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Resilient Buildings and Distributed Energy: A Grassroots Community Response to the Climate Emergency

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Abstract: The severity and incidence of extreme weather events are increasing with climate change. In particular, wildfires are becoming more frequent, more intense, and longer lasting than before. Fuelled by long periods of dryness and high temperatures, the Australian wildfires of 2019/2020 were record breaking in terms of destruction and chaos. Rural communities were severely affected by power cuts disabling access to essential services. Following the wildfires, a concept for energy resilient public buildings ("Emergency Distributed Energy System") emerged as a grassroots community idea from the wildfire-affected area of Gippsland, southeast Australia. A combination of desktop and empirical research explored international examples of energy resilience and climate mitigation, the local services and technologies that are needed in Gippsland, and the legal and regulatory challenges and enablers in Australia. The findings were informed by case studies of responses to natural disasters that included California and Greece (wildfires), New Zealand (earthquake), and India (cyclone). The results determined that community resilience can be increased by offering a more reliable electricity supply that would support greater social, political, and economic structures. The deployment of resilient energy systems should be driven by political will, economic incentives and working with communities to support a concerted shift towards low-emissions and distributed energy technologies.

Keywords: climate change; renewable energy; communities; grassroots movement; energy resilience; distributed energy systems; multi-governance; energy transition; grid infrastructure; buildings

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1. Introduction

1.1. The Global Context

Global economies are rapidly transitioning away from fossil fuel energy sources towards zero carbon alternatives [1,2]. Driving the transition is the threat of climate change, the falling cost of renewable energy, the emergence of disruptive technologies and business models, and increased energy consumer empowerment in developed countries [3–5]. At the same time, more extreme weather events and resulting environmental disasters are stressing the conventional energy infrastructure and exposing grid reliability issues, which have major impacts on lives and communities [6–8]. Distributed generation (DG) and storage options provide enormous opportunities for rural areas to move towards reliable and clean energy supply, especially when electricity services are lacking [9]. In areas where the centralised grid is already installed, DG can improve grid resilience by providing reliable electricity during hazards such as extreme weather events [9].

1.2. The Australian Context

The latest IPCC 2021 report shows that Australia is highly vulnerable to the impacts of global climate change. "Warmer climate will intensify very wet and very dry weather . . . , with implications for flooding or drought, . . . [Although] ecosystem responses to warming [are] not yet fully included in climate models, such as CO_2 and CH_4 fluxes from wetlands, permafrost thaw and wildfires, [there is high confidence such events] would further increase concentrations of these gases in the atmosphere" [3]. Considering the plethora of terms describing fires (wildfires, bushfires, forest fires—depending on the geographical context), this study uses the term wildfires, which is used in the IPCC report (2021). The term includes all types of vegetation fires, grass, crop, scrub and forest fires.

Extreme events, including wildfires, are the result of various environmental preconditions. When multiple events are combined, risks are compounding. Compound risks are defined by environments that are failing at multiple levels thus "amplify [the] overall risk and cause cascading impacts" (Section 6.8.1 of [10]), see Figure 1. Human influence has likely increased the chance of compound and extreme events since the 1950s [3]. The IPCC states that for Australia, "there is medium confidence [that the] increase in fire weather conditions [is] due to human influence [3]."

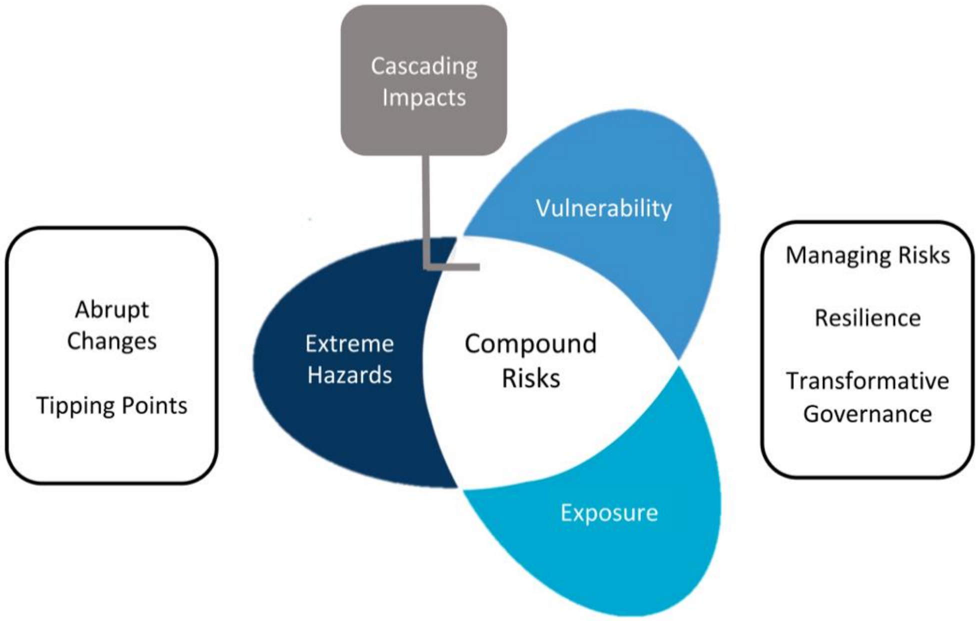

Figure 1. The framework to manage risks includes enhancing resilience, disaster risk reduction and the transformative governance. Adapted from Figure 6.1 in the *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [10]. Adapted with permission from ref. [10]. Copyright 2019 IPCC.

As natural environments become more vulnerable, they are also becoming less habitable for communities. Kopp et al. warn that "repeated extreme and compound events are leading to critical transitions in social systems [can] cause the disruption of communities ... and in some cases [lead to] migration [11]. Hence, developing suitable response mechanisms is crucial." For example, adopting strategies to enhance the resilience of public buildings—which can act as refuge centres—will strengthen rural communities, and build trust in governance structures. One strategy involves increasing the buildings' reliable energy supply during a disaster or crisis.

In this article, the term climate change or global warming is no longer applied and instead has been replaced by the term climate crisis and/or climate emergency, stressing the urgency of climate action in the next decade [3,12].

1.3. Case Study Background

Across Australia, the 2019/2020 wildfires, referred to as Black Summer fires, burned up to 24 million hectares, an area as large as the size of the UK (England, Scotland, Wales and Northern Ireland), resulting in AUD 10 billion in economic losses, 33 deaths, and 3000 destroyed homes [13,14]. Rural Australia, in particular, is highly vulnerable to fire risks. East Gippsland in regional Victoria gained significant media attention in late December 2019, when out-of-control fires threatened tourist destinations, including Mallacoota, a coastal town surrounded by National Park in the East Gippsland district (Figure 2). On New

Year's Eve 2019, 4000 people, including 3000 tourists, were trapped in Mallacoota as fires surrounded the town, leaving the beach as the only place to go [13]. On 1 January 2020, the Australian Navy evacuated 1000 people from the beach, mainly tourists—many locals stayed behind [15,16]. Figure 2 shows a map of the Australian southeast coast including the Gippsland region ranging from Mallacoota on the coast to Bairnsdale including the inland region, Figure 3 shows the Gippsland region, the research site of this study.

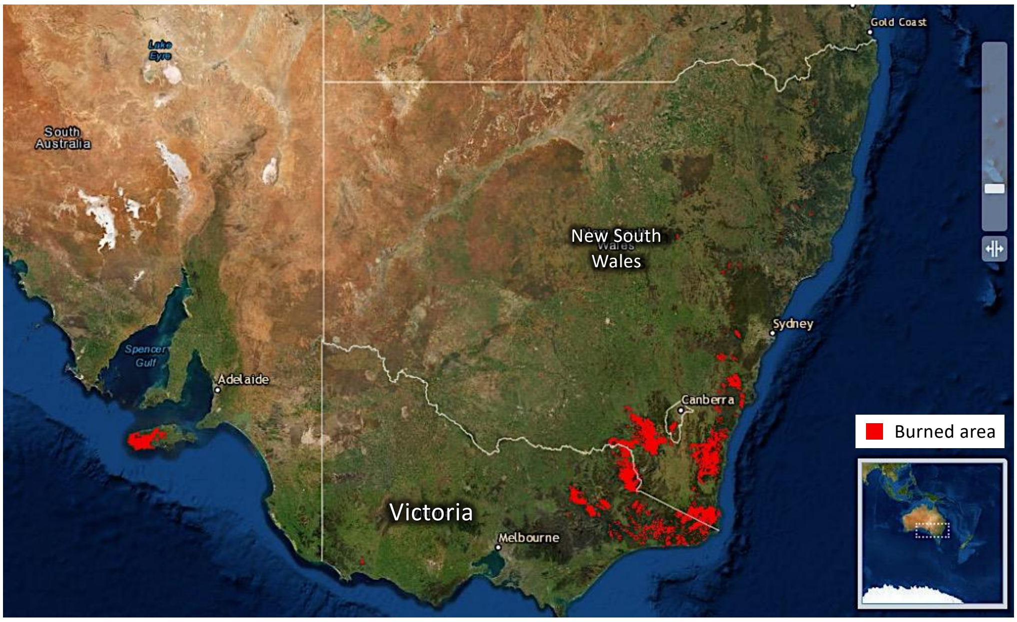

Figure 2. Map of wildfires in southeast Australia impacting the states New South Wales and Victoria during the 2019/2020 Black Summer fires. The map shows burned areas in January 2020. Source: Commonwealth of Australia (Geoscience Australia), 2021 [17].

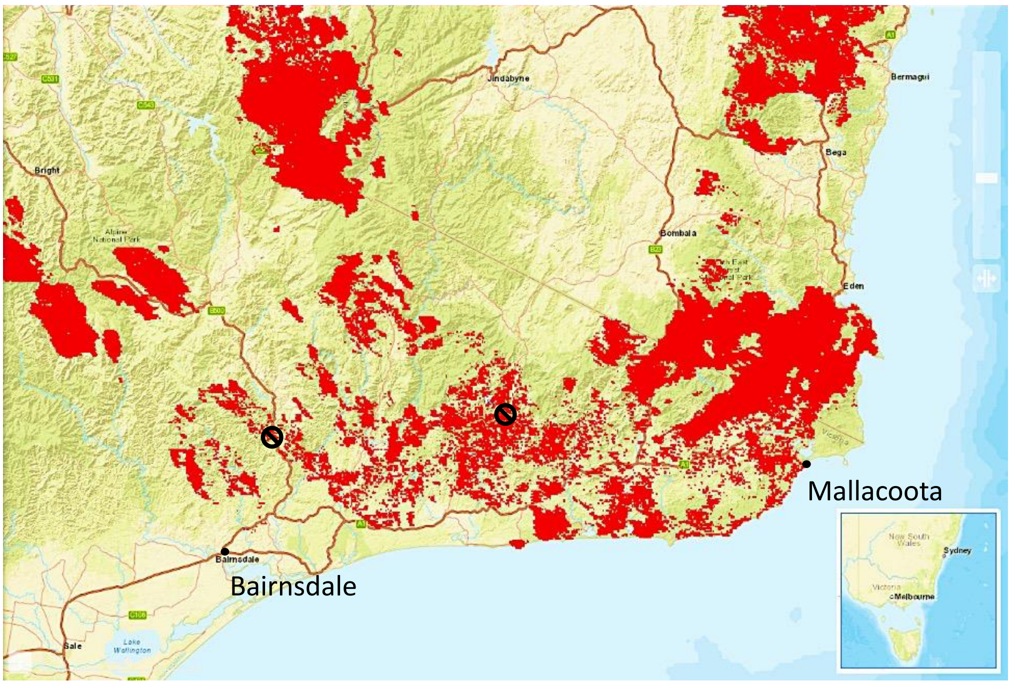

Figure 3. Detailed map of the East Gippsland region (west of Mallacoota including Bairnsdale) during the 2019/2020 Black Summer fires. The map shows burned areas in January 2020. Source: Commonwealth of Australia (Geoscience Australia), 2021, informed by Vic Emergency, 2019 [18].

East Gippsland communities located further inland are at the fringe of the electricity distribution network. During the Black Summer fires, these communities were cut off from the main grid as distribution lines were damaged by falling trees and the intensity of fires rushing through the Gippsland area. In the media, the Gippsland fires were unevenly reported on, while coastal towns such as Mallacoota received considerable media attention as tourists were trapped during the end-of-year celebrations, inland communities received less media attention as inland regions are less known to holidaymakers and have experienced fires in the past [19]. With the Gippsland community being isolated for weeks, roads and other essential infrastructure destroyed (*ibid*), the community itself has proactively pursued climate adaptation measures to increase its resilience to future extreme weather events.

Here, we present an example from Gippsland in Australia, where an Emergency Distributed Energy System (DES) concept has been developed through regional community-government collaboration. This study explores other similar community action as a response to both climate emergencies and environmental disasters in Australia and internationally, using empirical and desktop methods. The research proposes this as an effective way for rethinking the way energy infrastructure is designed and deployed in rural areas affected by climate disasters.

The key group behind the Emergency DES idea was the community group Voices of the Valley (VotV). This group advocates for the well-being and needs of the Latrobe Valley community. The group formed in response to the Hazelwood coal mine fire in 2014, and has an interest in community based renewable energy. Community members came together during the midst of the Gippsland fires on social media and shared their experiences of power outages caused by the fire and the challenges they faced. After observing and discussing the 2019/2020 wildfire events, in particular the events unfolding in Mallacoota, the E Voices of the Valley brought the concept to the Latrobe Valley Authority, who then supported them in collaborating with other key regional actors, including state government representatives, academia, and industry.

An Emergency DES was subsequently defined as a decentralised energy system powered by solar PV, combined with battery storage, which is installed on public buildings and provides low-cost and clean electricity supply daily, and especially during climate emergencies when the connection to the main grid becomes unreliable. The detailed conceptualisation of the Emergency DES was guided by community concerns around energy supply and ensuring the well-being of vulnerable community members during times of crisis.

1.4. Research Objective and Research Questions

The study aimed to find answers to the following research questions:

- Which countries or regions should Gippsland/the Latrobe Valley be comparing itself to, what can the region learn about disaster management and Emergency DES solutions?
- What energy services are supplied by these international examples (e.g., lights and appliances, refrigeration, hot water, heating, cooling, etc.)?
- What type/size of distributed energy resources (DER)/technologies have been integrated (e.g., solar PV, batteries of various chemistries, diesel generators, geothermal, small wind, electric vehicles, etc.)?
- What are the legal and regulatory challenges (e.g., who is responsible, how have they been managed elsewhere, etc.)?
- What other enablers are involved (e.g., supportive policy frameworks, close collaboration with local industries, local identity, etc.)?

2. Methods

2.1. Overview of the Research Design and Data Analysis

In this study, we applied a mixed-methods approach combining empirical and desktop research. The empirical part included a domestic stakeholder forum, and semi-structured interviews which were conducted between July and September 2020 in Victoria, Australia. The desktop study involved the assessment of DES adoption at the domestic (Australian) and international level as a response to climate emergencies and as part of disaster prevention strategies.

This study consisted of four main research blocks (Figure 4):

1. The understanding of the Emergency DES concept developed by the community group Voices of the Valley in Victoria, Australia (empirical research);
2. An assessment of domestic DES uptake in Australia, includes all states and territories (desktop research);
3. An international market scan (broad overview of potential case study examples);
4. The development of four international case studies demonstrating DES uptake in response to climate disasters. These case studies inform the proposed Emergency DES application in East Gippsland, Australia.

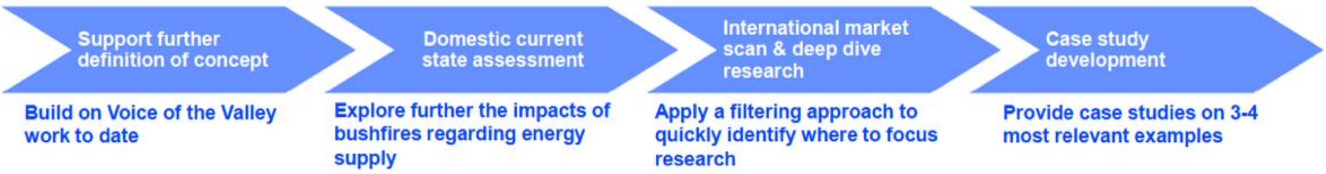

Figure 4. Linear flow of methods/research blocks used in this study.

Australian examples of Emergency DES applications were explored through empirical and desktop research (Figure 5). Qualitative data were collected during a stakeholder workshop held in Gippsland, Victoria (Section 2.2). Next, semi-structured interviews were conducted with key players identified during the workshop. The qualitative data collected during the interviews were analysed using NVivo Version 12 (keyword search). A PESTEL analysis was applied to broaden the analysis and understand the political, economic, socio-cultural, technological, environment and legal issues that frame Emergency DES adoption in East Gippsland (Figure 5). Parallel to the empirical research, we used desktop research to review existing information on examples of domestic (Australian) DES adoption, some of it was provided by the Victorian government agency (LVA).

The international case studies have been explored using desktop research (Figure 5). First, through a high-level screening we selected countries that have demonstrated the ability to innovate (Section 2.3). Next, we refined the search for international case studies based on several considerations that will inform the Gippsland Emergency DES uptake (see list of bullet points at the end of Section 3.4). The case study selection has also been confirmed through expert interviews, i.e., a small number of phone calls with relevant foreign government departments and agencies.

The combined results of the empirical and desktop research will offer practical and policy implications for the adoption of the Emergency DES concept in East Gippsland.

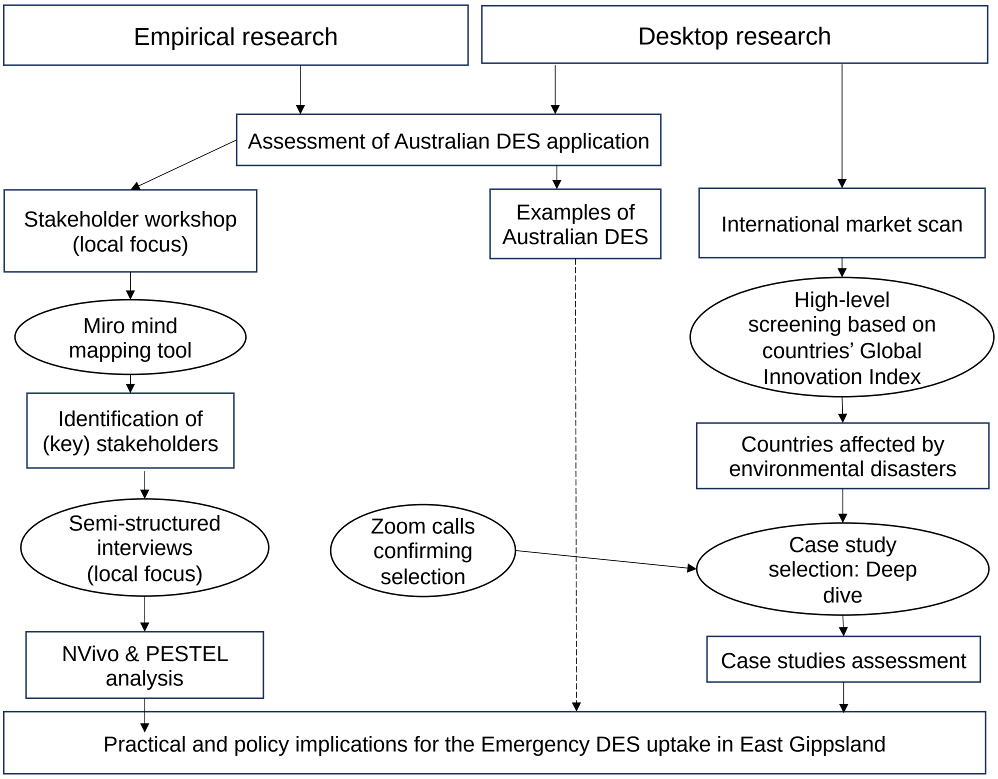

Figure 5. Analytical framework of the study. The empirical and desktop research combined support the development of recommendations for Emergency DES adoption in East Gippsland.

2.2. Methods Used to Assess the Case for Emergency DES in Australia

This section summarises the research steps applied to explore DES adoption and opportunities at the domestic level. First, the study sought to develop a better understanding of the Emergency DES concept through a stakeholder workshop and expert interviews. The DES concept had been put forward as part of the Gippsland's Smart Specialisation Strategy, a project led by the Latrobe Valley Authority (LVA) and has been further developed by the Gippsland community group Voices of the Valley as a response to the 2019/2020 Black Summer fires (introduced in Section 1.3). Second, we assessed the impacts of the recent wildfire events on energy supply and energy infrastructure in Australia through desktop research and semi-structured interviews.

A stakeholder workshop, the "Smart Grid Innovation Forum", was organised by the LVA to discuss the Emergency DES concept. The forum was attended by representatives from government agencies (local, state), the energy and solar industry, community groups, research and education including the research team, as well as hybrid groups with members from diverse backgrounds, such as the (Smart Grid) Innovation Group. Throughout the forum, the 'Innovation Group', together with the research team, reviewed existing information on DES, which was provided by the LVA and the community group. Workshop participation has been documented using the mapping software 'Miro'. The stakeholder map allowed us to visualise participants' roles in the process of DES adoption and identify key stakeholders, some of whom we later invited to the interview process.

We conducted desktop research to explore DES applications in Australia. The Black Summer wildfires impacted the energy infrastructure in large parts of South-East Australia. The events in Gippsland present only one example where the infrastructure was destroyed, and communities were isolated. We explored domestic DES projects (mostly microgrids), objectives for technology adoption and funding mechanisms through desktop research. The assessment also included planned projects which have been put forward in response to climate extremes.

Semi-structured interviews were held via Zoom and were about 30 min in length. Interviewees were asked a list of questions related to the Black Summer wildfires (which were recent at the time of the interviews), the impact of the fire on their day-to-day work and their understanding of DES application as a response to climate emergencies. Interview participants included representatives of local councils, technology companies, electricity distribution companies, state government agencies (environment department, state emergency services) and community groups. The interview transcripts have been analysed using the NVivo text analysis software (Version 12; keyword search). We then used a Political, Economic, Socio-cultural, Technological, Environment and Legal framework to organise the interview findings and identify the macro factors that would influence the successful adoption of an Emergency DES concept in the East Gippsland district. PESTEL is a high-level assessment of the external environment and is often used to analyse market strategies or evaluate business ideas [20].

2.3. Methods Used to Select and Analyse International Examples of Emergency DES Applications

Third, the selection of international case studies involved a number of processes, including an international market scan, a high level screening that creates a list of potential case studies, the selection of four respective case studies, a deep dive into the four examples where further research was conducted to develop the case studies (Figure 5). Overall, the international market scan represents a filter approach which narrows down countries where Emergency DES relevant approaches have been implemented in response to the climate crisis or environmental disasters. Using this approach, we provided a shortlist of regions and countries, which have:

- A track record for innovation and technology development;
- Been impacted by extreme weather, environmental disasters, or similar over the last 20 years;
- Relevant distributed energy-related examples.

First, we performed a high-level market scan of countries' assessing their innovation potential. To filter countries at a high level, we ranked countries according to the Global Innovation Index (GII), see Box 1. The index displays a country's ability to innovate.

Box 1. Global Innovation Index.

> The Global Innovation Index (GII) takes the pulse of the most recent global innovation trends. It ranks the innovation ecosystem performance of economies around the globe each year while highlighting innovation strengths and weaknesses and particular gaps in innovation metrics. Envisioned to capture as complete a picture of innovation as possible, the Index comprises around 80 indicators, including measures on the political environment, education, infrastructure, and knowledge creation of each economy. The different metrics that the GII offers can be used to monitor performance and benchmark developments against economies within the same region or income group classification [21].

We acknowledge that the GII ranking is centred around a nation's accessibility to economic and intellectual resources, which is indicated by Switzerland leading the ranking (number 1) and Australia's high ranking (Australia is ranked number 25) [21]. Therefore, the index is limited in its ability to capture innovation beyond a nation's economic setting.

Second, based on the selection of countries with a high innovation index, we then narrowed down our list to countries with a history of extreme weather events, environmental disasters, or similar impacts over the last 20 years. This selection of international examples has also been informed by the nature of extreme events or climate emergencies (type and scale) that affected a region (Table 1).

Table 1. List of extreme events (here: natural hazard type) considered in this research.

Natural Hazard Categories	Natural Hazard Examples
Climatology	Hurricane, Typhoon, Cyclones Extreme temperatures Wildfire Drought Winter storms
Geophysics	Earthquake Tsunami Landslide Volcanic activity
Hydrology	Avalanche Flood
Technology or human-made	Environmental degradation Pollution, industrial Travel accidents

Source: Modified, based on [22].

There is a range of challenges, such as climate change, unplanned-urbanisation, under-development, and poverty as well as other global threats (for example the current COVID-19 pandemic) that will shape disaster responses in the future. These aggravating factors will also increase the frequency, complexity, and severity of climate emergencies. We expect that this type of natural hazards grouping as shown in Table 1, which is used by international aid agencies, is becoming more intermingled as climate change will continue to modify natural phenomena and will become the dominant driver. According to the UN Global Assessment Report on Disaster Risk Reduction, "decades-old projections about climate change have come true much sooner than expected. With that come changes in the intensity and frequency of hazards" ([23], p. ii). Thus, the term "natural disaster" or "natural hazard" will gradually disappear in the literature and will be substituted by the term 'climate emergency'.

Third, we applied further criteria to the crisis-prone countries to select the respective case studies. The potential case studies were narrowed down to four example regions. Here, a broad representation of different socio-economic systems, i.e., a combination of developed and developing countries—especially in the context of building resilience in rural areas, was essential. Another aspect which has been considered for the selection of the international case studies, includes the location of the DES examples. Here, remoteness is of particular relevance for the comparison with East Gippsland.

The selection process was supplemented with Zoom calls where possible and offered further clarity on the potential case study. In cases where the literature findings were unclear, we arranged conversations with governance bodies to understand if Emergency DES were considered in the aftermath of the environmental disasters.

Four international case studies were nominated, assessed and compared based on the following criteria:

- Historical background;
- Technology/business model approach, i.e., deployment of the DES;
- High-level discussion of the target markets (beneficiaries from the technology uptake);
- Enablers, including specific policy measures and the extent to which Emergency DES other/distributed renewable energy resources contribute to the 'identity' of each region;
- Legal and regulatory issues;
- Stakeholders involved (where possible facilitating new network connections).

The international case study examples will inform the proposed Emergency DES in East Gippsland, the comparison is based on the criteria outlined above (bullet points). These criteria will contextualise the planned Gippsland Emergency DES and showcase international examples of where emergency situations have prompted innovations in energy supply and related policies, practices and energy sharing approaches.

3. Results

3.1. Findings from the Literature Review

This section identifies the drivers for adopting distributed energy sources (DES) technology in response to climate change and distinguishes DES applications for developing and developed countries.

The United Nations (UNFCCC) has undertaken Technology Needs Assessments to address the impacts of climate change. The initiative has identified the energy supply and consumption sector as a high priority sector for climate mitigation in non-Annex I countries [24]. DES uptake in developing nations is primarily driven by transitions from fossil fuel-based electricity generation towards clean energy sources. Examples include the uptake of solar-powered DES systems replacing coal-fired electricity generation in rural China [25,26] and in rural Colombia the adoption of renewable energy DES replaced diesel generators securing energy supply, providing variable energy demand and overall improving the livelihood of rural communities [27]. While energy supply and the mitigation of climate impacts is a major driver for DES uptake in developing nations, DES uptake in developed countries often occurs as a climate adaption measure. Preparing for extreme weather events is crucial to manage inevitable climate risks and reduce community vulnerability [28]. Climate adaptation can be achieved through decentralisation of essential services for both risk management and transformative governance [29]. Although climate change is a dominant driver, DES adoption is highly complex and requires analytical assessments that consider a wide range of drivers [27,30].

The concept of electricity grid modernisation or decentralisation, and securing reliable electricity supply brings together social, environmental, political, and economic aspects. The literature reveals that developed and developing countries share concerns related to DES uptake. Decentralised grid infrastructure must be accepted and trusted by the community to contribute to increased community resilience [8,9]. For example, in rural Bangladesh, trust is developed through peer influence and personal networks, the adoption of new technologies is supported through word of mouth [31]. In the German renewable energy sector, trust-based relationships have been important in the early uptake of solar PV through the sharing of experiences among PV users [32] and continue to be crucial in ensuring the acceptance of the energy transition by emphasising the transitions socio-economic fairness [33].

In the developed world, the adoption of distributed energy systems also has demonstrable grid reliability and grid management benefits that can reduce the risk of energy cut-offs and infrastructure damage [34,35]. In developing countries, energy decentralisation has been shown to promote higher levels of electrification to, in turn, more rapidly decarbonise energy systems to support the achievement of the UN Sustainable Development Goals [34].

DES implementation must be supported by other transformations (e.g., decarbonisation policy objectives) that support strong climate objectives at the local, regional and national level [36]. Grassroots movements provide a mechanism to drive these multiple objectives to achieve the best environment, social and economic outcomes specific to the community it will impact. The emergence of grassroots movements, including their social and political significance during times of crisis, has been studied extensively. One such example is the grassroots response to Hurricane Katrina in New Orleans (2005), which initially came from a poor community with largely black leadership, but and have since become diverse and cross-generational movements [37]. Many forms of contemporary environmental activism have evolved around the internet, which offers marginalised communities a voice and also supports social solidarity developments [38]. Online platforms have become important means of communication for a grassroots movement, especially during times of crisis or political suppression [39].

In this study, the Voices of the Valley community group engages with, and is embedded in, a multi-level governance structure. This allows the community group to influence the adoption of Emergency DES and enter a pathway that meets community needs and provides long-term social and economic benefits for the Gippsland community. A crucial organisation in this governance structure is the Latrobe Valley Authority (LVA), funded by the Victorian state government, which guides the infrastructure developments of the former coal-mining region towards a just transition. The LVA covers three local government areas: Latrobe City Council, Baw Baw Shire Council and Wellington Shire Council, and acts as an intermediate agency between government, industry, and communities, and develops frameworks to encourage collaboration among stakeholders [40,41]. An important element is building trust and creating transparency between local communities, businesses, and the multiple levels of government.

Maintaining a critical perspective towards technical and economic developments is crucial. The literature shows that it is important to maintain a critical perspective towards technical and economic developments that emerge in the aftermath of climate emergencies. We use the term 'extreme event' or 'climate emergency' and therefore avoid the term 'natural disaster' (where possible) to stress that climate change is a major driver behind many of the events discussed in this article [42,43]. The terminology around external drivers has advanced since the 2000s, where terms were less specific, for example, Luft (2009) used the term "na-tech" to describe the partly natural, partly human-made disasters [38]. The literature discussing Hurricane Katrina was particularly critical of government-led responses. Dawson (2010) refers to legislative changes which had been advertised as solutions but were "seek[ing] to profit from the ... crisis" as 'green capitalism' [44]. In the case of the 2019/2020 Australian Black Summer fires, a "green recovery" for wildfire-affected communities is anticipated including the roll-out of sustainable fire-proof homes and grid modernisation [44]. Adopting Emergency DES supports grid reliability as the electricity supply is based on renewable energy and can operate independently of the main grid. There are also economic objectives including lower cost electricity and it is predicted to stimulate clean energy employment in regional economies [41].

Disaster prevention requires coherent institutional and social structures supportive of long-term economic planning, including secure funding for emergency and recovery services [45,46]. The Australian government's response towards wildfire prevention and the economic recovery from the Black Summer fires shows considerable shortcomings in response to this event. Global Insurance company MunichRE estimates overall economic losses caused by the 2019/2020 fires came to around USD 2 billion (AUD 2.54 billion), a 50 percent increase compared to 2008/09 [43]. Despite the Australian government's establishment of an AUD 2 billion Bushfire Recovery Fund in January 2020, spending has been low. In October 2020, about half (AUD 1.2 billion) had been spent, AUD 0.77 billion by the federal government itself and AUD 0.47 by state and territory governments [47]. In addition to the Bushfire Recovery Fund, the federal government has nearly touched on other funds. Only 2% (AUD 0.045 billion) of the Local Economic Recovery Fund have been spent so far, while the AUD 4 billion Emergency Response Fund has been untouched (*ibid*).

The literature shows that a combination of quantitative and qualitative methods are applied to assess the large number of variables that determine DES technology adoption [27,31,48]. Interviews are a crucial method to collect empirical data, connect with local communities and consult with experts [31,33]. Desktop research is crucial to explore the dimensions of sustainable energy research and the use of multi-criteria approaches [48,49]. Different models have been applied to assess the social, economic, environmental and demographic variables, which influence the ability and decision-making of communities in the uptake of DES [27,28]. Cherni et al. (2007) assesses technical and non-technical criteria to understand the communities' strengths and weaknesses relevant for technology adoption, including physical, financial, social and human assets—together these create the conditions for technology uptake and institutional innovation [27]. Ajaz (2019) applies an empirical model to explore microgrid adoption in the United States, the study focuses on local conditions, including demographic aspects, institutional and economic incentives. For example, Ajaz (2019) considers positive GDP growth as an indicator that is contributing to microgrid uptake [28]. Other modelling approaches solely focus on technical and financial parameters when assessing the adoption of DES solutions to mitigation climate change in rural China [26].

In the literature, data are largely derived from publicly available sources or from empirical research. For example, Ajaz (2019) sourced the majority of data on microgrid adoption in the US from documents and databases published by federal government agencies [28]. Götz and Wedderhoff (2018) derived data from extensive empirical research. More than 2000 interviews were conducted, through a market research agency, on the public acceptance of Germany's energy transition, the collected data were then analysed using a statistical model [33]. In developing countries, collecting field data is important to ensure trust implementation and O&M of DES. Siegel and Rahman (2011) conducted interviews on influences of DES uptake in Bangladesh, their empirical data complemented energy market data (electricity prices, cost savings, etc.) [31].

The following section discusses the literature findings on the applications of DES in Australian states and territories.

Our desktop research found that DES projects exist across almost all Australian states and territories and more projects are planned (Table 2). While the majority of DES have been driven by remoteness and economic advantages (e.g., installations on islands), the impacts of the Black Summer wildfires on energy infrastructure and a recent rule changes at the regulator level have accelerated DES technology uptake through Distribution Network Service Providers (DNSPs) [50]. The rule change by the Australian Electricity Market Commission (AEMC) means that electricity distributors can now help customers to transition to off-grid supply "where it would be economically efficient to do so". AEMC has mapped potential sites for SAPS aiming to reduce the high "costs of providing a grid-connected service [in] remote areas, at the fringes of the grid" (*ibid*).

Table 2 lists examples of existing domestic DES projects and announced potential DES sites.

Across Australia, numerous examples of DES are being deployed to improve accessibility, affordability, and reliability of energy for communities. While some projects, such as King and Flinders Island, are being driven by the desire to replace costly to run diesel generators, others such as the project in Gippsland, are being proposed as a way of better serving fringe of grid communities. In both cases, the deployment of DES technologies can also serve to provide energy resilience during wildfires and other extreme events.

3.2. Findings from the Stakeholder Workshop

The results presented in this section are a response to the question which stakeholders are involved in the Emergency DES concept? It includes the mapping of forum participants, domestic examples of existing and planned DES projects, and the analysis of stakeholder interviews using the PESTEL framework.

Table 2. Climate impacts, and existing and potential DES in Australia states and territories.

State/Territory	Climate Impacts	Existing DES Projects	Potential for Stand-Alone Power Systems (SAPS)
Tasmania	2018/19 wildfires [51]	King Island (2010–2016) and Flinders Islands (2014–2021) have been pioneering in DES uptake [52,53].	TasNetworks has identified 5 possible SAPS sites over the next 5 to 10 years [54].
Western Australia (WA)	Over 90% of WA is wildfire-prone [55]	A microgrid is also trialled in Kalbarri, a major tourist site [56]	Western Power, a state-owned energy company, has identified 15,000 potential DES sites until 2030 [54]
South Australia (SA)	2019/20 Black Summer fires, Kangaroo Island was severely impacted [57]	2017: The SA government installed a utility-scale Tesla battery storage system, the largest installation worldwide at the time. The battery capacity (129 MWh) is currently undergoing a 50% expansion [58] 2016: 100% RE proposal for Kangaroo Island was unsuccessful due to lack of support to remove the undersea network cable [59,60]	Two potential SAPS sites have been identified by the South Australian Power Network [54]
Queensland	2019/20 Black Summer fires, and is at risk of extreme weather events	2019: University of Queensland installed a Tesla battery system and showcases its economic and environmental benefits [61]	1000–2000 potential sites have been identified for SAPS over the next 10 to 20 years [54]
Regional New South Wales	2019/20 Black Summer fires		In the Essential Energy network there is potential for 2000 SAPS over the next decade [54]. The network covers 95% of NSW customers and parts of Southern Queensland [62]
Victoria	2019/20 Black Summer fires	Yackandandah (TRY) [63] and Licola Wilderness Village (located 50 km off the grid and 254 km east of Melbourne) has installed 600 solar panels and 2 large batteries [64]	The regulator identified 300–400 SAPS sites operated by AusNet Services [54], focused on Regional Victoria including East Gippsland

3.2.1. A Core Finding Was That Actor Diversity Is Key for Building Energy Resilience

All three dimensions of governance—local, regional, state and beyond—will contribute to the development of a resilient energy system piloting in East Gippsland (Figure 6). The map shows the diverse stakeholders and how they are connected. The connections associated with the Smart Grid Innovation Group (Figure 6, yellow post-it) demonstrate the relevance of hybrid groups to increase interconnectedness among stakeholders. The red arrows in Figure 6 indicate connections between organisations that have been identified as core players and may influence and/or be affected by a "resilient and reliable energy system". The critical path to implementation is highlighted in orange, and involves government departments, emergency services, communities, the LVA and associates.

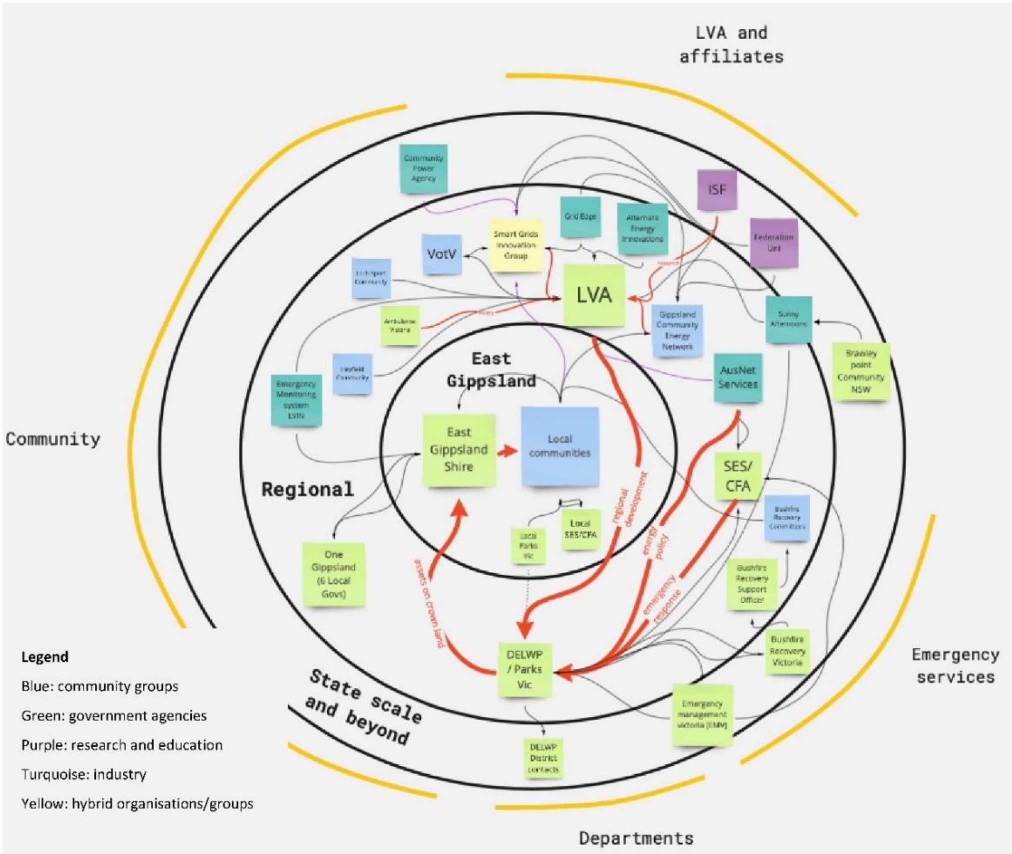

Figure 6. Stakeholder map shows critical organisations for the development of an Emergency DES in East Gippsland. The Gippsland community group Voices of the Valley (VotV) is represented as a blue sticky note.

3.2.2. Another Important Finding Was That Community Needs Must Inform the Vision of the Emergency Distributed Energy System Concept for Gippsland

Here, we present an example from Gippsland in Australia, where an Emergency Distributed Energy System (DES) concept has been developed through regional community-government collaboration. This study explores other similar community actions as a response to both climate emergencies and environmental disasters in Australia and internationally, using empirical and desktop methods. The research proposes this as an effective way for rethinking the way energy infrastructure is designed and deployed in rural areas affected by climate disasters.

An Emergency DES was subsequently defined as a decentralised energy system powered by solar PV, combined with battery storage, which is installed on public buildings and provides low-cost and clean electricity supply daily, and especially during climate emergencies when the connection to the main grid becomes unreliable. The detailed conceptualisation of the Emergency DES was guided by community concerns around energy supply and ensuring the well-being of vulnerable community members during times of crisis. The next section (Section 3) discusses community-level responses to extreme events and their relevance towards climate adaptation through Emergency DES. It would also provide a proof-of-concept to help the community move towards more reliable, affordable, and clean energy into the future. The community group Voice of the Valley expressed the need for an Emergency DES to address energy resiliency among other issues, these may involve any combination of technologies integrated into a single system for use in times of crisis, which include solar PV and/or wind power, energy storage, an emergency generator (for fuel pumps, fridges, freezers), and satellite communications with extended Wi-Fi and other systems crucial for emergencies (water purification, cooling, heating, cooking and hot water. In addition, the community envisions the DES system to include an electric vehicle charging station and other electricity grid support devices. Figure 7 shows the concept including essential functions of an Emergency DES as developed by the Gippsland community and other stakeholders during a forum on the topic. The graph includes the above-mentioned technologies and the system opportunity to connect to the grid.

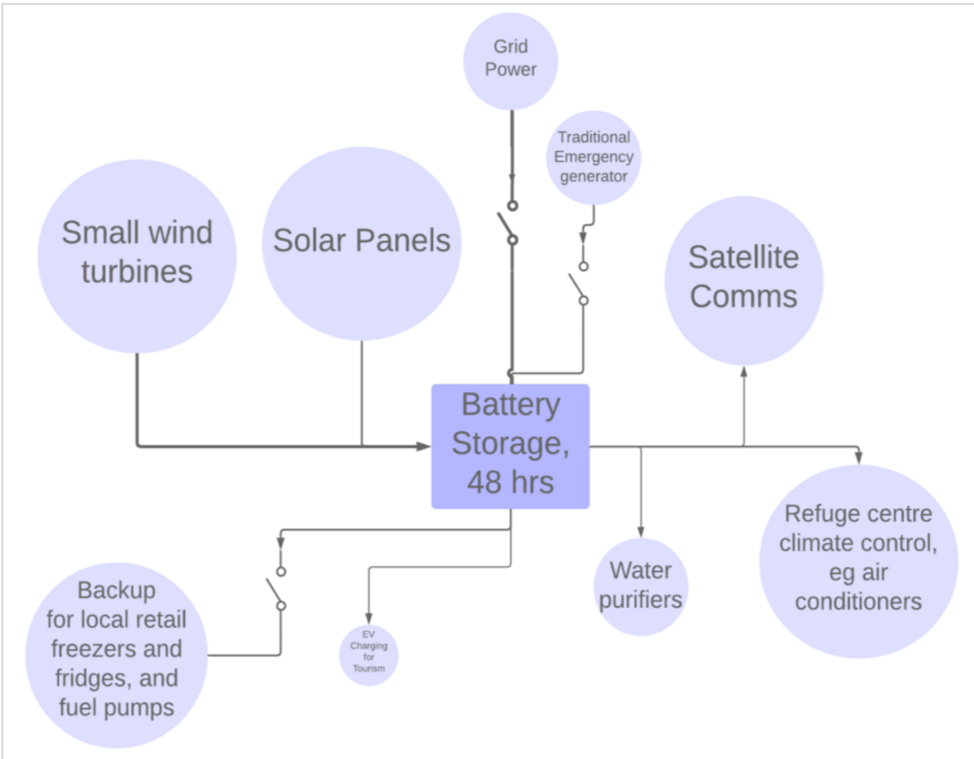

Figure 7. Emergency DES concept as envisioned by the Gippsland community group. Adopted from Innovation Proposal put forward by the Smart Grids Innovation Group (SGI), Gippsland Smart Specialisation Initiative, 2020. This image came from Voices of the Valley via the SGI Program, a community program managed by the Latrobe Valley Authority, Victoria/Australia.

3.3. Findings from the Semi-Structured Stakeholder Interviews

We conducted semi-structured interviews with stakeholders that have been affected by the East Gippsland Black Summer fires as well as those who have been identified as important players in the recovery and resilience building process. Stakeholder interviews helped to understand where the Emergency DES would be located best and why, and what are the opportunities and challenges for Emergency DES adoption in East Gippsland (Section 3.4).

This section discusses a possible location for the installation of Emergency DES technology in Gippsland, which has been informed by the district's emergency governance structure. Information about this governance structure was provided by an interviewee in a follow-up conversation. A relief facility hierarchy was developed by the local council, outlining the function, resources, amenities, and equipment requirements for each type of facility in an emergency (Table 3). The initial assessment shows that an Emergency DES concept could work at all facility level types, but the "District Level" appears to be the most promising scale at which to apply the Voices of the Valley concept (Table 3).

The municipal and local level are least suitable. Municipal facilities are typically located in less remote, more populated areas further from the flame zones. The requirement to accommodate a larger number of people and equipment indicate that major energy services are required, thus a microgrid will not generate sufficient electricity. The local level is also unsuitable as many shelters are located in the flame zones. If the facilities at both the municipal and local level would be scaled up, they could be considered in the future. Ultimately, the district level is most suitable for the adoption of the Emergency DES concept. Here, facilities can be located further away from emergency services and major populations, but closer to the flame zones. The district level provides some level of energy resiliency, but at a smaller scale, which might be the best option.

East Gippsland Shire Council's relief facility hierarchy can help determine the appropriate scale, requirements, and location for the Emergency DES. Once this is defined, the legal and regulatory implications associated with the chosen technologies and infrastructure can be fully explored and addressed. Starting with a pilot project that will involve a small number of engaged communities is an important first step to developing a replicable approach and a scalable model. However, there remain definitional issues on what constitutes as "safe", that can impact whether systems can be located at relief centres and whether they could be formally 'islanded' from the grid. The impact of lost communication plays a crucial role in the Emergency DES concept, but it is being further explored with telecommunications companies [65]. The domestic state assessment finds that public buildings, and buildings that serve as places where communities gather during an emergency, offer a good opportunity for the implementation of the Emergency DES concept. There have been other projects in the region which support such an approach, for example, the Solar on Public Buildings Project [66]. Next, we discuss the results of the PESTEL analysis on opportunities and challenges of DES uptake in East Gippsland.

Table 3. Most suitable location for installing an Emergency DES in East Gippsland considering various operational aspects of such a facility.

<table>
<tr><th>Facility Level</th><th>Intended Function</th><th>Operational Resources</th><th>Amenities</th><th>Equipment Requirements</th><th>Suitability for Emergency DES Concept</th></tr>
<tr><td>Municipal Self-sufficient/24-h activation (i.e., set up) time</td><td>• Long term (5+ nights) shelter for people, pets, large animals, vehicles, etc.
• Municipal facilities to be designate as ‘safe’ during fire/flood events</td><td rowspan="2">• Space to accommodate medical support staff
• State Police
• Ambulance</td><td rowspan="2">• Meeting space/facilities
• Heating/cooling
• Full kitchen
• Bedding
• Bathroom/s
• Accommodate small to large animals
• Space for cars, boats, caravans, etc.
• Secure storage of relief resources (i.e., food, clothing, donations</td><td rowspan="2">• Wi-Fi
• Mobile coverage
• TV/AV system
• Backup power/water/amenities
• External power outlets for caravan, etc.</td><td>Least suitable</td></tr>
<tr><td>District Self-sufficient/ 12-h activation time</td><td>• Short term (<5 nights) shelter for people, pets, large animals, vehicles
• Managed by council staff and/or trained volunteers</td><td>Most suitable</td></tr>
<tr><td>Local 6-h activation period</td><td>• Short term relief (<2 nights) for people and pets
• Accommodation for local residents</td><td>Not specified</td><td>Meeting facilities
- Heating/Cooling
- Basic kitchen facilities
- Bathroom/s</td><td>• Wi-Fi
• Mobile coverage</td><td>Less suitable</td></tr>
</table>

Source: Provided by East Gippsland Shire Council.

3.4. Findings from the PESTEL Analysis

This section presents the findings from the PESTEL analysis summarising the opportunities and challenges for Emergency DES adoption in East Gippsand. Findings have been analysed using the PESTEL framework and are summarised in Table 4.

Table 4. Political, social, technical, environmental, and legal (PESTEL) opportunities and challenges of Emergency DES adoption in East Gippsland.

External Factor	Opportunities	Threats/Challenges
Political	• Solar on Public buildings projects	• Consistent definition of "safe" across all government agencies
Social	• Identifying important and isolated communities—pilot projects • Hierarchy of essential services	• Research gap: impacts of lost (tele)-communication on emergency response • What is considered an "essential service"?
Technical	• Regional areas supplied by radial power networks • battery storage would be useful in frequently disconnected areas • connecting remote towns on single line to a microgrid is achievable but requires the collaboration with local utilities	• Issues related to safety of batteries in fires, e.g., Tesla batteries are fire-resilient • Codified regions have their own set of network designs in response to wildfire risk (de-energising lines, underground service lines–adds to complexity) • Required maintenance of technology may be challenging at the local level
Environmental	• Cogeneration where different renewable energy generators are integrated can address the reliability of solar in this instance.	• Extended wildfire recovery/preparation • Wildfire smoke can reduce solar generation substantially—as low as 3% of capacity but has year around benefits
Legal	• Upgrade of public buildings • Responsibility shared across multiple levels of governance	• Site-specific regulations for construction, licensing operation, etc. • Ownership/investment models • Off-grid options

The interview content was structured around external factors covering political, economic, social, technical, environmental, and legal aspects, which shape the opportunities and threats linked to the installation of the DES technology.

3.4.1. Political Opportunities and Challenges

Politically, there are opportunities related to access to government buildings. In particular, recreation sites or relief centres offer a good opportunity for Emergency DES technologies that have been previously been installed in Gippsland, an example is the "Solar on Public Buildings Project" funded by the Victorian government [66]. Other government programs and policies include the Built Environment Plan or the Community Recovery Committee [67,68]. A political challenge to the adoption of the Emergency DES concept is the definition of what constitutes "safe". This definition can determine whether systems can be located at refuge centres and whether they can be formally islanded. To derive an appropriate decision, all parties need to be engaged in the political process, including communities, councils, emergency agencies, Distribution Network Service Providers (DNSPs), state governments environmental agencies, e.g., Victoria's Department of Environment, Land, Water and Planning (DELWP), and others. Throughout this process, community consultation is a critical first step.

3.4.2. Economic Opportunities and Challenges

Economic factors that support the adoption of Emergency DES include the system's opportunity to provide year-round benefits and ideally it would provide a competitive advantage for the area. In addition, the East Gippsland Shire has applied for AUD 10 million in Australian government funding to upgrade (wildfire) relief centres. Furthermore, network incentives that economically stack up, include improved demand management and other service-related incentive schemes. In this context, it would be interesting to explore the economic cost to local communities caused by power outages during and after the fires. A major financial barrier wildfire-affected communities are likely to face is covering the costs of new infrastructure that is more resilient and is able to operate autonomously from the grid if required.

3.4.3. Social Opportunities and Challenges

Social opportunities emerge around small pilot projects, the location of isolated communities needs to be identified and the importance of securing energy supply in emergency situations needs to be assessed. As discussed in Section 3.3, DES opportunities at the community level must follow the hierarchy of energy services: water for sewage (flushing), refrigeration, other water pumping, communication. Emergency DES also offer educational opportunities, for example, high school students can develop knowledge around new energy technologies and the impacts of climate change on the natural environment ("Eco School Grant program" [69]). The mental health impacts of the 2019/2020 Black Summer fires are yet to be understood in greater depth. What has been clear is that already vulnerable groups (sick, aged residents and victims of domestic violence) in rural regions are at greater risk of health and mental health (trauma) impacts than others [70,71]. Another aspect that requires attention, is the impact of lost communication on the residents' well-being and their emergency responses [72]. As mobile phone networks are not categorised as an "essential service" (but radio networks are), lost communication due to telecommunications outages affects the emergency response [73] and will potentially affect future DES operations. While it is important to communicate that "resilience starts at home", not all community members have the skillset or the financial resources to fire-proof their homes. Interviews also revealed that there is a lack of community acceptance for adopting DES and "cut the wire to the main grid".

3.4.4. Technical Opportunities and Challenges

There are numerous technical opportunities that emerge with the adoption of DES. For example, regional areas are supplied by radial power networks (one line in/out). This type of distribution system is vulnerable to disruption, a fault in the line can cause the system to fail [73]. The simplicity of the set-up also means it is easy to connect remote towns to operate autonomously from the main grid as a DES (also referred to as a microgrid) because there is only one line in each direction. It is important to work with the utility to ensure their support. As part of this type of installation, sufficient battery storage is required. Through stakeholder interviews, we understood that two days of battery storage would be very useful in areas that are regularly disconnected. Battery storage would match diesel back-up, in the village of Omeo in East Gippsland/Victoria, diesel back-up only lasts four days. The majority of solar PV and battery storage systems are commercial and can provide enough electricity to towns for 3 days. Such an example is the Men's Shed (a communal workshop space) at Bawley Point (6.48 kW) [74]. Another issue that requires attention is to understand more about the safety of batteries in wildfires, e.g., Tesla batteries can often withstand wildfires [75]. Codified regions often have their own set of network designs that create challenges—e.g., on days of high wildfire risk, the network needs to be de-energised, and many regions have underground service lines—this adds to the complexity of technical solutions [73,76]. Access is a major constraint for mobile emergency energy systems, particularly in rural regions [73]. Ongoing maintenance of technology in rural regions is already challenging for the conventional grid [*ibid*], and may be as challenging to maintain locally for an Emergency DES.

3.4.5. Environmental Challenges and Opportunities

This section first discusses the environmental challenges and then the opportunities. The management of wildfire affected areas regarding future backburning strongly depends on the intensity of the fire and area's capacity to regrowth. The 2019/2020 Black Summer Fires were longer, hotter, affected larger areas and affected ecosystems which rarely burn (high altitude regions in South-East Australia/Tasmania, rainforest). The 2019/20 fire regime has altered the recovery of Australian ecosystems for the unforeseeable future and will require major changes to existing wildfire management plans and the preparations for future fire seasons in the "new normal" [77]. Thick wildfire smoke can reduce solar generation substantially [78,79]. During the interview with a solar installer, we learned that with no breaks in smoke, solar performance can be less than 3% of its capacity. The trade-off is obvious, rooftop solar PV is likely to provide better year-round benefits, but other generators (including diesel) may be more suitable in a climate emergency. In this context, an opportunity evolves around cogeneration, by integrating different renewable energy sources in the mix, the reliability of solar PV can be increased.

3.4.6. Legal Considerations

The legal issues and barriers of an Emergency DES depend on its technical configurations, the size and scale of the planned project. It is important to understand whether new infrastructure will be required, including generation, network, and storage systems. Through community stakeholder interviews, the project has identified the need for DES which can power emergency support services for the community (heating, cooling, communications, water, etc.) at a centralised location for short to medium term (up to five nights). The Emergency DES will be powered by local generation, supported by battery storage, with much of the infrastructure located at public buildings (e.g., council buildings)

To further explore the legal considerations of potential emergency DES uptake, questions on ownership and licencing have been considered.

3.4.7. Who Should Invest in, Own, and Operate the Emergency DES?

First, the operation of an Emergency DES will require licencing and registration at the national and state level. Options include a retailer, the network service provider, or a dedicated microgrid operator (not yet a category). Given the focus on providing emergency relief, public ownership by councils or community ownership could also be considered, although currently not an option in Australia's liberalised electricity system. If community ownership is considered, different ownership and/or investment structures will need to be assessed see ([80], p. 11) for community-led solar garden business model.

3.4.8. What Electricity Industry Law and Regulation Applies?

Registrations and licenses are required for the Emergency DES to sell energy to consumers and/or the market. Registration at the national level (National Electricity Market) as a generator/distributor is required to feed electricity back into the market during 'non-emergency' conditions. At the state level, a license is required under the Electricity Industry

Act, either as a distributor, retailer, or generator—this is model dependent, unless the project falls within one of the exemptions in the general exemption order. There are also considerations around Embedded Network Regulation and Consumer protections. As the market moves towards free retail competition, embedded networks must open full retail contestability to all customers: they cannot be forced to exclusively stay in the microgrid and could switch if better offers are present.

There are also legal considerations around emergency management that interface with emergency/OH&S legislation, e.g., if management changes in case of fire/emergency. Here, the following questions arise: How can this be secured in a retailer or network-led emergency DES? What are the responsibilities under the critical infrastructure regulations? Lastly, other legal issues emerge around land use planning and property rights.

3.5. Findings from the Case Study Comparison

3.5.1. Who Should the Latrobe Valley/Gippsland Be Comparing Itself to Regarding Emergency DES Responses?

The high-level screening based on the Global Innovation index, found 130 countries that could act as potential case studies. The initially large pool of potential countries has been further narrowed down to six regions applying additional factors including the occurrence of recent extreme events and the risk type of these events. Six regions were shortlisted including the United States, Europe, Japan, India, Indonesia, and New Zealand (Table A1) discusses some of the factors that have been considered for the high-level analysis.

Four case studies (California/USA, Christchurch/NZ, Odisha/India and Aegean Islands/Greece) were selected based on their proneness to environmental disasters, evidence of DES response and other relevant aspects, such as community energy and sustainable development (Table 5).

Table 5. Inclusion parameters for the selection of international case studies.

Case Study Location	Proneness to Environmental Disasters	Evidence of Emergency DES	Specialisation Strategies (Community Energy, Sustainable Development, Bioenergy, Geothermal)
California/USA	X	X	X
Christchurch/New Zealand	X	X	X
Aegean Islands, Greece		X	X
India, Odisha	X	X	X

Note: The table shows the location of the international case studies (first column) and the criteria that contribute its selection (top row). The cross ("X") indicates the prevalence of the respective criteria.

3.5.2. Microgrid Adoption in California—Case Study Findings

California is particularly prone to wildfires. Like Victoria, the fire season runs from Spring to Autumn driven by hot, dry and windy conditions. The frequency and scale of fires in California have been increasing with climate change, with 2018 being the largest, most destructive, and deadliest on record. About 2% of the state's area was burned, 100 people died, and the economic costs have been estimated at USD148.5 billion (equivalent to 1.5% of California's annual GDP) [81]. The largest fires were caused by human activity and lightning, but the main cause (accounting for 50% of largest fires) is not clear (*ibid*). Downed power lines have been blamed for igniting a large number of fires. During the 2018 fires, California's centralised utility PG&E had to cut power to 100,000s of homes. In 2019, PG&E filed for bankruptcy, this was also to avoid payouts to wildfire victims [82].

We explored microgrid/DES adoption in Sonoma County, a famous wine making region in North California. The Stone Edge Farm Estate Vineyards & Winery promotes sustainability through resource conservation and organic farming [83]. To reduce its carbon footprint and grid dependency, the winery in 2012 installed an off-grid system. Today, it includes a solar system, a gas/hydrogen-powered microturbine, a battery/hydrogen storage system and EV charging [83]. The storage system includes Lithium-ferro-phosphate (SimpliPhi) batteries (five 50 kW packs) and hydrogen fuel cells (H2 electrolyser) which is combined a Heila IQ optimizer. Battery storage is combined with a real time monitoring system. This system enabled the winery to survive the 2017 wildfires by switching to full island mode, allowing the business to operate for 10 days independently (*ibid*). The vineyard aims to become carbon neutral by 2030 (*ibid*).

The Santa Rosa Junior College (SRJC campus) microgrid demonstrates how the shift towards distributed energy benefits the campus at multiple levels. The SRJC campus is powered by a 2.6 MW solar carport and supported by 1.3 MW Tesla battery storage [84]. The grid connected-microgrid supplies up to 35% of electricity on campus, and halved peak load. The campus' achievements (GHG reductions, RE share) are line with California's 2016 Global Warming Solutions Act and the Clean Energy and Pollution Reduction Act [84]. Funding was received from the California Energy Commission, the California Public Utility and the City of Santa Rosa.

The regulatory challenges for Sonoma County are similar to those of the Latrobe Valley. The system is seeking 'off gridding' in the fire season while maintaining essential services. To avoid legal challenges due to grid-induced wildfires, utilities now employ public safety power shutoffs during adverse weather events. This is further driving consumers towards off-grid solutions. While the Californian utility PG&E follows a centralised model, meaning the utility operates the transmission networks and provides retail services, alternatives, such as Community Choice Providers, are increasingly emerging. Community Choice Providers are local non-profit organisations established to provide electricity services to residents and business that have been found to be effective in negotiating better rates and greener power sources while being more accountable to its community. Bespoke campus-style microgrid solutions are preferred over extensive grid integrated projects connecting multiple customers. Importantly, regulatory change by the regulator (California Public Utilities Commission) is now being considered for designing a framework for the commercialisation of microgrids. A range of rules for standardising microgrids is considered, including for impact studies, tariffs, system, public and workers safety, interconnection processes and costs—all to be developed over the next 36 months [85].

3.5.3. Aegean Islands/Greece—Case Study Findings

Tilos is part of the Aegean Island group south-east of Greece. The island's small population (around 500 residents) fluctuates strongly as 13,000 visitors pass through every year. (Eco)-Tourism is the main income. Tilos' electricity supply was based on diesel generators fuelled by imported oil from the mainland, which is associated with high economic and environmental costs. In the tourist season, energy demand exceeded maximum capacity, especially during peak times and caused regular blackouts, which largely impacted on businesses and livelihoods [86,87].

The island's reliance on fossil fuels contradicts the focus on nature conservation. Under the EU's Natura 2000 program, the largest network of protected areas worldwide, Tilos is declared National Park. A shift towards clean energy (renewable electricity, EVs) is required to ensure high-quality tourism and promote ecological sustainable development. An innovative microgrid with integrated renewable energy and battery storage has been funded through the Horizon 2020 program, an EU innovation program for low carbon energy, next-generation batteries and e-mobility [88]. The system is operated by a private renewable gentailer (Eunice Energy Group), and the grid is provided by electricity distribution company HEDNO, a state owned Distribution System Operator (DSO).

Tilos' achieved 100% renewable energy in 2019, contributing to Greece's 2030 RE target of 32% RE [86]. Tilos' hybrid power station is connected to a wind turbine (800 kW) and a solar farm (400 kW), an EV charging station has also been built. Wind energy alone meets 70% of Tilo's electricity demand [88]. The energy transition has a focus on public engagement and social issues are guiding business development models and policy instruments. With a more reliable energy supply, businesses were able to extend the holiday season.

Tilos acts as a pilot and offers opportunities for Eunice Energy Group to replicate the model on larger islands, Lesbos and Chios are powered by diesel generation and have seen population growth through refugees migration [86]. The reformed EU Energy Market Directive 2019/44 acknowledges the effectiveness and cost-efficiency of community energy initiatives [89]. Further innovation and consolidation of regulatory approaches can be expected.

3.5.4. Ganjam, India—Case Study Findings

Ganjam is a coastal district in the state of Odisha in East India. Its economy is based on agriculture and the population is concentrated along the Bay of Bengal and the valleys among the main rivers. Ganjam is frequently affected by cyclones and subsequent flooding, which displace large proportions of the population, leaving behind major destruction. The most destructive cyclone hit in 1999, others followed in 2013, 2014 (cyclone Phailin), and most recently cyclone Fari in 2019.

Microgrids have been adopted at various levels to reduce the economic losses caused by damaged energy infrastructure and the long-lasting power outages. Disaster responses involve state-led, utility-centred grid transformation and community-led energy projects. In 2014 after Phailin hit, the Asian Development Bank offered a loan of USD 100 million to the state government to build cyclone-proof energy infrastructure. While the opportunity for a microgrid was discussed, the utility focused on reinforcing and diversifying the existing infrastructure (underground cabling, pole upgrade, additional grid sub-stations and multiplying power sources to each grid). Other improvements involved grid automation, smart meter uptake and some rooftops solar and solar streetlights [90,91].

An example of a community microgrid is Maligaon, a village in rural Odisha (50 homes). In 2009, Australian energy company Ekistica in collaboration with Indian NGO Gram Vikas installed a solar microgrid, which was more cost-effective than connecting to the main grid [92]. The project was overseen by a village committee, and monthly payments covered the operation and maintenance undertaken by villagers. By 2013, the village was connected to the main grid, and the microgrid became redundant, oversight failed, and the project derailed. When villagers became dissatisfied with the unreliability of the main grid, Gram Vikas agreed to rebuild the microgrid, this time with a focus on household electricity demand and adjusted tariffs that reflected affordability.

The regulatory environment in India—the main grid is state-owned but both public and private ownership arrangements occur for generation—allows for a diversity of energy supply options, in particular in regions that are not grid-connected or where electrification is insufficient and unreliable.

3.5.5. Christchurch/South Island New Zealand—Case Study Findings

The historic city of Christchurch sits on the Pacific ring of fire, and experiences regular seismic events, most are minor, but the 2011 earthquake was one of the most destructive and deadly. About 70% of inner-city buildings collapsed, other parts were uninhabitable. Around 10,000 homes were destroyed, and 185 people died. The city took a holistic approach to the rebuilding of Christchurch as a "smart city". This approach was driven by the risk of repeat events, the scale of infrastructure damage (buildings, roads, power grid), and the desire to shift to a lower-carbon path and a more livable city.

The earthquake and the geology of the local area led to severe soil liquefaction and extreme ground shaking. This contributed to the extent of the destruction but also led to generation-level outages and affected buried cables and transformers. Interviews with key stakeholders confirmed that the development of a microgrid was not considered during the initial recovery phase or the rebuild of the inner-city as the destruction of essential infrastructure was too large. Instead, diesel generators, of which many locals owned their own, were deployed. Like Odisha, the rebuild of the energy infrastructure did not involve a microgrid but focused on grid resilience.

Enhanced energy efficiency and renewable energy use for buildings will reduce the city's carbon footprint [93]. A core pillar for Christchurch's target for net zero emissions by 2045 (excluding methane), is the Electric Vehicle initiative, which will decarbonise the transport sector [94]. The rebuilding of a smart city has drawn national and international attention to Christchurch as an innovation hub and a climate change leader.

Table 6 shows how the case studies differ regarding their enablers and barriers, however, the demand for grid resiliency appears to be a common driver among all examples. A common barrier is the reliance on public/external funding and regulatory issues.

Table 6. Summary of the findings from the international case studies: enablers, barriers to Emergency DES adoption and lessons to be learned.

Region	Type/Size of DES Technologies	Additional Enablers	Barriers, Including Legal and Regulatory Challenges	Lessons to Be Learned
California, Sonoma county (Stone Edge Winery only)	• Capacity: 785 kW • Components: solar PV, microturbine, hydrogen fuel cells, 50 kW battery storage, real time monitoring	• Weak electricity grid • Demand for grid resiliency amid worsening wildfire seasons • Falling cost of DER • Large number of microgrid market players present • Public outreach approach • Regulatory reform • Progressive policies supportive of RE	• High capital costs—greater need for standardised solutions • Reliance on public funding Regulatory challenges remain • Initial resistance from utilities but this is changing	• most relevant example, but bespoke project • reliance on public funding • Utility-driven regulatory change supportive of microgrids
Aegean Islands/Greece	• 800 kW (Wind turbine) + 160 kW (solar PV) • Innovative battery ($NaNiCl_2$) storage • EV charging	• Access to EU funding • Shift from imported diesel fuel to RE • Highly variable demand during summer (tourist season) • regular power outages (up to 2 weeks)	• Costly/problematic to maintain electricity grid/interconnection • Reliance on EU funding • Variable demand (season) • Need for engaged distribution service operator to own and operate	• Operated with EU support • utility run project • in Gippsland this would be equate to AusNet (network provider) investing in and operating the emergency DES
Ganjam district, State of Odisha/India (Maligaon Project only)	• Regional areas supplied by radial power networks • battery storage would be useful in frequently disconnected areas • connecting remote towns on single line to a microgrid is achievable but requires the collaboration with local utilities	• Issues related to safety of batteries in fires, e.g., Tesla batteries are fire-resilient • Codified regions have their own set of network designs in response to wildfire risk (de-energising lines, underground service lines—adds to complexity) • Required maintenance of technology may be challenging at the local level	• Mismatch of household demand and payments • community involvement in governance/maintenance structures (third party-run) • Reliance on external funding	• Shows the need for ongoing management and maintenance • Important in the context of back-up infrastructure used in emergency situations
Christchurch/New Zealand	• Cogeneration where different renewable energy generators are integrated can address the reliability of solar in this instance.	• Extended wildfire recovery/preparation • wildfire smoke can reduce solar generation substantially—as low as 3% of capacity but has year around benefits	• More reliable, low-carbon • Damage was too extensive for microgrid to be adopted • Fewer remote areas • Privatised deregulated market • Monopoly of distribution network provider Orion	• Fewer solar PV resources and less uptake than Australia • Regulatory lessons for the specific model envisioned in this report remain limited

4. Discussion

Our study shows that responses to extreme weather events differ among the international case studies. The adoption of DES (typically in microgrid configurations) appears to be more suitable as a response to assist remote communities in accelerating the economic recovery from, and the mitigation of, climate extremes. None of the international examples are designed with an Emergency DES in mind, with one exception: California. Therefore, the Californian case studies are most suitable for comparison as Sonoma County faces similar challenges to the Latrobe Valley/East Gippsland region—both seek reduced dependence on the centralised grid and 'off gridding' during the wildfire season while maintaining essential services and operations.

Technologies which have been integrated into the DES largely involved solar PV arrays/solar parks, small wind turbines and in bespoke cases hydrogen fuel cells. All microgrids were backed up by battery storage, but the battery's chemical composition varied. In addition, a control system allowed the islanding of microgrids and the independent operation of electricity powered systems in times of crisis. The control system can also assist to optimise the DES economic efficiency, e.g., batteries are charged during off-peak times and deliver electricity during peak times. The size of DES discussed here, did not exceed 1 MW, all systems were bespoke served different purposes as they included businesses, university campuses and/or remote communities. DES also support e-mobility and encouraged the installation of EV charging stations (Greece, California).

Our findings reveal that DES uptake is driven by environmental concerns. Climate change is a major driver behind microgrid adoption (California, Greece) as well as the uptake of low-emission technology solutions such as EV charging infrastructure (California, Greece, New Zealand), while in developing nations (India) electrification and energy security drives decisions for the types of energy infrastructure. As Australia is highly vulnerable to the compound risks of global climate change (droughts, wildfires, strong winds, ocean-atmosphere coupled climate phenomena), addressing environmental concerns are synthesised into incentives to address climate-related infrastructural damages.

We found that DES adoption is strongly driven by economic incentives, microgrid adoption proves to be more cost-effective over the recovery and/or (re)connection to the conventional electricity infrastructure following extreme weather events. The financial losses for communities, and in particular the costs faced by utilities, due to temporarily power interruptions/outages and permanent damages to energy infrastructure (high costs of recovery) caused by extreme weather events, exceed the costs of installing new distributed energy systems, which show higher climate resilience (California, Greece, Australia). In remote India, the connection to the centralised grid is more costly than the cost of installing a microgrid.

DES also meet community needs (rural India, Greece, rural Australia/islands). The development of suitable business models in collaboration with the community allows increased flexibility in meeting individual household electricity demands, adjusting to household incomes (India) and improving the overall economic position of residents (Greece).

The examples also confirm that the adoption of Emergency DES is supported by a multi-stakeholder approach related to the governance and financing of microgrids.

Desktop research and research calls with relevant stakeholders have also shown that the scale of the disaster matters. In the case of the Christchurch earthquake, the access to electricity required immediate solutions, and resulted in the use of diesel generators and the modernisation of the conventional electricity infrastructure (underground cables, rewiring, etc.), thus a microgrid was not considered.

The institutional environment (funding, regulatory aspects) determines the governance of energy solutions in response to extreme events. The case studies shown demonstrate that energy solutions are addressed by different institutions. The Indian examples (capital city vs. rural area) show, despite both projects relying on external funding (Asian Development Bank, international NGO), their energy solutions strongly differ; the community/NGO-led project favoured an innovative pathway, while the public utility rebuilt and modernised the conventional infrastructure. It should also be recognised that the cause of the power outage and the community's energy needs (city/rural) strongly differed. While our study confirms that initial resistance from utilities (public, private) is evident across all case studies, business models of public utilities are changing. As the decisions by the centralised utility model (PG&E/California) and rule changes in favour of DES by energy regulators (Californian public energy utility, Australian Energy Regulator) confirm. The microgrid on the Greek Island Tilos is governed and financed through a supranational body (EU project), and demonstrates the success of community consultation, engagement of local energy companies and piloting replicable island solutions for distributed energy.

In summary, the main considerations for Emergency DES are:

- Different suites of technologies are available, and Emergency DES can gradually be upgraded or modified to meet and adjust to community needs;
- The size of the disaster-affected community and the scale of damage determines the technical response (microgrids might not be the quickest and most suitable solution at the time of recovery);
- Multi-level governance-style leadership assists the energy transition (administratively, financially, legally), and building climate resilience;
- Community engagement and consultancy processes are key to ensuring social acceptance and persistence of a microgrid (i.e., the organisation of maintenance and operation, community needs/various levels of income).

5. Conclusions

This study applied an analytical framework combining empirical and desktop research to explore international case studies of Emergency DES uptake and inform innovations in energy supply in wild-fire prone regional Victoria/Australia. The case study investigations were based on several criteria and included the historical background, technology/business model approaches, target markets (i.e., beneficiaries of DES up-take), enablers, e.g., policy measures and regional 'identity', legal issues and stakeholders involvement. In addition, a PESTEL analysis was conducted.

The PESTEL analysis findings indicate that the adoption of the East Gippsland Emergency DES concept covers five areas of interest.

From a technical perspective, the adoption of DES can lead to a permanent transformation of the electricity grid. The uptake of DES technologies in consultations with utilities and distribution companies support the implementation process. The increasing frequency of extreme weather events requires adequate technical solutions. Distributed energy infrastructure can better survive extreme weather events and therefore is more climate resilient. Federal agencies such as the Bureau of Meteorology and climate experts from academia and government can provide information on regional climate projections and data of extreme weather events to support technology choices.

Although energy supply is primarily informed by technical options, the main beneficiaries of Emergency DES are communities, which subjects technology choices to political processes. There is a high potential for a multi-beneficiary stakeholder effect. The diversity of stakeholders, in particular local communities and councils, will highlight the local impacts of climate change and assist in the proposal and planning of technical solutions which will have social and economic benefits for the directly affected stakeholders, i.e., remote communities and network providers. Planning and thorough consideration of stakeholder engagement processes will support technology choice and implementation.

The study also exemplifies the value of multi-level governance approaches integrating local, regional, state and in particular federal government organisations, and other economically relevant stakeholders, such as utilities, to amplify overall efforts to build resilient outcomes (consistency of risk understanding, secure long-term funding). Stakeholder engagement must be embedded in a framework that recognises government hierarchies, distinctive priorities at various levels and should suggest respective adjustments of approaches when engaging various representatives.

Economically, DES adoption is likely to have economic benefits for all stakeholders involved. On the prosumer side energy security, lower bills, etc., and supply side benefits include low generation costs, no transmission or distribution costs. Although challenges are concerning the governance of maintenance and operation. The upfront costs of DES might be higher than existing structures, but most likely equivalent to or lower than rebuilding/recovering conventional energy infrastructure which depends on the scale of damage. The long-term benefits outweigh future financial losses as DES infrastructure shows higher resilience to extreme events and thus reduces the time off-line.

DES uptake underlies deep social implications. The evolution of DES projects exemplifies a just transition, which describes a shift towards renewable energy that places communities and their needs (and changing needs) at the centre of the conversation, most importantly it includes all residents regardless of household income. The focus on and pathway towards a just transition must be reflected in the political agenda and explicitly in the engagement process.

Limitations of the Study Design

We faced limitations during the empirical research in form of time and budget constraints, which only allowed for a small quantity of semi-structured interviews to be conducted and the limitation of the assessment to four international case studies.

There are limitations related to the legal and regulatory review of the Emergency DES concept for East Gippsland. The review could have been more extensive if the Emergency DES would have been at a later stage of development and surpassed the conceptual stage. Under these circumstances, the review of the Emergency DES was merely of theoretical nature. There are opportunities for future research once a prototype of the Emergency DES has been developed. Our research does not involve work on business model concepts, which had the potential to gain greater insight into possible ownership arrangements, the role of the existing utility/network companies and diverse funding opportunities. It would be valuable to undertake a more detailed study in the future.

Limitations also resulted from the COVID-19 pandemic as the research took place in the first 6 months of the pandemic, between June and September 2020. During this period, border restrictions between the two neighbouring states New South Wales (NSW) and Victoria were in place and resulted in limited interactions between the NSW-based research team and the project participants located in Victoria. We had been limited to virtual meetings (Zoom) and had no opportunity to undertake site visits, which would have supported the research considerably. In person visits would have complemented the research team's understanding of the impacts of the Black Summer fires on the community, landscape, wildlife, and infrastructure.

DES adoption contributes to renewable energy uptake and a zero emission pathway. However, most importantly it reduces the risk of fire danger posed by conventional energy infrastructure. The study confirms that replacing poles and wires with distributed or stand-alone energy systems, substantially reduces the risk of fire ignition and assists with hazard reduction.

Finally, the 2019/2020 Black Summer wildfires in South-East Australia have been broken all records and changing the ways we generate and transport electricity, in particular in remote communities located in ecologically highly valuable bushland. DES adoption is an easy and socially and economically feasible approach to contribute to a zero emission and ecologically sustainable pathway in the face of future climate challenges.

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Appendix A

Table A1. Overview of short-listed countries showing the adoption smart-grid technologies.

Country/Region	GII	Risk Level	Types of Hazard/Climate Extremes	Energy Relibability/Past Grid Impacts	DES Specialisation Drivers	Rationale
United States	3	High	Climatological (hurricane, wildfire) Geophysical Hydrological	In 2018, wildfire in California caused widespread outages. In 2012, Hurricanes Sandy and in 2005 Katrina led to major power outages.	DES: Leading microgrid market (especially 'Sandy States'), West coast looking to follow in wake of wildfires. Visitor economy: examples of eco-tourism	For: commonality with wildfires, existing cooperation on disaster management, similar smart specialisation drivers to Latrobe Valley. Against: challenge to pick a single example from the US Suggestion: North America with focus on California and its DES response to the wildfire.
Europe	High	Low-Medium	Climatological (Portugal, Greece wildfire) Geophysical (Italy–earthquake) Hydrological (central-Europe—floods)	Pan-European floods (central/south Europe), southern European wildfire (Portugal, Greece, Spain, Italy); Earthquake (Italy, Greece)	DES: Examples of microgrids, although energy resilience is less of a driver (increased carbon reduction). Europe experienced major power outages. Italy had issues with battery telecoms back up during earthquake—needed longer duration. Other drivers: Vary among regions	For: high on innovation scale, leader in DES, varying type and propensity for disasters. Against: challenge to pick a single European example. Suggestion: Choice between Portugal (forest fires) or Greece (sustainable resilient islands). Additional research still being undertaken to narrow focus.

Table A1. *Cont.*

Country/Region	GII	Risk Level	Types of Hazard/Climate Extremes	Energy Relibability/Past Grid Impacts	DES Specialisation Drivers	Rationale
New Zealand	25 out of ?	Low-Med.	Geophysical	2011 Christchurch earthquake caused major destruction and led to long power outages.	DES: applied a 'smart city' approach for its rebuild; NZ becomes innovation & tech hub Visitor economy: used "containerised" shop units as tourist attractions, aim to improve liveability of city. Geothermal element in DES energy mix.	For: proximity to Australia, existing cooperation on disaster management, similar smart specialisation drivers to the Latrobe Valley. Against: Geophysical hazard different to wildfires. Suggestion: New Zealand is included; similar drivers and likelihood of building cooperation and links quickly.
India	52	High	Climatological (cyclone). Geophysical Hydrological	2014 Cyclone affected the of Odisha leading to power outages.	DES: Project received funds from the Asian Development Bank; holistic approach Drivers: Internet of Things/IT-enabled DES, local RE resources, citizen-led)	For: investing in DES/IoT, high variety of and propensity for disasters, large potential market. Against: lower on innovation scale, high population density throughout despite large rural areas—quite different from regional Australian example.
Japan (Tohoku region)	16	Med.-High	Geophysical (earthquake/tsunami). Climatological (typhoons) Hydrological	2011 earthquake/tsunami led to outages. Typhoons pose a more frequent threat. Grid is highly reliable otherwise	DES: High degree of innovation, microgrid examples show resilience to power outages during earthquakes/storms Visitor economy/geothermal: Onsen (spa) towns could provide insights for Latrobe Valley	For: innovative, industrially focussed economy with expertise in Emergency DES technology, examples of successful resilient systems. Against: could be some similarities with New Zealand and their response to their last major earthquake.
Indonesia	85	High	Geophysical Climatological Hydrological	2004 Aceh tsunami saw distribution networks damaged for several months. Storms, floods, earthquakes lead to frequent power outages.	DES: lack of relevant examples from market scan, low rates of electrification. However, possible future drivers for this but faces challenges—frequent power outages, low access to electricity (in rural, less densely populated areas), underdeveloped distribution network, lack of inward investment in energy.	For: remote, low density population in parts. Against: lack of examples of Emergency DES activities compared with other shortlisted countries. This could be a useful future market but looks to be a lower priority market to undertake deeper dive research at this stage.

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