N., 2016. Participation in Transition(s): Reconceiving Public Engagements in Energy Transitions as Co-Produced, Emergent and Diverse. *J. Environ. Policy Plan.* 18, 585–607. <https://doi.org/10.1080/1523908X.2015.1110483>
- Chilvers, J., Pallett, H., Hargreaves, T., 2018. Ecologies of participation in socio-technical change: The case of energy system transitions. *Energy Res. Soc. Sci.* 42, 199–210. <https://doi.org/10.1016/j.erss.2018.03.020>
- Cooper, A.C.G., 2017. Building a socio-technical energy research community: Theory, practice and impact. *Energy Res. Soc. Sci.* 26, 115–120. <https://doi.org/10.1016/j.erss.2017.02.001>
- Dahlgren, K., Strengers, Y., Pink, S., Nicholls, L., Sadowski, J., 2020. Digital energy futures: review of industry trends, visions and scenarios for the home. Monash University.
- Day, R., Walker, G., Simcock, N., 2016. Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy* 93, 255–264. <https://doi.org/10.1016/j.enpol.2016.03.019>
- Devine-Wright, P., 2022. Decarbonisation of industrial clusters: A place-based research agenda. *Energy Res. Soc. Sci.* 91, 102725. <https://doi.org/10.1016/j.erss.2022.102725>

- Droubi, S., Heffron, R.J., McCauley, D., 2022. A critical review of energy democracy: A failure to deliver justice? *Energy Res. Soc. Sci.* 86, 102444. <https://doi.org/10.1016/j.erss.2021.102444>
- Eriksson, E.L.V., Gray, E.MacA., 2017. Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems – A critical review. *Appl. Energy* 202, 348–364. <https://doi.org/10.1016/j.apenergy.2017.03.132>
- Farhangi, H., 2010. The path of the smart grid. *IEEE Power Energy Mag.* 8, 18–28. <https://doi.org/10.1109/MPE.2009.934876>
- Farrelly, M.A., Tawfik, S., 2020. Engaging in disruption: A review of emerging microgrids in Victoria, Australia. *Renew. Sustain. Energy Rev.* 117, 109491. <https://doi.org/10.1016/j.rser.2019.109491>
- Fazey, I., Schöpke, N., Caniglia, G., Patterson, J., Hultman, J., van Mierlo, B., Säwe, F., Wiek, A., Wittmayer, J., Aldunce, P., Al Waer, H., Battacharya, N., Bradbury, H., Carmen, E., Colvin, J., Cvitanovic, C., D'Souza, M., Gopel, M., Goldstein, B., Hämäläinen, T., Harper, G., Henfry, T., Hodgson, A., Howden, M.S., Kerr, A., Klaes, M., Lyon, C., Midgley, G., Moser, S., Mukherjee, N., Müller, K., O'Brien, K., O'Connell, D.A., Olsson, P., Page, G., Reed, M.S., Searle, B., Silvestri, G., Spaiser, V., Strasser, T., Tschakert, P., Uribe-Calvo, N., Waddell, S., Rao-Williams, J., Wise, R., Wolstenholme, R., Woods, M., Wyborn, C., 2018. Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. *Energy Res. Soc. Sci.* 40, 54–70. <https://doi.org/10.1016/j.erss.2017.11.026>
- Fossati, J.P., Galarza, A., Martín-Villate, A., Fontán, L., 2015. A method for optimal sizing energy storage systems for microgrids. *Renew. Energy* 77, 539–549. <https://doi.org/10.1016/j.renene.2014.12.039>
- Fouché, E., Brent, A., 2020. Explore, Design and Act for Sustainability: A Participatory Planning Approach for Local Energy Sustainability. *Sustainability* 12, 862. <https://doi.org/10.3390/su12030862>
- Gregoratti, D., Matamoros, J., 2015. Distributed Energy Trading: The Multiple-Microgrid Case. *IEEE Trans. Ind. Electron.* 62, 2551–2559. <https://doi.org/10.1109/TIE.2014.2352592>
- Guerrero, J.M., Matas, J., Garcia de Vicuna, L., Castilla, M., Miret, J., 2007. Decentralized Control for Parallel Operation of Distributed Generation Inverters Using Resistive Output Impedance. *IEEE Trans. Ind. Electron.* 54, 994–1004. <https://doi.org/10.1109/TIE.2007.892621>
- Guerrero, J.M., Vasquez, J.C., Matas, J., de Vicuna, L.G., Castilla, M., 2011. Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization. *IEEE Trans. Ind. Electron.* 58, 158–172. <https://doi.org/10.1109/TIE.2010.2066534>
- Hafez, O., Bhattacharya, K., 2012. Optimal planning and design of a renewable energy based supply system for microgrids. *Renew. Energy* 45, 7–15. <https://doi.org/10.1016/j.renene.2012.01.087>
- Hajiaghahi, S., Salemnia, A., Hamzeh, M., 2019. Hybrid energy storage system for microgrids applications: A review. *J. Energy Storage* 21, 543–570. <https://doi.org/10.1016/j.est.2018.12.017>
- Hicks, J., 2021. Claiming the double entendre of community power. Presented at the Climate Justice Research Centre.
- Katiraei, F., Iravani, M.R., Lehn, P.W., 2005. Micro-grid autonomous operation during and subsequent to islanding process. *IEEE Trans. Power Deliv.* 20, 248–257. <https://doi.org/10.1109/TPWRD.2004.835051>
- Liévanos, R.S., Horne, C., 2017. Unequal resilience: The duration of electricity outages. *Energy Policy* 108, 201–211. <https://doi.org/10.1016/j.enpol.2017.05.058>
- Long, C., Wu, J., Zhou, Y., Jenkins, N., 2018. Peer-to-peer energy sharing through a two-stage aggregated battery control in a community Microgrid. *Appl. Energy* 226, 261–276. <https://doi.org/10.1016/j.apenergy.2018.05.097>

- Lovell, H., Watson, P., 2019. Scarce data: off-grid households in Australia. *Energy Policy* 129, 502–510. <https://doi.org/10.1016/j.enpol.2019.02.014>
- Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C., 2018. Designing microgrid energy markets: A case study: The Brooklyn Microgrid. *Appl. Energy* 210, 870–880. <https://doi.org/10.1016/j.apenergy.2017.06.054>
- Mohamed, Y.A.-R.I., El-Saadany, E.F., 2008. Adaptive Decentralized Droop Controller to Preserve Power Sharing Stability of Paralleled Inverters in Distributed Generation Microgrids. *IEEE Trans. Power Electron.* 23, 2806–2816. <https://doi.org/10.1109/TPEL.2008.2005100>
- Nicholls, L., Strengers, Y., Tirado, S., 2017. Smart home control: exploring the potential for enabling technologies in vulnerable, disengaged and regular households. Centre for Urban Research, RMIT University.
- Olivares, D.E., Mehrizi-Sani, A., Etemadi, A.H., Cañizares, C.A., Iravani, R., Kazerani, M., Hajimiragha, A.H., Gomis-Bellmunt, O., Saadifard, M., Palma-Behnke, R., Jiménez-Estévez, G.A., Hatziaargyriou, N.D., 2014. Trends in Microgrid Control. *IEEE Trans. Smart Grid* 5, 1905–1919. <https://doi.org/10.1109/TSG.2013.2295514>
- Paudel, A., Chaudhari, K., Long, C., Gooi, H.B., 2019. Peer-to-Peer Energy Trading in a Prosumer-Based Community Microgrid: A Game-Theoretic Model. *IEEE Trans. Ind. Electron.* 66, 6087–6097. <https://doi.org/10.1109/TIE.2018.2874578>
- Pogaku, N., Prodanovic, M., Green, T.C., 2007. Modeling, Analysis and Testing of Autonomous Operation of an Inverter-Based Microgrid. *IEEE Trans. Power Electron.* 22, 613–625. <https://doi.org/10.1109/TPEL.2006.890003>
- Ramli, M.A.M., Boucekara, H.R.E.H., Alghamdi, A.S., 2018. Optimal sizing of PV/wind/diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm. *Renew. Energy* 121, 400–411. <https://doi.org/10.1016/j.renene.2018.01.058>
- Ransan-Cooper, H., Lovell, H., Watson, P., Harwood, A., Hann, V., 2020. Frustration, confusion and excitement: Mixed emotional responses to new household solar-battery systems in Australia. *Energy Res. Soc. Sci.* 70, 101656. <https://doi.org/10.1016/j.erss.2020.101656>
- Rocabert, J., Luna, A., Blaabjerg, F., Rodríguez, P., 2012. Control of Power Converters in AC Microgrids. *IEEE Trans. Power Electron.* 27, 4734–4749. <https://doi.org/10.1109/TPEL.2012.2199334>
- Roux, D.J., Nel, J.L., Cundill, G., O'Farrell, P., Fabricius, C., 2017. Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn. *Sustain. Sci.* 12, 711–726. <https://doi.org/10.1007/s11625-017-0446-0>
- Royal Commission into National Natural Disaster Arrangements, 2020.
- Sadowski, J., Levenda, A., 2020. The Anti-Politics of Smart Energy Regimes. *Polit. Geogr.* 81, 1–8.
- Soshinskaya, M., Crijns-Graus, W.H.J., Guerrero, J.M., Vasquez, J.C., 2014. Microgrids: Experiences, barriers and success factors. *Renew. Sustain. Energy Rev.* 40, 659–672. <https://doi.org/10.1016/j.rser.2014.07.198>
- Sovacool, B.K., Kivimaa, P., Hielscher, S., Jenkins, K., 2017. Vulnerability and resistance in the United Kingdom's smart meter transition. *Energy Policy* 109, 767–781. <https://doi.org/10.1016/j.enpol.2017.07.037>
- Sovacool, B.K., Ryan, S.E., Stern, P.C., Janda, K., Rochlin, G., Spreng, D., Pasqualetti, M.J., Wilhite, H., Lutzenhiser, L., 2015. Integrating social science in energy research. *Energy Res. Soc. Sci.* 6, 95–99. <https://doi.org/10.1016/j.erss.2014.12.005>
- Spreng, D., 2014. Transdisciplinary energy research – Reflecting the context. *Energy Res. Soc. Sci.* 1, 65–73. <https://doi.org/10.1016/j.erss.2014.02.005>
- Strengers, Y., 2013. Smart energy technologies in everyday life. Smart utopia? Palgrave Macmillan, London, UK.
- Strengers, Y., Nicholls, L., 2017. Convenience and energy consumption in the smart home of the future: Industry visions from Australia and beyond. *Energy Res. Soc. Sci.*

- Energy Consumption in Buildings: 32, 86–93.
<https://doi.org/10.1016/j.erss.2017.02.008>
- Szulecki, K., Overland, I., 2020. Energy democracy as a process, an outcome and a goal: A conceptual review. *Energy Res. Soc. Sci.* 69, 101768.
<https://doi.org/10.1016/j.erss.2020.101768>
- Temby, H., Ransan-Cooper, H., 2021. 'We want it to work': understanding household experiences with new energy technologies in Australia. Final report of the VOICES project (Victorian Energy and Water Ombudsman's Investigation of Consumer Experiences).
- The Australia Institute, 2022. *Climate of the Nation 2022*, Climate of the Nation.
- Valencia, F., Billi, M., Urquiza, A., 2021. Overcoming energy poverty through micro-grids: An integrated framework for resilient, participatory sociotechnical transitions. *Energy Res. Soc. Sci.* 75, 102030. <https://doi.org/10.1016/j.erss.2021.102030>
- Wahlund, M., Palm, J., 2022. The role of energy democracy and energy citizenship for participatory energy transitions: A comprehensive review. *Energy Res. Soc. Sci.* 87, 102482. <https://doi.org/10.1016/j.erss.2021.102482>
- Wang, H., Huang, J., 2018. Incentivizing Energy Trading for Interconnected Microgrids. *IEEE Trans. Smart Grid* 9, 2647–2657. <https://doi.org/10.1109/TSG.2016.2614988>
- Wang, J., Chang, N.C.P., Feng, X., Monti, A., 2015. Design of a Generalized Control Algorithm for Parallel Inverters for Smooth Microgrid Transition Operation. *IEEE Trans. Ind. Electron.* 62, 4900–4914. <https://doi.org/10.1109/TIE.2015.2404317>
- Wang, R., Hsu, S.-C., Zheng, S., Chen, J.-H., Li, X.I., 2020. Renewable energy microgrids: Economic evaluation and decision making for government policies to contribute to affordable and clean energy. *Appl. Energy* 274, 115287. <https://doi.org/10.1016/j.apenergy.2020.115287>
- Wickson, F., Carew, A.L., Russell, A.W., 2006. Transdisciplinary research: characteristics, quandaries and quality. *Futures* 38, 1046–1059. <https://doi.org/10.1016/j.futures.2006.02.011>
- Wilkinson, S., Hojckova, K., Eon, C., Morrison, G.M., Sandén, B., 2020. Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia. *Energy Res. Soc. Sci.* 66, 101500. <https://doi.org/10.1016/j.erss.2020.101500>
- Winzer, C., 2012. Conceptualizing energy security. *Energy Policy* 46, 36–48. <https://doi.org/10.1016/j.enpol.2012.02.067>
- Yang, Y., Bremner, S., Menictas, C., Kay, M., 2018. Battery energy storage system size determination in renewable energy systems: A review. *Renew. Sustain. Energy Rev.* 91, 109–125. <https://doi.org/10.1016/j.rser.2018.03.047>
- Zhang, C., Wu, J., Zhou, Y., Cheng, M., Long, C., 2018. Peer-to-Peer energy trading in a Microgrid. *Appl. Energy* 220, 1–12. <https://doi.org/10.1016/j.apenergy.2018.03.010>
- Zhao, P., Pendlebury, J., 2014. Spatial planning and transport energy transition towards a low carbon system. *DisP - Plan. Rev.* 50, 20–30. <https://doi.org/10.1080/02513625.2014.979040>

Appendices

Appendix A: Summary of quantitative and qualitative assessment

Indicator (Sub)Locality	Quantitative analysis		Diversity & representativeness				
	Final score (risk x consequence)	Final score (sum of points)	Population (Australian Bureau of Statistics 2016)	Percentage of households who speak other than English at home (Australian Bureau of Statistics 2016)	Presence of shared residential or industrial estates	Network topology (options): geographical size (large, medium, small), density (high, medium, low), grid (spur/meshed)	Technical ease (easy, medium, hard)
Bodalla	7	44	739	3%	Single storey - Agriculture, industry, retail	(1) medium/low/meshed (2) medium/medium/meshed (3) large/medium/meshed	All options medium
Broulee	3	43	1717	3%	Free standing - Retail	Two options, both medium/high/meshed	Two options medium
Central Tilba	8	42	288	10%	Timber construction - Agriculture, industry, retail	(1) medium/medium/ spur (2) large/medium/ meshed	(1) easy, (2) hard
Congo	5	38	245	17%	Single dwelling - Limited economic activity	Small/low/Spur	(1) easy
Meringo	7	38	322	12%	Single dwelling - Limited economic activity	(1) medium/medium/ spur (2) large/low/meshed	(1) easy, (2) medium
Mogo	12	45	322	12%	Small businesses, touristic sites	Small/medium/meshed	Medium
Moruya Heads	4	35	976	12%	Mixed housing types - Marine economic activities	Medium/low/spur	Easy
Mossy Point	2	31	569	8%	Free standing - Retail	(1) large/medium/ meshed (2) large/high/meshed	Both options medium

Mystery Bay	5	33	191	6%	Agriculture, pumping station, retail, tourism	Small/low/spur	Easy
Nelligen	7	36	332	11%	Single dwellings - Cafe, caravan park	(1) large/medium/ meshed (2) large/ medium/meshed (3) small/low/spur	(1) hard (2) medium (3) easy
Nerrigundah	5	35	25	10%	Nil	(1) medium/low/spur (2) medium/low/spur (3) small/medium/spur	(1) easy (2) easy (3) easy
Potato Point	3	28	135	10%	Single storey - Agriculture, industry, retail	(1) medium/low/spur (2) small/high/spur	(1) easy (2) easy
Rosedale	5	32	221	15%	Single or double storey - Agriculture	No data	No data
South Durras	3	27	341	17%	Large holiday lets and 3 RV parks - Agriculture, tourism	(1) small/high/spur (2) large/medium/ meshed	(1) easy (2) hard
Tilba Tilba	9	40	95	10%	Timber construction - Agriculture, industry, retail	(1) large/low/meshed (2) small/high/spur (3) large/low/meshed	(1) med (2) easy (3) hard
Tomakin	4	41	1001	12%	Large homes - limited economic activity	(1) medium/high/meshed (2) medium/high/ meshed (3) large/low/meshed	(1) hard (2) hard (3) hard
Turlinjah	7	37	157	6%	Nil	(1) small/medium/spur (2) large/low/meshed (3) large/low/meshed	(1) easy (2) hard (3) hard
Tuross Head	4	41	2241	8%	Two storey (low energy efficiency)	(1) large/medium/spur (2) medium/high/spur	(1) easy (2) easy (3) easy

				- Golf and bowling club	(3) small/high/spur	
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