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VIEWPOINT

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Unlocking the transformative potential of community microgrids in Aotearoa New Zealand

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ABSTRACT
Community microgrids hold significant promise to address the challenges posed by the growing electrification of transportation and other energy-intensive demands, such as the electrification of heating. This potential is further supported by rigorous scientific research, which highlights their capacity to enhance energy resilience, reliability, and sustainability. In the specific context of Aotearoa New Zealand, community microgrids exhibit the potential to significantly improve energy resilience and self-sufficiency. This article outlines the evidence-based benefits, challenges, and high-potential use cases of community microgrids in Aotearoa New Zealand, drawing on both domestic and international research.

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Introduction

Amid the growing global consciousness of environmental imperatives and the pursuit of enhanced energy security, Aotearoa New Zealand finds itself at the nexus of an energy transition. In this transformative journey, community microgrids (MGs) have emerged as a beacon of hope and progress, holding the promise to revolutionise the nation's energy landscape (Warneryd et al. 2020). The orchestrated integration of grid connection, photovoltaic (PV) solar arrays, wind turbines, battery storage systems, hydrogen production and utilisation systems, and electric vehicle (EV) charging infrastructure within community MGs presents a compelling vision for the future (Mbungu et al. 2023). This article delves into the multi-faceted dimensions of community MGs, addressing their potential, challenges, and the critical role they can play in enhancing energy resilience and self-sufficiency, ensuring reliability, affordability, environmental sustainability, and energy security, in the face of increasing extreme weather events associated with climate change and other natural disasters, as well as vulnerabilities associated with the high-voltage direct current (HVDC) link between the North and South Islands.

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Defining community microgrids

Community microgrids are a specific subtype of microgrids that are owned, operated, or managed by local communities or groups rather than commercial entities. These microgrids often involve active community participation in energy production and distribution, offering unique benefits such as increased local resilience and energy sovereignty (Eklund et al. 2023). While commercial partnership-led microgrids focus on profitability, community microgrids prioritise community benefits including affordability, reliability, and sustainability, despite facing unique challenges and barriers in regulatory, financial, and operational contexts.

Objectives, scope, and methodological approaches

This viewpoint is underpinned by a series of technical feasibility studies and empirical research conducted over more than five years, focusing on various aspects of community microgrids in Aotearoa New Zealand and informed by international research. The research involved artificial intelligence (AI)-based modelling frameworks to develop cost-effective solutions and extensive case studies across both the North and South Islands, including communities such as Ohakune (Mohseni et al. 2021b), eco-villages such as Totarabank (Mohseni et al. 2020), islands such as Stewart Island (Mohseni et al. 2021a) and Great Barrier Island (Mohseni et al. 2022), as well as regional studies covering all 16 regions with comprehensive scenarios considered. Additionally, international studies provided insights into best practices, technological advancements, and economic feasibility from diverse contexts, including Europe (Uddin et al. 2023), North America (Muttaqee et al. 2023), Asia (Brown et al. 2024), and Australia (Tahir et al. 2024). These studies aimed to calculate the levelised cost of electricity (LCOE) for context-specific microgrid projects, evaluate post-commissioning performance, and analyse operational data to inform future developments.

The potential of community microgrids

Community MGs represent a paradigm shift from conventional energy models, envisioning local communities as active participants in energy production and distribution (see Figure 1 for a typical community MG). This transformation can significantly reduce reliance on centralised power generation and fossil fuel-based electricity, improving energy sustainability in Aotearoa New Zealand (see Table 1). Furthermore, as the demand for energy grows, MGs driven by renewable resources have the capacity to dynamically scale, ensuring an increased proportion of the energy load is accommodated.

The assertion that community MGs in Aotearoa New Zealand can replace a significant portion of extant power generation, with a particular emphasis on the phased displacement of fossil fuel-fired plants (see Figure 2), is supported by innovative cost optimisation modelling.

The comprehensive research efforts demonstrated comparable LCOEs linked to renewables-driven MG-based solutions when compared to the costs associated with sourcing electricity exclusively from the main grid (Mohseni et al. 2020, 2021a, 2021b, 2022).

Several converging factors support the assertion that community MGs in Aotearoa New Zealand have the potential to significantly contribute to the energy mix. The continuous reduction in the costs of renewable energy sources, particularly solar and wind,

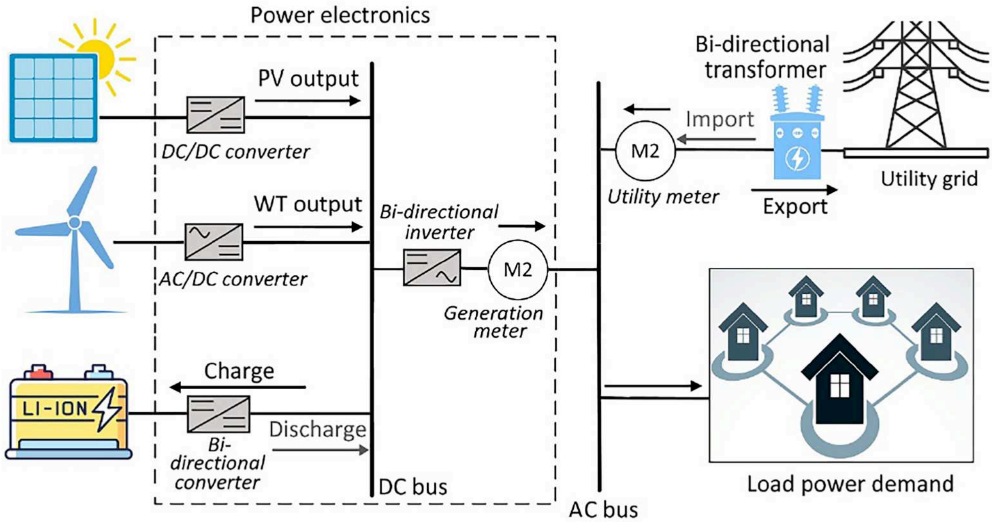

Figure 1. Illustration of a typical community MG integrating solar PV, wind, and battery storage.

coupled with advancements in energy storage technologies such as batteries, has significantly enhanced the economic feasibility of MG solutions. Concurrently, the escalating efficiency of both renewable energy systems and the underlying technologies has contributed to increased energy yield and reduced operational costs, rendering community MGs more viable. Furthermore, the momentum gained from international decisions, such as those emerging from the 2023 United Nations Climate Change Conference (COP28), accentuates the global commitment to transition away from fossil fuels. Aotearoa New Zealand, aligning with this global trajectory, stands poised to leverage these collective advancements in technology, economics, and international policy to expedite the phasing out of fossil fuel-based power generation, making the integration of community MGs an integral component of a sustainable energy future.

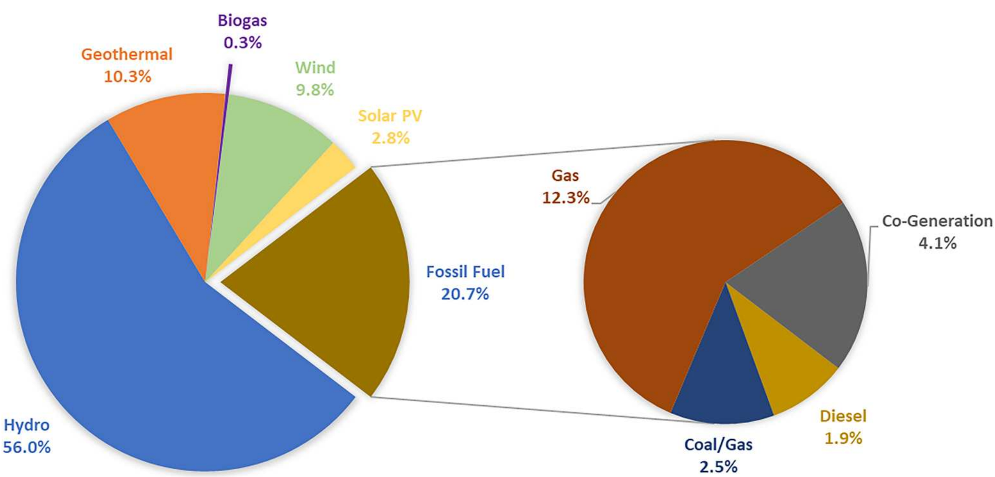

Figure 2. Share of fossil fuel-fired generation in Aotearoa New Zealand's power generation mix in 2023.

Table 1. Operational electricity generation capacity by plant types (MW).

	Electricity only plants									Co-generation plants			
Year end	Hydro	Geothermal	Biogas	Wind	Solar PV	Diesel	Coal/Gas	Gas	Sub-total	Gas	Other	Sub-total	Total
2015	5,435	982	37	689	44	180	500	1,130	8,953	327	311	638	9,591
2016	5,435	977	33	690	63	180	500	1,130	8,946	157	311	468	9,413
2017	5,435	977	33	690	90	180	500	1,130	8,945	157	315	472	9,417
2018	5,435	1,001	33	690	107	183	500	1,130	8,972	157	315	472	9,444
2019	5,443	1,001	33	690	131	183	500	1,130	8,980	157	315	472	9,452
2020	5,442	1,035	33	690	162	191	500	1,230	9,121	159	257	416	9,537
2021	5,442	1,035	33	913	206	191	500	1,230	9,344	159	257	416	9,760
2022	5,680	1,042	33	994	284	191	250	1,245	9,435	160	257	417	9,852

Source: MBIE (2023).

Enhancing resilience in the face of extreme weather events

Extreme natural events – cyclones such as Gabrielle or seismic activities – pose significant challenges to the reliability and resilience of traditional centralised energy systems (Wang et al. 2022; Zhang et al. 2022). Community MGs, by design, offer robust solutions by providing the following advantages (see Figure 3):

- Islanded operation: MGs can operate independently from the main grid when necessary, ensuring uninterrupted power supply to critical facilities such as hospitals and emergency response centres during grid failures caused by extreme weather or natural disasters.
- Distributed energy resources (DERs): DERs, including solar PV arrays, wind turbines, and energy storage systems, are integral to MGs. These resources can continue to generate and store energy, even when the main grid is down, providing a lifeline during power outages.
- Localised generation: MGs decentralise energy generation, reducing the vulnerability of a single point of failure in the grid. If one part of the MG is affected by extreme weather, other parts can continue to function, minimising downtime.

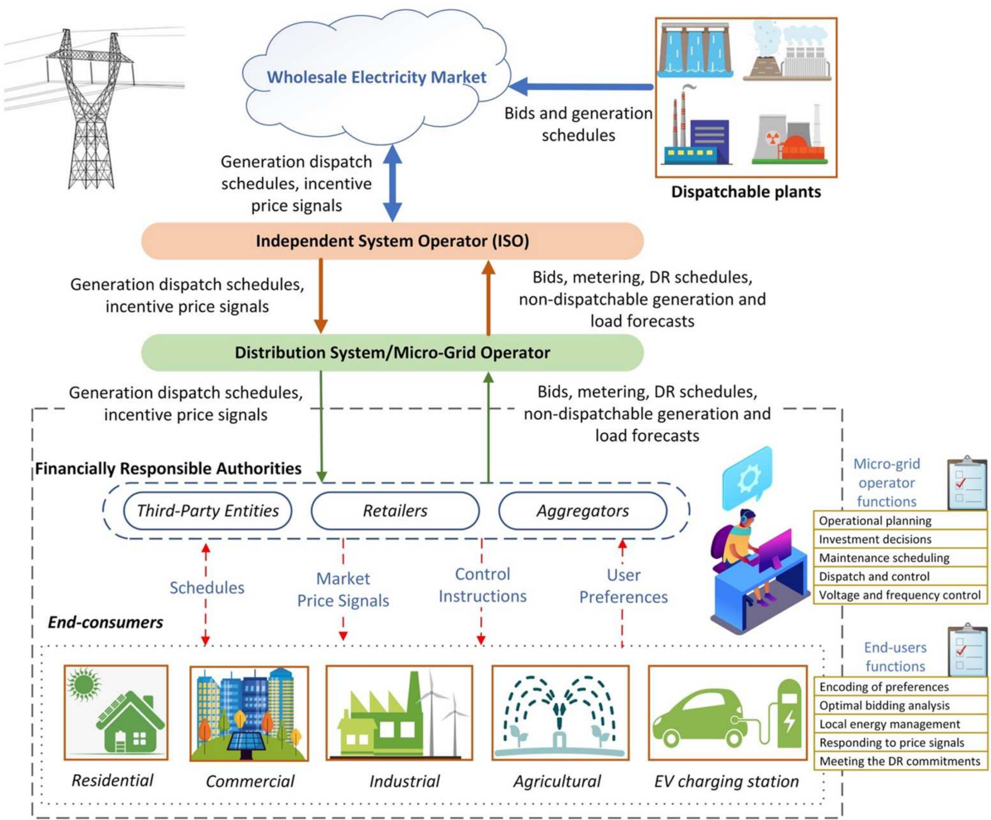

Figure 3. Illustration of the inter-connections and relationships between various entities in a smart grid integrating microgrids.

- Resilient infrastructure: MG components are often designed to withstand extreme conditions, making them more resilient in the face of weather-related challenges. For example, wind turbines can be built to withstand high winds, and energy storage systems can be housed in weather-resistant enclosures.

Reliability and affordability

Community MGs enhance resilience and contribute to the reliability and affordability of energy supply. By reducing reliance on centralised generation and optimising the use of local resources, MGs can (Burger et al. 2020; Majdi Nasab et al. 2021):

- Minimise energy transmission losses: Localised generation and distribution reduce the need for long-distance energy transmission, which is associated with energy losses. This results in more efficient energy delivery and cost savings.
- Stabilise energy costs: MGs can provide more stable and predictable energy costs for communities, helping to shield them from price fluctuations in the wholesale electricity market.
- Promote energy efficiency: The integration of DERs, energy storage, and smart technologies within MGs allows for efficient energy management. Excess energy can be stored for later use, and energy consumption can be optimised, reducing waste.
- Empower communities: MGs empower communities to have more control over their energy supply and consumption, fostering a sense of ownership and responsibility. This empowerment can lead to more judicious energy use and cost savings.

Reducing fossil fuel dependency in the electricity sector

The introduction of community MGs holds the transformative potential to significantly reduce fossil fuel-based electricity generation in Aotearoa New Zealand. This includes a notable reduction in coal, gas, and diesel power generation, marking a crucial step towards decarbonisation. Moreover, in off-grid areas, particularly those relying on conventional generators, MGs offer a clean and sustainable alternative. By integrating renewable energy sources and innovative energy storage solutions, MGs not only reduce greenhouse gas emissions but also enhance energy resilience and sustainability, ushering in a cleaner, more reliable, and environmentally responsible era in the nation's energy landscape.

Impediments for implementation

While community MGs offer substantial benefits, their widespread implementation faces a complex array of impediments that are universally encountered across the globe due to the nascent stage of these developments (Müller and Welpe 2018; Azimian et al. 2022; Kerr 2024):

(1) Regulatory barriers: Existing regulations may not adequately accommodate the integration of MGs into the nationwide energy landscape. Addressing regulatory challenges, such as grid inter-connection standards and tariff structures, is essential to enable the seamless adoption of community MGs at a national scale.

(2) Optimising investment strategies: The upfront costs of establishing MGs, including infrastructure and technology investments, can be significant. Identifying cost-effective nationwide investment strategies and securing funding mechanisms are critical to making MGs financially viable across the country.
(3) Community engagement: The success of community MGs nationwide depends on active community participation and support. Fostering nationwide community engagement, building awareness, and addressing concerns are essential components of successful nationwide implementation.
(4) Cybersecurity and data privacy: The reliance on digital communication channels raises concerns about cybersecurity and data privacy. Robust measures are essential to safeguard against cyber threats and unauthorised access.
(5) Interoperability and standardisation: Achieving seamless communication among diverse MG components demands standardisation efforts. Interoperability becomes crucial to ensuring compatibility across varied MG configurations.
(6) Communication technology integration: Incorporating advanced communication technologies poses another challenge for widespread MG adoption. The intricacies of real-time monitoring and dynamic grid optimisation for establishing localised mini electricity markets and peer-to-peer trading platforms require careful navigation, hindering seamless integration and wider adoption.

Key enablers for the success of community microgrids

Within the realm of community MGs, several essential enablers work in tandem to ensure their effectiveness and sustainability. Community batteries act as energy reservoirs, capable of storing excess electricity generated by renewable sources during periods of low demand for later use or in emergencies, contributing to grid stability. Load flexibility, often achieved through smart grid technologies and demand response (DR) programs, allows for the dynamic management of energy consumption, optimising the MG's operation. Energy efficiency upgrades at both residential, commercial and industrial levels not only reduce overall energy waste but also enhance the MG's overall performance. Effective EV charging management ensures that EVs can be charged efficiently while minimising strain on the MG. Additionally, virtual power plants (VPPs) provide a centralised platform for the coordination of behind-the-meter batteries, allowing for effective load balancing, peak shaving, and demand-side management, which collectively help defer or deter the need for extensive network investments[1] (Piltan et al. 2022).

Furthermore, demand response aggregators (DRAs) play a pivotal role in optimising energy consumption patterns by coordinating and aggregating flexible loads within the community MG. This enables efficient DR strategies, contributing to overall grid reliability (Harsh and Das 2022). Additionally, the integration of peer-to-peer (P2P) energy trading platforms empowers local energy communities by facilitating the direct exchange of surplus energy between participants (see Figure 4).

Together, these elements constitute a resilient and adaptable energy ecosystem, capable of meeting the diverse needs of modern communities while promoting sustainability and reliability.

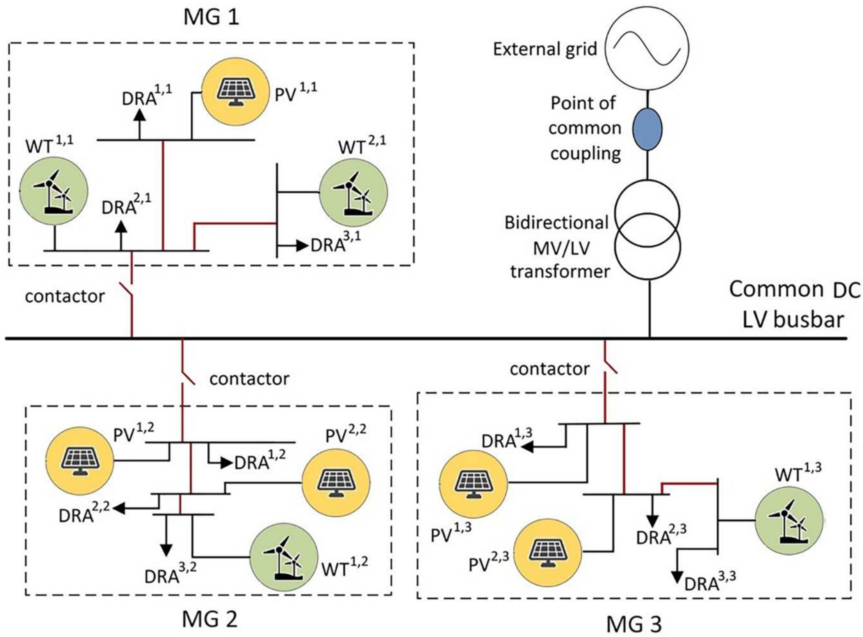

Figure 4. Illustration of a notional P2P trading scheme between DRAs of a grid-connected multi-MG system driven by solar PV and wind turbine (WT) units.

Conclusions

Community MGs, with their transformative potential, are poised to usher Aotearoa New Zealand into a more resilient, reliable, affordable, and sustainable energy future. They offer a robust response to the challenges posed by extreme weather events, natural disasters, and vulnerabilities associated with the HVDC link between the North and South Islands while aligning with the nation's environmental and energy security goals. As Aotearoa New Zealand embarks on this journey, collaboration among policymakers, industry leaders, communities, and researchers become paramount. This helps better navigate the challenges and seize the opportunities presented by community MGs, ensuring a cleaner and more resilient energy future for the nation.

Note

1. Particularly in the face of not-yet-monetised services such as frequency control and voltage regulation ancillary services.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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