

Delivery of Energy Services in Unfamiliar Contexts: Learnings from Fiji

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Abstract

How does one best ensure success in photovoltaic (PV) energy access initiatives? By documenting the design process for a technology-based intervention, developed through a UNSW Sydney and University of the South Pacific (USP) collaboration with the Viwa Island community in Fiji, the study presented in this paper investigates, tests and assesses best practices in implementing PV solutions for the purpose of sustainable development. The work serves as a foundation for project continuation, providing recommendations for implementation and arguing that a sociocultural focus must be prioritised when technologies operate within complex systems.

Pacific Island countries are experiencing compounding pressures as a result of climate change, urbanisation and population growth. In the broader context of the Sustainable Development Goals, this necessitates the urgent deployment of innovative solutions to build on livelihood assets and enhance the resilience of base of pyramid populations. As the nascent off-grid solar refrigeration sector develops, the possibility of clean and affordable temperature-controlled supply chains - cold chains, could play a vital role in empowering remote island communities that are dependent on agriculture or fishing for livelihoods.

Through literature review, participatory fieldwork, technology assessment and desk-based ideation, recommendations have been drawn to facilitate the implementation of energy services enabling cold storage within the Viwa community. Based on a systems thinking approach, this study also highlights how a collaboration between UNSW and USP could assist in deployment of new technologies; delivering direct benefits to remote island fisherfolk, whilst providing learning opportunities for the research community as a whole. Importantly, success critically depends on community consensus and specific measures including a comprehensive and ongoing monitoring program.

1. Introduction

The world is undergoing rapid change and development. This current period, characterised by the immense potential of technological advancement amidst increasing threats of climate change and rising inequalities between and within countries, represents an intersection of grand challenges and great opportunities. Within this evolving nexus of challenges sits energy access for everybody. Its explicit inclusion under the United Nations (UN) 2030 Agenda (Sustainable Development Goal (SDG) 7) not only reaffirms the importance of energy access as a pathway to prosperity, but it acknowledges the role of energy as a gateway to the achievement of other goals. As just two examples, light provides a means to study, thereby enhancing education (SDG 4) and refrigeration enables vaccine storage, thereby improving health (SDG 3).

The UN's ambitious collection of targets, underpinning the SDGs, serves as an overarching framework of *what* must happen, without detailing *how*. Energy service delivery is a priority on the international stage, as 'without urgent action, the world will fall short of achievement of SDG 7 and consequently other SDGs' [1]. The enormity of this challenge has sparked significant interest in innovative solutions, particularly those leveraging the transformative potential of solar power. However, when new technologies are introduced within new contexts, the resultant complexities

extend far beyond those of a techno-economic nature. Designers of development initiatives must pre-empt this impact, be it positive or negative. This paper serves as a narrative of that process, exploring potential sociocultural tensions associated with the implementation of energy services for the purpose of sustainable development. Section 2 and 3 review the global and local context within which change is to occur, with Section 4 describing a participatory fieldwork process and experience. Relevant technologies are assessed in Section 5, with key sociocultural factors identified, connected and mapped in Section 6. Collectively, this depicts a complex socio-technical system, which is further emphasised by Section 7, where varying possible approaches to achieve similar outcomes are outlined. Context-specific recommendations are presented in Section 8 but the underlying learnings, as communicated in Section 9, are widely applicable.

2. Literature Review

2.1. Energy Access and Energy Services

Rural electrification has always been a challenge. It is expensive (per unit of energy) to provide small quantities of energy to remote and dispersed base of economic pyramid (BOP) populations [2] and when compounded with a lack of financial capital, the task becomes so significant that up to 14% of the world population remain without electricity [3]. As defined by the IEA, energy access at the household level involves reliable and affordable access to an increasing bundle of energy services [4]. Under the UN Sustainable Energy for All (SEforAll) initiative, this is mapped on a multi-tier framework (MTF); a matrix of factors that can be aggregated to produce an index of access [5], describing a household's position on a spectrum which stretches from a single kerosene lantern to a reliable grid connection.

There is an argument that 'microenergy is no substitute for grid electricity' [6], yet with only 1% of energy access finance dedicated to affordable, decentralised energy solutions [7], the potential off-grid solar (OGS) holds for the 87% of those without electricity that live rurally [8] is not being realised. While pico-solar (small and portable PV appliances) do not constitute energy access, these products accounted for 94% of all OGS sales in 2016 [9]. Beneficiary desires should transcend MTF indexes, yet rigid energy access metrics can inadvertently pigeon-hole development interventions, compromising unique community-level needs. Productive energy services, defined as: energy products catering beyond household consumptive needs to enable productive end-uses, are an 'experienced good' [10]. After receiving access, end-users typically display an increasing willingness to pay for further services. This phenomenon can be leveraged to enhance financial sustainability, however, interventions must ensure local, as well as global, targets are being achieved.

2.2. The Role of Photovoltaics

Solar photovoltaics (PV) is a powerful enabling technology. Modular, affordable, clean, robust and disruptive; the same cells that power a single lightbulb can also power a factory. In Australia, peer-to-peer energy trading has the potential to undercut traditional retailers [11, 12]. In Papua New Guinea, PV provides a bottom-up alternative to government courting of fossil fuel companies [13]. In 2017, M-Kopa raised \$80 million to distribute solar products across Africa [15]. In Germany, residential storage systems are being pooled to balance grid power [14] and in Fiji, PV energy services can subvert control of remote island fish markets.. Silicon PV is the 'cheapest, fastest-growing power source on Earth' [16] and three primary factors are converging to unlock its disruptive potential in BOP markets:

1. a rapid decline in equipment costs [17, 18];
2. major improvements in end-use appliance efficiency [19, 20], and;
3. innovative business models that sidestep capital costs [10, 19].

2.3. The Inherent Complexity of Socio-technical Systems

There is no silver bullet solution for energy access. From the transition towards AC electrical systems during the 1800's to the deployment of cold storage products in small island developing states (SIDS), technical energy services solve only half of a 'socio-technical' problem. While a pathway for the former was forged largely through engineer-to-engineer discussions [21], today's uptake of PV occurs in complex and stakeholder-rich environments: engineer-to-everyone. Energy technologies bring forth inherent technical, social, political and cultural elements which, when

amplified by issues such as conventional thinking among leaders and fluctuating market distortions, can form significant barriers to uptake [22].

Energy access is a polycentric issue that exists at an overwhelming scale. It is interlinked with cross-cutting and underlying social problems and influenced by overlapping stakeholders with varying perspectives. These characteristics describe a ‘wicked problem’ [23], for which there is no definitive formulation. As a result, there is no definitive solution and approaches must strive not for ‘success’, but *improvement*. This necessitates a collaborative design process. Iterative, empathetic and participatory interventions have the capacity to make positive changes within complex socio-technical systems [24]. This, however, is challenged by the increasing prominence of social entrepreneurship, which simplifies engineer-to-everyone systems by championing an engineer-to-end-user approach. The ‘sustainability of energy projects largely depends on the degree of acceptance within its host population’ [25], yet many entrepreneurial initiatives are heralded as successful based on business-oriented metrics [26]. A perceived importance of market participation compromises community participation, which is vital for sustained impact. In response, social innovators are increasingly being encouraged to examine problems through systems thinking techniques [27–29] rather than focussing solely on the rapid deployment of scalable solutions.

2.4. Solar Graveyards

To ensure improvement without harm, designers must be held accountable for the consequences their actions generate [23]. Often, there is an ‘inescapable tension between two very legitimate impulses: the impulse to respect a community, and the impulse to change it’ [30] and in the pursuit of positive change, the context of the changer will inevitably be imposed on the context of the changee. From the perspective of the intended beneficiary, if this does not occur in a ‘reasonable, recognisable and respectable’ manner, failure is a likely outcome [31].

A recent study tracked 31 solar systems installed at remote health posts in Ethiopia [32]. All stopped working within three years, depriving the intended users of the relevant energy service and generating a reputation for PV as ‘unreliable’ [32]. Such experiences create a barrier of reluctance, counteracting the shift towards clean and practical energy solutions. This outcome is a common theme [22, 33–36], as are the reasons attributed to the system failures. Berger found that installation did not involve managing staff. The resultant lack of ownership saw limited system management and when this caused break-downs, no maintenance action. Furthermore, the distinct societal role of women in rural Ethiopia was largely ignored, meaning that the generalised training program was ineffective in educating the primary user group [32].

Similar experiences from PNG identify barriers including unrealistic expectations, financial illiteracy and cultural heterogeneity [13], which can be exacerbated when communities accept projects for the fear of seeming ungrateful, as has been observed in Fiji [37]. In Mexico, user attitudes were a key determinant of program failure [38], which are largely influenced by program design, as pointed out in a subsequent study [39]. Similar conclusions have been drawn throughout the Asia Pacific region [40], while surveys across South America reiterate the importance of holistic community participation [41]. Once a poor energy initiative is implemented, it becomes intractable, however, every failed initiative produces a unique set of learning opportunities for the next. Four themes are recurring:

1. Engage with the community, specifically women and leadership figures
2. Focus on practical end uses that the community identifies as important
3. Provide robust training and awareness programs that create a sense of ownership
4. Establish an ongoing method of monitoring and allow for adaptation

The aforementioned case studies span 25 years, yet experiences and ‘learnings’ are continuously repeated. Consequently, the designer must first and foremost understand the problem from the perspective of the community. In tackling the seemingly contradictory demand for location-specific, yet replicable solutions, the importance of commencing community conversations with ‘teach us how, or if, we might be helpful’ [30], is often neglected. Additionally, to date, research on ‘energy’ and ‘entrepreneurship’ has largely occurred in silos [42]. This fragmentation limits opportunities for joint learnings in concurrent fields. In an engineer-to-everyone environment, it is crucial that socio-technical systems are well understood. Integration of learnings across the social innovation, international development and PV spheres could facilitate greater success.

2.5. Research Methods

It is desirable to understand an initiative's effects on all of the 'capabilities, assets and activities required for living' within a given community [25]. The Sustainable Livelihoods Framework (SLF) is designed to capture these basic needs, enabling holistic assessment in terms of sustainability. The framework depicts individuals that live in a context of vulnerability, with access to a set of five asset categories. These assets have the capacity to create livelihood outcomes such as increased income, well-being, food security and environmental sustainability [43]. Not all outcomes are relevant to all initiatives, and only the outcomes which the community perceive as important should be employed as indicators. This can be achieved through Participatory Action Research (PAR), which generates knowledge through 'the lived experience of participants' [44]; 'beneficiaries' become 'experts', and solutions are developed in a way that honours a community's agency [45]. PAR is well-aligned with complex systems and wicked problems [46], as it enables all stakeholders to collaboratively determine the most suitable indicators of success.

3. Gone Fishing: A Complex Problem

3.1. From the Desk to the Community

Section 2 found that OGS services are disruptive, yet can help to improve lives and build livelihoods, with community participation a key to success. In designing community-level initiatives, how does one reconcile disruption and participation, particularly when local transformative processes and structures are unfamiliar?

This project is centred around fieldwork on Viwa Island, Fiji, which lies 80 kilometres North-West of Vitu Levu. The island is renowned for its fishing, and the authors were engaged by a local project coordinator to develop a cold storage solution for fish catch. Among ten core principles, PAR demands 'a reversal of learning' and 'handing over the stick' [47]. This has been enabled through appraisal of the Kakala Research Framework, a methodology which 'recognises and gives value to Pacific philosophies, values and customs' [48]. As well as conducting a series of semi-structured interviews with different stakeholder groups, the fieldwork involves *Talanoa* (a community discussion requiring 'deep listening, respect, humility, compassion and generosity') and *Nofo* observations (meaning 'to stay') [48], with three primary aims:

1. to inform energy service recommendations specific to Viwa Island fisherfolk, for improved livelihood outcomes
2. to involve the community in this process not as beneficiaries, but as agents of change
3. to further explore the sociocultural complexities surrounding energy-based initiatives

3.2. Compounding Challenges

Fish is 'one of the most-traded food commodities worldwide, with more than half of fish exports originating in developing countries'. This is significant, particularly when contrasted against the fact that 25% of all landed fish are lost due to wastage [49] and recent projections that fish catch potentials across PICTs will fall by more than 50% by 2100 [50]. In Pacific Island Countries and Territories (PICTs), fishing is a social and cultural mainstay [51–53]; contributing upwards of 50% of the protein sustaining populations [54] and serving as a primary source of income. Here, sustainable development is a fragile process that must negotiate the pressures of increasing debt burdens [55], disproportionately borne impacts of climate change [50, 56] and limited access to technology, infrastructure and financing mechanisms [57]. Not only are small-scale fishers (SSF) exposed to these compounding pressures into the future, but they already sit 'at the bottom of the socio-economic ladder' [49]. The ability to sustain livelihoods in this setting is tenuous. The harvest nature of production, lack of fish storage options and a dependence on intermediaries [49] adds further layers of complexity to interventions aiming to empower the most vulnerable.

4. Fieldwork

4.1. A Tropical Island Paradise

Fiji is often characterised as a tropical island paradise, yet a number of its 100 inhabited small islands remain with limited access to modern energy services, water, sanitation and hygiene (WASH) and education [37, 58]. Viwa Island is one such example. This secluded volcanic outcrop, the outermost island of the Yasawa group, comprises

three small villages: Naibalebale, Najia and Yakani, and is home to 296 people. Access to energy is limited to solar home systems (SHSs) and traditional methods of cooking and lighting, while water is collected during rainy season by a number of large tanks scattered throughout the villages. Research focussed on Najia village, where 68 people live. The researchers were accommodated by the Turaga Ni Koro (village spokesperson) and welcomed in a traditional sevusevu ceremony in the community hall, with approximately half of the village in attendance. The talanoa session was held immediately afterwards, co-led by the local project-coordinator, TNK and researchers. Sixteen individual surveys were conducted; nine male and seven female. Four spouses answered together, and the remainder were individual. Respondents were selected based on recommendations from the TNK ('he is an excellent fisherman', 'she is the local nurse' etc.), through chain-referrals (a respondent introducing the next participant, as they would add a valuable perspective) or simply because a particular individual expressed interest in being involved. Saturation was reached within the first ten surveys. As the results are entirely qualitative, they have been distilled and collated below, grouped under the five livelihood asset categories of the SLF.

4.1.1. Human Capital

As captured in Figure 1, Viwa houses its own solar graveyard. Past experiences have a profound effect on the community's willingness to embrace new technologies, particularly when thirty or forty 350W SHS and both of two 25kW desalination plants are inoperable, many damaged just three years after installation during 2016 Cyclone Winston. The systems were installed without training and at no cost to the residents, meaning that upon failure, villagers either revert to traditional fuels or purchase cheap and often mismatched replacement components. Not only is solar energy perceived as unreliable, but the researchers dispelled many misconceptions around the causal links between solar energy, poor health and climate change. There are few knowledge agents on the island, as educated young people migrate to the mainland for work. This occurs out of necessity and despite a reluctance to transition to the 'busy mainland life'. Facebook, for example, is viewed as a distracting accessory that many of the villagers are glad to be without.



Figure 1: A broken SHS, a 'fixed' SHS and the school's neglected solar system

4.1.2. Social Capital

Najia has three separate clans and 16 households, linked by a strong sense of social cohesion. The chief is in charge, but the TNK executes the majority of the operational decisions, and is therefore well respected. This structure ensures everyone is provided for, including the most vulnerable. Administrative and practical matters are discussed in weekly elders' meetings and a church service is held at 6am, four days per week. The community is the village's strongest asset; facilitating a high capacity to co-operate, both internally and externally. During the dry season, water tanks are deemed as shared assets and managed centrally. Consequently, the creation of a committee, including women, for the management of new technologies was a familiar concept. While women are permitted to fish, men are responsible for providing finances and are therefore the primary fishers on the island. In a household setting, women make the majority of decisions, however, these gender roles are reversed at the community level. Men spoke more frequently in the talanoa session and hold all prominent leadership positions.

4.1.3. *Natural Capital*

Viwa's natural environment is unblemished. The nearby resort commands prices exceeding FJD \$1000 per night for its seclusion, beaches and fishing. Despite the trends outlined in Section 3, village residents have not experienced shifts in ocean productivity; fish is plentiful and people do not catch at capacity. Climate change is, however, a major concern. Houses sit within meters of the ocean and people are well aware of the dominating influence of weather and climate on their livelihoods. Crops are limited to subsistence plots of yams, cassava and coconuts, meaning households are almost entirely dependent on fish availability.

4.1.4. *Physical Capital*

Residents have rigged a small wooden platform, resembling a bird feeder, to hang in a central tree. Approximately 70% of households have access to a phone and 'this is where we receive reception'. Not only are communication services limited, but Viwa has no roads, airstrip or machinery. Women spend a significant amount of time collecting firewood every day, and children must board for high school on the mainland. Asthma and eye diseases are common due to household air pollution, as are illnesses related to poor water quality. Energy services are limited to lights, fans and televisions. From Monday to Thursday, people fish. During this period, excess catch is stored on ice in a broken and rusting communal chest freezer before it is shipped to the Lautoka markets by the TNK. The island has only one boat for this purpose. Through an open-ended question about energy services, it was determined that access to cold storage is the priority for 80% of respondents.

4.1.5. *Financial Capital*

Only two respondents (both women, both small business owners) reported that they were not directly reliant on fishing for their livelihoods. Individuals are capable of catching 10 - 20kg of fish per day, with all A-grade fish sold to the TNK at a standard price of FJD \$4/kg. 300 - 400kg of ice is purchased weekly from the Lautoka Fish Markets, at FJD \$0.13/kg. The return trip costs the TNK FJD \$600 in fuel. Villagers were comfortable with paying for storage, however, as observed on other remote islands, the concept of financial services and loans can be largely incompatible with village culture [37]. While behaviours reflect this notion - ten island pigs are shared, not owned - survey responses do not; respondents repeatedly stated their priorities reside with income generation. The TNK was also affectionately referred to as 'wealthy'.

5. **Technological Review**

5.1. *Technical Parameters*

After catch, fish spoils rapidly. Refrigeration slows this process, but freezing enables storage for considerable lengths of time. To avoid a 'protein denaturation' process, which occurs between the temperatures of -1°C and -2°C, FAO guidelines stipulate that fish must be kept on ice during transit and then frozen rapidly, ideally to below -20°C [59]. A stable temperature is also required to mitigate freezer dehydration, a phenomenon which affects sale prices.

Eleven Najia households engage in subsistence fishing full time. Reportedly, this corresponds to an annual catch potential exceeding 50T. In 2014, Fiji's total subsistence catch was estimated at 16000T, shared among 23000 fishers [60], suggesting that while Viwa represents only 0.07% of the subsistence fishing population, it captures 0.31% of the fish catch. Is this another over-exaggerated fishing story? Not necessarily. Population statistics are unreliable, with another study estimating a population of just 3000 [60]. Figure 2 illustrates the current storage capacity of 500kg. An operational freezer would effectively double the number of fishing days, increasing weekly catch potential to 1.35T. This requires a freezer volume of 2000L, which could also reduce the frequency of fishing trips. The minimum freezer volume should allow for storage of a month of fish storage during cyclone season. At an annual per-capita consumption of 50kg [60], this corresponds to 390L. A cold storage solution should therefore provide:

- rapid and deep freezing to -20°C;
- 390L of fish storage in addition to ice for transportation, and;
- temperature autonomy to mitigate dehydration and enhance food security during storms.



Figure 2: Going fishing, fish storage and fish - Naja Village, Viwa

5.2. AC or DC?

Since 2015, USP has installed five PV-powered AC freezer systems in remote Fijian islands to mitigate catch wastage [61, 62]. Although reliable, this commands a number of components, contributing to high system costs. There are repeated examples of AC fridges being converted for PV applications [63–66], however, dedicated DC refrigeration is on the cusp of becoming widely available [10, 67]. First deployed in 1981 [68], vaccine refrigerators have been responsible for much of the growth and development in the OGS cold chain sector [69] and recently, the emergence of solar direct-drive (SDD) refrigerators have enabled batteries, a key failure point [18, 69], to be eliminated altogether. This technological advancement employs variable speed compressors to optimise energy usage across all levels of sunshine, with excess ‘cold’ stored as ice. Interestingly, the single positive PV experience on Viwa was reported by the nurse; a 60W Vestfrost SDD vaccine fridge, supplied by UNICEF, has been working for twelve years. Ice machines are another burgeoning technology, but sub-1kW case studies to date [18, 70, 71] produce less than 30kg of ice daily, at an equivalent cost exceeding FJD \$0.50/kg.

Table 1 summarises the results of a technology review, which was undertaken for the ten most-cited fridge and freezer manufacturers within the reviewed literature. All available models were assessed based on volume, energy efficiency and temperature range and autonomy, with the key specifications of appropriate products extracted for cross-manufacturer comparison. Although not comprehensive, it provides an indicative sample of the available technologies and is useful in consolidating the work of GIZ [20], CLASP [72] and the IFC [10] in a format relevant for this particular context.

The standard AC freezer, its DC counterpart (solar battery freezer), and SDD fridges and freezers are represented. Volumes range from 50L to 457L, meaning multiple devices may have to be deployed. Designed for medical end-uses, SDD fridges often conform to strict WHO regulations and are therefore expensive. Agri-processing equivalents are not yet consumer-ready, however, end-uses such as milk-cooling for rural smallholder farmers are driving development. Achieving high autonomy at sub-0°C is a further challenge yet to be overcome, as demonstrated by the lack of SDD freezers. These findings reaffirm the Energy for Access Coalition’s classification of cold-chain technology as ‘near-to-market’ [67], with the tabulated characteristics enabling assessment based on direct comparisons:

- Option I is prohibitively expensive
- Options II and III are technologically suitable, but lack technical and economic data
- Options IV and VI are similar in volume, price and low temperature limit, but are smaller than Option VII, which falls in the same price bracket
- Options V and IX are currently only available as fridges, and are therefore unsuitable for fish storage
- Option VII offers the same core features as option VIII, but at a significantly lower price point
- Option X is the only SDD freezer, but is expensive, low-volume and designed for medical ice bags

Consequently, Options II, III and VII are therefore the most suitable. All require batteries.

Table 1: Freezer Technology Assessment

	Name	Type	Supplier	Price \$/FJD	Cited	Compon- entry	Advantages	Disadvantages
I	<i>Dulas</i>	SDD Fridge	UK	9400	[20]	PV: 400Wp	10 year warranty	Expensive and
	VC200SDD	132L	dulassolar.org		[10]			vaccine-specific
II	<i>Modyl</i>	AC Freezer	Fiji	-	[62]	PV: 500Wp E: 980Wh Inv: <1kW	Locally available	Componentry Energy efficiency
III	<i>Palfridge</i>	Solar battery freezer	Swaziland	-	[73]	E: 1.4kWh	Palfridge 2017 Global LEAP winner	Limited information
	CF315	292L	thefridgefactory.com		[72]			
IV	<i>Phocos</i>	Solar battery freezer	US	3000	[20]	PV: 200Wp	Low T of -16°C	2 year warranty
	FR240MP	240L	phocos.com		[10]	E: 550Wh		
V	<i>SolarChill</i>	SDD Fridge	Switzerland	2500 ^a	[18]	-	Cost-effective	In development
	-B	100L	solarchill.org		[20]			
VI	<i>Steca</i>	Solar battery freezer	Germany	3500	[70]	PV: 72Wp	Variable speed compressor, low T of -20°C	Expensive
	PF 240-H	240L	steca.com		[20]	E: 500Wh		
VII	<i>Sundancer</i>	Solar battery freezer	US	3300	[18]	PV: 275Wp	Large volume	Battery capacity
	DCF390	390L	sundancer.com		[20]	E: 800Wh		
VIII	<i>Sunfrost</i>	Solar battery freezer	US	7800	[18]	E: 1.4kWh	Two separate compartments	Expensive
	F19	457L	sunfrost.com		[20]			
IX	<i>SureChill</i>	SDD Fridge	UK	-	[20]	-	Icebank technology for autonomy	Vaccines only, underdeveloped
			surechill.com		[72]			
X	<i>Vestfrost</i>	SDD freezer	Germany	3700	[20]	PV: 300Wp	Slow freezing rate	SDD freezer, SolarChill technology
	VFS 084	50L	vestfrostolutions.com					

^aProjected future sale price - not yet commercially available [73]

7. Ideation

Can the products of Table 1 be implemented whilst respecting the socio-technical complexities illustrated by Figure 3? Section 5 found that SDD is available for vaccines and nearly available for milk, but not yet available for fish. Uptake of innovative products drives progress, but action must prioritise community benefits. This creates a dilemma; not only does technological progress ultimately make better solutions available for villages like Najia, but for fish storage, these solutions are just around the corner. This is a manifestation of the ‘buy now or wait?’ question that arises with consumer goods like smart phones, but with greater consequences. Should unproven technologies be implemented in vulnerable communities? To explore these questions, context-specific examples are needed. Table 2 and the subsequent subsections outline a range of hypothetical solutions for Viwa; qualitatively comparing the relative complexity, risk, readiness and potential positive impact.

Table 2: Solution Ideation

	Reliable	Scalable	Circular	Techno-centric	Entrepreneurial	Futuristic
Complexity	●	●●	●●●	●●●	●	●●●
Risk	●	●●	●	●●●	●●	●●●
Readiness	●●●	●●	●	●	●●	
Impact	●●	●●	●●●	●●●	●	●●

7.1. A Reliable Approach

An USP cold storage solution in Wainika, a remote village north of Vanua Lavu, currently provides fish storage for 23 local households and three surrounding villages. Within three months, the freezer generated FJD \$6000 in revenue through fish storage and the sale of ice-blocks [62]. A similar system has also been installed in Yanuca Island with a six year simple payback time [75], serving community needs in a reliable and replicable manner. For Viwa, two Modyl chest freezers could be installed, leveraging USP experience. High capital costs inhibit scalability, however, researchers could analyse the Viwa project with respect to past initiatives to explore which community commonalities and differences behave as determinants of success and failure over time, thus realising wider impact.

7.2. A Scalable Approach

To see cold storage rolled out across SIDS rapidly, capital costs must be reduced. The SunDanzer DCF-390 negates the need for an inverter, whilst halving power and storage requirements. Viwa is the outermost island of the Yasawa archipelago; twenty islands with a collective population exceeding 5000 [76]. While solar battery freezers have a limited track record in-field and replacement parts cannot be sourced locally, a Yasawa-wide program would mitigate logistical challenges through bulk deployment. Viwa could serve as a pilot, and the development of a robust, capacity-building maintenance and monitoring plan could inform future initiatives for other SIDS.

7.3. A Circular Approach

Batteries are likely to fail prematurely. Beyond system maintenance concerns, this creates a significant waste problem, which exists as a symptom of societally-embedded extractive consumption behaviours: worldwide, 90% of all materials undergo a linear lifecycle; take-make-use-dispose [77]. By 2050, it is expected that PV will represent more than 10% of all e-waste [78], while second-life electric vehicle batteries will collectively contain an excess storage capacity of 108 GWh within a decade [79]. To convert these challenges into opportunities, focus must be shifted towards reuse, remanufacturing and recycling [80]. A battery which is no longer fit for long distance drives will still satisfy the demands of even the largest solar freezer. Circularity aligns closely with the UN 2030 Agenda, but it demands system-wide change, commencing with the manufacturer. The necessary logistical structures and market mechanisms are currently unavailable, but for environmental and economic benefit, any long-term cold storage program should monitor new opportunities to integrate principles of circularity throughout its duration.

7.4. A Techno-centric Approach

Hardware-wise; SDD is optimal. Although limited flexibility constricts potential end-uses, simplicity enables longevity. If combined with a subscription-based financing mechanism, concerns around capital costs and end-of-life processes could also be alleviated. Mobile payments enable a cashless system, and a local committee could be established to enforce payments and report on system performance. Committee remuneration would also incentivise diligent management, whilst creating a source of income for non-fisherfolk. Service fees should be set at a rate that covers maintenance and generates sufficient revenue to deploy the same solution in a neighbouring village; creating a self-financing program. If deployed across Yasawa, a trustworthy fish broker could travel to each village on a fortnightly basis, purchasing fish at fair market prices, thereby removing the power of middlemen and distributing profits transparently. Such a solution is reliant on phone service, a reputable backbone organisation and the commercial availability of SDD freezers.

7.5. An Entrepreneurial Approach

Two starkly contrasting communities reside in Viwa: that of the local villagers and that of the luxury resort. This situation is replicated across SIDS, and can be leveraged for local outcomes. Fiji is an unrivalled surfing destination, but its powerful waves damage hundreds of tourist surfboards beyond repair. These are left with resorts for disposal or to be kept as trophies. Despite being made of the same foam and fibreglass as surfboards, high quality iceboxes are expensive and Viwa fisherfolk often rely on plastic drums, as seen in Figure 2. A social enterprise could engage tourists in an icebox-making class at surfing resorts, creating value from waste. Icebox autonomy is largely dependent on the thickness of insulation, and providing individual households with the ability to store fish in a decentralised manner is empowering; particularly if deployed in tandem with PV-powered ice-makers, which are SDD by definition. This approach is not particularly scalable and doesn't generate wide-spread impact, however, it creates a multitude of intangible benefits through its engagement of tourists with social and environmental issues.

7.6. A Futuristic Approach

In response to a growing global middle class and climate-induced risks to food security, the Birmingham Energy Institute is pioneering a new cold chain system [81]. Cold energy can be captured through LNG regasification facilities and liquefaction of air, to be stored cryogenically. Fiji has an abundant solar resource, but cold chains demand near constant cooling power in both static and transportable forms. A piston engine, powered by the vaporisation and expansion of liquid air, is undergoing development and could enable emerging economies to use liquid air as both a zero emissions fuel and a cooling agent [82]. Case studies in Tanzania and India have demonstrated the techno-economic potential of such an approach, however, significantly more research is required for application within PICTs. Can zero emission engines serve boats as well as terrestrial vehicles? Can liquid air be transported to islands as an ice replacement? Can new co-benefits be derived, such as through the use of LNG for both cooling and clean cooking? These questions illustrate that this approach is not ready for Fiji, but also demonstrate the value of novel solutions. To solve compounding grand challenges in a sustainable manner, business as usual is often not an option.

7.7. What's the Catch?

Innovation can drive significant impact, which creates hype. In turn, hype can divert attention from the root causes of the problems which catalysed the initial innovation. The freezer is being implemented not to freeze fish, but to improve livelihood outcomes. Therefore, success cannot be determined by energy efficiency or autonomy days, but by the positive changes it enables in the socio-technical system within which it operates. The above 'ideation' stage paints a wide canvas of what *could* be done, allowing each approach to be critically assessed within a broad context of possibilities. However, when assessed against Figure 3, even the simplest initiatives introduce complexity. Education ensures system longevity, but may heighten power relationships. Cold storage enables income generation, but may exacerbate wealth inequalities. This raises further questions: will income generation result in improved community wellbeing, or has this concept been unknowingly imposed on the community by researchers? Analysis of complex problems can lead to paralysis. Figure 3, an exercise in systems thinking, can overcomplicate potential flow-on effects because it doesn't incorporate the community's ability to self-manage and adjust to unfamiliar situations. USP has repeatedly deployed freezer systems which provide villages with a multitude of benefits, without the accompanying concerns. Such initiatives must therefore be taken as worthwhile. How then, can these be built upon?

8. Recommendations

It is recommended to install two SunDanzer DCF-390 freezers, Freezer A at Viwa and Freezer B at USP, with additional island revenue captured by a newly-established 'fisherfolk collective'. A comprehensive training program will be delivered by UNSW and USP, incorporating technoeconomic and sociocultural monitoring methods. Daily energy, temperature and financial data are to be collected and community experiences documented to gauge intervention influence on all facets of the complex system. Each freezer requires only 275W of PV and 300Wh of storage. Staggered installation creates an iterative process, the importance of which was emphasised in Section 2.3. During phase one, Freezer B should be used for experimentation to determine SDD potential and to compare performance at USP with Freezer A at Viwa. This approach incentivises ongoing engagement from all stakeholders; enabling the research community to explore a novel technology and Najia village to earn its second freezer in phase two.

Lautoka market prices for A-grade fish range from FJD \$15 - 30/kg [83], corresponding to weekly surplus profits of FJD \$1000 - 5000. The exact amount and distribution of this capital is a key determinant of the way in which livelihood assets will change in response to a new freezer system. Until this is confirmed, it is recommended that the net profits extracted by the TNK are capped at their current levels. Freezer B is to be 'purchased' by the community, at a price to be determined by an economic analysis, that necessitates twelve months of successful system management. This economic analysis should be conducted alongside a review of suitable remote and high-granular monitoring technologies. Importantly, these recommendations can be overridden by community preferences, provided they are to be communicated clearly and to all residents, ensuring decisions are made collectively; particularly around storage pricing.

9. Key Learnings

9.1. 'Glocal' and global solutions

Despite exploring a technological initiative, this paper is largely sociological. Social change methodologies often review SDGs in early planning stages; ensuring local initiatives are aligned with global targets. Although introduced within that context, the participatory methodology of this project limited the influence of SDGs on its outcomes. A 'glocal' approach - designing initiatives around local experiences; then considering opportunities to scale widely - is a bottom-up alternative for addressing global challenges. Here, this enhances the likelihood of success. The recommendations of Section 8 will be communicated to the community. They may not be accepted. For this particular initiative, that is uncontroversial, however, for initiatives focussed on fundamental rights such as gender equality, health and education, it is more complex. To what degree is the researcher empowered to decide how best to address the long-standing root causes of complex issues? This is just one of many issues that could be explored further.

9.2. Market participation and community participation

A desire for scalability can result in a substitution of community participation for market participation. While market-driven solutions have potential to catalyse significant positive change, thoughtless-but-financeable products can also induce harm on already-vulnerable communities. As social entrepreneurship increases in prominence, further integration with existing sustainable development methodologies is important. Initiatives must honour a community's agency by embedding ownership within the design process. While entrepreneurial approaches champion a 'lean' philosophy, beneficiaries must be regarded not as consumers, but experts. This distinction is grounded in respect for their familiarity with their context, livelihood assets and vulnerabilities, and a recognition of the potential to upset this balance. Furthermore, game changing innovation and the resultant disruption can, but should not, overshadow the value of incremental innovation. Iteration enables a staggered, reflective and adaptable deployment of new interventions.

9.3. Unfamiliar contexts go both ways

Unfamiliarity has been presented largely through the researchers' lens; failing to acknowledge that in suggesting changes to a community's socio-technical system, a new context is being created, unfamiliar to everyone. This oversight embodies the ease with which external ideals can be unintentionally imposed on a community. This work, and its subsequent phases, will be of great value if viewed as a case study in itself. Sociocultural impacts should be monitored and compared to those predicted in the systems map of Figure 3. This will enable a retrospective reflection on the value of this particular process in designing thoughtful development initiatives.

10. Conclusion

This paper explores the challenges, complexities and considerations accompanying initiatives that involve the introduction of novel technologies to meet development goals. The Viwa project experience has been conveyed not only for the purpose of specific recommendations, but also to communicate insights into a wide array of associated challenges. Energy access is complex, but urgent. As a result, there are a multitude of approaches to the deployment of energy services in unfamiliar contexts. The underlying philosophies and success metrics differ for each, and while there is no ‘correct’ approach, some practices are better than others. In undertaking the initial design stages of specific project and then critically assessing its outcomes, a greater appreciation for the interlinking challenges has been realised. For Viwa, it is recommended to install a DC freezer and establish a fisherfolk collective to manage this new community-owned asset.

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