energies

MDPI

Perspective

Electricity Supply Systems for First Nations Communities in Remote Australia: Evidence, Consumer Protections and Pathways to Energy Equity

Md Apel Mahmud [1,*] and Tushar Kanti Roy [2]

[1] College of Science and Engineering, Flinders University, Tonsley, SA 5042, Australia
[2] School of Engineering, Macquarie University, Sydney, NSW 2109, Australia; tusharkanti.roy@mq.edu.au
* Correspondence: apel.mahmud@flinders.edu.au

Abstract

Remote First Nations communities in Australia experience ongoing energy insecurity due to geographic isolation, reliance on diesel, and uneven consumer protections relative to grid-connected households. This paper analyses evidence on electricity access, infrastructure and practical experience along with initiatives for improving existing infrastructure; highlights government policies, funding frameworks and regulation; demonstrates the benefits of community-led projects; provides geographic and demographic insights; and relevels key challenges along with pathways for effective solutions. Drawing on existing program experience, case studies and recent reforms (including First Nations–focused strategies and off-grid consumer-protection initiatives), this paper demonstrates that community energy systems featuring solar-battery systems can significantly improve reliability and affordability by reducing reliance on diesel generators and delivering tangible household benefits. The analyses reveal that there is an ongoing gap in protecting off-grid consumers. Hence, this work proposes a practical agenda to improve electricity supply systems for First Nations community energy systems through advanced community microgrids (including long-duration storage), intelligent energy management and monitoring systems, rights-aligned consumer mechanisms for customers with prepaid metering systems, fit-for-purpose regulation, innovative blended finance (e.g., Energy-as-a-Service and impact investment) and on-country workforce development. Overall, this paper contributes to a perspective for an integrated framework that couples technical performance with equity, cultural authority and energy sovereignty, offering a replicable pathway for reliable, affordable and clean electricity for remote First Nations communities.

Keywords: first nations energy systems; electricity supply systems; energy security; energy system reliability; consumer protections and energy equity

check for updates

Academic Editor: Jianjian Shen

Received: 19 August 2025
Revised: 22 September 2025
Accepted: 25 September 2025
Published: 26 September 2025

Citation: Mahmud, M.A.; Roy, T.K. Electricity Supply Systems for First Nations Communities in Remote Australia: Evidence, Consumer Protections and Pathways to Energy Equity. *Energies* **2025**, *18*, 5130. https://doi.org/10.3390/en18195130

1. Introduction

Remote and very remote First Nations communities in Australia face ongoing disadvantages for the electricity supply system arising from geographic isolation, legacy diesel dependence and gaps in consumer protections relative to grid-connected urban households. Although these regions cover most of Australia's landmass, they are home to a small share of the population. First Nations people are disproportionately represented in these areas, who frequently rely on off-grid energy systems rather than the National Electricity Market (NEM). In many locations, power is unreliable, expensive or absent altogether, with prepaid metering common and self-disconnection a pervasive risk. In this paper, the definitions of 'remote' and 'very remote' are adopted from the Australian Bureau of Statistics (ABS) as articulated in the Australian Statistical Geography Standard (ASGS). These definitions are based on relative access to services with 'remote' areas typically located several hours of travel from major service centres, while 'very remote' areas encompassing the most isolated parts of the country, which often require flights or multi-day travel for access. This operational definition frames the scope of this study population and highlights the unique infrastructural and logistical challenges shaping electricity supply for these communities.

The current infrastructure spans large utility-operated diesel generators with solar-battery systems in medium-voltage distribution networks to serve remote communities. Administrative and logistical constraints (including fuel delivery, upkeep in extreme climates and limited local technical capacity) compound affordability pressures and undermine reliability. Recent prepaid metering evidence from the Northern Territory (NT) further illustrates the depth of this energy insecurity, as households experience very high numbers of disconnections each year.

Over the last two decades, programs such as Bushlight and the NT Solar Energy Transformation Program (SETuP) have demonstrated that well-designed solar-battery systems can displace diesel and improve service quality when coupled with community engagement and training. More recently, First Nations–led initiatives, exemplified by several community energy systems, have demonstrated the effects of solar-battery systems on equitable benefit-sharing (e.g., prepay crediting) and islanding capability for delivering tangible household-level relief and resilience. These project-level successes sit alongside policy momentum, including the First Nations Clean Energy Strategy (2024–2030) [1] and jurisdictional funding arrangements (e.g., Indigenous Essential Services in the NT). Still, gaps in nationally consistent consumer safeguards for off-grid customers remain.

This paper synthesises the evidence on access, infrastructure, regulation and practical experience across remote First Nations communities; it critically compares diesel, hybrid, and solar-battery models for remote communities and maps these against evolving Australian consumer-protection reforms. Building on documented case studies and program outcomes, this work outlines a practical agenda for advancing energy equity through advanced community microgrids (including long-duration storage), artificial intelligence (AI)/Internet of Things (IoT)-enabled energy management systems, rights-aligned consumer mechanisms for prepaid meter contexts, fit-for-purpose regulatory settings, innovative financing and on-country workforce development. The goal of this paper is to articulate implementable pathways that couple technical performance with cultural, social and economic self-determination.

The opportunities and risks of large-scale renewable energy development on Indigenous lands are highlighted in [2], arguing the necessity of equitable participation frameworks for First Nations communities to achieve the desired benefits from such projects. Furthermore, the strategy in [2] reveals the importance of governance structures and benefit-sharing agreements in determining the effects of investments on renewable resources for advancing or undermining Indigenous self-determination. The work in [3] presents how First Nations communities are increasingly central to Australia's clean energy agreements. The analysis in [3] shows that new forms of partnership based on equity stakes, long-term agreements and cultural authority are reshaping the governance of renewable projects. This shift illustrates both the potential and complexity of embedding Indigenous leadership in the energy transition. Building on such academic analyses, this paper takes a different approach by providing a perspective highlighting community practice, government policy and programmatic evidence, while offering a practical framework for addressing the persistent inequities in electricity access.

While previous studies have examined specific technologies (such as solar-battery systems), government programs (e.g., Bushlight, SETuP) or policy frameworks in isolation, few have offered a holistic model that integrates technical design with consumer rights, cultural authority and community ownership. The distinctive contribution of this study is in developing an integrated framework that brings together:

- the technical performance of renewable–based community energy systems,
- regulatory and consumer protection innovations tailored for off-grid contexts related to First Nations communities and
- cultural and governance mechanisms underpinning energy sovereignty for First Nations.

By advancing beyond descriptive case studies and technical comparisons, this work synthesises these dimensions into a replicable agenda for energy equity in remote First Nations communities. This contribution is both analytical, expanding the conceptualisation of energy equity beyond affordability and reliability and methodological, combining policy review, program evidence and case study synthesis into a unified lens for future practice. The research gaps along with the problem statement, key research questions, contributions and scope (including the approach) are discussed in the following subsections.

1.1. Research Gap and Problem Statement

While prior studies have briefly examined some key technical aspects of renewable integration or the policy dimensions of consumer protections for First Nations communities, few have offered a holistic analysis that integrates infrastructure evidence, community-led practice and evolving regulation into a single framework for ensuring energy security and reliability. These issues limit the capacity of policymakers and practitioners to design solutions that are simultaneously technically robust, socially equitable and culturally aligned.

1.2. Key Research Questions

This paper addresses several research questions which include: (a) How do existing electricity supply systems in remote First Nations communities perform in terms of reliability, affordability and equity, (b) What lessons can be drawn from past renewable energy initiatives, community-led projects and government programs and (c) What policy, regulatory and financing reforms are required to support sustainable and rights-aligned energy transitions in these communities?

1.3. Contributions

By addressing these key questions, this paper contributes to providing some perspectives for an integrated framework that couples technical design (e.g., advanced microgrids and AI/IoT-enabled energy management systems), consumer protection (rights-aligned mechanisms for prepaid metering contexts) and cultural authority (community-led governance and ownership). Unlike descriptive program reviews, the paper advances an actionable agenda for achieving energy sovereignty and equitable access, offering replicable pathways for remote First Nations communities in Australia.

1.4. Scope and Approach

This article is positioned as a Perspective Paper and does not follow the structure of an empirical research article. Rather than applying a formal methodological design, it synthesises multiple sources of evidence from government datasets, program evaluations and documented case studies, alongside recent regulatory and policy developments. The focus is on integration and interpretation, presenting a framework that couples technical, cultural and regulatory dimensions of energy equity for remote First Nations communities in Australia. The intention is to bridge practice, policy and scholarship to propose actionable pathways rather than to conduct original quantitative analysis.

It should be noted that this paper is written as a perspective, aiming to synthesise insights from program experience, government reports and policy documents rather than undertaking a systematic literature review. The intention is to provide a practical and forward-looking agenda for improving energy equity, security and reliability in remote First Nations communities, drawing from real-world evidence and community experiences.

2. Overview of Existing Infrastructure and Electricity Access

First Nations communities in Australia generally live in remote or very remote areas and experience unique challenges in accessing electricity. While remote and very remote areas in Australia account for around 90% of its land area, only 3.8% of Australia's total population resides there [4,5]. First Nations Australians are disproportionately represented in these remote and very remote areas. Roughly one in seven (around 15.4%) First Nations people live in remote or very remote locations, compared with only about 1.7% non-Indigenous Australians [4,6]. Many of these remote communities lack a reliable, safe, and affordable energy supply. Basic services such as electricity can be inconsistent or entirely absent in some areas. For example, recent surveys indicate that about 14% of remote Indigenous homelands in the Northern Territory have no formal power supply at all [7]. In other cases, power may be available but is often unreliable and expensive, undermining living standards and community well-being.

In contrast, the majority of Indigenous people living in non-remote towns and cities are connected to the National Electricity Market (NEM) or main grids. This urban-remote division indicates that most Indigenous households in cities enjoy similar electricity access as other Australians (with grid connections and having a security of continuous power supply). In contrast, First Nations people in remote communities need to rely on standalone energy systems with very limited or no energy security. There are around 1187 discrete First Nations communities in Australia, and the vast majority (approximately 95%) is in four jurisdictions: Western Australia (WA), Northern Territory (NT), South Australia (SA), and Queensland (QLD) [8]. These states and territories encompass large sparsely populated areas, where extending the national grid is often not feasible for these remote and very remote communities. Because of this, remote communities depend on small and local electricity systems, often powered by diesel generators, and these systems frequently face challenges in reliability, affordability, and ongoing maintenance.

Diesel or hybrid power generation systems, i.e., diesel in conjunction with renewable energy sources (RESs) and/or battery energy storage systems (BESSs) in existing electricity supply infrastructure in remote and very remote powering First Nations communities, require fuel to be delivered over long distances. Such diesel deliveries over long distances result in high operating costs and increase vulnerability to fuel supply disruptions. Fuel delivery to remote and very remote areas is also weather-dependent and logistically difficult, leading to frequent power shortages or outages. Moreover, pre-paid electricity meters are widely adopted in some of these remote and very remote First Nations communities (particularly in the NT, WA and QLD), which require the residents to pay upfront for their electricity usage. However, these pre-paid meters lead to self-disconnections of households if they cannot top-up on time or afford the electricity, though these meters are deployed to ensure autonomy for households to manage their electricity bills. A recent study revealed that smart meters were used in 3300 households in 28 remote First Nations NT communities and the data from these meters indicated that almost all (91%) households in 2018/19 experienced electricity disconnections, where these disconnections for around 74% of these households were over 10 h (average disconnection time was 10.62 h) [8]. Table 1 shows the number of disconnections, number of households affected and average disconnection hours between 2018/2019 and 2023 for First Nations communities in NT.

Table 1. Disconnection information for households in First Nations communities in the NT.

Year	Number of Households Experienced Disconnections	Number of Disconnections	Average Disconnection Duration (Minutes) per House	Average Disconnections per House
2018/2019	3300	Not Available	637	-
2019/2020	2409	69,888	380	34
2020/2021	2173	84,439	504	39
2022	2158	88,252	408	41
2023	2430	103,895	355	43

Source: [8].

Table 1 shows that power cut-offs have become more frequent over time across NT's First Nations communities on prepaid meters. Both the total number of disconnections and the average per household have risen year-on-year, indicating persistent and worsening interruption frequency. Although household counts in the dataset vary by year, the overall pattern is clear: residents are experiencing increasingly frequent power outages, underscoring ongoing energy insecurity. In this table, the reason behind the varying number of households is due to the fact that these are only the households that experienced disconnections.

These disruptions affect refrigeration, lighting, water supply (for electric pumps), and even medical equipment, severely impacting the health and quality of First Nations people's lives. In summary, First Nations Australians in remote and very remote areas face significantly higher rates of energy insecurity than those in grid-connected communities.

The nature of electricity supply infrastructure in remote and very remote First Nations communities varies widely, as larger communities (with populations of hundreds) are generally powered by centralised diesel power stations with medium-voltage distribution networks. Such medium-voltage distribution systems are often operated by government utilities or contractors. Smaller communities and family outstations (homelands) with only a few households often rely on very basic systems, e.g., a portable generator shared among several houses or small solar panels charging batteries for minimal lighting. However, much of the existing infrastructure is either insufficient or nearing the end of its operational life. For example, earlier government-funded renewable energy installations, including solar-battery systems deployed in the 2000s, are now approaching the end of life, with no clear plans for their replacement or upgrade [7]. Hence, the reliability issue remains unresolved, as many households in remote and very remote areas will still experience frequent disconnections from the electricity supply system. Moreover, housing conditions are closely linked to energy access due to the fact that insulation is extremely poor for these houses and appliances are inefficient, making them energy-intensive to power during extreme weather conditions (i.e., difficulties in cooling during extreme heat and warming during the winter). Overall, the current state of electricity networks in First Nations communities is one of inequitable access, while some communities enjoy 24 h access to electricity and others struggle with unreliable electricity supply or lack any grid connection at all. This inequity in electricity access and infrastructure quality is now recognised as a serious hurdle to closing the gap in health and living standards. To provide a clearer comparative framework, electricity supply systems in remote First Nations communities can be categorised into three dimensions:

- Technical specifications: (i) centralised diesel stations with medium-voltage distribution, (ii) hybrid diesel–solar–battery systems and (iii) small-scale portable or household-level generators/solar systems;
- Service capacity: (i) large community systems serving several hundred residents, (ii) medium systems serving tens of households and (iii) small homelands or outstations serving only a few families;
- Governance structures: (i) utility-operated systems (e.g., Indigenous Essential Services in NT), (ii) contracted service providers and (iii) community/family-managed systems.

This taxonomy enables systematic comparison across different settings and underscores the stark inequities in reliability, affordability and consumer protections among different categories.

This section deliberately presents descriptive evidence drawn primarily from government reports, statistical datasets and program documentation. The aim is to provide readers, many of whom may not be familiar with the realities of remote Australia, with a clear contextual understanding of current infrastructure and access challenges. While academic literature is referenced where appropriate, the narrative prioritises clarity and accessibility over extensive citation, consistent with the perspective nature of this work.

3. Renewable Energy Initiatives and Tailored Programs

Over the past few decades, a variety of renewable energy projects and custom programs have been launched to bring reliable power to First Nations communities. By slashing their dependence on expensive diesel, these efforts deliver cleaner and more sustainable electricity that aligns with both their cultural values and their household budgets. Notably, many projects have sought to incorporate solar photovoltaic (PV) generation, BESS, and other renewable technologies into community power systems.

The Bushlight program was one of the earliest and most influential initiative, operating from 2002 to 2013 under the Centre for Appropriate Technology—a First Nations-led renewable energy effort for powering remote and very remote communities. Over 130 solar-powered off-grid systems were designed and installed in the NT, WA and QLD under this Bushlight program with the aim of providing reliable and affordable energy to First Nations communities [9]. Each Bushlight system included solar panels, BESSs and a standby diesel generator to ensure 24 h electricity supply for small First Nations communities that were previously powered solely by diesel generators with very low reliability. The Bushlight program was developed using a community-centric approach where the system designers worked closely with community members to identify their energy requirements and then designed the system accordingly. In addition, local community members were trained to manage the systems themselves, reducing the need to bring in technicians from far away, a process that often comes with high call-out fees and drives up maintenance costs. This collaborative model, grounded in cultural understanding and local ownership, led to high acceptance and long-term success for adopting RESs by First Nations while improving power reliability. Many Bushlight systems continue to operate today, powering First Nations communities for more than two decades and supporting refrigeration, lighting, and other essential services [10]. The Bushlight program demonstrated that renewable energy can significantly improve the reliability and quality of life for First Nations communities through off-grid RESs while reducing diesel consumption.

Building on the successes of the Bushlight program, Australian governments and agencies have implemented larger-scale renewable energy programs. For example, the NT Government, in partnership with the Australian Renewable Energy Agency (ARENA), established the Solar Energy Transformation Program (SETuP) in 2014, which integrated 10 MW of solar PV systems and BESSs with existing diesel generation systems for 25 remote communities across the Territory [11]. This initiative resulted in a 15% reduction in diesel fuel use across many installed systems. For example, the remote First Nations community of Titjikala in NT now meets approximately 83% of its electricity demand from solar energy, and its 200 residents receive renewable power for an average of 20 h per day each month [12]. Thus, the diesel generator operates only for a few hours during the night. These outcomes highlight the potential for well-designed solar-battery systems to dramatically cut fuel costs and emissions while improving energy security.

While solar power remains the most prevalent renewable energy source in remote Australia due to its abundance, some programs have also explored the feasibility of wind and other renewable technologies where conditions permit. However, the potential of wind and biogas is more limited and varies significantly across regions, often making it less feasible compared to solar [13]. In 2023, ARENA committed $125 million for the Regional Microgrid Program with an embedded initiative of supporting First Nations through $75 million for new microgrid projects [14]. This program supports projects that go beyond installing solar panels and batteries; it also focuses on building local skills, creating jobs, and ensuring that First Nations communities actively share in the benefits of the clean energy transition. Another significant effort is the East Kimberly Clean Energy Project, which is a coalition among three traditional owner groups, government and industry [15]. The focus of this project is the development of a large-scale solar-power hydrogen production system, demonstrating a shift towards developing clean energy projects aligned with community aspirations and ownership.

Many programs are now taking a more customised approach to meet the specific energy needs of households and communities. In some areas, this has included subsidised solar panels, BESSs, and home upgrades to improve energy efficiency and help families lower their power bills. Community organisations and social enterprises (e.g., Original Power and the First Nations Clean Energy Network) have stepped up with hands-on initiatives, such as running local energy planning workshops, training Indigenous renewable energy technicians and setting up demonstration projects like community-owned solar farms. These programs recognise that one-size-fits-all solutions do not work in every setting; instead, energy systems need to match the local climate, geography, and cultural values. For example, in remote desert communities that risk being cut off by flooding, solar-diesel hybrid systems with strong battery backup are used to keep power running during road closures. In other places where people want to be free from grid dependence, fully off-grid renewable systems are built. Increasingly, these projects are shaped by the communities themselves through consultation and leadership. Hence, these solutions are not only technically sound but also meaningful and sustainable for those who live there.

4. Government Policies, Funding Frameworks and Regulation

Government policies play a critical role in determining whether First Nations communities have access to reliable and affordable electricity. For many years, remote Indigenous settlements were excluded from mainstream energy rules and forced to rely on short-term solutions, which started changing in recent years. Governments at both federal and state/territory levels are now recognising that fair energy access is a fundamental right and requires clear and long-term policy support. A significant step forward came with the launch of the Australian Government's First Nations Clean Energy Strategy (2024–2030), in late 2024 [1]. This national plan outlines how First Nations communities can be central to Australia's clean energy transition and share in the benefits of this shift. This strategy also focuses on increasing renewable energy in First Nations communities, improving the energy efficiency of their homes, and creating more opportunities for them in the energy workforce. To support these objectives, the federal government has committed around A$70 million in initial funding for grants, skills and capacity-building programs, and incentives to attract private investment into First Nations community-led clean energy projects [16].

There are also specific funding programs designed to ensure that remote communities can afford and access electricity. In the NT, for example, the government runs essential services in 72 remote communities through a not-for-profit company called Indigenous Essential Services (IES) Pty Ltd. [17]. Funded by the NT Government, IES operates diesel power stations and maintains local electricity networks, while increasingly integrating solar power into existing systems. Through this initiative, households in these remote areas pay electricity tariffs comparable to those in Darwin or Alice Springs, despite the fact that power generation is substantially more expensive for these communities. Similar support models exist in other parts of Australia. For example, Ergon Energy in Queensland offers a remote area subsidy to supply far-north communities at the same rates as the rest of the state and state-owned Horizon Power in Western Australia also cross-subsidises electricity for remote towns. These subsidies are essential, as diesel-generated power in remote areas can cost five to ten times more than grid power. Without them, many households simply would be unable to afford electricity. In addition, governments contribute to the upfront costs of new infrastructure, such as solar systems, often through ARENA co-funding or state renewable energy programs.

Regulatory coverage is another key consideration, as many remote community energy systems in First Nations communities are not part of the interconnected National Electricity Market (NEM) and, therefore, fall outside the standard national consumer protection regimes. It was found that around 5 million Australians (20% of the population), who are primarily in remote or First Nations communities, lack access to the full suite of electricity consumer protections that urban grid-connected customers receive [18]. These protections include regulated disconnection processes, requirements for retailers to offer hardship assistance, enforceable reliability standards and independent complaint resolution. In jurisdictions such as NSW and Victoria, comprehensive energy consumer protections and strong schemes exist. However, in remote NT or WA communities served by off-grid power, residents do not enjoy the same safeguards. For example, prepayment metering (which is effectively banned in the major south-eastern states for residential customers) is permitted and widely used for remote communities in NT, WA and QLD. Until recently, there were no requirements to report or limit disconnections for customers on these prepaid systems. Recognising this gap, policy advocates have called for regulatory reform, including nationwide mandatory disconnection reporting and the prohibition of involuntary prepay disconnections, to protect customers in remote First Nations communities. There is a pressing need to harmonise consumer protection regulations so that fundamental rights, such as access to life-support power, fair billing and complaint processes are guaranteed irrespective of locations.

Government policies are also evolving to actively encourage community-owned and community-led energy solutions. Several states have introduced or proposed specific support for First Nations renewable energy projects, including grants, technical assistance or streamlined approvals. The integration of land rights and energy development is a key policy frontier, given that approximately half of Australia's planned renewable energy infrastructure is located on Indigenous-owned land. As a result, governments are establishing protocols to ensure Traditional Owners are active participants and beneficiaries of these projects. This includes negotiating benefit-sharing agreements, offering Indigenous equity stakes in projects like large solar farms or wind farms, and creating training programs to employ First Nations people in renewable energy jobs [1]. The First Nations Clean Energy Strategy explicitly prioritizes equitable partnerships, ensuring that

First Nations communities act as partners in project development rather than remaining passive stakeholders. Policies are being shaped to facilitate this, for instance, by providing partnership agreements templates and supporting First Nations communities in energy planning and governance.

It is evident that the policy and regulatory landscape is gradually shifting towards recognising the need for reliable and affordable energy in First Nations communities. Through dedicated strategies, such as the recently developed First Nations Clean Energy Strategy-governments aim to ensure that remote First Nations communities receive not only reliable and affordable but also sustainable electricity. Ongoing challenges include securing long-term, stable funding for remote infrastructure, updating outdated regulations and improving coordination across all levels of government. However, the current momentum of initiatives (e.g., First Nations Clean Energy Strategy) suggests a promising trajectory that places cultural respect, community leadership, and equitable access at the forefront of national energy policy.

A capability-building approach to demonstrate the effects of clean energy transitions on Indigenous communities in northern Australia is presented in [19]. Based on the case studies and policy analysis, the authors in [19] reveal that renewable energy projects can both enhance and inhibit community capabilities depending on governance, participation, and structural arrangements. Renewable energy sources can also support energy security, reduce costs and enable local economic opportunities when communities have decision-making power, training pathways for managing their energy systems and culturally appropriate engagement. However, poorly designed projects risk undermining autonomy, creating dependency on external providers and overlooking cultural priorities. Hence, energy justice (embedding Indigenous voices in planning and ensuring that transitions expand real freedoms) is also important in parallel to technological solutions.

5. Community-Led Projects and Case Studies

This section presents two community-led projects as case studies for illustrating the effects of First Nations initiatives for community-based renewable energy systems. While these examples (i.e., Marlinja and Titjikala) are not exhaustive, they serve as in-depth illustrations of successful models. Other similar initiatives around the country through different programs, also provide valuable evidence of diverse First Nations community contexts and approaches for electricity supply systems. Together, all these projects highlight both opportunities and challenges in accelerating community-led energy transitions for First Nations across Australia.

While government programs provide essential, broad-based support, many of the most transformative outcomes have emerged from community-led projects in which First Nations peoples lead the planning, implementation and management of their local energy solutions. These projects demonstrate the effectiveness of models grounded in community ownership and empowerment, offering valuable lessons on integrating technology with cultural priorities and local knowledge. This section presents two such community-led projects, highlighting their primary benefits.

5.1. Marlinja Community Microgrid [20]

The Marlinja Community Microgrid is a community-led renewable energy project in the remote First Nations community of Marlinja, Northern Territory. Home to the Mudburra and Jingili peoples, Marlinja has around 60 residents and 18 households located at the end of a 25 km feeder line from Elliott's diesel/gas hybrid power station. Like many NT communities, households rely on prepayment meters, leading to frequent disconnections and associated social, health and economic impacts. Partnering with First Nations-led not-for-profit organisation Original Power in 2019, the community aimed to secure cleaner, more affordable and reliable energy. Initially, the plan was to install rooftop solar and batteries for each home, but regulatory barriers around Indigenous social housing prevented this approach. Consequently, the project pivoted to a centralised 100 kW solar array with a 136-kWh battery connected to the low-voltage grid of the community, designed to operate as a zero-export system and capable of islanding during outages. In this project, a ***credit upload*** system was developed to directly integrate solar benefits into prepay meters, allowing daily solar credits proportional to the output of the community energy system and providing tangible bill relief to all participating households. This was the first community-scale application of this model in Australia. At the beginning, the project experienced several technical (strict grid hosing limits and custom integration), regulatory (inability to install rooftop solar on Territory Housing properties, complex and slow approval process) heritage assessments delaying deployment), financial (around A$550,000 for a battery connection) and commercial (higher costs of centralised design, zero-export restrictions and first-of-its-kind crediting model requiring custom commercial agreements) challenges. However, these were ultimately overcome through strong partnerships, targeted advocacy and significant philanthropic and industry support (including donated solar arrays and inverters). This community-led First Nations energy system is currently offering the following benefits:

- Affordability: Direct crediting reduces energy costs for households on prepay systems;
- Reliability: Islanding capability improves supply security and reduces the impacts of sudden power outages;
- Energy Sovereignty: First Nations' ownership ensures local control over assets and benefits;
- Replicability: The model provides a scalable blueprint for other remote communities.

The Marlinja Solar Microgrid demonstrates how First Nations leadership, innovative technology, and cross-sector collaboration can deliver cleaner, more reliable, and more affordable power to remote communities while also challenging existing regulatory and technical barriers to equitable clean energy access.

5.2. Titjikala Hybrid Energy System [21]

The Titjikala hybrid energy system is another illustrative example of how adding solar-battery storage to an existing diesel power station can make a big difference for a remote community energy system. Titjikala lies about 125 km south of Alice Springs and initially had three diesel generators (320 kW, 270 kW and 138 kW) and later a 400 kW solar array was originally installed under the SETuP program. For years, the contribution of solar to the overall systems was between 11% and 16%, as there was no way to store excess solar power for later use during night or cloudy periods. As a result, a lot of solar energy went to waste, which was changed in March 2021 when a 300 kVA/970 kWh BESS was installed with the funding support from the NT Government. The BESS was designed to be a low-cost, practical solution to store most of the excess energy from Titjikala's relatively large solar array, though oversized compared with most other communities. Once the battery came online, the results were immediate and striking as Titjikala's renewable energy share jumped to over 60% between March and June 2021. Around 40% of the solar power generated during the day could now be stored and used after the sun goes down. On several occasions, the battery and solar together kept the entire community running without any diesel for more than 24 h, including two separate runs of 33 h in April 2021. The battery not only made it possible to capture and use more of the available solar energy but it also smoothed out the supply during times of variable sunlight and shifting demand. Overall, this made the whole system more reliable while cutting back on fuel costs and greenhouse gas emissions. These outcomes demonstrated that a strategic investment in solar-BESS can transform the performance of an existing diesel system by offering a practical, cost-effective way to boost renewable use, reducing reliance on diesel and improving local energy resilience.

These case studies underscore a common theme that the outcomes tend to be more sustainable and culturally appropriate when First Nations communities have the agency and resources to shape their energy solutions. Projects like Marlinja Community Microgrid did not simply drop in technology; instead, they involved the community at every step, from deciding system size and location to establishing local energy committees for ongoing governance. This sense of ownership often leads to better care of the equipment (reducing vandalism and neglect) and stronger continuity (new generations see the value and learn the skills to keep it running). Furthermore, community-led projects generally integrate social benefits such as training community members as the system installers or using cost savings to fund community services, thereby multiplying the positive impacts of electrification. They also demonstrate innovative business models, like community energy enterprises, which can sell surplus energy or offer energy services on a not-for-profit basis to residents in the community.

In academic and policy discussions, these examples provide valuable real-world evidence for decentralised community-centric energy transition. They highlight both practical barriers to overcome, such as navigating complex regulatory approvals for a community-owned grid or designing tariffs suitable for a small customer base and success factors (like partnerships with technical advisors that respect Indigenous knowledge and decision-making). For First Nations communities elsewhere, these stories inspire and serve as blueprints, reinforcing the idea that energy sovereignty (the right to reliable, affordable and clean power under community control) is an achievable goal.

6. Geographic and Demographic Insights for Community Energy Systems

Building on the lessons from the community-led initiatives discussed in the previous section, it is clear that location-specific factors play a decisive role in shaping both the feasibility and the design of energy systems for First Nations communities. Australia's First Nations communities are diverse and spread across a vast geography. This distribution pattern directly influences electricity network configurations and energy solutions, as these communities are often located thousands of kilometres apart in some of the most sparsely populated regions on Earth. As highlighted earlier, the concentration of discrete First Nations communities in certain states/territories is significantly growing. WA and NT alone account for a large share of remote communities, with significant numbers also in the northern parts of Queensland and South Australia's Anangu Pitjantjatjara Yankunytjatjara (APY) Lands. All these regions are characterised by long distances from urban centres, rugged terrain and often extreme climates (tropical heat, desert conditions), which together require a complicated and specialised infrastructure development.

This demographic reality means that many communities cannot achieve economies of scale in power supply, as each may require its own generation and distribution systems unless they are close enough to link with a neighbour. Distance to the existing primary grid is a key geographic factor, as most remote communities are tens to hundreds of kilometres away from their nearest power line. For instance, communities in the Western Desert or Arnhem Land are too distant to connect to the NEM feasibly. As a result, they operate standalone power systems. Only a few remote communities are near mining operations or towns and can tap into those grids (for example, some communities in the Pilbara receive power from mining company infrastructure). For the vast majority, isolation necessitates self-contained electricity solutions.

Another geographic insight is the influence of the natural environment on energy needs and technology choices. Northern First Nations communities (tropical climate) face very high humidity and temperatures, leading to heavy reliance on electricity for refrigeration and air conditioning to maintain health and comfort. The seasonal monsoons and cyclones can disrupt fuel delivery and damage infrastructure, so renewable systems with battery storage and robust design are often the preferred choice to ensure resilience. In central desert communities, extreme heat and cold (high diurnal temperature ranges) also necessitate climate control and refrigeration. Housing quality becomes a demographic factor here as overcrowding and substandard housing in these areas amplify energy demand and create urgency for efficient cooling solutions. By contrast, some cooler-climate First Nations communities (for example, in alpine NSW or coastal Tasmania, where a small minority live) might have heating needs and different renewable opportunities like small-scale wind or micro-hydro power. However, the vast majority of remote First Nations communities are in sun-rich environments, which is why solar power is the most preferred option.

Demographic trends further complicate system planning. Population growth and mobility trends in First Nations communities also affect the energy system planning. Many remote communities have growing populations (some due to a return-to-Country movement by Indigenous families) and relatively young demographics. This means electricity demand is expected to rise in the coming years, putting further strain on small diesel generators if not upgraded. On the other hand, some very small outstations see seasonal occupancy as families might move between a regional town and their homeland seasonally. Designing systems that can handle such variability (for instance, by having modular or easily serviceable generators) is another consideration.

Additionally, the geography of remote communities intersects with Indigenous land rights. Much of the land where communities are located is Indigenous-owned under various titles (Native Title, Aboriginal Land Rights Act territories, etc.). This ownership structure has enabled some communities to directly negotiate with renewable energy developers who wish to build projects on their land. This is an emerging trend that can bring substantial economic benefits. For example, large solar farm proposals in outback areas often involve Indigenous land councils as key stakeholders. Geographically, many of the best renewable energy resource areas (solar radiation in the NT and WA, wind in SA) overlap with Indigenous land. This alignment presents a strategic opportunity: carefully planned renewable energy projects can both power remote communities and export surplus energy to the grid or as hydrogen, creating revenue for Indigenous landowners. However, it requires careful sequencing to ensure communities themselves secure reliable power before surplus energy is transmitted elsewhere.

In summary, understanding the geographic dispersion and demographic characteristics of First Nations communities is critical in crafting equitable energy solutions. The patterns described here help explain why the barriers identified in the next section persist and why one-size-fits-all approaches cannot work. Instead, solutions must account for community size, location, climate, and cultural context. Incorporating geographic and demographic insights will allow policymakers and engineers to design energy systems that are resilient to local conditions and responsive to the needs of the First Nations people.

It is worth mentioning that this analysis is deliberately descriptive and aimed at synthesising existing evidence rather than providing predictive spatial or demographic models. Rigorous analyses based on advanced geographic information system (GIS) and long-term demographic projections would undoubtedly provide quantitative insights. However, such analyses would require dedicated datasets and methodologies that fall beyond the scope of this work. Instead, the intent here is to highlight key geographic and demographic patterns, such as community dispersion, climatic diversity and youthful population growth that shape the design and operation of community energy systems. Future research could build on this qualitative framing by employing GIS-based spatial modeling or demographic forecasting to support more granular and location-specific system planning.

7. Key Challenges and Barriers to Equitable Energy Access

As highlighted in the previous section, the geographic dispersion, demographic characteristics, and environmental conditions of First Nations communities significantly influence the feasibility and design of their energy systems. However, even with these factors understood, achieving equitable energy access remains a complex challenge. Most barriers are interrelated, spanning technical, economic, social, and regulatory domains. This section synthesises these obstacles, many of which are rooted in the realities described earlier and explains how they constrain progress toward reliable and affordable electricity for First Nations communities.

7.1. High Costs and Affordability

The cost of supplying electricity in remote areas is substantially higher than in cities. Diesel is expensive to purchase and transport, leading to a very high generation cost per kWh. As noted in Section 6, geographic isolation compounds these costs by requiring long supply chains that are vulnerable to disruption. Even with government subsidies, remote households often spend a significant part of their income on their electricity bills, more than the average Australian household. Maintaining power infrastructure (diesel engines, solar inverters and batteries) is also costly due to the need for specialised technicians who must travel to the site. These costs translate into affordability issues, and many families struggle to pay for sufficient electricity, resulting in self-rationing or disconnections. Financial sustainability of remote power systems remains a core challenge as systems can fall into disrepair or fuel supply can become unaffordable without ongoing subsidies or community revenue streams.

7.2. Technical Challenges and Maintenance

Remote power systems experience harsh operating conditions (extreme heat, dust and cyclones) that can shorten the lifespan of equipment. The small-scale community power stations often lack redundancy, meaning a single generator failure can plunge a whole community into darkness. As discussed in Section 5's case studies, limited local technical capacity and infrequent maintenance visits can exacerbate reliability. Ensuring regular maintenance is difficult, and given the remoteness, qualified electricians or mechanics might visit only infrequently. There is also a historical legacy of systems being installed without adequate training for local residents to perform the basic maintenance. A lack of maintenance funding is another common issue, as capital grants may cover initial installation but not the long-term maintenance contracts required for ongoing service. This has led to many renewable energy systems failing to power after a few years. Technical challenges also include integrating new technology with existing infrastructure, nearing to the end of their lifetime. For instance, adding solar panels to an ageing diesel grid can be complex without upgrading control and protection devices. Many remote grids have limited capacity and as a result, servicing growing loads (especially air-conditioning) is hard during heatwaves as the demand for cooling can overwhelm systems which is crucial for health.

7.3. Housing and Energy Efficiency

Poor housing conditions are a significant barrier to energy equity, as many houses in remote communities were built without considering the effects of insulation and, hence, poor thermal performance. This means they can become extremely hot in summer or cold in winter, requiring large amounts of energy for cooling or heating, respectively. Overcrowding (multiple families in one house) further increases energy usage for lighting, appliances and climate control. These factors mean that even if a community has power, the demand can be exceptionally high relative to the capacity of the supply system, leading to frequent power outages or load shedding. Energy-inefficient appliances (e.g., old refrigerators or air conditioners) compound the issue. Addressing this requires parallel efforts in improving housing insulation and ventilation while providing efficient appliances so that communities can achieve thermal comfort without straining their power systems.

7.4. Prepayment Metering and Disconnections

As mentioned earlier, the prepaid electricity meters are a double-edged sword for community members. While these meters help utilities to manage revenue in hard-to-reach areas, all disconnection risks are passed onto the consumers. Frequent self-disconnection is a widespread problem, especially during extreme weather when households face the tough choice of paying for electricity and other essentials. In some communities, disconnections happen so regularly that living without electricity is considered a regular part of life. This situation is clearly inequitable compared to urban standards and it also erodes community trust in the energy system. The challenge is finding alternative payment and tariff models that ensure suppliers get paid but do not leave vulnerable households in the dark. Some trials, for example, have introduced weekly billing with emergency credit allowances or community pooled payment systems to reduce disconnection instances. However, scaling these solutions and mandating protections (like never disconnecting critical medical equipment users) remains a barrier where regulations are lax.

7.5. Community Engagement and Ownership

Previously, many infrastructure projects in First Nations communities were implemented in a top-down manner, leading to feelings of disempowerment for the community or apathy toward the system operators. Problems (e.g., vandalism or neglect of equipment) can arise when people lack a sense of ownership. For instance, there is little incentive for residents to protect or maintain solar panels or wires if these are seen as the property of an external utility that provides no local benefit. Cultural factors also play a role, as energy projects that fail to respect local customs (for example, restricting power during cultural events or not consulting with the community) can face resistance. Overcoming this requires deep community engagement from the planning stage onward. Recent evidence highlights that the long-term sustainability of remote energy systems depends on the technical design as well as on the depth of Indigenous engagement [22]. Such engagements can range from basic consultation to genuine co-governance and Indigenous-led control. Higher levels of participation are consistently associated with stronger service reliability, equity and community trust. Developing local energy champions or committees can help bridge cultural understanding. A positive example is when communities are involved in selecting the location of a solar farm to avoid sacred sites and in setting rules for how energy is shared.

7.6. Geographic Isolation and Logistics

The sheer remoteness of many communities presents logistical barriers. The construction of new energy infrastructure is challenging as transporting solar panels, batteries or heavy generators to off-road locations can be difficult. Weather events (e.g., flooded roads in the wet season, accessibility during bushfire seasons, etc.) can cut off access for weeks, delaying projects or fuel deliveries. This means any solution must be robust enough to operate through isolation periods. It also drives up costs and can deter private sector involvement. Some communities are so remote that they lie outside mobile coverage and reliable telecommunications, complicating modern solutions that rely on internet connectivity for smart meters or remote monitoring. These practical barriers necessitate innovative and resilient approaches, which can include pre-positioning spare parts in communities, training local community members and designing systems that can operate autonomously for extended periods.

7.7. Regulatory and Administrative Barriers

There are institutional challenges as developing or upgrading electricity systems requires navigating a series of regulations (e.g., electrical safety codes, environmental approvals and land tenure issues), including the involvement of multiple jurisdictions (federal, state, local and Indigenous). Many remote communities find it challenging to navigate through these processes as their own. For example, the current law requires that sharing electricity between separate properties might technically require a retail license even if it is performed communally and not-for-profit. Such regulations, designed for urban markets, do not fit well in remote community contexts. Moreover, existing funding mechanisms are not suitable as these are mostly for achieving short-term objectives, which do not align with the long-term energy infrastructure. In some cases, well-crafted policies have failed to reach remote communities due to poor coordination or a lack of awareness. Bridging these gaps requires tailored policy measures and probably new regulatory frameworks specifically for standalone community energy systems for First Nations people. Encouragingly, some jurisdictions are now examining light-handed regulation or special licenses for community microgrids to simplify compliance.

Addressing these challenges will require a multifaceted effort. Technical fixes alone will not be sufficient without tackling affordability, capacity building and policy reform. A holistic approach is the way forward, which should consider improving the housing for energy efficiency, subsidising operating costs, training local operators, strengthening consumer protections and involving communities in the governance. Though the path to equitable energy access is complex, overcoming these barriers is essential to ensure that First Nations communities have the reliable electricity access needed for health, education and economic development, irrespective of their locations.

8. Potential Solutions for First Nations Community Energy Systems

As outlined in the previous section, the barriers to equitable energy access for First Nations communities are multifaceted, involving technical, financial, regulatory, and social dimensions. Addressing these barriers requires a coordinated approach that goes beyond incremental improvements. Instead, solutions must be forward-thinking—integrating advanced technologies, community-focused policy reforms, and local capacity building to create sustainable, culturally aligned energy systems. The following future-focused approaches are designed to overcome these challenges, close the equity gap, and support energy sovereignty for First Nations communities. Each directly addresses one or more of the issues identified in Section 7 while building on the community-led successes and geographic realities discussed in Sections 5 and 6.

8.1. Advanced Community Microgrid Design

One of the most promising directions for future energy systems in remote First Nations communities is the development of advanced hybrid microgrids combining different types of renewable energy sources with a provision for a long-term energy storage solution. These systems would integrate solar PV units and vertical-axis wind turbines with both battery storage and green hydrogen production. In such a hybrid system, excess energy can be used not only to charge batteries for short-term needs but also to power electrolysers that produce hydrogen for achieving long-term storage solutions. The green hydrogen produced in this way can be stored and converted back into electricity through fuel cells, providing long-duration storage to accommodate seasonal variations and extended cloudy periods. Furthermore, community microgrids designed as modular and scalable units will offer flexibility and cost control. For example, prefabricated and containerised systems can be transported to remote areas and quickly assembled to supply electricity to remote First Nations communities. Such community energy systems will allow First Nations communities in remote Australia to start with a smaller but affordable system that can be expanded as their energy needs grow. This approach will assist in avoiding the high upfront costs of oversized infrastructure and ensure that investments match community demand over time.

8.2. Smart Energy Management System and Remote Monitoring

Managing variable renewable generation and fluctuating community demand in remote areas requires energy management systems (EMSs) considered as the brain of the system to be not only automated but also adaptive and predictive. These EMSs need to respond in real time to changing conditions (e.g., sudden drops in solar irradiation due to cloud cover, variations in the wind speed or surges in the community's electricity demand caused by community events and weather conditions) without relying solely on human intervention. Artificial intelligence (AI)-driven algorithms can forecast the electricity demand and renewable power generation with high precision by processing large datasets that include historical consumption records, weather patterns, solar irradiance forecasts and seasonal community activity trends. Such AI algorithms can be incorporated with existing EMSs as forecasts allow the system to make proactive operational decisions, e.g., pre-charging batteries ahead of a predicted cloudy afternoon or ramping down diesel generation when a sunny period is expected. In parallel, Internet of Things (IoT) technology is considered the eyes and ears of the system, enabling continuous and detailed monitoring of every component in the remote community energy system. Smart sensors monitor key performance parameters such as battery state-of-charge, solar power generation, wind power generation, energy consumption, environmental temperature, load factors for the diesel generator and voltage stability at the consumer end. This level of visibility supports the overall system operation and predictive maintenance, where potential problems (e.g., such as abnormal vibration in a diesel generator, future loading conditions or potential energy production from renewable sources) can be detected early so these can be addressed before causing any operational issues for the system. A practical example of such an innovation is *Marshall*, an intelligent monitoring system developed by Zeco Energy in Australia. It integrates IoT sensors, cloud-based analytics and user-friendly dashboards to give operators, community leaders and even residents real-time insights into the overall performance of their energy systems [23]. Such a monitoring platform can detect abnormal patterns, trigger alerts and recommend corrective actions while recording operational data that can be used to fine-tune system design over time. Combining predictive analytics with a community-accessible monitoring system, the technical performance can be significantly improved while building local trust and community engagement in operating community energy systems. Intelligent EMSs will create a feedback loop where data continuously informs decision-making, which will enhance system efficiency, reduce the reliance on diesel, lower operational costs and increase reliability. All these are critical benefits for remote First Nations communities where outages can disrupt essential services and supply chains.

8.3. Innovative Consumer Protection Mechanisms

While technical advancements in renewable energy-based community energy systems are essential, it is equally important to ensure that First Nations households in remote areas enjoy the same level of consumer rights and protections as those in grid-connected urban centres. Under Australia's National Energy Consumer Framework (NECF) and state-based regimes, customers in the NEM benefit from safeguards such as hardship assistance, fair billing practices, clear disconnection protocols and guaranteed access to life-support equipment supply. Yet many customers in off-grid and remote communities (including First Nations communities) remain outside the scope of these protections. Future electricity consumer mechanisms should be designed to bridge this gap, embedding consumer rights directly into operational and billing frameworks. One promising model can be the digital energy wallet, building on the success of the existing prepaid metering system. Energy wallets can be directly linked to prepay meters so that households can automatically receive solar generation credits, targeted government subsidies or community-generated revenue from renewable projects rather than relying on third parties. This would provide a transparent and rights-aligned way to reduce the risk of involuntary disconnections by ensuring credit top-ups are seamless and predictable. Moreover, energy wallets can be programmed to comply with consumer protection standards such as maintaining a minimum credit reserve to provide essential supplies and preventing disconnection for households with life-support needs. In addition, future systems should incorporate automated hardship support protocols integrated into the smart metering infrastructure. For example, if consumption data indicates that a household's credit balance is low, usage is unusually reduced, or essential medical devices are at risk, the system could automatically trigger alerts to the energy provider, local community liaison or an independent ombudsman. These alerts can activate hardship provisions mandated under Australian consumer law, such as temporary credit extensions, payment plan options or government-funded emergency assistance. Embedding these protections directly into the technology will ensure that the right to essential energy access is not dependent on geographic location, while adhering to consumers' energy protection rights. By combining digital innovation with the strong regulatory alignment, remote First Nations households can be guaranteed fair treatment, protection from disconnection and a genuine voice in how their electricity services are managed.

8.4. Policy and Regulatory Reform

The most advanced community energy systems will not achieve their full potential unless these are supported by policy and regulatory frameworks that ensure equitable access, consistent standards and robust consumer protections. Under the current National Electricity Rules (NER) and associated National Energy Retail Rules (NERR), many protections (e.g., obligations for reliability, transparent billing, hardship assistance and life-support safeguards) are designed primarily for customers in the interconnected NEM. Remote First Nations communities often fall outside these existing frameworks, resulting in some gaps. This is also clear in the context of Australia's evolving consumer protection framework, as guided by the Australian Energy Market Commission (AEMC). In its final report on consumer protections for grid-connected customers [24], the AEMC reaffirmed that a consistent baseline of rights (e.g., fair billing, reliable supply, hardship support and effective dispute resolution) must apply across states and delivery models to ensure equity. This report proposed a tiered framework to protect consumers who use remote off-grid energy systems while minimising regulatory complexity and compliance burdens [24]. Building on the AEMC's proposed approach, the regulatory system should embed a tiered framework under national principles, even for small-scale off-grid systems. At the lower tier (smaller microgrids or individual systems), jurisdictions should enforce essential protections such as transparent billing, reliability standards and basic safety protocols. For larger systems that serve multiple households, a complete set of protections comparable to those in the grid-connected market should apply, potentially involving oversight by the Australian Energy Regulator (AER) if the system meets a coverage threshold. The AEMC emphasises that off-grid power users should not receive weaker consumer rights simply because they are not connected to the grid. This must be enshrined in legislation to mandate equal access to protections as indicated earlier. When a Distribution Network Service Provider (DNSP) or another integrated utility supplies off-grid power (effectively acting as both network provider and retailer), the system should be treated as a standard control service under the NER. This creates accountability, ensures price controls and provides a mechanism for oversight, maintaining similar protections available to grid-connected customers. Complementing technical regulation, tailored policy support should encourage First Nations community energy systems. These supports include concessional financing, grants and tax incentives that enable local ownership and governance, while contracts ensure compliance with national consumer and reliability standards. Such measures reinforce energy sovereignty and support economic self-determination without sacrificing consumer safeguards. A priority reform can be the development of a National Off-Grid Energy Consumer Protection Code/Framework or something similar (e.g., off-grid energy consumer protection framework in South Australia for Off-Grid Retail Electricity Code [25]), which can be embedded within or directly linked to the NER and NERR. Such a code/framework will guarantee that all Australians, regardless of their geographic locations, have access to the same baseline protections. Embedding these rights in national legislation or subordinate instruments under the NER will ensure that remote First Nations households are no longer treated as an exception in the regulatory landscape. In parallel, the NER can include incentive mechanisms for community-owned energy systems to recognise the energy sovereignty from the perspective of both an economic and cultural priority for many First Nations communities. These incentives can include targeted grants, concessional finance, and tailored tax arrangements for First Nations–owned energy enterprises. By enabling communities to own, operate and profit from their energy infrastructure while complying with nationally consistent technical and consumer standards, such reforms will help close the equity gap, strengthen local economies and embed self-determination in the clean energy transition.

8.5. Innovative Financing Models for Remote Community Energy Systems

An ongoing challenge in rolling out renewable energy sources in First Nations communities is the high upfront capital investment on infrastructure. Traditional funding approaches often place a significant financial burden on communities or require a lengthy approval process. Emerging models such as Energy-as-a-Service (EaaS) can offer a pathway to overcome these barriers. In an EaaS arrangement, a specialist provider owns, operates and maintains the community energy system. The community pays a predictable service fee for the energy supplied, much like a utility bill. This removes the need for significant initial investments, spreads costs over time and shifts technical and operational responsibilities to an experienced operator. In Australia, this model aligns well with state and territory renewable energy targets and can be combined with government incentives such as the NT's Renewable Remote Power Program or ARENA co-funding to reduce service costs further. Another promising pathway is social impact investment, where private capital is directed towards projects that deliver both financial returns and measurable community benefits. In the remote Australian context, renewable energy projects can be linked to outcomes such as lower household energy bills, reduced diesel dependence, fewer involuntary disconnections or improved health and well-being indicators (for example, through better indoor air quality from reduced generator use). By translating these benefits into measurable terms, future projects can attract funding from different sources to support both climate action and Indigenous economic empowerment. These approaches do not replace public or philanthropic funding rather complement existing schemes, revealing a blended financial model that draws from multiple sources. By diversifying capital streams and embedding long-term service agreements, remote communities can access clean and reliable energy without being locked into unsustainable financial commitments.

8.6. Skills Development and Local Workforce Capacity

For renewable energy systems in remote First Nations communities to thrive in the long term, technical solutions must be matched by strong local capacity to operate, maintain and grow these systems. This means equipping community members with the skills, knowledge and confidence to manage their own energy future. One powerful approach is to establish on-country renewable energy training hubs. These hubs can be dedicated spaces where community members can receive hands-on and accredited training in system installation, day-to-day operation, troubleshooting and preventative maintenance. By tailoring training to the environmental, cultural and logistical realities of remote Australia, these hubs can ensure that learning is both nationally recognised and locally relevant. Formal partnerships with TAFEs, universities and industry providers will allow participants to work towards formal qualifications, opening pathways into broader renewable energy careers while strengthening on-ground capacity. Beyond formal training, mentorship programs can provide an ongoing bridge between learning and professional practice. By pairing First Nations trainees with experienced industry professionals, whether through in-person visits, rotational placements or remote mentoring, communities can build a deep and practical understanding of energy system management. Over time, this will nurture a new generation of local energy specialists who can diagnose faults, upgrade systems and lead new projects without relying on external contractors. This shift will offer multiple benefits by reducing operational costs and speeding up response times for maintenance while keeping control, revenue and expertise within the community. It also creates meaningful employment and career progression opportunities, ensuring that renewable energy projects are not just technical assets, but platforms for social and economic empowerment.

9. Conclusions

The analysis in this paper has shown that across remote First Nations communities, diesel-dominant electricity supply systems consistently underperform on affordability and reliability, while well-designed solar-battery systems deliver clear gains in both areas. Evidence from government programs, community-led initiatives, and geographic and demographic assessments confirms that battery energy storage paired with renewable generation can significantly accelerate energy transitions and reduce reliance on diesel generators. However, as highlighted in the challenges section, consumer outcomes remain constrained by persistent regulatory gaps, particularly the lack of consistent protections for off-grid customers. This is reflected in the high rates of disconnection recorded in remote communities, underscoring the urgency of pairing technical improvements with rights-aligned consumer safeguards. The proposed solutions illustrate that technical upgrades, robust consumer protections, and community governance must advance together to realise energy sovereignty and close the equity gap. Looking ahead, priority actions should include: (i) Piloting modular vertical-axis wind clusters alongside solar-battery systems to strengthen evening and seasonal supply, (ii) Codifying "no-worse-off" consumer protections—covering transparent billing, hardship assistance, life-support safeguards, and access to dispute resolution for all households, regardless of grid connection, (iii) Standardising rights-aligned prepaid crediting systems to integrate renewable benefits directly into household accounts, and (iv) Deploying AI/IoT-enabled monitoring platforms with on-country training to ensure long-term system performance and local engagement. When coupled with fit-for-purpose financing models, tailored policy reforms, and sustained investment in local skills, these measures can deliver reliable, affordable, and culturally aligned electricity services for remote First Nations communities. Such an integrated approach ensures that the clean energy transition is not only technologically achievable but also socially just placing community leadership, cultural authority, and equity at the centre of Australia's energy future. The main focus of this work is to provide a perspective rather than embedding evaluation approaches with standardised metrics for assessing the effectiveness of different programs. The future work will consider establishing criteria for measuring success across technical performance, economic impact, social benefits and environmental outcomes. Future works will also focus on analysing the sustainability of First Nations community energy systems, focusing on operational longevity, along with examining the broader institutional and financial factors that determine long-term viability.

Author Contributions: Conceptualization, M.A.M.; formal analysis, M.A.M. and T.K.R.; investigation, M.A.M.; resources, M.A.M. and T.K.R.; writing—original draft preparation, M.A.M.; writing—review and editing, M.A.M. and T.K.R.; project administration, M.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. *The First Nations Clean Energy Strategy 2024–2030*; Department of Climate Change, Energy, the Environment and Water: Canberra, ACT, Australia, 2024. Available online: https://www.energy.gov.au/sites/default/files/2024-12/First%20Nations%20Clean%20Energy%20Strategy.pdf (accessed on 24 April 2025).
2. Quail, K.; Green, D.; O'Faircheallaigh, C. Large-scale renewable energy developments on the indigenous estate: How can participation benefit Australia's First Nations peoples? *Energy Res. Soc. Sci.* **2025**, *123*, 104044. [CrossRef]
3. O'Neill, L.; Thorburn, K. First Nations at the forefront: The changing landscape of clean energy agreements in Australia. *Energy Res. Soc. Sci.* **2025**, *127*, 104183. [CrossRef]
4. *Aboriginal and Torres Strait Islander Health Performance Framework-Summary Report*; Australian Institute of Health and Welfare: Canberra, ACT, Australia, 2025. Available online: https://www.indigenoushpf.gov.au/Report-overview/Overview/Summary-report (accessed on 28 July 2025).
5. *Remote & Indigenous Communities*; Infrastructure Australia: Sydney, NSW, Australia, 2016. Available online: https://www.infrastructureaustralia.gov.au/sites/default/files/2019-06/ia_j16-2330_fact_sheet_remote_and_indigenous_v1.1.pdf (accessed on 24 April 2025).
6. *Remoteness and the Health of Indigenous Australians*; Australian Institute of Health and Welfare: Canberra, ACT, Australia, 2014. Available online: https://www.aihw.gov.au/getmedia/3fae0eb7-b2be-4ffc-9903-a414388af557/7_7-indigenous-health-remoteness.pdf.aspx#:~:text=For%20example%2C%20Indigenous%20Australians%20in,Australians%20living%20in%20Major%20cities (accessed on 26 April 2025).
7. Heard, R.; Berris, M.; Cain, A.; Croker, C.; Frangos, M.; Fraser, D.; Grant, A.; Riley, B.; Rodden, P. The current state of power supply to remote Indigenous communities, Accelerating Energy Transition Series. *Eng. Aust.* **2025**, 1–11.
8. *Data to Support the First Nations Clean Energy Strategy*; Department of Climate Change, Energy, the Environment and Water: Canberra, ACT, Australia, 2024. Available online: https://www.energy.gov.au/sites/default/files/2024-12/Appendix%20C%20-%20Data%20to%20support%20the%20First%20Nations%20Clean%20Energy%20Strategy.pdf (accessed on 24 April 2025).

9. Bushlight Energy Archive; Centre for Appropriate Technology Limited: Alice Springs, NT, Australia, 2002–2013. Available online: https://www.cfat.org.au/bushlight-archive (accessed on 28 April 2025).
10. *What the Grid Can Learn From the Bush: How Small Energy Systems Can Make Big Changes*; Murdoch University: Perth, WA, Australia, 2025. Available online: https://www.theguardian.com/murdoch-university-a-brighter-future-is-here/2025/apr/24/what-the-grid-can-learn-from-the-bush-how-small-energy-systems-can-make-big-changes (accessed on 30 April 2025).
11. *Solar Energy Transformation Program Performance Report #1*; Power and Water Corporation: Darwin, NT, Australia, 2020. Available online: https://arena.gov.au/knowledge-bank/nt-setup-performance-report-1/ (accessed on 1 May 2025).
12. *Titjikala Powered by Renewable Energy*; Legislative Assembly of the Norther Territory: Darwin, NT, Australia, 2023. Available online: https://territorystories.nt.gov.au/10070/925761/0 (accessed on 1 May 2025).
13. *Energy Transition #12: Remote Communities in Australia and the Energy Transition*; Stellae Energy: London, UK, 2020. Available online: https://stellaeenergy.com/energy-transition-12-remote-communities-in-australia-and-the-energy-transition (accessed on 12 May 2025).
14. *Regional Microgrids Program*; Australian Renewable Energy Agency: Canberra, ACT, Australia, 2023. Available online: https://arena.gov.au/funding/rmp/#step-1-reading-the-program-guidelines (accessed on 12 May 2025).
15. East Kimberley Clean Energy Project: First Nations Clean Energy Network. Available online: https://www.firstnationscleanenergy.org.au/east_kimberley_clean_energy_project (accessed on 15 May 2025).
16. *First Nations Peoples Key to Australia's Clean Energy Revolution: The Conversation*; First Nations Clean Energy Network: Melbourne, VIC, Australia, 2024. Available online: https://www.firstnationscleanenergy.org.au/first_nations_peoples_key_to_australia_s_clean_energy_revolution_the_conversation (accessed on 15 May 2025).
17. *Remote Operations*; Power and Water Corporation: Darwin, NT, Australia, 2025. Available online: https://www.powerwater.com.au/about/what-we-do/remote-operations (accessed on 15 May 2025).
18. White, L.V.; Riley, B.; Wilson, S.; Markham, F.; O'Neill, L.; Klerck, M.; Davis, V.N. Geographies of regulatory disparity underlying Australia's energy transition. *Nat. Energy* **2024**, *9*, 92–105. [CrossRef]
19. Hunt, J.; Riley, B.; O'Neill, L.; Maynard, G. Transition to renewable energy and indigenous people in northern Australia: Enhancing or inhibiting capabilities? *J. Hum. Dev. Capab.* **2021**, *22*, 360–378. [CrossRef]
20. *Marlinja Solar Microgrid: A Case Study in Community Energy*; Original PowerJune: Willamette Falls, OR, USA, 2024. Available online: https://assets.nationbuilder.com/originalpower/pages/94/attachments/original/1722912942/Marlinja_Case_Study_Final.pdf?1722912942 (accessed on 20 May 2025).
21. *Solar Energy Transformation Program Performance Report #3*; Power and Water Corporation: Darwin, NT, Australia, 2022. Available online: https://arena.gov.au/knowledge-bank/nt-setup-performance-report-3/ (accessed on 1 May 2025).
22. Jackson, M.; Stewart, R.A.; Fielding, K.S.; Cochrane, J.; Beal, C.D. Collaborating for sustainable water and energy management: Assessment and categorisation of indigenous involvement in remote Australian communities. *Sustainability* **2019**, *11*, 427. [CrossRef]
23. ZECO Energy's Marshall Technology Enhances Compliance with Victoria's Emergency Backstop Mechanism. Available online: https://www.zecoenergy.com.au/zeco-energys-marshall-technology-enhances-compliance-with-victorias-emergency-backstop-mechanism/ (accessed on 7 February 2025).
24. *Consumer Protections for Off-Grid Customers: FINAL Report*; Australian Energy Market Commission: Sydney, NSW, Australia, 2019. Available online: https://www.aemc.gov.au/news-centre/media-releases/consumer-protections-grid-customers-final-report (accessed on 1 June 2025).
25. *Consultation Paper: Off-Grid Energy Consumer Protection Framework Review*; Essential Energy Services Commission of South Australia: Adelaide, SA, Australia, 2021. Available online: https://www.escosa.sa.gov.au/ArticleDocuments/21794/20211118-Energy-OGECP-ConsultationPaper.pdf.aspx?Emsbed=Y (accessed on 13 July 2025).