A research and innovation agenda for energy resilience in Pacific Island Countries and Territories

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Pacific Island Countries and Territories have set ambitious targets for energy access and the transition to sustainable energy. These efforts, however, are being severely impacted by shocks and stresses such as climate change, natural hazards and the COVID-19 pandemic. Resilience is a central pillar for energy policy in the region, but innovative approaches are needed to address these urgent challenges. Here we examine the role of research and innovation in supporting energy resilience in Pacific Island Countries and Territories. We argue that research and innovation in three key areas is needed: energy planning and innovative finance approaches tailored to the particular strengths and challenges in Pacific Island Countries and Territories; greater recognition and inclusion of community responses to energy challenges; and promotion of decentralized approaches to energy in terms of governance and technologies. Emerging from these three areas, we identify 11 research and innovation priorities to build the evidence base that will mobilize stakeholders in a collaborative effort to accelerate action on energy resilience.

Pacific Island Countries and Territories (PICTs; Fig. 1) face multiple short-term shocks and long-term stresses that impact on their energy systems. Short-term shocks include cyclones and associated storm surges, and geological disturbances causing both earthquakes and tsunamis. Long-term stresses include sea-level rise and coastal flooding. Most of these risks are increasing in severity due to global climate change, and their impacts are exacerbated by the economic isolation triggered by recent COVID-19 disruptions to supply chains and travel. PICTs dominate the World Risk Index's list of most-at-risk countries—with four of the top eight countries with the 'highest disaster risk' being located in the region: Vanuatu (first), Tonga (second), Solomon Islands (fifth) and Papua New Guinea (eighth)¹. This reflects the exposure that these countries have to hazards, and the remote locations of these communities. The small scale of many PICTs also leads to technical and institutional capacity limitations in terms of coping with and responding to hazards¹.

These risks have substantial implications for the achievement of the Sustainable Development Goals (SDGs) within the region, including SDG7, which focuses on universal energy access, increasing the share of renewable energy in the energy mix and improving energy efficiency. Current electricity access levels in the PICTs range between 60% and 100%, while the share of renewable energy in the electricity sector varies between 0% and 50% in different jurisdictions^{2,3}. However, these figures include people who only have access to basic household energy services (such as lights, refrigerators, fans and radios)⁴. Access to a wider range of energy services is still limited for many communities in PICTs⁵. Energy efficiency is also problematic across PICTs, with generally poor quality and quickly

deteriorating energy appliances and generators, as well as a lack of comprehensive measures and targets for energy efficiency⁶.

PICTs have ambitious renewable energy targets to reduce their dependence on imported fossil fuels (including diesel for electricity generation), improve energy security and provide leadership for international climate action by setting an example for other regions. Some progress is being made via national strategic plans and sector-specific policies, as well as via international agreements such as Nationally Determined Contributions to the Paris Agreement and Energy Compact submissions as part of the High-Level Dialogue on Energy^{7,8}. Tokelau has been celebrated as the world's first nation to achieve 100% renewable electricity⁹ and almost all other PICTs have similarly ambitious renewable energy targets, with many planning to achieve 100% renewables by 2030 or sooner. Electricity access targets remain a key focus for countries such as Papua New Guinea, Solomon Islands and Vanuatu that have lower levels of energy access.

Resilience is a way to better understand and navigate complexity and uncertainty that has been used in many different contexts and fields¹⁰. Energy resilience can be defined as the "ability to reduce the impact of shocks and stresses, including the capacity to anticipate, absorb, adapt to, and rapidly recover from such events and to transform where necessary"¹¹. The inclusion of energy resilience in policy and programme design can safeguard and accelerate the transition to clean and affordable energy for all, and enable PICTs to achieve their ambitious but vitally important targets. Indeed, the region has been a frontrunner in transitioning to a resilience approach in energy policy through the Framework of Action for Energy Security in the Pacific 2010–2020, and the new Framework for Energy Security and Resilience in the Pacific 2021–2030.

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Fig. 1 | Location of PICTs. Map created using mapchart.net.

Energy resilience is also embedded in the Framework for Resilient Development in the Pacific 2017–2030. At the national level, disaster resilience has increasingly been integrated into energy and climate policies, including in Fiji, Vanuatu and Tuvalu^{12–14}, while Palau considers resilience to be a key aspect in ensuring the security of their energy supply¹⁵.

Nevertheless, much remains to be done. Innovative approaches that address the unique challenges and make use of the strengths in the region are needed to realize the ambitions of PICTs, and these would greatly benefit from greater focus on energy resilience. There is a particular need for work that integrates relevant knowledge from diverse fields such as energy, resilience and innovation with a deep understanding of the region.

In this Perspective, we identify key research and innovation priorities that will need to be addressed to achieve energy resilience while also meeting the renewable energy and energy access targets in the region. These priorities were informed by an ongoing collaboration with key regional stakeholders as well as international researchers. This included a review of the literature, case studies of six countries and a series of workshops in 2020^{16,17}. We argue that three core themes need to be addressed. The first is better integration of energy planning and innovative finance approaches tailored to the energy resilience strengths and challenges in PICTs. The second is greater engagement with community responses. Existing forms of resilience exist within the region's communities that can be enhanced and deployed in the energy sector. The final theme is promotion of decentralized approaches in terms of both governance and technologies to enhance energy access and resilience. The boom in smaller-scale solar technologies offers new means for realizing access, but the technology needs to be combined with salient governance approaches to achieve its resilience potential.

Planning and finance

Planning well is always challenging. It benefits from well informed stakeholders, broad consensus on objectives, a suitable range of options, and processes to engage all key stakeholders in formulating anticipatory decisions, with an appropriate allocation of autonomy, transparency and accountability. Planning for energy resilience is particularly challenging for PICTs given the wider resilience challenges that these communities face. Many communities in PICTs are remote and dispersed, routinely exposed to challenging weather and dependent on small-scale marine transport for critical supplies including diesel fuel. Accounting for threats and vulnerabilities in energy planning decisions must therefore extend beyond natural hazard response and critical infrastructure planning. Planning for energy resilience means embedding robustness and ways of recovering from disruptions into all energy decision-making. This requires further research and innovation to incorporate resilience principles into routine planning tools and processes.

Energy planning in PICTs is primarily focused on grid-based electricity supply. However, energy infrastructure is often ageing and poorly located due to land access challenges, and therefore vulnerable to cyclones and storm surges^{18,19}. Asset management is also challenging due to the harsh environment and financial constraints of small national budgets, typically leading to a 'maintenance on failure' approach²⁰. Energy planning could better focus on energy services as an enabler for communities, particularly those services that are critical to community resilience. It should also recognize that access to energy services may be achieved in different ways, especially during emergencies. This requires incorporation of diverse stakeholder perspectives into planning processes, and linkage of energy planning to end use goals such as water, health, education, food security and income-generating applications that

meet community priorities, including those that can increase resilience. Research is needed to identify key linkages between energy resilience and broader development goals to deliver better policy integration.

A number of PICTs have put in place plans to mitigate the increasing threats to infrastructure posed by climate change. For instance, Fiji has implemented a policy to increase building standards and minimize loss of infrastructure²¹, including energy infrastructure, to extreme events. However, the costs of increased standards largely fall on households and businesses, and implementation has been hampered by lack of government support and the inability of communities to afford building according to the new standards²².

Energy efficiency standards may also play a role in both meeting Nationally Determined Contribution targets and improving resilience²³. However, implementing appropriate technical standards for products, installation and maintenance can be financially challenging under project-based funding arrangements. Also, improving the quality of systems through standards must not be done at the expense of reparability—for example, high-quality products that are imported may not be repairable locally and result in longer power outages if and when they fail. Further research is needed to map potential trade-offs between high quality standards for energy systems, and the ability to maintain and repair systems.

Beyond investment in renewable generation capacity, both grid investments²⁴ and technical capacity to manage increased operational complexity are required to successfully transition to renewables, particularly variable solar and wind. This is further complicated by the load growth that is common when more reliable electricity becomes available. To reach small islands and less accessible regions of larger islands, PICTs also need to be able to plan and make decisions across all of the main grid, standalone minigrid and off-grid options available to them, while technologies, cost structures and stakeholders continue to evolve and change (for instance, as tourism sectors have in light of the disruptions of COVID-19). The lack of data and modelling tools for planning has been identified by stakeholders as a key barrier to improved planning²⁵, while the changing dynamics of both challenges and possible options for delivering energy services require process-driven planning trajectories, not one-off plans. This requires research and innovation for improving field data, demand modelling and planning tools for energy.

The already limited public finance abilities of PICTs⁹, which are heavily dependent on external financial support to finance energy projects, will be further strained with the need to integrate resilience. However, to date climate finance made available for energy projects has focused on renewable energy investments rather than grid readiness²⁴ or adaptation²⁵. There is recognition that substantial private finance will also be needed to achieve the scale of investment required. Such private investment has thus far been limited by perceptions of PICTs as small and risky markets²⁶. This further emphasizes the importance of appropriate planning as well as data-gathering on past, present and future projects²³ to identify appropriate financing mechanisms. Standardization of contracts, regulatory reform and regional approaches may have a role to play in derisking projects and demonstrating 'readiness' to receive financing, but have been criticized as potentially perpetuating disempowerment and dependence on external agencies²⁶. Proposals have been put forward for innovative financing mechanisms that can support longer-tenor finance, and support for domestic financial institutions to manage risk to build capacity of domestic finance sectors and investors²⁴. Attention to gender mainstreaming and equity in climate finance is also needed to ensure that it works for the most vulnerable²⁷.

Due to their small scale, lack of access to resources and the need to manage a range of ongoing challenges, PICTs face a number of barriers to planning for energy resilience²⁸. This includes technical and

technoeconomic capacity, but also weak institutional arrangements with lack of autonomy, lack of transparency and local accountability for decision-making. For instance, Tokelau is a dependent territory of New Zealand and is heavily reliant on New Zealand for support in the energy sector. This puts planning decisions and implementation timeframes outside local control²⁹. In Papua New Guinea, planning for climate change and resilience is being framed within a pre-existing energy access agenda. Investments in the energy sector have focused on LNG and grid extensions, but other options such as solar farms, refurbishing hydroelectric plants and off-grid solutions could improve resilience by diversifying the resource base and could also be more suitable for dispersed populations in rugged terrain⁵. Lack of land for new energy projects is also an issue throughout the Pacific. Institutional capacity building for resilient planning is required, with frameworks to ensure accountability and transparent review processes. Research is needed to inform the design of multistakeholder planning and implementation review processes to build capacity, autonomy, transparency and accountability for energy-related decision-making. In addition, research is needed to identify pathways for addressing land conflicts and broader community politics associated with energy projects, and to create conflict resolution mechanisms that can be integrated into planning processes.

Despite their ambition, many PICTs' national and regional level plans for renewable energy and energy access have remained unfilled and become rapidly outdated. Ongoing planning processes that incorporate feedback on evolving stakeholder priorities and barriers to implementation are needed. There is a particular need for innovative planning tools that include resilience in routine planning processes, and integrate across sectors, both on and off grid. This requires a structured process of regular data collection of actual energy system performance in the field to input to planning. PICTs have existing regional mechanisms that could be utilized to overcome challenges of scale and capacity, but past challenges of translating regional plans to national action³⁰ must be addressed. Leveraging a regional approach with a strong interface to national planning will be key. Further research is needed to identify leverage points in existing regional mechanisms that can interface with national planning to overcome challenges of scale and capacity.

Community responses

A community is a group of people who live in the same area, have common interests or have a common identity. Communities can play an important role in energy resilience³¹, while renewable energy technologies can contribute to community resilience³². Due to the remoteness and frequent disasters faced by communities in PICTs, there is greater reliance on communities to maintain their renewable energy systems to prevent premature breakdown and to repair them in the aftermath of disasters³³. Communities in the Pacific have strong identities of resilience³⁴ which should be acknowledged in the energy sector. Traditional customs and practices have contributed to disaster resilience and adaptive capacity in PICTs. For example, smallholder farmers in Papua New Guinea have adopted more flexible land access arrangements, based on indigenous systems of land sharing that traditionally operate through kinship, as a risk management strategy in response to pressures from population growth and climate change³⁵. These longstanding relationship-based sources of community resilience can extend beyond geographic boundaries. Families replicate the adaptive behaviour of others within their social network, and these networks are often clustered by common livelihood strategies³⁶. To spark transformative action at the local level, energy resilience initiatives must bolster existing livelihood strategies.

National energy planning must be integrated with and tailored to specific community energy resilience strategies, such as community members taking an active role in restoring energy services after

disasters³¹. Building on the energy resilience strategies of each community is essential because adaptive capacity and relative exposure to risks can vary substantially between communities, even those that are geographically close together. When objectives are written in broad and administrative terms rather than direct outcomes for communities, it becomes difficult to assess impact³⁷. The Vanuatu Community Resilience Framework offers an example of how community-scale disaster risk reduction and climate adaptation work can contribute to national planning through building local capacity and networks³⁸. Holistic planning of innovation processes is needed to ensure that opportunities to enhance community resilience via energy services are maximized³².

'Communities' are not homogeneous and community-based resilience projects should not overlook issues of equity. Local inequalities can lead to unequal distribution of benefits from such opportunities. Experience with climate adaptation and resilience initiatives in Vanuatu particularly highlight the vulnerability of women and people with disabilities, and the need for including marginalized groups in decision-making^{39,40}. Local power dynamics are important to consider, as those in charge may resist initiatives that threaten their current standing³⁷. Securing the support of local leaders and the diverse groups within the community is needed. The Pacific tradition of *talanoa*, of inclusive, participatory and transparent dialogue for decision-making for the greater good, is essential for ensuring energy access in the long term by ensuring community engagement and ownership. Simply including the preferences of communities is not enough; initiatives need to include local representation and interface with existing structures to identify appropriate entry points across regional, national and community scales⁴¹.

Further research is needed on the resilience strategies that communities currently deploy, including those that build on traditional customs and practices, which could be used to improve resilience in the energy sector. This would inform best practices for community-based energy resilience initiatives, including how diverse communities can participate in creating innovative business models and technologies for energy services that are more resilient and create livelihood opportunities. Innovation in the policy space is needed to integrate community resilience and national energy planning, including fine-grained data and tools to enable communities to better understand and participate in energy planning. To improve diversity and inclusion in these plans, further research is required to build a more detailed understanding of the energy needs and resilience strategies of historically marginalized groups. As one key example, there has been a lack of research on clean cooking energy needs and preferences in PICTs, a space predominantly relevant to women in several PICT cultures. It is critical to address this research gap, as the Oceania region, excluding Australia and New Zealand, has the lowest level of access to clean cooking fuels and technologies in the world, at only 15% (ref. ⁴²).

Decentralized approaches

Emerging energy technologies, such as solar off-grid systems, have created new and more decentralized approaches to energy dissemination and governance in PICTs. Given the archipelago-like geographical nature of much of the Pacific, decentralized approaches present an opportunity to effectively deliver energy services where centralized electricity grids are not appropriate. Minigrids and microgrids powered by varied mixes of renewable and fossil-fuel generation are already supplying electricity on larger islands^{43,44}. Around 6,900 minigrids have already been installed in the Asia-Pacific region overall, with expectations of rapid growth in upcoming years⁴⁵. Compared with more complex and large-scale grid infrastructure (large generators and transmission infrastructure), smaller-scale off-grid solar products (such as solar lanterns and solar home systems) have the potential to offer resilient forms of energy access during disaster events due to their modular design

and flexible application. They are less susceptible to widespread disruption during disaster events such as floods, hurricanes and earthquakes⁴⁶.

Smaller off-grid solar products have also been important for disaster response efforts—being rapidly distributed in post-disaster contexts to supply lighting to blacked-out households⁴⁷. Over the past decade, there has been rapid change in the political economy of how these products are disseminated, with some shifts from aid to enterprise^{48,49}. Earlier projects in the off-grid energy space were largely facilitated with aid funding and through the not-for-profit sector^{50,51}. More recently, however, there has been the emergence of a self-directed off-grid solar sector, whereby a diverse range of start-up companies, with funding from private sector investors, have developed market-based models to disseminate off-grid solar products to poorer populations in the Global South⁵². Over the past five years there has been a rapid increase in off-grid solar products being sold as a household commodity, globally and across PICTs, although there are considerable variations between countries. Off-grid systems in Tuvalu and Tokelau, for example, tend to be larger installations and have been heavily driven by aid donor programmes⁴³. Vanuatu and Papua New Guinea have recently been experimenting with pay-as-you-go solar financing systems, which were launched, and are now widely used, in the East Africa region⁵³. In Vanuatu in particular, the private sector (with some aid donor and government support) has played a key role in setting up an off-grid solar market⁵⁴. In Vanuatu's 2016 census, an estimated 64% of households were using off-grid solar as their main lighting source—a meteoric rise from 2009, where only 2.8% of households were using the technology⁵⁵. Research and innovation are needed in PICTs on business models for more resilient energy systems, including the potential for greater private sector involvement, to capitalize on recent developments in the off-grid solar sector.

Research is also needed on the governance and maintenance implications of different ownership schemes for decentralized energy systems. While the emergence of decentralized energy technologies is an encouraging prospect for energy resilience, questions around how they are best integrated to the broader PICT energy melange remain open. Who should own off-grid solar infrastructure? Who should be in charge of its distribution? Who is responsible for its repair and maintenance? How effective could pay-as-you-go models of financing solar, which are common in East Africa⁵⁶, be if applied in PICTs? Governments, aid donors, the private sector and communities all undoubtedly have a role to play, but the most appropriate configuration for their interactions is still contested, and will probably vary across different geographical contexts within the region^{26,51,57}. In Tokelau, for example, there is an emerging issue of photovoltaic battery waste, with a lack of local capacity and clear responsibility in terms of who should address the issue¹⁷. Meanwhile, in Fiji there have been occasional disagreements between communities and the government in terms of who should be responsible for the maintenance and upkeep of off-grid solar power systems⁵⁸. As such, there is a need to understand how off-grid solar products can be best situated in the broader political economy of energy governance across the PICTs. These challenges are not unique to PICTs and there is potential to learn from other regions and contribute to ongoing global debates on these issues.

Energy resilience research and innovation priorities

PICTs face some unique energy resilience challenges. These include very high dependence on fossil fuels and the difficulties in sustaining energy supply chains for small, remote locations under increasingly challenging weather conditions. Energy utilities currently require support from international development partners who may be limited by their own funding cycles. PICTs have ambitious renewable energy targets, but land scarcity and a high proportion of renewable energy on grids can increase planning challenges. Energy

Box 1 | Research and innovation priorities for energy resilience in PICTs**Planning and finance**

1. Incorporate resilience principles into routine planning tools and processes.
2. Identify key linkages between energy resilience and broader development goals to achieve better policy integration.
3. Map potential trade-offs between high quality standards for energy systems and the ability to maintain and repair systems.
4. Improve field data, demand modelling and planning tools for energy.
5. Design multistakeholder planning and implementation review processes to build capacity, autonomy, transparency and accountability for energy-related decision-making.
6. Identify pathways for addressing land conflicts and broader community politics associated with energy projects, to create conflict resolution mechanisms that can be integrated into planning processes.
7. Identify leverage points in existing regional mechanisms that can interface with national planning to overcome challenges of scale and capacity.

Community responses

8. Identify the resilience strategies that communities currently deploy, including those that build on traditional customs and practices, that could be used to improve resilience in the energy sector.
9. Understand the energy needs and resilience strategies of historically marginalized groups.

Decentralized approaches

10. Build viable business models for more resilient energy systems, including the potential for a greater private-sector involvement.
11. Understand the governance and maintenance implications of different ownership schemes for decentralized energy systems.

resilience will also require careful coordination between grid, mini-grid and smaller off-grid energy products. Finally, limited technical capacity and weak governance in some jurisdictions can hamper implementation.

At the same time, PICTs have unique strengths in tackling the challenges of energy resilience. With excellent renewable energy resources and a strong fiscal motivation to reduce reliance on imported fossil fuels, PICTs have already made energy resilience and sustainable energy a core part of their policy agenda. Existing regional organizations can help to further coordinate efforts, and communities have existing customs, practices and local knowledge that can enhance resilience in the energy sector.

This Perspective has highlighted key opportunities for improving energy resilience in PICTs through research and innovation in three areas. The first area is energy planning and innovative finance approaches tailored to the particular strengths and challenges in PICTs. The second area is greater recognition and inclusion of community responses to energy challenges. The third area is promoting decentralized approaches to energy in terms of governance and technologies. Emerging from these three areas, as discussed above, we have identified 11 research and innovation priorities, summarized in Box 1.

This Perspective supports the implementation of the Framework for Energy Security and Resilience in the Pacific 2021–2030 which

was recently endorsed at the 51st Pacific Islands Forum Leaders Meeting in August 2021. The framework was prepared by the Pacific Community in collaboration with the Council of Regional Organisations in the Pacific Energy Technical Working Group, including the Pacific Power Association, the Secretariat of the Pacific Regional Environment Programme, the University of the South Pacific and the Pacific Islands Forum Secretariat. As such, the Framework for Energy Security and Resilience in the Pacific represents the beginning of a new phase for collaboration on energy policy in PICTs, which places resilience at its centre. Successful action on energy resilience will require locally led and regionally coordinated initiatives, and will need to ensure that they can leverage the necessary knowledge, partnerships and capacity. We call for a global, multidisciplinary effort to address the research and innovation priorities (Box 1) in partnership with stakeholders in PICTs. This can support evidence-based decision-making including further development of action plans relevant to regional, national and local agendas. Addressing these research and innovation priorities will also contribute a Pacific perspective on energy resilience to global debates, illustrating how other countries might address similar challenges.

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Competing interests

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Additional information

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