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Affordable Innovation Facilitating Renewable Energy Deployment: Two 'Smart' Energy Poverty Alleviation Case Examples

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Abstract

This paper considers one aspect of UN Sustainable Development Goal SDG7 - the intention to 'leave no-one behind' in the transition to renewable energy. The target beneficiaries have access to affordable electricity restricted in some way. Two examples of affordable innovation based on artificial intelligence-driven microgrid technology serving clients in developing and developed economies are presented. These initiatives provide direct economic, environmental and social benefits, but also add to the quantum of renewable energy generated in their local areas. A multiplicity of community, enterprise and government actors cooperate in establishing and operating the particular programs described, and community benefits extend beyond simple economic outcomes, e.g., building social capital and trust in the technology. A model characterizing a broader view of SDG 7 realization dynamics is presented. This includes the identification of four kinds of learning space and the notion of tipping points, which may be topics for further research.

Keywords: Energy Poverty, Energy Justice, Renewable Energy, Service Dominant Logic, Service Ecosystems.

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1 Introduction

In 2015 the United Nations identified 17 Sustainable Development Goals (SDGs) to be achieved in supporting regional and global social, environmental and economic security. One of these, was SDG 7: *Ensure access to affordable, reliable, sustainable and modern energy for all.* The UN website (https://unstats.un.org/sdgs/report/2016/goal-07/) suggests there are still 1.1 billion people in the world with no access to electricity and that growth in the use of renewable energy is modest. For others, affordability may be a primary concern, and the terms energy poverty and energy justice have been used to reflect such situations. Specific targets and outcome indicators have been declared as follows:

- Target **7.1** By 2030, ensure universal access to affordable, reliable and modern energy services
- Target **7.2** By 2030, increase substantially the share of renewable energy in the global energy mix
- Target **7.3** By 2030, double the global rate of improvement in energy efficiency
- Target **7.a** By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and

cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology

- Target **7.b** By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support

A UN working group (UNSDG7, 2021) reviewed progress and updated an SDG 7 implementation roadmap with a suggested need for accelerated action in the following focus areas:

1. Closing the energy access gap,
2. Rapidly transitioning to decarbonized energy systems,
3. Mobilizing adequate and predictable finance,
4. Leaving no-one behind on the path to a net zero future, and
5. Harnessing innovation, technology and data.

The UN working group suggested that SDG 7 was in reach, but we must act now. Complex interactions between these five intentions can be observed in practice. Some examples follow. What makes business sense in financing the deployment of a particular technology or a particular disadvantaged group? How might a particular technology / innovation help close the energy access gap? Birol (2007) had suggested there is a gap in the associated literature and in practical action: "*The global energy system faces three major strategic challenges in the coming decades: the growing risk of disruptions to energy supply; the threat of environmental damage caused by energy production and use; and persistent energy poverty. The first two challenges have attracted a lot of attention from the energy-economics community, much less so the need to address the problem of energy under-development*". The ambition is, combining established and emergent technologies, to deliver societal and environmental benefits in an economically sustainable way in the process of increasing the scale of renewable energy generated. The particular question being explored in this paper is how this might be achieved in different energy poverty alleviation settings.

The paper begins by exploring theoretical narratives related to affordability characterization and value co-creation followed by observations from related applied studies. This leads to a context-specific representation of affordable innovation. Affordable innovation case studies describing the utilization of pervasive digital technology in supporting the needs of two different kinds of disadvantaged group are presented. The cases illustrate some entrepreneurial actions that support the twin objectives of energy poverty alleviation and expanding renewable energy capacity. Renewable energy access is viewed as the provision of a service, and a service-dominant-logic framework (Vargo and Lusch, 2016) is used to analyze the cases. It is observed that the realization of SDG 7 goals involves the establishment of and parallel engagement with four different kinds of learning space.

2 Some Theoretical Concepts

'Leaving no-one behind' and closing the energy gap requires collaboration between multiple actors with differing interests providing complementary resources. Leach et al (2012) had argued that innovation in a sustainability context - *"requires a radically new approach, to innovation, one that gives far greater recognition and power to grassroots actors and processes, involving them within an inclusive, multi-scale innovation politics."*

The following sections briefly consider engagement from energy poverty, energy justice, affordable innovation, technology adoption and value co-creation theoretical perspectives.

2.1 Energy Poverty, Energy Justice and Affordable Innovation Concepts

The results of a thematic analysis of the multi-dimensional nature of the problem is presented in Table 1. The integration of diverse actor contributions with 'appropriate' technology is a common solution theme.

Table 1. Some concepts supporting energy poverty alleviation

Theme	Observations	Source(s)
Indication of problem scale and distribution	- More than one billion people worldwide with no access to electricity - 57% of rural Chinese households considered energy poor - 34 million people in the EU experiencing energy poverty	UN SDG 7 (2022): Jiang et al (2020); EPAH (2022)
Energy poverty context: limiting access to affordable energy dampens economic activity, poor affordability limits uptake	- Lack of affordable access to energy, not just access to supply - Energy poverty observed in both developed and developing economies, in remote and urban communities - Energy supply conditions, relative economic status of households, home ownership are influence factors. Renters may be denied direct access to renewable energy benefits. - Costs associated with renewable energy transition may be a barrier - Some studies have a planning perspective and some an action framework orientation.'	Nussbaumer et al, (2012;) Sovacool, (2012;) González-Eguino, (2015); Bednar and Reames (2020); Pachauri and Rao (2020); Adom et al (2021); Dalla Longa et al (2021); Nguyen and Su (2022)
Energy justice representation: a focus on equitable access to affordable energy	Three requisite tenets summarised as: - Distributional justice: where energy technologies are located and who can access their outputs, taking into account 'temporal variations and risks to future generations'. - Recognition justice: identifying where inequalities may emerge, and which communities may be particularly impacted in supporting equitable outcomes. - Procedural justice: the right of inclusion may be necessary but not sufficient if not supported by social and legislative processes	McCauley et al (2019); Hanke et al (2021)

Theme	Observations	Source(s)
Affordable innovation practice: community-engaged development and deployment	- Need to complement technology perspectives with social, cultural and institutional perspectives - Affordable does not necessarily mean low cost provided the innovation is matched with an appropriate business model. - A variety of perspectives in the literature: Bottom of Pyramid innovation, frugal innovation, inclusive innovation, grassroots innovation, affordable innovation, each associated with different application domains, but all involving grassroots engagement in some way, - Three application domains: 'business as usual', 'reform' and 'transformational' - Transformational domain requires entrepreneurs and innovation providers to collaborate, to draw on a combination of 'appropriate' technology, grassroots engagement and 'new economics'	Ernst et al (2015); Pansera and Martinez (2017); Rosca et al (2017); Hossain (2018); Mazumdar-Shaw (2018); Patnaik and Bhowmick (2020)
Selecting 'appropriate technology', making business sense	- Opportunity to support sustainable development by integrating elements of a green and a digital economy technology - Data may help inform appropriate action. Digital technologies may transform the way business is done, subject to infrastructure development - Technology scalability. Network effects cause firms to "invert", shifting production from inside the firm to outside it. They cannot scale inside as easily as outside - Diverse resource accessibility. Facilitating dynamic interaction between different kinds of independent but interdependent actors – adopting a supporting ecosystem perspective - Combining multiple technologies and data to generate and access renewable energy requires a focus on multi-actor orchestration to deliver value.	Ayres and Williams (2004); Carlsson, (2004); Ciocoiu, (2011); D'souza and Williams (2017); Tsujimoto et al, (2018) Jacobides et al (2019); Perelet (2019); Fuller et al, (2019); Somin et al (2020)

Garud et al (2016) viewed innovation as a complex adaptive process where novelty may emerge from the reinterpretation and recombination of existing ideas. Poutanen et al (2016) reviewed the innovation literature from a complexity perspective. On the microlevel, the innovation process was seen to involve interactions, relationship formation, and knowledge creation among different agents. They noted temporal asynchronies at a macro-level could cause disruptions over time, coevolving with other actors shaping dominant discourses.

2.2 A Multi-Actor Service View of Affordable Renewable Energy Deployment

Smith and Stirling (2008) viewed transition management as niche-based, complex and evolutionary within an iterative, four-stage cyclical governance framework starting with problem structuring and goal envisioning followed by establishing transition pathways and experiments that lead to learning and adaptation, with viable outcomes being institutionalised. Feedback, monitoring, action and reaction were part of the process. Polese et al (2017) viewed value co-creation as a complex adaptive process, not just involving dyadic interactions, but occurring in extended settings where "actors do not obtain value directly from the product itself but rather from its use, processing or consumption and by interacting with other entities interested or involved in the process." They discussed the idea of combining service-dominant-logic concepts with systems thinking in considering the multiplicity of interactions involved. Sarno and Siano (2022) reviewed the utility of systems and institutional theories in characterizing the transition to renewable energy. They suggested a service-dominant-logic model could incorporate elements of these theories with feedback as an essential element of the evolution of sustainable practices. **Delivering access to renewable energy may be represented as providing a service that requires the cooperation of multiple actors,** and their paper draws on the service-dominant-logic (SDL) concept to help understand the underlying dynamics. Sarno and Siano (2022) represent value co-creation as a causal loop with actors being involved in resource integration and service exchange that is enabled or constrained by institutions and institutional arrangements embedded in an endogenously generated service ecosystem that in turn engages nested and overlapping actors. Value co-creation is at the core of widely accepted SDL concepts developed by Lusch and Vargo (2008) and extended by Vargo and Lusch (2016), Vargo et al (2020) in supporting business model innovation and services innovation (Maglio & Spohrer, 2013). Barrett et al (2015) had supported the utilization of SDL in exploring service innovation in the digital age. Table 2 presents five axioms associated with the SDL concept and the author's interpretation of them in an energy poverty context.

Table 2. An interpretation of SDL Axioms

SDL Axiom	Energy Poverty Alleviation Interpretation
Axiom 1: service is the fundamental basis of exchange	A Service Entity (e.g., an energy provider of some kind) is responsible for orchestrating the process of value co-creation and for integrating requisite resources. In return, clients and suppliers provide financial and / or other services to the service entity
Axiom 2: Value is created by multiple actors, always including the beneficiary	Value creation and delivery involving multiple actors is orchestrated via one or a set of customer interaction events, with different kinds of events supporting the customer at different stages in establishing access to affordable clean energy.
Axiom 3: All social and economic actors are resource integrators	Collaborating actors contribute access to resources and to industry and community social networks.
Axiom 4: Value is always uniquely and phenomenologically determined by the beneficiary	The value-in -use realized by the client in comparison with other potential alternatives drives deal-making and ongoing support.
Axiom 5: Value cocreation is coordinated through actor-generated institutions and institutional arrangements	A service entity business model identifies a value proposition supported by social and economic services ecosystem actor norms and resources required to deliver value.

Desired and realized outcomes are determined by the beneficiary, but other stakeholders will also have an interest in value realized from their own perspectives. One outcome is the development of mutual trust (or otherwise) (Maglio & Spohrer, 2013). Saviano et al (2017) took

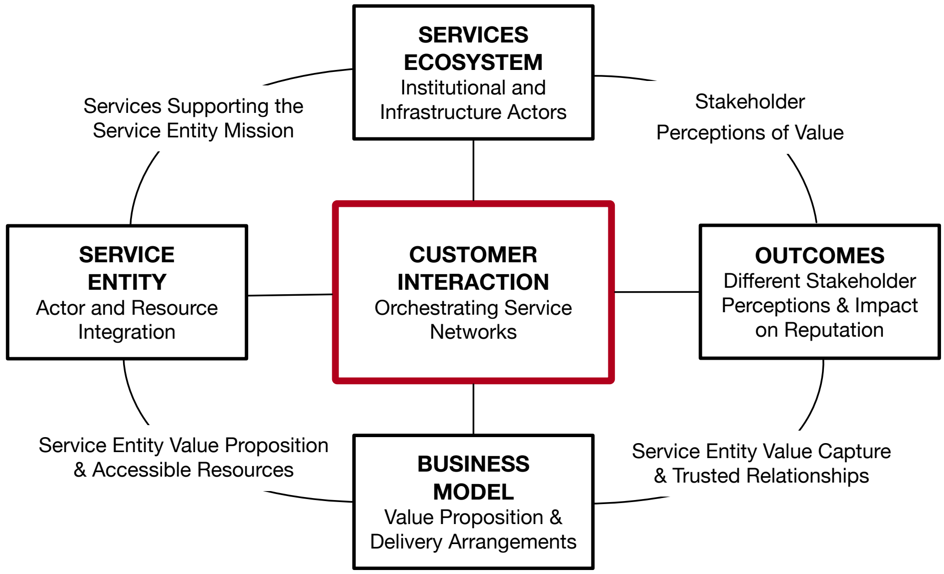

Figure 1. A Service Systems View of Customer Engagement (Beckett and Dalrymple, 2020)

a meta-view of service in addressing sustainability issues, noting the need for cross-sector and cross-disciplinary boundary spanning across a broad services ecosystem.

Renewable energy services ecosystem actors may include entrepreneurs establishing new enterprises, established electricity providers, government regulators, multiple levels of government supporting renewable energy deployment, private investors, business and social enterprises supporting renewable energy deployment as an aspect of corporate social responsibility. A previously utilised SDL-based model (Beckett and Dalrymple, 2020; Beckett, Berendsen and Dommerholt, 2021; Beckett and Berendsen, 2022) combining the prior viewpoints and including feedback loops (Figure 1) will be used in case study analysis. This model may also be viewed from a systems thinking perspective as a form of boundary-spanning object development tool consistent with a function modelling methodology standard, IDEF 0 (1993) (Beckett, 2015).

Summarising the previous sections: in the context of viewing access to renewable energy as the provision of a service, an interactive service systems model with feedback loops (figure 1) may help understand the complex interactions between the related actors, activities and resources involved in delivering a beneficial energy poverty and energy justice outcome (Table 1 concepts).

3 Some Applied Studies: Orchestrating Value Co-creation

The previous sections suggest *what* might need to be done, but not *how*, with community engagement being an important consideration. The following overview brings together contributions from the academic and 'grey' literature reflecting practitioner experience (e.g. Haddaway and Baylis, 2015; Adams et al, 2017) and related academic perspectives. A thematic analysis is presented in Table 3.

Table 3. Identifying potential energy poverty alleviation delivery enablers

Theme	Observations	Source(s)
Learning from renewable energy community deployment studies	- Renewable energy deployment practice has generally been viewed as a socio-technical process with some studies oriented towards the societal aspect, and others towards the technology aspect - A variety of theoretical models have been used as a framework to help gain insights into the process and interpret observed practice, but each may offer a partial view: Social Network Analysis (SNA), Technology Acceptance Model (TAM), Strategic Niche Management (SNM), Business Model Canvas - Diverse activities, institutional forms, goals and values that were not always mainly about energy were observed. - Multi-level networking and learning are at the core of the management academic models - Increasing the scale of renewable energy resources required centralised systems to be re-organised around integrated distributed energy systems	Huijts et al, (2012); Hargreaves et al, (2013); Seyfang et al (2014); Koirala et al (2016); Ruggiero et al, (2018); Tsaur and Lin, (2018); Li et al (2021)
Stimulating entrepreneurial action	- Entrepreneurial action may be categorized as (a) social entrepreneurs developing a business orientation (sustainability, job creation motivation) or (b) business entrepreneurs with a social orientation (business opportunity or utilization of clean energy motivation) - acting as consultants, distributors or integrators - A focus on social entrepreneurship may help alleviate energy poverty and can accelerate a just energy transition - Changing the rules to remove barriers or stimulate action may support balancing ecological and societal considerations - In pursuing global markets international skills and experience-based knowledge about the energy sector and entrepreneurship were essential - Renewable energy entrepreneurs showed a stronger tendency to collaborate with a more diverse set of partners - Investors showed a preference for supporting 'customer intimacy' business models, providing the best service as preferable to the lowest price or the best technology	Loock (2012); Gabriel and Kirkwood (2016); Surie, (2017); Christensen et al (2019); Haldar (2019); Zolfaghari et al (2019); Eitan et al (2020); George et al (2021); Manjon et al (2022)
Engaging with international intermediary and philanthropic organizations	- The World Bank is responding to the twin challenge of poverty alleviation and climate change mitigation in its renewable energy project sponsorship. - Resource flows from non-traditional providers (NTPs) have increased significantly from the 2010's, over the past decade, giving partner countries more choice and more finance; ownership, alignment and speed of project delivery. - New structures of philanthropy may imbue capitalist business principles into the non-profit sector and enhance their potential for social transformation. - Some international philanthropic organizations see micro/mini grid technology and empowering local communities to deploy them as important enablers	Käkönen and Kaisti, (2012,);Morvaridi, (2012); Greenhill et al (2016); Rockefeller (2022)

The three themes: learning from the experience of others, stimulating entrepreneurial action and engaging with international and philanthropic actors are pursued in the following section.

3.1 Some Practitioner Action Programs

In the process of considering potential case studies for this paper, some European and US energy poverty alleviation initiatives were identified. A European Union case 'Atlas' outlined several hundred energy poverty alleviation and energy justice initiatives around the world at various stages of development (EPAH, 2022). An overview of each project was provided and a sample of these was explored further. The majority were situated in developed economics and variously focused on promoting energy usage efficiency, seeking ways to finance programs for the energy-poor or ways to provide direct cash supplements to them. Whilst these were important initiatives, they may not directly add to renewable energy capacity. Others oriented towards solving a particular local renewable energy access problem generally involved some form of micro-grid arrangement. And whilst what was learned may help others with similar aims, no integrating system that could be directly replicated elsewhere was identified, although this remained an aspiration. Some project examples follow.

The Californian Single-family Affordable Solar Homes (SASH) program is structured to promote or provide energy efficiency, workforce development and green jobs training opportunities, and broad engagement with low-income communities. It provides low-income families with free or low-cost solar photovoltaic (PV) systems reducing household energy expenses and allowing families to direct those savings toward other basic needs. More than 40,000 volunteers and job trainees have helped promote and install solar in low-income communities, adding about 30 MW to grid capacity. It may be noted that this program excluded renters and recognises the contributions being made by corporate energy service providers. An initiative in Seville, Spain involved a combination of community education and multi-enterprise collaboration to install PV solar panels on the roofs of public schools and share most of the energy generated with energy-poor families. A South Australian initiative helped alleviate the up-front cost of installing solar PV panels for low income citizens by installing the systems and making quarterly payments over a 10-year period such that saving on electricity bills more than offset the capital charges. A Danish initiative in one area of Copenhagen is combining PV solar and water heating technologies in multi-story buildings having a total of 3700 tenants. The tenants pay a small premium on top of their monthly rental but can access low-cost energy. A microgrid supports electricity distribution and water heating is linked with local cooperative district heating.

One European Union multinational project (POWERTY) has the objective of developing action plans to increase the use of renewable energy by vulnerable groups. In 2020 forty-four Belgium social housing providers formed a cooperative society to ultimately install more than 600,000 solar panels on about 60,000 dwellings. These are generally government-facilitated initiatives with a focus on rooftop solar installation as a cost-effective solution.

Pick (2019) saw the under-representation of solar PV energy generation in Australian apartments as a missed opportunity, with uptake being about 5% of that in detached dwellings. She saw potential solutions to remove barriers to uptake as procedural:

- Reforming strata title legislation
- Reforming network service provider and selling exemption frameworks, and
- Having developers install solar throughout construction

These examples are all situated in developed economies. One large US social enterprise, the Rockefeller Foundation, has made one of its commitments helping to end energy poverty as a trigger to reducing economic poverty, supporting projects in Africa, India and South-East

Asia (Rockefeller, 2022). It sees micro/mini grid technology and empowering local communities to deploy them as important enablers. The Foundation suggests that four times the currently committed investment in renewable energy is needed to meet the goal of restricting global warming to 1.5°c by 2030 and facilitating services to energy-poor communities can be an important part of that. By way of example "*Smart Power India, a wholly owned subsidiary of The Rockefeller Foundation was created to support last-mile electrification in Bihar, Uttar Pradesh, and Jharkhand, three states with high concentrations of energy poverty. By providing technical support to local renewable energy mini-grid companies and promoting an ecosystem for local enterprises to thrive, this institution has emerged as a recognized center of excellence for rural electrification. Over the last six years, Smart Power India has been field-testing new technologies and business models that can take decentralized renewable energy from an off-grid alternative to a mainstream component for widespread rural electrification*." One ambition of this initiative is the establishment of smart grid development and operations to support the delivery of clean affordable energy to some 25 million Indians.

In summary: in practice, combined community and government level initiatives and institutional change were the norm, with an emerging focus on smart micro-grid technology (e.g., Rockefeller, 2022) combined with associated business models (e.g., table 3).

4 Research Gaps

The UN roadmap (UNSDG7, 2021) indicates there is an urgent need to move beyond planning to expanded action if the 2030 targets are to be met. Whilst there are bodies of literature associated with social entrepreneurship supporting energy poverty and justice initiatives, there are fewer reported describing related responsible business entrepreneurship having the same intent. It is argued that business needs to be better mobilized and entrepreneurial action needed to help reach the targets (table 3). The identification of effective, scalable business engagement practice utilizing reliable technologies in "leaving no-one behind" is seen as a gap to be explored.

The need for value co-creation is highlighted, and like affordable innovation, this is seen as a complex dynamic process (Garud et al, 2016; Poutanen et al, 2016; Polese et al, 2017). Studies of innovation in an organization as a complex adaptive process have highlighted learning as a key success factor. The orchestration of government, community and business actions is needed to support rapid renewable energy deployment to meet SDG 7 targets. This begs the question of what has to be learned by who to progress the deployment of affordable innovations in having an impact.

The author has utilized the model shown in figure 1 founded on value co-creation to explore the dynamics of private-public partnerships supporting the long-term maintenance and reliable operation of complex public assets, the dynamics of different forms of entrepreneur incubation services, and the rollout of community energy initiatives in developed economies. But the utility of the model in exploring energy poverty alleviation initiatives remained to be tested, and this was seen as a theoretical gap.

Pansera and Martinez (2017) had explored the affordable innovation literature that could be associated with poverty reduction. They mapped nine types of initiative against three scenarios: business as usual, restoration and transformation. They suggested the transformation scenario involved the development of appropriate technology, grassroots interaction and new economics, but did not provide specific examples, and this was seen as a research gap

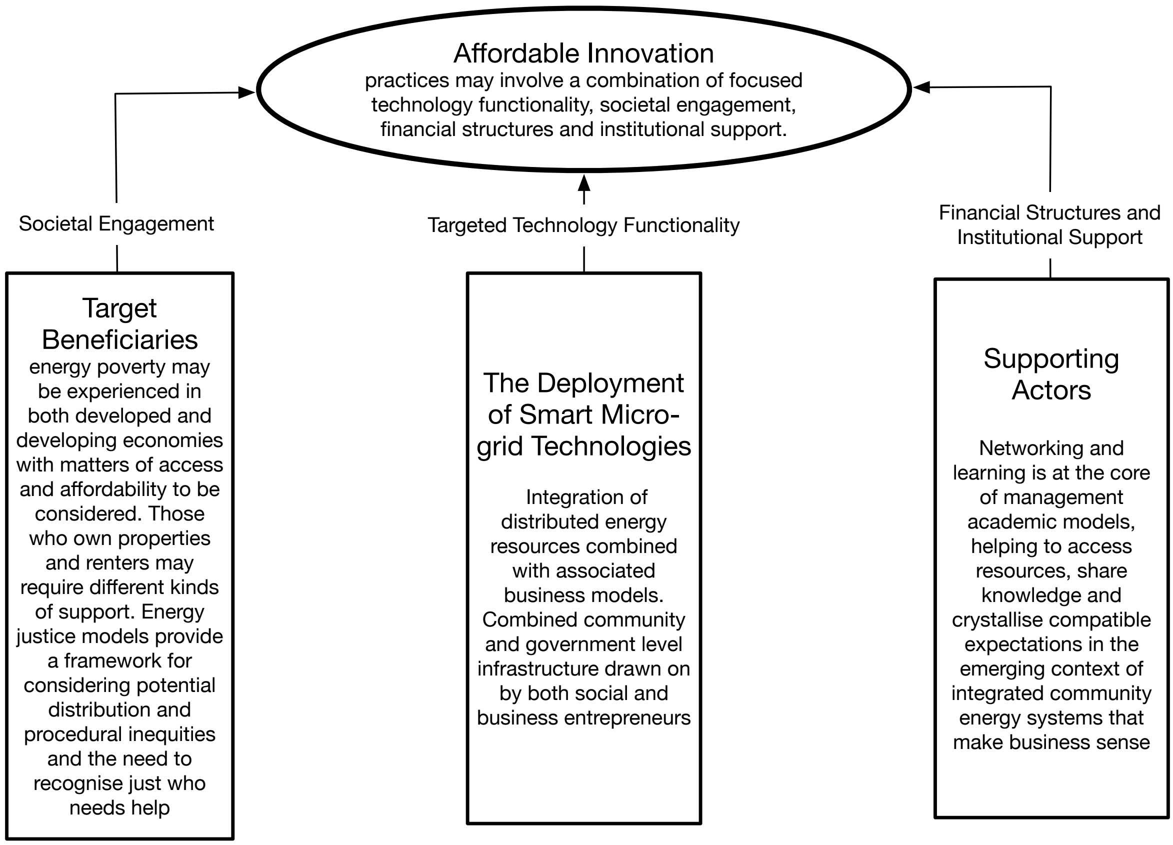

Figure 2. Elements of Affordable Innovation Associated with Energy Justice Delivery

Based on the observations from theory and practice in sections 2 and 3, the following practical assumptions are to be tested in exploring the research gap(s).

1. The pursuit of affordable innovation initiatives orchestrating societal, technological and financial considerations is an appropriate strategy to be deployed drawing on an entrepreneurial mindset to help overcome potential development and deployment barriers.
2. In confronting energy poverty and energy justice issues societal engagement in the process includes the targeted beneficiaries or an intermediary representing them (e.g. a community cooperative or apartment landlord)
3. The targeted technology functionality to be explored is digitally enabled microgrid management systems that integrate established solar energy generation and storage technologies
4. Service ecosystems providing institutional support, access to financial structures and physical infrastructure that may be drawn on in different ways at different stages of entrepreneurial development.

An affordable innovation model summarizing these assumptions is presented in figure 2.

5 The Research Approach

The research question being considered is *how might rapidly deployable affordable innovation initiatives support the alleviation of energy poverty in developed and developing economies whilst enhancing the expansion of renewable energy capacity?* A case study methodology was adopted, which according to Yin (2014) is appropriate in exploring questions of how and why in a contemporary setting. Case studies may have an exploratory or explanatory orientation. Exploratory studies may be used to collect data to support theory-building. Haverland and Blatter (2012) suggest an appropriate explanatory study methodology is dependent on the research goal. A goal may be to test if a particular variable makes a difference or to compare the explanatory merits of alternative theories or to help understand what makes a particular outcome possible, revealing the interplay between multiple influence factors. The latter approach was deemed appropriate utilizing Causal Process Tracing (Blatter and Haverland, 2014) to investigate what made the observed outcomes possible and how they could be scaled up taking into account matters of timing, interaction effects and context. Several authors had adopted a case study approach to consider cause and effect in the context of SDG realization. Tan et al (2019) proposed the co-creation of place-based case studies to support a systems approach in characterizing local initiatives, identifying causal loops and involving local actors in decision-making. The approach taken was referred to as 'placially-explicit, system-based' case study. Ebolar et al (2022) noted that SDG realization may be constrained by local conditions, leading to a focus on frugal solutions. They used a four-part selection process to identify candidate cases: (1) is the innovation sustainable, (2) is there a substantial cost reduction, (3) is there a core functionality focus, and (4) is performance optimized. Wagner et al (2023) considered the role of SDGs as an accountability mechanism and suggested that quantitative research on SDG reporting had utilized statistical analyses of large high local data bases. They identified a need for supplementary qualitative case study research to help provide a more detailed understanding of what was happening at an enterprise level.

In this paper, two kinds of actor experiencing energy poverty recognized in the previously presented theoretical studies – remote communities and renters were considered and one case study of each scenario was selected to facilitate pattern-matching. (Volmar and Eisenhardt, 2020). The unit of study was individual, globally active providers of novel technology platforms supporting the twin objectives of energy poverty alleviation and expanding renewable energy capacity.

5.1 Case Selection

The business enterprise cases were selected by purposeful sampling consistent with the four assumptions outlined in section 4 constrained to Australian entities for convenience. Criteria were firstly, to restrict context variability they had to deploy one form of renewable energy: micro-grid supported solar powered PV electricity generation in confronting an energy poverty/ energy justice issue. Secondly, to establish research boundaries and case credibility, they had to be launched by award-winning entrepreneurs establishing a global presence and having scale-up potential. This was viewed as a causal process element as awards arose from peer review that also considered other possibilities and provided credibility in attracting government and financial support. By way of example, in one case (Allume) an international award was won from a field of more than 450 applicants from 89 countries. Thirdly, the cases had to target potentially excluded energy access beneficiaries, one group serving developing economies and the other serving developed economies. Fourthly, there was good access to longitudinal case data including supporting actors covering the period from enterprise formation in 2016 to mid 2022 to enable the development of 'comprehensive story-lines' (Blatter and Haverland, 2014). In both cases selected there was some variety in the technology deployment arrangements in different settings, providing a rich source of data. The cases are briefly described in Table 4.

Table 4. Two affordable innovation cases confronting energy poverty / access inequity issues

Case	Case Overview
Okra Solar: 'Overcoming the unseen barrier to sustainable energy uptake.' A core team of 25+ employees orchestrating projects in a network form of organisation	Launched in 2015, Okra Solar has developed an AI- and IoT-powered solution that lets energy companies set up autonomous local low voltage mesh grids, along with software that manages billing and monitoring. It has won IoT technology community awards and continues to be deployed in remote communities across Cambodia, the Philippines, Haiti and Nigeria. The solution uses distributed energy technology that can bring a unique form of micro-grid to under-served communities via interconnected systems of solar panels and batteries. Adding renewable energy capacity in these communities also supports the pursuit of government sustainability objectives.
Allume Energy 'We built the SolShare, world's only hardware for sharing rooftop solar to apartments.' A core team of 35+ employees orchestrating projects in a network form of organization	Unlike many emerging technologies that launch in the premium market and trickle down, Allume is deliberately launching into places where renters in particular will benefit the most from savings on their energy bills and the use of the application may flow up.. Launched in 2015, Allume has won an Australian Clean Energy Council innovation award in 2020, a UK Energy Innovation Centre award in 2022, and has been utilized by landlords, social housing providers and newbuild developers who see the addition of solar energy access as a selling point. Allume installations may also attract government support for adding to installed solar capacity.

5.2 Case Data Collection and Analysis

Secondary data was collected from public sources that included company websites, news articles released by the companies or their collaborators, government data relating to grants provided and information related to innovation award announcements. The novelty of the ideas had attracted the attention of industry and regional journalists who reported on milestone achievements and published the outcomes of their semi-structured interviews. The collection covered questions of company startup motivation and conditions, technology development, market deployment, financing arrangements and benefits delivered. In each case multiple recorded founder interviews of up to 30 minutes duration with industry journalists provided detail about company formation and initial development. There were also interviews with other company officers covering particular aspects of operations. Some 30 items were collected in each case, with significant overlaps in topics between them. Data on the nature and timing of investment in the companies was available from finance sector sources. The case study companies also published brief outlines of some projects they had undertaken, and additional information on those projects could be obtained via internet searches. In both cases there was some information on outcomes delivered. In the Okra case, a formal external review, facilitated by data collected on-line, was conducted after more than 12 months of operation of their first deployment in Cambodia, and interim feedback on operations in Nigeria was provided by a partner organization. In the Allume case, 12-month usage data collected from eleven installations was utilized to characterize and quantify financial and energy delivery outcomes. An overview of the data collected is shown in Table 5.

Table 5. An overview of data collected

Data Type	Okra Data Item and (Source*)	Allume Data Item and (Source*)
Interviews covering questions of company startup motivation and conditions, technology development, market deployment, financing arrangements and benefits delivered.	10 interview records: 4 CEO, 2 Manufacturing and Market Lead, 1 Ops Manager, 1 Account Manager, 1Field Supervisor, 1 Village Chief	6 interview records: 2 CEO, 1 Policy Director, 1 GM Europe, 1 CTO, 1 Installation Engineer
Nature and timing of financial support contributions	11 records – early-stage crowdfunding, current status:13 investors (including grants), latest deal $6.5m (FI, 2022)	4 records – current status: 10 investors (including grants), latest deal $6.8m (FI, 2021)
Technology data and status	9 records related to energy micro-mesh system, billing system, simulation tools	8 records related to the core technology, manufacturing and applications
Market deployment announcements	6 records related to Cambodia, Philippines, Haiti and Nigeria	11 records related to Australian. UK and US markets
Individual project case studies	13 records relating to projects and performance in four countries	7 records relating to cases in three countries

*Sources: CW (company websites providing technology information, news items and brief project case studies), IN (industry on-line newsletters providing project announcements, interview transcripts – e.g. https://onestepoffthegrid.com.au , https://www.pv-magazine-australia.com), FI (finance sector websites providing company investment history data – e.g. https://pitchbook.com)

Data items were stored in a commercial data library system that supported multiple data formats, with notes and multiple tags associated with each item to help associate them with underlying themes. Data snippets were first organized into categories shown in Table 3, then within each category into calendar year sets to help identify evolutionary pathways. The cases were compared in two ways: one considering firm establishment pathways to explore how they engaged with a multitude of actors involved, and secondly, to examine how they delivered value to the intended beneficiaries. Consistent with the suggestion of Volmar and Eisenhardt (2020) case data was framed in terms of model components (in this research shown in figure 1) to help unravel the mechanics of the renewable energy deployment practices in a consistent way and facilitate cross-case comparisons. This generic model indicates requisite causal processes supporting the desired outcome are:

- Establishing an appropriate service entity whose mission is consistent with the broader services ecosystem expectations it is part of.
- Establishing a viable service entity business model attractive to potential clients
- Providing access to a supportive services ecosystem, recognizing this may have associated institutional rules, and can provide access to financial, technological and knowledge resource infrastructure

- The orchestration of value co-creation events drawing on the associated service ecosystem and the service entity business model to deliver client value-in-use and identify broader societal value-in-impact

6 Findings

The following presents an overview firstly in terms of the case evolutionary pathways illustrating how the capability to deliver outcomes for multiple stakeholders developed and secondly in terms of operational aspects showing how value was delivered as represented in the model shown in figure 1, with some modification shown as figure 3 for convenience. It may be noted in passing that the individual projects undertaken by the case study firms could be viewed in the same way, as they typically required some time to negotiate and implement and may involve different groups of actors.

Key Findings
- An internationally connected service entity providing an affordable 'smart' micro-grid renewable energy technology platform evolves through a series of stakeholder value co-creation episodes similar to those described in the entrepreneurship literature but with an more diverse set of stakeholders
- The structure of an appropriate service entity and associated business models is conditioned by the particular regional services ecosystem it is embedded in and contributes to
- Value co-creation occurs at multiple levels: with the intended beneficiaries, with project investors, and with government policy-makers and includes perceived value-in-use and value impact considerations.

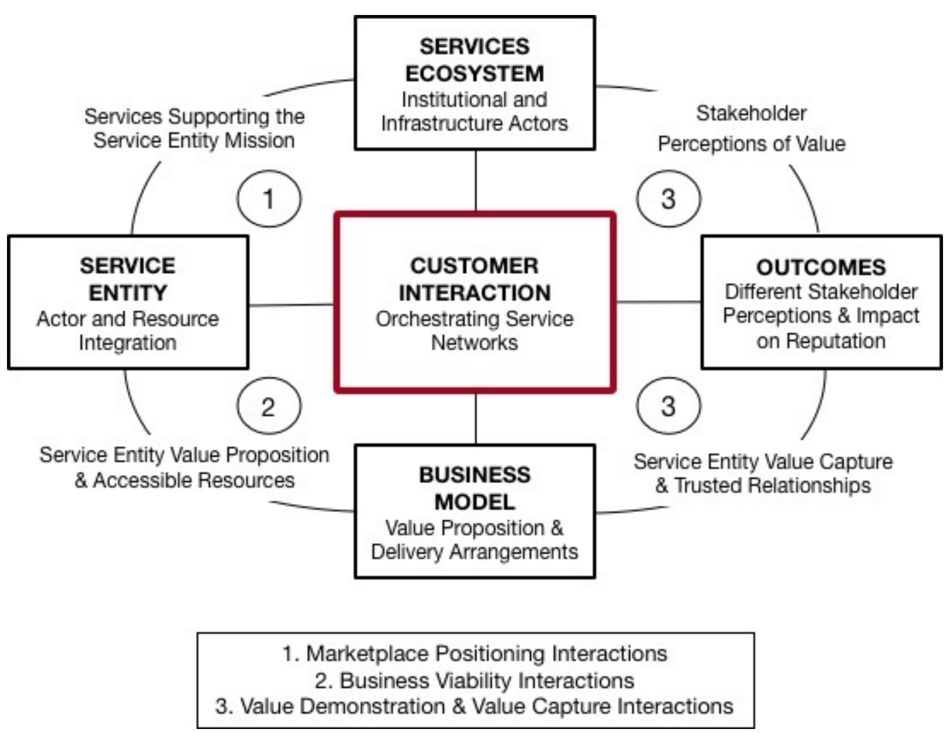

Figure 3. A Service Systems View of Customer Engagement and Interaction Domains

6.1 Stages of Evolution

In both cases, the companies were launched as entrepreneurial business startups with a social mission, and the timeline analysis could be interpreted in terms of the evolutionary stages of such enterprises, as shown Table 6.

Table 6. Case evolutionary pathways

Evolutionary Stage	Okra Case	Allume Case
Concept Development	Pre-2016 - One founder was stimulated to act following a visit with poor villagers in Bangladesh. Later drew on technology tools used in smart building systems development work.	2015 - Founder participation in a university team project to identify technology and a business model to support remote Australian Aboriginal communities.
Start-up Launch, Goal Structuring and Visioning	2016 - Product development was supported by an international virtual team of passionate in-kind contributors. Managing and analyzing large volumes of data that is exported from the system was also important for future development.	2016 - Launched with private equity, participated in formal university accelerator program drawing on experienced mentors and leveraging potential client and investor connections made in 'pitch' sessions.
Business Model Development	2017 - The core electronics could be readily produced and deployed globally but realizing a 50% capital cost reduction compared with a conventional mini-grid required regulatory change.	2016 - 2017 adaptation of a social housing business model to appeal to other building owner and building developer groups.
Initial Customer Launch, Transition Pathways and Experiments	2019 - The company located operations in Cambodia where the initial client village was located and used online data collection and analysis to help optimize outcomes.	2016 - Pilot demonstration program on one building in conjunction with a local government intermediary organization.
Initial Growth, Learning and Adaptation	2019 - 2020 Installations in the Philippines, Haiti and Nigeria followed, each having different regulatory and financial support regimes.	2017 - 2019 - Teamed with innovative manufacturing firm. Completed additional building installations in Australia.
Positioning for Future Growth, Institutionalization	2021+ Expansion into Nigeria was seen as an important scale-up opportunity, serving the largest off-grid population in the world. The role of geopolitics and matters of timing also had to be appreciated. Integrating with a variety of service provision opportunities (e.g., Electric Vehicle charging stations) is seen as a future development opportunity.	2020+ Continued expansion of the Australian base including retrofitted and new building complexes with 8 - 44 tenants. Launch into US and UK markets with regulatory approvals and local partners. Winner of European and US innovation awards. Engagement with international accelerator programs to help make regional connections.

In both cases it took about five years to establish a scale-up base, with market access arrangements rather than technology development being the pacing item and during that time community, government and investor norms changed, reflecting an increasing perception of urgency to limit climate change impact.

6.2 The Service Entities and their Associated Business Models

Associated activities were clarifying the mission and value proposition, pursuing economic viability in building value co-creation capabilities (figure 3, bottom left quadrant: interaction domain 2)

Okra Solar

The company was founded by two Australian technology entrepreneurs who felt they could adapt ideas learned in a different energy management application environment to confront energy poverty issues in developing countries. Okra was formally launched as a private venture in 2015 and established a presence in Cambodia where they would trial the technology. One of the founders moved to Cambodia for three years to better understand the world of the intended beneficiaries and to establish social networks facilitating project development and deployment. Okra provides a smart device that allows energy service providers to integrate local solar / battery energy distribution and financial management in remote villages at a lower cost than alternatives. The term micro-mesh reflected local power distribution via low voltage DC connection, with conversion to conventional AC power at each household. End users may not only be provided with solar energy equipment, but with energy-efficient appliances so they do not have to rely on fossil fuels. No user capital outlay is required, and small usage payments are managed via an e-commerce tool through mobile phone connections. Internet connection may be provided as part of the service. The energy delivery service entity supported by Okra may be a commercial, community or government enterprise, depending on the particular location. By the end of 2022 Okra had installed systems in isolated communities in Cambodia (6), Haiti (3, 1 planned), The Philippines (3) and Nigeria (3, 1 planned), typically serving 20 – 200 households, with plans to increase this to 700, depending on community scale. Reflecting on this expansion, the Okra CEO had noted "*understanding policy and matters of timing is important*" (2021 interview).

Allume Energy

Founded by two Australian Entrepreneurs, Allume Energy was part of the Melbourne Accelerator Program in 2016. Over the following years seven investors supported development through the seed funding and early growth stages. The technology provides renters access to rooftop solar in multi-tenant low-rise environments, including apartments and shopping centres. There are two underlying value propositions: one providing access to reduced cost electricity for "energy-poor" building tenants and the other to access additional building rooftops to increase national solar power generation capacity. The technology is approved for use in Australia, the UK and the USA. An early pitch to investors attracted attention from the real estate sector as an opportunity to support growth in their renewable energy initiatives. Whilst clients and their tenants normally have energy access through the commercial electricity grid, they may not have direct access to the cost and environmental benefits of solar power. Equitable sharing of available solar power between households is managed via embedded algorithms that average power allocation over 30-day periods. The company primarily targets city markets where grid connectivity is well established, providing market access to sell any excess power generated and providing top-up power if there is an Allume system shortfall. No tenant capital outlay is required, although there may be a small monthly landlord fee which is more than offset by savings from behind-the-meter connection to the building's Allume micro-grid. Capital cost may be met by building owners or external investors. By way of example:

> *"On the business side of the equation, the rooftop PV system is installed at no upfront cost through a 10-year "roof licence" with the landlord or the owners corporation, through Allume's financial backers, Ovida. Ovida have obtained an electricity retail exemption from the Australian Energy Regulator for all states and territories except Western Australia and the Northern Territory."* Allume CEO interview 2018

Building owners may be social or commercial enterprises or strata-title collectives. By the end of 2021 more than 300 installations had been completed with projects across three continents.

6.3 The Supporting Services Ecosystem

This involved identifying and engaging with a diverse group of supporting actors in both developing service entity capability and the co-creation of value (figure 3, top left quadrant: interaction domain 2)

Okra Solar

Okra provides a technology platform that helps alleviate energy poverty issues in developing economies in conjunction with institutional, financial, commercial and social enterprise actors establishing projects for that purpose. Access to renewable energy is provided where this did not exist before. The internet and blockchain technology are also necessary supporting platforms, facilitating the accumulation of data from multiple sources that supports reliable system management and ongoing improvement. Okra may simply provide its intelligent management system (called the pod), a complete kit that includes solar panels, an inverter, batteries and the pod and additional services that include provision of a satellite internet connection and distribution system design tools. The actors involved may vary with local conditions, even within one country. In Cambodia the first project was supported by the Ministry of Mines and Energy, the Swedish International Development Cooperation Agency and the United Nations Development Program. Changes to regulatory frameworks were needed to deploy the technology more broadly. The Haitian government, the Inter-American Development Bank and the World Bank had created a license and subsidy approval process for the electrification of communities using microgrids, and Okra established a pilot project under that umbrella in conjunction with a commercial energy supplier. Local social enterprises may be established to participate in some aspects of system deployment and operation. For example:

> *"I trained a LMA (Local Maintenance Agent) on using the Harvest Mobile app – in the native Igbo language – so that they could operate & maintain the mesh-grid network locally. The entire process of travelling to Onono, learning how to deploy Okra's technology, getting household sign-ups, installation, and onboarding the local maintenance agent, took 4 days."* Distributed grid field supervisor, Nigeria

Allume Energy

Allume provides a behind-the-meter technology platform that helps alleviate energy justice issues in developed economies in conjunction with industry sector / government institutional, financial, commercial and social enterprise actors in multi-tenant building situations. This provides previously inaccessible direct access to renewable energy cost savings for tenants. After experimenting with direct-to-consumer selling, Allume is now focusing on developing project-based partnerships with solar providers and apartment developers. Australian real estate group Mirvac is installing the system in its new apartment complexes, and a UK apartment installation was retrofitted with one aim of improving the building Energy Performance Certificate accreditation.

> *"We were so impressed with the technology that we have partnered with Allume and will deliver their shared solar technology on select apartments and we are now assessing it for use across all our assets," ---- " For Mirvac, the partnership is also about the company's commitment to being net positive on energy and water by 2030."* Head of Mirvac Residential, 2019

In working with strata-title apartment owners, engagement may be with one or more body-corporates or an associated social enterprise. Allume has won six innovation awards across Australia and Europe and has won places in startup accelerator programs in Australia and the US, which provides linkages with potential investment and application partners.

> *"Winning the SET Award for Demand Side Innovation is true testament to Allume solving a global problem – how to install solar on apartments. This will help to accelerate our business growth across the world and solidify the SolShare as the go-to technology for apartment solar."* Allume GM Europe 2021

By 2021 Allume had established teams across Australia, in the USA, UK and Europe.

6.4 Orchestrating Value Delivery and Observed Outcomes

The focus was on negotiating and delivering on a succession of 'deals' to deliver value-in-use and value-in-impact (figure 3, two right hand quadrants: interaction domain 3)

Okra Solar

Value co-creation required orchestrating the contributions of different actors at different development and deployment stages. System development was facilitated by a virtual team of technology actors providing pro-bono services as their way of supporting the intended outcome. There were more than ten small scale investments supporting Okra and there have been two formal venture capital funding rounds, one at the seed stage and the other supporting the growth phase. System deployment is via a succession of individually negotiated projects combining the needs of a particular community with contributions by the services ecosystem actors described earlier. Each deployment provides learning that is formally captured in the style of an agile project management 'retrospective', potentially informing the next project. The operational stage is where the real value is delivered. The first Cambodian project was independently reviewed after it had been operating for more than 12 months, also drawing on stored system data. This showed a progressive increase in income for the service provider and an accumulation of benefits for the community. The provision of additional appliances; particularly laptop computers supporting enhanced access to education and washing machines to reduce the time taken for washing. Combined with the time released by not having to harvest firewood, this enabled the community to undertake tasks that earned more income. Although the operation was small in scale, savings in CO_2 emissions were estimated as equivalent to planting 230 trees. In Nigeria, microgrid system maintainability was improved following the introduction of Okra technology, the training of a local maintenance agent and access to data from a multitude of sources.

Allume Energy

As with Okra, value co-creation required orchestrating the contributions of different actors at different market development and deployment stages. Following technology development activities in 2015, Allume participated in an Accelerator program that helped in skill development and offering a clear value proposition to green / ethical investor and government actors. Collaboration with a local entrepreneurial manufacturing firm supported product refinement, regulatory approval and scale-up. System deployment was via a geographically distributed succession of individually negotiated projects, each with a unique combination of service ecosystem actors and perceived value. Building owners / developers may make their buildings more attractive to potential clients and represent their adoption of the Allume system as a demonstration of corporate social responsibility, enhancing reputation. Energy retailers supplying to a building may experience a reduction in income, but still collect connection charges to offset transmission infrastructure costs whilst capturing some excess energy that may be sold elsewhere. Some emergent trends were: (a) connection of the Allume system to electric vehicle charging stations may further enhance building attractiveness, and (b) daytime energy cost reduction may help offset working-from-home costs. For tenants on marginal incomes, reduced electricity costs may provide a small increase in discretionary income. A review of business tenant uptake indicated that not all eligible tenants signed up to the deal offered. For some, independent negotiation with energy retailers could offer a better deal, e.g., if they had a head office that had negotiated bulk-buy rates. Government investment in social housing and in Allume installations support increased renewable energy capacity, helping to achieve committed targets for greenhouse emission reduction.

> *"It's nice for us to create an environment where the Salvation Army is saving money and reducing their carbon footprint and also able to make a little bit of money by selling any additional energy to their tenants' -- Under the pilot program, financier Green Peak Energy will sell the output from 487kW of solar installed on 10 multi-unit commercial properties owned or tenanted by The Salvation Army and other non-government organisations."* Allume Head of Business Development, 2020

7 Discussion

The following discussion considers what may be learned from the cases from practical and theoretical perspectives. The research reported in sections 2 and 3 suggested what had to be done. The cases provided insights into how this might be delivered. The research question has two parts. Firstly, how does affordable innovation support the alleviation of energy poverty in developed and developing economies. Secondly, how does affordable innovation support the expansion renewable energy capacity in developed and developing economies. The cases illustrate complex interactions were needed between multiple actors in developing and deploying their solutions to energy poverty issues. In the literature, affordable innovation deployment was seen as a complex adaptive process, and what might be learned from the cases is considered from this perspective. The expansion of renewable energy capacity, albeit at a small scale is achieved by replication of distributed systems, and this is discussed. Subsequent discussion considers some theoretical perspectives - the utility of the SDL service systems framework (figure 1) and its relation to other models / frameworks, and reflection on interactions between the UN SDG7 implementation focus areas mentioned in the introduction.

7.1 Affordable Innovation Addressing Energy Poverty, Energy Justice Issues

The affordable innovation model shown in figure 2 indicates the need to orchestrate societal engagement, technology functionality with financial structures and support, and how this was implemented in the cases is indicated in the following discussion.

Societal Engagement

Drawing on socio-technical and energy justice literatures, Sareen and Haarstad (2018) argued that sustainable energy transitions needed to consider the co-evolution of Institutional (rules and regulations), material (technological innovation, infrastructure access) and relational (private-public) change in addressing energy poverty issues. They drew on three Portuguese solar PV projects of different scale to illustrate how one of these factors may have the dominant effect in a particular situation. From an energy justice perspective (MCauley et al, 2019) the cases illustrate the following:

- Distributional justice: *where (energy) technologies are located and who can access their outputs.* Both cases delivered their technology packages at the point of use, guaranteeing access. Supporting grassroots access to clean energy from renewable resources was also a strong motivator in attracting talented supporters. Material change away from biofuel/fossil fuel use was a specific driver in the Okra case
- Recognition justice: *identifying where inequalities emerge*. The cases supported two different local community scenarios - remote communities in the Okra case and renter communities in the Allume case. The respective needs initially observed directly by the case firm founders provided a motivation to establish their entrepreneurial enterprises.
- Procedural justice: *the right of inclusion supported by social and legislative processes*. Regional regulatory adaptation and approval was required to permit use of the respective technologies in both cases. Outcomes leading to enhanced community prosperity and wellbeing were dominant in the Okra case. Whilst economics were a consideration in the Allume case, demonstrating support for clean energy uptake was also seen as influential, firstly from the perspective of some renter beneficiaries, and secondly from a landlord corporate social responsibility perspective. In both cases, a significant effort was needed to support relational change in orchestrating private and government sector activities and imperatives. Okra provided energy access in a developing economy where there may have previously been none, and deployment arrangements were inclusive. Allume did not directly engage with intended developed economy beneficiaries (renters) where affordability rather than access could be a primary concern, but instead engaged with actors who could help deliver the desired outcome.

Technology Functionality

Both cases were part of an expanded services ecosystem, providing a digital technology, local level energy integration platform to an under-served energy market sector. This was combined with established solar panel / battery technology provided by partners with a common theme being the need to collaborate across over the whole product life-cycle. A statement made by Okra case CEO in defining its technology development strategy was that *"smart sensors are now cheaper than a bowl of rice"*.

In both cases embedded artificial intelligence helped assure the equitable distribution of available solar power and reliability maintenance, albeit in different ways. Operation of the system was transparent to users in both cases and both enabled expansion by replication of modular system elements. Both systems could be rapidly deployed.

> *"In Bassa in Nasawarra State we have 50 systems installed powering about a hundred households - we were able to install 50 systems in four days and it can make about 15 kilowatts — we are getting about 60% utilisation. You don't need 15 kilowatts to get started, you can even if you have just five systems and keep expanding at low cost'"*
> Engineering Technical Director, Creeds Energy, Nigeria

This outcome in Nigeria helped further a national policy promoting smart electricity frameworks (Monyei et al, 2018).

In a recorded interview, the Allume CEO suggested that the rate of change in the digital economy can make it difficult for government regulators to keep up, and mutual learning activities had to be promoted. He suggested that whilst governments need to frame broad policy initiatives (e.g., set renewable energy uptake targets) that provide broad direction and support large-scale infrastructure development, industry needs to proactively support and help refresh these policies (e.g., Abbott, 2012). In a 2019 interview the Allume CEO observed:

> *"Being a hardware startup in a regulated industry where you have a lot of critical infrastructure and safety concerns, for good reason, to connect to and abide by, can make it very difficult to develop a new product. It takes time and it takes money and when things take time it becomes more difficult to gather money from investors."*

Financial Structures and Support

Both development and deployment structures are discussed here. Both cases were able to reach an early growth phase relatively fast, utilising sweat equity motivated by a common goal, and both won awards, helping to enhance technical credibility. Okra used social media to engage with kindred spirits. Allume used accelerator program engagement in multiple countries to build business networks.

In both cases an entrepreneurial duo with complementary skills established their enterprises after meeting during post-graduate studies. The founders had lived / worked in a number of countries where their observations led to the enterprise focus adopted. They generally worked on foundation technology development before launching the company. This highlights the agency aspect of innovation - the need for champions and entrepreneurs (e.g., Klerkx et al, 2013). They subsequently engaged with an entrepreneurship services ecosystem, interacting with other entrepreneurs, intermediaries and investors, receiving mentoring support and making new connections (Beckett and Dalrymple, 2020). Shakeel et al (2017) had suggested that renewable energy project commercialization occurred through the interaction of technology, market and regulatory considerations, and the case study firms focused on all three, seeking regulatory approvals in conjunction with pilot projects. Three or four years later when both cases had completed a number of projects and were establishing a presence in several countries, they were able to attract venture capital from ethical investors (e.g., Hudson, 2005) to support expansion. Both attracted green investment finance. A commercial investor in the Okra Nigerian projects said:

> *'We are thrilled to invest in and support Okra Solar as it's rare to see an Australian company scale so successfully into many international markets so quickly. Okra Solar*

brings an impact multiplier that intersects and positively contributes towards energy access (SDG #7), better health outcomes (SDG#3), and gender outcomes (SDG#5). This is a great example of how an impact multiplier also drives scale with commercial outcomes, while solving the world's GHG emissions and climate change problems.

A study by Gaddy et al (2017) into venture capital investment in cleantech suggested such investments may pose high risks with low returns, particularly where new materials, chemicals or manufacturing processes were involved. Both cases integrated established technologies in a novel way, and through pilot projects demonstrated a low investment risk. The other aspect of financial structures was the provision of project funding, which was the responsibility of clients and others supporting them. This could involve access to government subsidies, and particularly in the Okra case, engagement with philanthropic organisations consistent with the observations of Greenhill et al (2016).

7.2 Affordable Innovation Expanding Renewable Energy Capacity

Both cases increased renewable energy capacity, albeit at a relatively small scale but important at a local level, providing a basis for ongoing government support and application in other jurisdictions. The Allume website claims that a typical installation will produce around 35MWH of electricity and reduce grid consumption by 35 - 40%. Okra allows for progressive upgrades starting with a 5-kilowatt system. The affordable and modular nature of the case study systems supports scale up by replication and this is an aspiration of the case study firms. An Australian government website indicates what may be possible from the combination of multiple individual initiatives: *Australia has the highest uptake of solar globally, with around 30% of homes with rooftop solar PV. As of 31 January 2022, more than 3 million rooftop solar PV systems have been installed across Australia*. This could be expanded further with a strong uptake of the Allume system in Australia.

Research by Venkateswaran et al (2018) may offer some insights into what to expect in deployment at scale involving grassroots engagement. They studied the impact of the rollout of a simple PV system at scale in India. One million solar lamps were provided to students across India in more than 10,000 villages, reducing kerosene lamp usage. NGOs supported training more than 1400 people from local communities in the assembly, marketing, sales, and after-sales repair service of solar lamps. 350 after-sales service centres provided a free repair service for a year. They observed significant barriers to implementation associated with inadequate understanding of the feedback between adoption, diffusion, and implementation processes. A causal loop analysis of interactions between the actors, activities and resources involved identified between three interdependent factors: affordability, localisation and saturation in delivering at scale. Engagement with a larger number of actors and a holistic life-cycle view was needed to sustain operations.

At the time of writing, both cases had established a business foundation that could support scale-up by replication, but were still gaining experience, and may require a transformation of company operations. In delivering at scale, replication could occur by adding new projects in jurisdictions served and by establishing a presence in new jurisdictions. The longitudinal data suggested both firms adopted an effectuation approach to their internationalization consistent with the observations of Galkina and Chetty (2015), networking with interested partners, rather than selecting international partners according to predefined network goals. By way of example, the Okra founder offered free consulting services to actors in a number of developing economies and chose Cambodia for initial launch following a positive response.

7.3 Affordable Innovation Deployment and Value Co-creation as a Complex Adaptive Processes

Carlisle and McMillan (2006) and Garud et al (2016) viewed innovation as a complex adaptive process where novelty may emerge from the reinterpretation and recombination of existing ideas. This was observed in both cases at the conceptual stage. As noted earlier in this discussion, affordable innovation requires social, technology and finance / support services actors to work together to co-create value, seen by Polese et al (2017) as a complex adaptive process. Poutanen et al (2016) reviewed the innovation literature from a complexity perspective. On the microlevel, they saw innovation process was about interactions, relationship formation, and knowledge creation among different agents. The fundamental question was how innovation emerges out of the interactions of the multiple different players at multiple different stages. Some complexity researchers highlight the dominance of emergent properties and suggest that the optimal way to utilize resources can be considered a self-organizing process. Self-organization is founded on the idea that entrepreneurially driven enterprises are embedded in larger systems; they are complex networks of many independent actors interacting with one another. Those independent actors, e.g. the project sponsors the case firms interact with, self-organise independently in response to changing conditions. This is observed in both cases, initially in the startup launch and business model development stages. More detail relating to each case is presented in the previous findings section 6.3.

As previously noted, Polese et al (2017) viewed value co-creation as a complex adaptive process. From a service-dominant-logic (SDL) perspective (see Table 1) Vargo and Lusch (2016) have argued that "all actors fundamentally do the same things: integrate resources and engage in service exchange, all in the process of cocreating value" (Axioms 1, 2 and 3 – Table 2). Financial transactions may be viewed in this light, recognizing that in the finance sector the term 'servicing a loan' not only means action by the borrower to assemble requisite payments, but also action by the provider to collect and distribute the money (e.g., part to interest, part to capital payment).

In the cases presented here the beneficiaries were not simply given handouts. They entered into some form of payment / income agreement. In the Okra case the agreement was simply based on a usage payment and the beneficiary had to assemble requisite cash, then directly or via an agent store this in a 'digital wallet' (e.g., Rathore, 2016) for subsequent electronic distribution. In the Allume case, the beneficiary agreed to still make payments to their grid energy supplier, and to share or sell energy generated but not used for which they receive a payment/credit. Okra and Allume themselves, whilst aiming to support beneficiaries, receive project-based payments from collaboration partners to recover energy service establishment costs. Those partners had to assemble resources to support such payments. The point to be made here is that thinking about something as simple as payment in terms of service exchange helps reveal potential complexities in the supporting processes.

SDL Axiom 4 (Table 4) states that: value is always uniquely and phenomenologically determined by the beneficiary. In the Allume case some individual renters chose to opt out of the solar access opportunity as the arrangements proposed were not as favorable to them as other alternatives. In the Okra case, the value of access to low-cost electricity was illustrated by the beneficiary's acquisition of additional appliances that could enable them to undertake activities not practical before.

In considering SDL Axiom 5 (Table 2): that value creation is coordinated through actor-generated institutions and institutional arrangements, institutional arrangements included both regulations and community norms that had to be addressed in both cases. Value created included social, economic and environmental benefits. A variety of actor-generated institutions were represented in two supportive services ecosystems, and included social, government and industry enterprises. The entrepreneur support ecosystem included other entrepreneurs, intermediary enterprises like accelerators, and investors, each of which followed their own self-organising agenda. The energy sector services ecosystem comprised solar and other technology providers, energy market distributors, government agencies concerned with regulation, those concerned with stimulating renewable energy deployment and property owners.

This discussion highlights practical aspects of service-providers and communities that also need to take socially responsible action. Supporting environmental corporate social responsibility initiatives can be a source of competitive advantage, and this may be a topic for further research. It may also be noted that external market, political and/or technological changes can influence the actors involved, relevant regulations and accessible resources. By way of example, increased fossil fuel prices may stimulate a stronger focus on renewable energy investment.

7.4 Linking Some Theoretical Models: A Complex Adaptive Process Perspective

Complex adaptive processes are influenced by endogenous and/or exogenous interactions (Carmichael and Hadžikadić, 2019), and in the literature, a variety of theoretical models have been used as a foundation to explore such interactions. As noted in sections 2 and 3 of this paper, it is recognized that some of these models only offer a partial view, and in the following discussion the SDL-based service systems model shown in figure 1 will be used as a holistic framework to suggest connections between these partial views. The potential value of this analysis is in highlighting the underlying complications and pointing to ways deeper levels of analysis may inform a holistic perspective. Customer interactions and orchestrating service networks that involve deal-making are shown as the core activity with four direct linkages to other elements. In this discussion these linkages are viewed as endogenous interactions. Four other linkages between elements of the model not directly linked with customer interactions are shown, and these are viewed as exogenous interactions. Theoretical concepts that may be associated with each linkage are suggested in table 8, along with associated case illustrations.

Table 8. Candidate Explanatory Theories for Exploring Endogenous and Exogenous Interaction Dynamics

Interaction Mode	Candidate Explanatory Theory(s)	Case Illustration
Endogenous Interactions: facilitating customer interaction and resource orchestration		
Service Entity – Customer Interaction	A value co-creation space, a complex adaptive process (Polese et al, (2017). Technology Acceptance Models (e.g. Tsaur and Lin, 2018) have also been used to explore this space	Value co-creation was observed at two levels, firstly in the negotiation of an installation project, and secondly, within a project. An example from the Okra case was bundling the supply of efficient cooking devices in with the supply of electricity. In the Allume case customised artificial intelligence algorithms reflected the needs of individual renters in a multiple s dwelling

Interaction Mode	Candidate Explanatory Theory(s)	Case Illustration
		facility, e.g. in terms of day-time vs night-time use, whilst ensuring each tenant got their fair share of available renewable energy averaged over a 30-day cycle
Service Entity Business Model - Customer Interaction	A space where pricing, terms and conditions that support value delivery are negotiated. Koirala et al (2016) had suggested the use of an adapted business model canvas to bring together the interests of multiple stakeholders involved	In both cases negotiation with the service entity involved an intermediary, commonly a government or private power utility in the Okra case, or a landlord / body corporate/ social housing provider in the Allume case. These entities took care of capital costs. Beneficiaries paid according to usage,
Services Ecosystem - Customer Interaction Two parts: complying with institutional rules and accessing complementary resources.	Some researchers have utilised institutional theory to consider the rules component, e.g. Ernst et al (2015), others have drawn on structuration theory, e.g. Tabares et al (2021). Business ecosystems theory may be used to characterize the resources component, e.g. Tsujimoto et al (2018)	An entrepreneur support ecosystem supported enterprise development and the social networking involved helped build relationships. A business ecosystem specifically supporting renewable energy deployment provided operational resources, with actors being project investors and technology providers, drawn together under individual project management arrangements. Some case specifics are described in section 6.2 of this paper.
Outcomes and Customer Interaction	Seen as a value-in-use space where the real stakeholder benefits accumulate. Macdonald et al (2011) argued that perceived customer value was an increasing topic of interest to a variety of stakeholders and noted an analysis framework should consider customer usage processes. They noted that value criteria may change as the customers goals change	In the Okra case both social and health benefits were observed. Villagers no longer had to collect and store fossil fuel and could use time released form fuel acquisition to help generate income and pursue on-line education opportunities. In the Allume case, funds released as a result of reduced electricity costs could be used to help fund basic needs or expand the discretionary income available. Further details are provided in section 6.3 of this paper.
Exogenous Interactions: independent of direct customer interaction		
Service Entity - Services Ecosystem Interaction	May be viewed through an effectuation theory lens. Drawing on this theory, Galkina and Chetty (2015) suggested that SME service entities work with interested partners rather than focusing on international partners consistent with predefined network goals.	In the Okra case, the CEO offered consulting services free to a number of developing economy actors, initially working with those who accepted the offer. In the Allume case, one outcome from a New York State green incubator pitch was an expression of interest from the city of Albany looking for ways to support 30,000 public housing tenants.

Interaction Mode	Candidate Explanatory Theory(s)	Case Illustration
Service Entity - Evolving Business Model Interaction	May be viewed through a Strategic Niche Management (SNM) lens (e.g., Ruggiero et al, 2018), considering the product-service system offered in the cases here as serving a niche market. Caniëls and Romijn (2008) utilised a SNM model bringing together learning through pilot projects, networking and goal compatibility development elements in studying the evolution of an African biofuels production initiative. They also explored the networking element in some detail via a social network analysis (SNA) to differentiate between core linkages and incidental linkages.	Information about the collaborative nature of the business models developed in the two cases presented here may be viewed in the findings section 6.1. with evolutionary stages shown in Table 6
Outcomes - Services Ecosystems Interaction	Suitable communication makes the different perspectives visible e.g. via triple bottom line reporting that is mandatory in some jurisdictions (e.g. Raar, 2002). Matthies et al (2016) researched the interaction between service dominant logic and an ecosystem service viewpoint. They observed "The incorporation of natural ecosystems includes accounting for the flow of positive and negative impacts through associated value networks. The term value-in-impact was proposed to describe these value flows."	In the current study both cases put significant effort into communicating the impact of their achievements through a variety of channels as evidenced in the volume of data collected for the study.

Interaction Mode	Candidate Explanatory Theory(s)	Case Illustration
Outcomes - Service Entity Business Model Interaction	Has been explored drawing on supplemented stakeholder theory propositions. Greenwood and Van Buren III (2010) considered the importance of trusted relationships between stakeholders. Pinto (2019) considered a key to long-term organisational performance to be at the intersection of stakeholder theory (characterising what had to be managed) and paradox theory (characterising how conflicting priorities may be managed).	An example from the Allume case was the relationship built with an innovative equipment manufacturer that to help ensure trust in the quality and reliability of their system. An example of trust in the Okra case was the use of embedded artificial intelligence trouble-shooting tools that could help maximise system up-time. For example, a Nigerian regional energy provider field supervisor commented: "Instead of spending time on dealing with debugging maintenance issues and organising fixes, I can now focus on elevating the community to utilize productive power and improving their quality of life" (e.g., providing access to additional appliances).

7.5 Interactions between SDG7 Themes: A Complex Adaptive Process

Whilst this study concentrated on the SDG7 theme of "leave no-one behind" interactions with other themes (Section 1) were associated with this intention, e.g. with the mobilization of supporting finance. Following the previous line of thought, the realization of all targets can be considered as a complex adaptive process requiring high levels of learning. Viewing the two cases as instances of affordable innovation and considering the associated activities (figure 2) required the orchestration of resources and the harmonization of expectations of different kinds of actors, as also observed in the academic literature. That literature had suggested networking and learning was at the core of a variety of generic management models utilized in renewable energy deployment studies. In the case data, different learning activities were associated with the different stages of enterprise evolution, but the focus of learning changed as each learning episode provided a foundation for the next one. This involved mutual learning with other actors in a variety of learning domains: learning about business model development in conjunction with other entrepreneurs, learning about access to both enterprise and project finance, learning about the application of rules and regulations to a novel technology in conjunction with regulators. A conceptual model combining observations from prior academic studies and case observations with SDG7 imperatives is shown in figure 4. Different learning domains are clustered and represented as learning spaces where actors from different ecosystems may interact. This concept of multiple generic learning spaces supporting the achievement of UN Sustainability Goals may be a topic for further research.

The SDG7 targets aim to achieve particular outcomes by 2030. These targets are driven by climate change as well as social considerations where there are concerns about global warming reaching 'tipping points' (e.g., Kiron et al, 2012) included in figure 3. A review of solar photovoltaic research by Kazmerski (2006) referred to that technology nearing a 'tipping point' where more efficient and adaptable kinds of solar cells may emerge. MacGregor et al (2007) introduced the idea of a social innovation 'tipping point' where a critical mass of community, government and business actors build momentum for the support of social initiatives. More recently, Koolen et al (2018) investigated the implications of an electricity market sustainable energy 'tipping point' being reached. Viewing the cases presented here from this perspective, tipping points may also be seen as a time to move from one learning space to another. For example, winning innovation

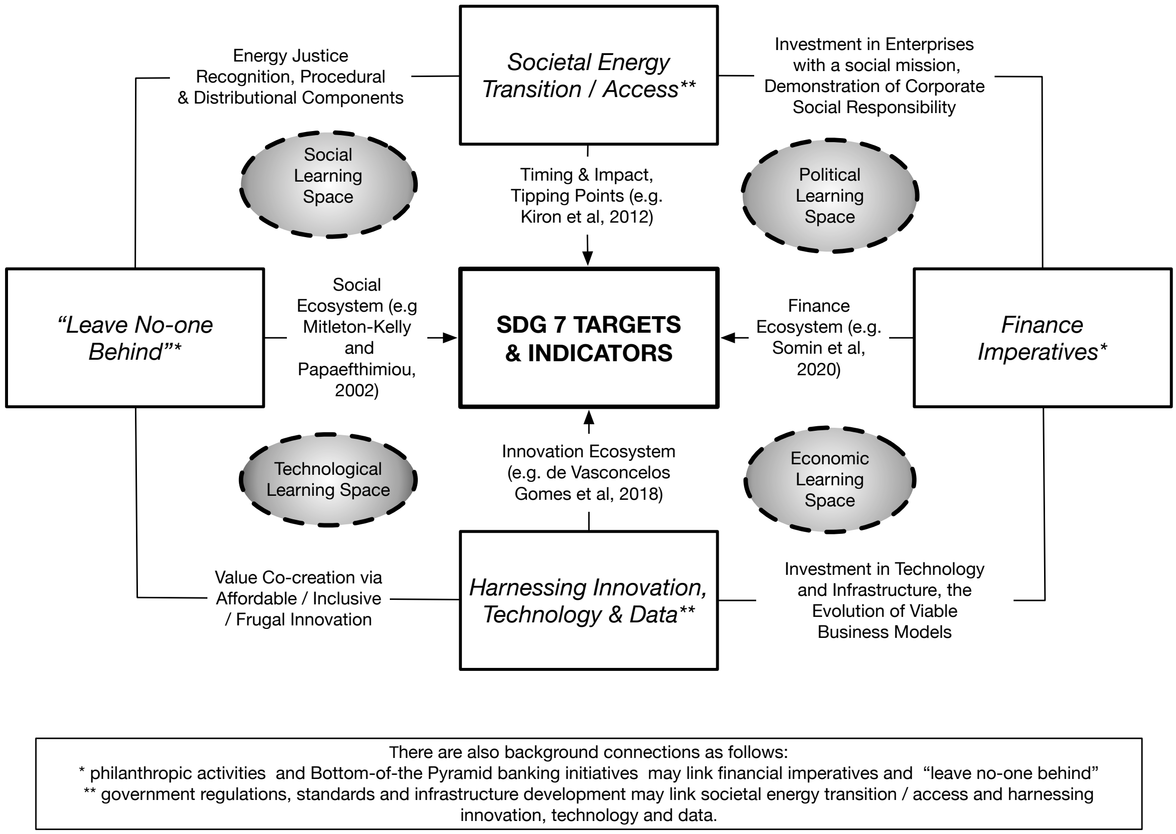

Figure 4. A model of SDG7 realization dynamics

awards helped the case study firms move from a technological learning space to an economic learning space, then to a political learning space as business activities expanded. This raises the question of whether the adoption of the case innovations will reach a 'tipping point' leading to accelerated global expansion, building towards a tipping point in 'leaving no-one behind'. The application of 'tipping point' concepts may also be a topic for further research (Werners et al, 2013; Lenton et al, 2022).

8 Conclusions

This paper considers the practical realization of the UN SDG7 goal to 'leave no-one behind' in the transition to affordable renewable energy. The research question being considered was *how might rapidly deployable affordable innovation initiatives support the alleviation of energy poverty in developed and developing economies whilst supporting the expansion of renewable energy capacity?* Two case studies illustrate how this may be achieved in different energy poverty settings. The short answer was to provide a readily deployable enabling platform based on a unique form of smart micro-grid combined with a compelling business model that could be utilised by local actors and replicated across multiple community installations. Embedded artificial intelligence helped assure equitable sharing of available solar energy between connected households, albeit in different ways. Whilst the case study innovations offered financial benefits to energy-poor beneficiaries or those with restricted access to renewable energy, they were not low-cost in themselves. The desired outcome was achieved in combination with a collaborative, project-based business model servicing small communities rather than servicing individual consumers directly.

Expansion into multiple international markets provided an increased level of economic activity for the case study firms, and their product-service offerings provided an enabling platform to help other influential actors address issues of energy poverty in their own domains. The energy user beneficiaries could subsequently increase their level of economic activity as one outcome of the technology deployment, but this is not the only community benefit. A direct reduction in greenhouse gas emissions and potential improvements in beneficiary health were other benefits in some cases.

The following begins with an outline of some theoretical perspectives applied in case analysis and what was learned from their application

8.1 Contributions to Theory

Three contributions are suggested. Firstly, literatures related to energy poverty and affordable innovation are brought together. A thematic analysis of literature concerned with energy poverty indicated this may be experienced in both developing and developed economies. Associated influence factors were seen as household income (relatively low), remoteness (energy supply more expensive) and home ownership (renters may be excluded). An associated body of literature adopted an energy justice perspective and suggested three aspects to be considered, and the case studies have been situated in this context in the prior discussion:

a) Distributional justice (Both cases delivered their technology packages at the point of use, guaranteeing access),
b) Recognition justice: identifying where inequalities emerge (the cases supported two different local community scenarios - remote communities and renter communities), and
c) Procedural justice - the right of inclusion supported by social and legislative processes. (both cases had to seek technology approval and stimulate the adaptation of regulatory / policy change in multiple jurisdictions)

The forgoing outlined what had to be done, but not how. This was considered to require transformational affordable innovation and a literature thematic analysis had indicated this would require entrepreneurs and innovation providers to work collaboratively, drawing on a combination 'appropriate' technology, grassroots engagement and 'new economics'. In both cases 'appropriate technology' was an intelligent microgrid digital energy distribution management product-service system combined with established solar photo-voltaic panel and battery storage technologies. Grassroots engagement was on a local project-by-project basis and involved representatives of the intended beneficiaries in project establishment. 'New Economics' involved the establishment of novel business models to make the installation and operation of capital equipment affordable to the intended beneficiaries whilst providing a return to investors. The combination of themes was encapsulated in a model (figure 2.) used in the selection and characterisation of the cases presented, and it is suggested this could be used in the study of other related cases.

Secondly, innovation development and diffusion was viewed as a complex adaptive process with associated micro and macro influence factors that in an energy poverty and renewable energy transition context was associated with value co-creation. The provision of affordable renewable energy was viewed as delivering a service requiring the co-creation of value by multiple stakeholders. The literature had suggested that value co-creation was also a complex adaptive process. The cases were analyzed drawing on an adapted version of a previously developed model (figure 3) based on the service-dominant logic (SDL) paradigm to capture story-lines in this context. This use of the SDL model extended its application domain. As with complex adaptive processes, the use of model indicated multiple interactions at micro and macro levels. The literature review had identified a number of theoretical models used by others in studying transition dynamics (e.g. Strategic Niche Management), but these were seen as offering partial views. How these partial views might be aligned with endogenous and exogenous interactions featured in the SDL-based model (figure 1) is discussed. For example, a Technology Acceptance Model might help explain the interaction between the service and customers in identifying value co-creation opportunities. This extension of the original model (figure 1) is seen as a contribution to theory, bringing together SDL and complexity constructs.

Thirdly, as also suggested in the literature, interactive learning is an attribute of complex adaptive processes. Case observations indicated such learning took place in different learning domains at different times – learning associated with technology development and deployment, learning what made economic sense, learning about political considerations and learning about social dynamics supporting deployment. This was applied at a macro-level to postulate the need to establish and engage with four different kinds of learning space in the pursuit of SDG7 targets, as illustrated in Figure 4.

8.2 Contributions to Practice

Whilst having an innovative product may be necessary, in this UN SDG implementation market space it is not sufficient. Both case firm founders had commented on the effort that had to be put into building relationships, as the platform technology they provided also required endorsement and uptake by other well-connected actors. Having a process for building social connections was important and learning from and with associated actors was important as all moved towards common long-term goals. Some of the collaborating actors may be beleaguered by competing possibilities however, so improvisational 'making do' with what is practical may be necessary to continue to build credibility via a succession of modest-sized projects. Some researchers have described this practice as 'network bricolage' that complements other aspects of creatively 'making do' (Baker et al 2003).

Strategies adopted were:

- Establishing a project-based service entity with a mission compatible with the societal expectations of a services ecosystem it was embedded in and evolving a business model enabling value capture to support ongoing economic viability. This entity may be a spinoff from an established firm or a start-up. The two start-up cases presented aimed to address ‘energy poverty and energy justice’ concerns in different settings.
- Building a business model with innovative value, transaction and resource structures (George and Bock, 2011). The cases adopted a collaborative project style of operation. Value structures included delivering value-in-use to clients and value-in-impact to a broader services ecosystem. The two cases had a usage payment orientation without the up-front need for beneficiary capital contributions. Service entity value was captured through the sale of a unique product-service bundle. Transaction structures included deal orchestration with investors and suppliers, and internal concurrent project management arrangements. Resource structures included recruiting staff passionate about the mission, internal knowledge-sharing arrangements and external collaboration networks supporting resource access appropriate to particular projects.
- Selectively engaging with an external services ecosystem having particular institutional rules and cultural norms oriented towards SDG implementation was necessary. This also provided

access to social networks, entrepreneur development support, appropriate technology and financial resources. Engagement with government and business actors to both access resources and show compliance with rules / norms (or helping to adapt them) was necessary.

- As a technology platform provider, establishing customer interaction spaces to orchestrate service entity and service ecosystem actor contributions to a succession of linked projects that build capability and trust. Negotiations were generally with third parties representing the interests of the intended beneficiaries (remote communities or renters).
- Actively reflecting on and communicating project outcomes reinforced stakeholder value delivered to a variety of stakeholders to garner ongoing support, and progressively enhancing the service entity business model. Mechanisms included service entity post-project reviews and independent external assessments on behalf of services ecosystem stakeholders. Communication channels included websites, social media and engagement with specialist industry journalists.

Whilst the case study firms had to learn about a variety of things, they appreciated that the intended beneficiaries, their collaborating partners and intermediary actors also had to learn about how to best use their technology in an energy transition environment. Adopting a mutual learning opportunity mindset may deliver unexpected outcomes, but certainly helped build social capital.

One consideration in the UN SDG7 implementation roadmap (ensure access to affordable, reliable, sustainable and modern energy for all) is 'mobilising adequate and predictable finance'. In the cases presented, the establishment of trust in the technology evidenced by winning a number of awards and obtaining product regulatory approval helped attract growth funding from green / ethical investment organisations. Energy sector investors are starting to move away from investment in fossil fuel sources, and such opportunities provide a relatively low risk alternative for them to establish an attractive 'green' portfolio.

8.3 Research Limitations

Drawing conclusions from two cases may be viewed as a limiting factor, however this strategy did support a level of in-depth analysis. Paradoxically, at the same time, practicalities restricted the potential depth of analysis. The case study enterprises delivered value via a multitude of system installation projects, and each project could be potentially viewed as a subsidiary case study post-installation, but only a few were considered in depth. Focusing on one form of renewable energy - PV Solar - might be considered limiting, however this was considered a lower capital cost, rapidly deployable option to support energy-poor communities, particularly in equatorial and sub-equatorial parts of the world (e.g. Yadav et al, 2019). Another limitation was the scale of impact that could be observed due to the relatively small size of the case study enterprises and their projects. As noted in the discussion however, large-scale replication of numerous small initiatives could have a powerful effect.

8.4 Suggestions for Future Research

It is suggested the analysis models presented in this paper (figures 1 and 2) may be applied to other energy poverty alleviation initiatives to better understand the underlying dynamics, e.g. some cases mentioned in the EU atlas of initiatives (EPAH, 2022). The particular cases show potential for rapid global expansion, and how this might take place could be considered as a future research theme by delving further into the dynamics of individual projects undertaken in different parts of the world. Evidence from other initiatives presented in the discussion section suggests an exponential growth in relationships has to be managed and that services need to cover the whole system life-cycle, not just the installation phase. Some supporting organisations saw addressing energy poverty alleviation as a demonstration of Corporate Social Responsibility practice, providing a potential source of competitive advantage in their core business. But just how this is realised could be further researched. The paper suggests there is a need to access multiple learning spaces to effectively implement the renewable energy transition (figure 3), and this could be explored further. The notion of 'tipping points' has been associated with emergence in complex adaptive systems and was mentioned in different ways in some of the references cited. For example, the point beyond which energy prices become a drain on household income, when a technology becomes influential, when government subsidies no longer have the desired impact. The interaction between different 'tipping points' and effective energy poverty alleviation is suggested as a topic for further research.

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