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# Electrification in Remote Communities: Assessing the Value of Electricity Using a Community Action Research Approach in Kabakaburi, Guyana

Niebert Blair <sup>1,†,\*</sup> , Dirk Pons <sup>2,†</sup>  and Susan Krumdieck <sup>3,†</sup> 

<sup>1</sup> Department of Mechanical Engineering, University of Canterbury, Christchurch 8041, New Zealand

<sup>2</sup> Industrial and Management Engineering, University of Canterbury, Christchurch 8041, New Zealand; dirk.pons@canterbury.ac.nz

<sup>3</sup> Co-Leader Global Association for Transition Engineering, Director Advanced Energy and Material Systems Laboratory, University of Canterbury, Christchurch 8041, New Zealand; susan.krumdieck@canterbury.ac.nz

\* Correspondence: niebert.blair@pg.canterbury.ac.nz; Tel.: +64-027-444-0176

† Current address: College of Engineering, Department of Mechanical Engineering, University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand.

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**Abstract:** **PROBLEM**—Provision of electric services in remote communities operating a subsistence economy has been challenging both for policy-makers and engineers. The value of electricity services and the choice structures in remote economies are not well understood. **NEED**—There are several technical, economic, and environmental challenges to the top-down approach of electrification. There is a need for methods that can integrate multiple dimensions of social development that can fit the environmental, economic, and technical aspects of community development. **APPROACH**—To create a system that best fits with the rural community, a bottom-up approach is recommended; this depends on community participation to provide a coherent from-the-ground-up decision-making framework for rural residents, engineers, and policy-makers. **OUTCOMES**—We have developed a from-the-ground-up community participation approach to power system design, where the community activity system is studied before investigating energy development options and assessing the risks and benefits from the perspective of the people in the community. We present the approach called Community Access Resource for Electricity Sustainability (CARES), with its foundation in action research methodology to explore the values in the community, the valued electricity services (VES) that the community feel they need, and the way the community adopts the different value types through problem-solving. We conclude that the CARES approach provides rural residents, engineers, and policy-makers with a new bottom-up approach to rural electrification in remote economies. **IMPLICATIONS**—The implications of this design calls for designers to extend their workspace beyond the design office and to facilitate with remote communities in devising solutions that best fit their needs. **ORIGINALITY**—Original contributions are the identification of the different value types and VES from-the-ground-up, and the integration of these into a gamified, interactive, and virtual-reality setting for participants to play through and discuss major consequences from which prudent decisions for development can be made. Additionally, we have proposed a new cost index for the feasibility assessment of rural electrification projects.

**Keywords:** participatory development; rural economies; transition engineering; remote electrification; community values

## 1. Introduction

Recent international agreements support the access to affordable, sustainable, reliable, and modern energy for all [1]. Poverty is the key factor limiting accessibility among urban households [2], while the remote communities beyond the extent of the grid have seen few successful electrification projects [3]. Since the 1980s, remote electrification projects have been completed through private and public sector investments and/or institutional loans [4]. Some of the electrification projects worked well initially and some were plagued with different challenges which impacted the functionality of the systems and limited the intended returns [5,6]. Access remains a problem as rural communities which received electricity services still have 20% to 25% of homes not connected [4].

Rural electrification faces many challenges. Some of these consist of but are not limited to inadequate maintenance, increase in demand, lack of commercial small-scale technologies, inadequate policy guidance, competing subsidies, mismatch of needs, insufficient finances, limited resources, and inadequate stakeholder management [7]. Meanwhile, practitioners and researchers have applied various techniques to mitigate these challenges using readily available technologies, but there is still a need for the design mechanism to adequately synchronize the technology, local resources, and the needs of the community [8]. The lack of community engagement matched with the unmanaged community expectations and an absence of extensive historical data for adequate system design negatively impedes rural electrification success [6].

This paper recognizes the need for community engagement in rural electrification and presents a from-the-ground-up, gamified community-based action research approach to rural electricity design entitled the Community Access Resource for Electricity Sustainability (CARES). CARES explores the community activity systems and values from the community's perspective to determine what residents need the most. Applying good conversational techniques and research methods in an unbiased yet structured way, we establish essential electricity needs in remote communities. It explores a way for establishing transformation projects that will allow for affordability, sustainability, reliability, and adaptation of modern electricity services.

In the following chapters we first review the top-down approaches to rural electrification under three categories: policy; economics; and engineering. Secondly, we outline our rationale to support a bottom-up approach for rural electrification. Then we outline the CARES approach and present a case study implemented in a small Amazonian village, Kabakaburi (Guyana). Finally, we identify a way that rural electrification can be designed to deliver sustained benefits that aligns with the local economy. Hence the paper presents a new way for policy-makers, economists, engineers, and villagers to collaborate towards successful rural electrification.

## 2. Background

Rural electrification has been conducted mainly through a top-down approach. This can be categorized into three distinct but overlapping areas: policy, economics, and engineering. Often, the community involvement in rural electrification is absent [6].

### 2.1. Top-Down Policy Approach

Policy implementation have tended to adopt a top-down approach. More than three decades ago Derthick [9] argued that policy making is a combination of events among politicians debating with each other and the monotonous routines of limited consultations among the most affected [9]. Rydin [10] recognized that debate in the policy process relates to the power structure and level of interests of the few [10]. In addition, policy requires skills in separating desires from the language that shapes the policy [10]. Pierson [11] argued that policies demand an examination into the policy processes and the outcomes [11]. What has changed in the policy design and implementation? Dols et al. [12] argued that evidence-based-practices is a new process in organizational policy development and must be given more attention since it requires individuals who are committed and familiar with the issues and

the meaning of the evidence [12]. The organizational level process allows for education, observation and new learning [12]. Rural communities require procedures to address the collective action problem and the societal differences in generating consensus with limited professional capacities, in a manner that will provide dialogue and agreement.

### 2.2. Top-Down Economic Approach

In many developing nations rural electrification has been financed by governments borrowing from the World Bank [13], Inter-American Development Banks [14] and donations from non-governmental organizations [15]. Rural electrification in America had its genesis in the rural electrification act of 1936, which allowed for the provision of loans from federal funds to cooperatives. These cooperatives were consumer owned and not-for-profit [16]. Compared to the American cooperatives, incurring external debt for rural electrification does not provide adequate institutional and financial support for all stakeholders in their various roles [17]. Some communities received government subsidies of 50% or long-term loans with low or no interest rates [18]. Zomers [18] noted that due to the relatively high costs of rural electrification, utilities find it unattractive to extend the service to these communities [18]. Why do utilities with all the expertise refuse to extend electricity service? The revenues from these services do not adequately compensate the investments due to expected low demand [19]. There is often a difficulty in extracting the rents for the assets, receiving payments for services, and costs of maintenance of the systems, as in the case of Tunisia [15]. Grid systems in the larger centres have connection fees and set access charges as well as the cost per kWh used [20]. The utility will have metering, billing and collection operations [21]. If a household does not pay the power bill, then the utility can disconnect the power [21]. The utility also has maintenance operations essential for sustainable operation [21]. The difficulty in obtaining rents for services is not because consumers cannot afford to pay but because they do not feel any need to [15]. In summary, at a superficial level the economic issue for rural electrification might appear to be financial inability of users to pay, but at a deeper level there are issues around the motivation to pay. Hence it becomes difficult to recover capital costs and this becomes a disincentive to central investment. The deeper issue remains: Why do people not want to pay? The answer to that appears to be rooted in the way the system is designed, either top-down or emergent, and the values that residents hold.

### 2.3. Top-Down Electricity Design Approach

Designing electrification networks have followed a top-down approach with utility engineers planning the implementation of electricity systems. While the main criteria for the design is the consumers expected/predicted demand; once the power system has been developed, the load quickly grows leaving the utility to expand the network in an unplanned and sometimes haphazard manner [22]. Besides, the unchecked demand surge, the nature of the fuel available is another limiting factor [22,23]. Utilities are often left to plan for uncertainties that are related to prudent decision-making/forecasting of deterministic parameters (such as, load growth rates, fuel costs construction time, interest rates, financial constraints, economic growth, and environmental constraints), as well as probabilistic aspects of load and equipment analysis [24]. The Typical Electrification System (TES) design outlined by Cavallaro [23] supports the generation of economic returns based on an estimated demand and future increases in uses for electricity [23]. Traditionally, the planning process of electric utilities consisted of comparing the electric production capacity with the projected demand and building the additional production capacity needed to meet the expected demand in compliance with safety regulations and environmental standards [25]. Wilson and Biewald [26] Integrated Resource Plan (IRP) system operates almost like the TES, with one notable difference of examining all possible sources and making a selection based on the most economically viable option [26]. The issue is that the is perceived as a project, and the economic

utility dominates the decision-making. This is problematic because not all community values can be expressed in economic utility.

#### 2.4. Bottom-Up and Emergent Approach

Altogether, the literature points to a need for more active participation of residents in rural electrification design process. The challenge is motivating residents to engage, and this seems to require a re-think of the design process itself. The evidence-based policy practices identified by Dols et al. [12] provides for some form of autonomous application where individuals develop policies to align with their ways. This method was proposed for use in a professional organizational (company) setting, but has not been extended to the societal setting. Whether it be Dols et al. [12] organizational policy practices, Derthick [9], Rydin [10] and Richardson [27] national policy methods, or Smit et al. [28] Community-Based System Dynamics (CBSD), they are all limited by absence of a mechanism to achieve this. There is a need for a process methodology that can be applied to emergent settings, and mechanisms to quantify outcomes.

### 3. Materials and Method

#### 3.1. Rationale for Developing the CARES Approach

The challenge in the bottom-up approach is for an engineer to take the perspective of the villagers or, better yet, to introduce the villagers to the engineering technologies so that they can identify areas in the design that work and those that do not fit. However, to actually implement this is challenging and poorly described in the literature.

#### 3.2. Designing from-the-Ground-Up

Designing from the ground up requires applying deliberative techniques such as public participation and resource assessment of local content, adoption of analytical measures for capturing values, establishment of a common design language, and a mechanism to assure design solutions.

#### 3.3. Public Participation and Local Resource Assessment

Community-based participatory research (CBPR) (Defined as: collaboration of “research methods and community capacity-building strategies to bridge the gap between knowledge produced through research and translation of this research into interventions and policies.” [29]) encourages equitable involvement from residents, organizational representatives, and researchers in every aspect of the research process [29]. The unique strengths and shared responsibilities are combined to enhance understanding of a given phenomenon and the social and cultural dynamics of the community [29]. The knowledge acquired is integrated to improve the health and well-being of that community [29]. CBPR has a structured framework that incorporates problem identification; study design methods; recruitment of participants; analysis and interpretation of data; design and implementation of corrective actions; and the analysis of the findings [29]. This approach requires the assembly of a research team and the development of a decision-making structure [29]. Notwithstanding, the level of external support required the method is mainly driven from the research perspective in a pre-identified area. It is best for the community to be able to identify what needs they have and how to satisfy them without being influenced by a researcher. Hence there is a need to develop methods that can help communities help themselves.

The Asset-based community development (ABCD) approach originates from an empirical review of the success stories of US communities in organizing themselves, mobilizing local skills and capacities through informal and formal associations [30]. McKnight and Kretzmann [30] have pioneered ABCD for communities to assess their resources, skills, and experience available, and mobilize residents around common issues, so that they can identify and deliver their own solutions [31]. It uses the assets and resources in the community to provide for their development; and residents are empowered and

encouraged to use what they already own [32]. ABCD meanwhile requires a form of institutional strengthening and governmental support for its sustainability; it provides a framework, a practical process and a series of tools that together captures the tradition of collective action for the eradication of contemporary issues.

#### 3.4. Analytical Measures for Capturing Values

The 21st century citizen is confronted daily with the designs and technologies that are not value neutral but rather impact human morals and environment [33]. Value Sensitive Design (VSD) is a theoretical and methodological framework to address the value dimensions of design work, via a tripartite method consisting of conceptual, empirical and technical investigations conducted iteratively [34]. VSD still lacks some major procedural elements such as: (1) an outlined method of identification of stakeholders; (2) a clear manner for the integration of conceptual information with empirical research; (3) an ethical stance on judgements rather than a naturalistic one; (4) a means of comparing the level of importance of choices; and (5) ethical theories to manage value trade-offs and to address arguments and considerations [34]. Complementing VSD is Value Conscious Design (VCD) which identifies entities of values, empirical methods to be used, precise objectives regarding values in the design and a values advocate who will be responsible for selecting the stakeholders, arbitrating value conflicts and evaluating design choices for adequate reflection of values in the solutions [33]. Value advocates are beneficial in ensuring that social value in design is achieved and ethical decisions are reflected in the designs [35]. Notwithstanding the cultural content of values, values also represents a psychological investment shaped by constraints and opportunities of a value system (Defined as: a set of preferred standards that are applied in a number of decision making tasks such as: selection of objects, actions, conflict resolution, invoking social sanctions, and coping with claims of choices made or proposed [36]) and a biophysical environment [36]. The value construct identified in the literature are presented in Table 1.

The measure of value is presented as the trade-off or perceived value. The trade-off is the “customers’ net valuation of the perceived benefits accrued from an offering that is based on the costs they are willing to give up for the needs they are seeking to satisfy” [37]. The trade-off is what the customer is willing to give in exchange of an unavailable and desired state [38]. Kumar and Reinartz [37] categorizes the methods used to determine customer preferences into compositional and decompositional [37]. Perceived value has two dimensions the objective (physical outputs) and the perceived (experiences). Together the measure of value is determined based on three distinct measures (1) perceived values, (2) attributes and benefits and (3) the weighted preferences between attributes/benefits and perceived value [37]. Kumar and Reinartz [37] propose a forward-looking approach to customer values measurement and hence, put forward the customer life time value (CLV) to create financial value (monitory profits) to firms [37].

Pearce and Pretty [39] justifies the purpose of the evaluation is to determine resource value and use [39]. Instrument event selection is used to determine decision-making capabilities resulting in the reflection of the values [39]. However, it can be difficult to test values outside of asking what people’s values are.

**Table 1.** Table showing the types of value construct.

Value Types	Value Construct	References
Cultural Values	Attitudes and behavior	[40]
	Systems of priorities	[41]
	Level of Importance (Essentiality and desires, Maslow needs framework)	[42]
	Ethical Principles	[43]
Perceived value	Trade-off (willing to “give” to “get”) attributes/benefits	[37]
Resource Value	Comparative costs	[39]
	Natural Capital	[44]

### 3.5. Adopting Appropriate Communication

An appropriate communication strategy is required for guiding the research developmental process. This strategy would identify research location, methods, tools, scope, quality, costs, time, data analysis, and validation.

Bessette [45], have used environment and natural resources management examples to outline participatory development communication (PDC) [45]. PDC encourages community ownership and is more ‘participatory’ than participatory rural appraisal (PRA). PRA is “a family of approaches and methods to enable rural people to present, share and analyse their knowledge of life and conditions to plan and act” [46]. PRA is applicable under the PDC however, its use must be restricted, and techniques used in collaboration with residents for gathering information [45]. PDC presents a way for the end user to identify, analyse, prioritize, and discuss problems, acquire knowledge, and identify, implement, and evaluate solutions; it alludes to need for assessing the short-term and long-term impacts as well [45]. How should we really assess development impacts both in the short term and long term? Krumdieck [47] presents the transition engineering (TE) as a seven-step approach to reducing fossil fuel use and its detrimental social and environmental impacts [47]. “Transition engineering is the general practice of changing existing engineered systems to reduce the risks of unsustainable resource use or pollution” [47]. Inherent in the impact assessment under TE is the Intime approach which examines scenarios of 100 years in the past and 100 years in the future [48]. This reflection builds on the knowledge of pass events and the expectations of what the future might be.

### 3.6. Design Assurance and Gamification

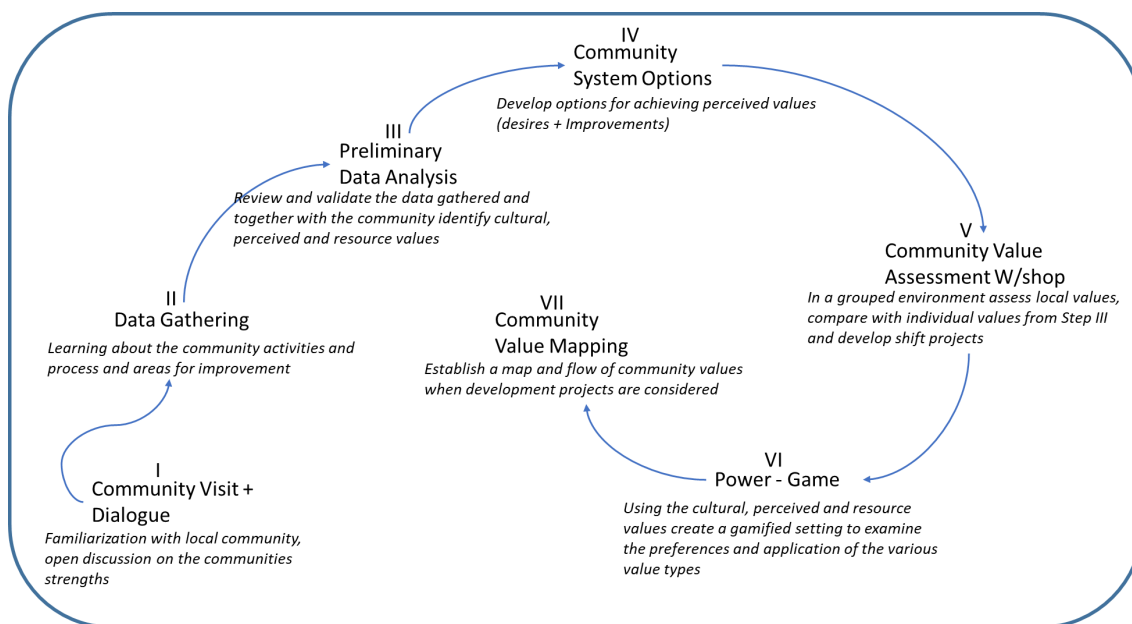
Technologies available will heavily impact the design selection, and the design selected needs to be conducted and evaluated with the community. Design assurance is employed to evaluate design effectiveness. Design assurance (Defined as: “those planned and systematic actions taken to provide confidence that the product design will satisfy the requirements of its intended use” [49]) provides the tools to deliver engineering excellence thereby generating competitive advantages for firms. It addresses the issues involving the production of defective parts and the supply of incomplete/incorrect information; resulting in reduced production costs [50]. This practice incorporates requirements definition, drawing specification control, design verification, control of changes and supporting documentation [50].

Game design can inform the design assurance process. Nick Pelling coined the term *gamification* (Defined as: Not a game; however, it consists of gamifying a real-life event by applying some of the positive characteristics of a game such as goals, rules, feedback system and voluntary participation [51]) in 2002. Gamification applications range from conditions of no technological applications to almost full techno-human interface application such as in video games [51]. Games have also been used to solicit user preferences in human factors work. The concept is promoted in Cline [52] “*Ready Player One*” and Brooker [53] “*Black Mirror*”. Gamification has been used to cultivate desired behaviours and generate feedback [54]. It has also provided for compelling, fun and informative learning [55]. In the

present application we wish to adopt its application in decision-making and assuring community value-proposition.

### 3.7. CARES Approach

This paper presents the CARES approach, for the development of rural electrification systems from the community's perspective by exploring their local values (cultural, perceived and resources) see Figure 1.



**Figure 1.** The seven-step CARES approach for identifying cultural, perceived, and resource values in rural communities.

The facilitator learns about the local activity system and facilitates the community with identification of areas for improvement. The community identifies options for achieving the intended improvements individually and collectively, then they assess their choices over the past 100 years and the implications for the next ('Intime'). The choices are examined in the areas of the identified value types, see Table 2. CARES adopts the following steps:

1. Community visit and dialogue—the researcher performs the function of a facilitator or enabler. The principle role of the researcher is to understand the community from the perspective of the residents. Listening first hand to what residents have to say. Ask about: What are the things the community is good at? What have they excelled in, in the past and will continue to excel in in the future? What are the things that make them feel privileged, happy, and satisfied? Intentionally, the discourses have nothing to do with electricity, conversations are not recorded, and the researcher is simply a neutral visitor. Instead, the discourse is all about developing genuine interest into what the community is good at, building trust, connecting with the local personnel and creating an appreciation of the local context. Such requires for the researcher to exercise good conversation techniques and effective listening discussed by anthropologist, and negotiation expert Ury [56].
2. Application of conventional and informal data collection—given the emergence of key concepts which the individual members will highlight, the facilitator applies conventional data gathering with the community to establish the built environment. This phase is quite delicate and will require interpersonal considerations on determining appropriate methods of engagement such as visits to residents' homes, work site visits, attending social events, and informal meet-ups. This exercise sets the context of any intervention that will be required and allows for the deeper

- understanding into systems, norms, practices, and culture. The season and other environmental factors can also impact the experience. During this interaction and cultural sharing, the facilitator learns the various processes and enquires from residents about what the process entails and what they think requires improvement? What do they want it to be? What it must do and what it should not do and why?
3. Preliminary qualitative and quantitative data analysis—is completed highlighting the areas of cultural values (pride, attitudes), perceived values (desires, improvements), resource values (wealth). The findings are re-framed into open ended questions and again randomly discussed with residents individually. For example: We identified that residents see the forest as an important resource. Re-framed question: *Why would you say is the forest an important resource?* Hence, the responses should coincide with the initial responses from which the analysis was made about the forest being important. The individuals with which the discussions are conducted are different in the data collection and in the preliminary analysis. This so that a wider span of persons can participate and as many views can be considered. At this stage individuals are asked what they will do about addressing their perceived values (desires and improvements). It is here that the need for assistance is made and the potential interventions discussed with the group.
  4. Establish community system options—Together with the community, explore the pathways of achieving the perceived values. Given the need for electricity supply, together explore electricity options. This inculcates a system of capacity-building and learning both with the designer and participants. With at least three design options proposed by the members together they can discuss and critique their designs. The designs are critiqued to the extent at which the cultural and resource values may be substituted for the perceived values.
  5. Community value assessment workshop—Following the need for electricity and with the support of the residents develop a workshop that will assess the activity systems, electricity demand, sensitivity, and operation. During the workshop, the perceived values are re-established and collectively shift projects are developed which identifies what the main outcomes will be, who will be responsible, how it will be done. The values identified in the workshop are compared with the preliminary data analysis. Irregularities are discussed. In addition, a questionnaire examining three critical issues:
    - Individual decision-making—How are decisions made? examining the ethical preferences deontology (Good rules: One should develop a system of rules to guide their behaviour and follow those rules. [57]), teleology (Good outcomes: One should assess the most feasible results of their actions and choose the option with the best outcome [58]) and virtue (Good principles: One should make decisions along the lines of honesty, compassion, kindness, courage and empathy [59])
    - Attitudes towards electricity—What are the main considerations, preferences and impacts of electricity?
    - Costs—What a local power supply should costs? An applicable tariff and the ability to pay.
  6. Develop a game that combines the individual electricity values and the workshop electricity values with the following elements:
    - Role play
    - Decision-making
    - Time impacts on the design (installation, maintenance, end-of-life, replacement, cost)
    - Intime review of the systems (value preferences and sequence)
  7. Value mapping—residents develop a system that combines their values, decision-making and existence.



**Table 2.** Table showing the various steps, inputs, instruments, and outputs of the CARES approach.

Steps	Inputs	Instruments	Outputs
STEP I—Community Visit and Dialogue	Arrange visit to local community	Observations, Informal interviews, Diary	Major strengths of the community, Building trust among residents and visitor, Appreciation and adjustment to local culture by visitor vice versa
STEP II—Data Collection	Community's invitation to engage in further learning of local activities	Observations, Informal interviews, Diary, Documents review, process and activity mapping	Background information on community, Community activity and process systems
STEP III—Preliminary Data Analysis	Outputs from STEP I and II	Qualitative Analysis	Community identified areas for improvement and future development projects
STEP IV—Community System Options	Outputs from STEP III	Electricity modelling packages (HOMER, ETAP)	Options for electricity delivery
STEP V—Community Value Assessment Workshop	Community request for workshop and plan workshop	Questionnaire, Focused groups, Presentations	Comparison of individual and community values, Shift projects briefs for future projects
STEP VI—Develop Power (Game)	Outputs from STEP I through V	Role Playing, Focused group, Debate	Lifetime consequences of electricity system choices, Cost/value of future developments
STEP VII—Community Value Map	Outputs from STEP VI	Qualitative Analysis	Community priority values, and sequence of value selection

## 4. Results

### 4.1. Background to the Case Study

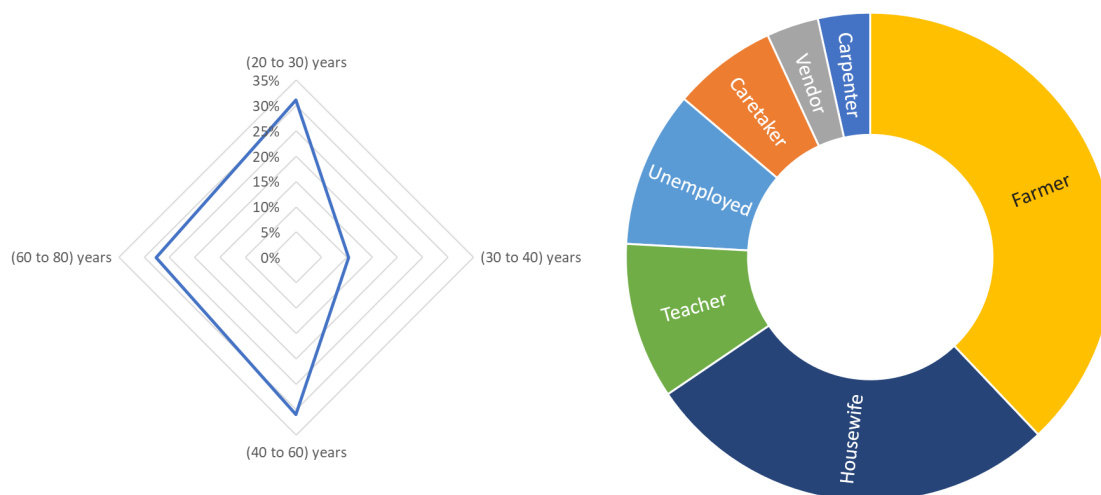
Kabakaburi is a hinterland village in Guyana, South America. The village is located approximately 56 km from the mouth of the Pomeroon river and the closest economic hub Charity. Kabakaburi is divided into four parts—Macaseema, Waiwaro, The Mission (Kabakaburi), and Aripiaico. In recent years there has been a continuous migration of young persons going to the city to work while others venture further into the interior to work on the mining camps. Most of the residents, mainly comprising of Arawaks and Caribs, reside along the bank of the river while farming and logging is done further in land. There is relatively minimal infrastructural development, low economic activities, marginal health services, and moderately equipped nursery and primary education systems. Residents in Kabakaburi also have cottage industries where a variety of craft and art is prepared and sold at exhibitions throughout Guyana. Logging is the main economic activity. The rangers in the area are challenged to ensure that proper sustainable logging practices are upheld.

Residential electricity provision is in the form of a dual supply system. This consists of a 65 kW lighting system delivered to residents of Kabakaburi in 2012 under the Government of Guyana Un-served Area Electrification Programme (UAEP). Kabakaburi was among the first batch of hinterland communities who received this service [60]. The solar lighting system delivers monthly approximately 12–15 kilowatts hours of electricity which is used to supply lighting to low energy lamps and a small radio [61]. The total system in comprised of a Photo-Voltaic Panel, DC charge controller—6 A/12 V,

67 Ah–12 V deep cycle gelled electrolyte battery with appropriate terminal connectors, sunlight resistant cabling, DC circuit breaker—10 A/1-pole, 9 W/12 V DC compact fluorescent lamps and a DC lightning arrester, altogether costing US\$241 [62]. Apart from the 65 kW lighting system majority of the residents have an additional gasoline electricity supply at their homes ranging from 1 kw to 3 kw. This is used to power other AC domestic appliances. Fuel to power the equipment is acquired from the closest commercial hub, Charity, usually in 5-gallon containers. The solar lighting replaced the kerosene lamps. It was intended that each household would contribute US\$2.5 monthly and this sum would increase by 20% in two years [62]. The purpose of this fund was for the operation and maintenance costs of the already installed units and to replace damaged components [62]. While the Solar Home Systems (SHS) were working well, the consolidated fund-supporting mechanism was not instituted.

A 10 kW engine installed next to the village council office was used to provide electricity to the surrounding neighbours, the schools, church, and playground. At the time of the visit this facility was not working. In addition, a solar lighting and diesel system installed at the school were also inoperable. As with the SHS, the expectations were for the villagers to develop a similar fund to offset operating costs.

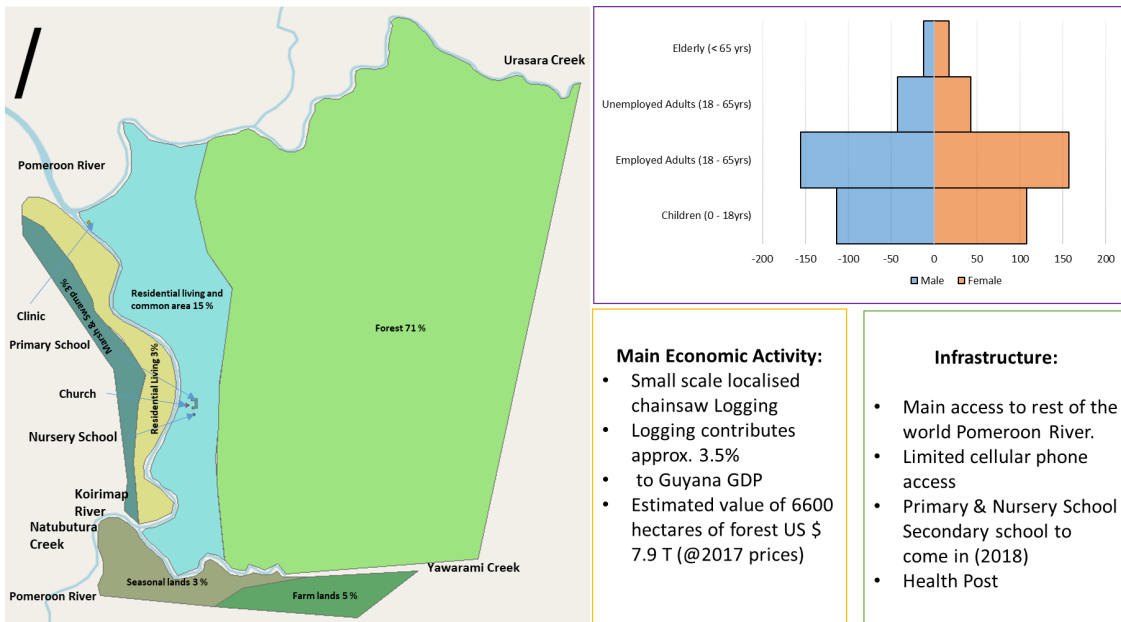
Sixty adults in the community between the ages of 20 to 80 years old participated in the community visit through to the workshop all together. A total of 29 questionnaires were issued and completed by residents who participated in the workshop see Figure 2. The age distribution and occupation of the participants are presented in Figure 3. The primary occupation is farming, while the education and health sector together employs 18 persons. The average family size is 6. Discussion with 40 individuals was also completed during the community visit and discussion stage. The population has an even ratio of men and women, with a greater number of residents within the working age of 18 to 65 years old, see Figure 4.



**Figure 2.** (Left) The age distribution of the participants involved in CARES Kabakaburi. (Right) The occupation of members involved in CARES Kabakaburi.



**Figure 3.** The participants on the second day of the workshop. (Top left) Toshao presenting on VES for the clinic. (Top right) Groups planning for their VES. (Bottom left) Another presentation on the VES for the school. (Bottom right) Facilitator sharing on biophysical economics as requested by the participants.



**Figure 4.** The Built Environment of Kabakaburi. (Left) The Map of Kabakaburi showing the 100 km<sup>2</sup> land area allocated to different activities. (Top right) The demographic distribution of Kabakaburi showing elderly, unemployed, employed and children. (Bottom Right) Sums up the main economic activity and local infrastructure.

4.2. Application of CARES to the Kabakaburi Case Study

Kabakaburi was identified for this study following prior visits to the village and conversations with villagers. An initial meeting was arranged with the democratically elected Toshao (village head), through a villager. After listening to the Toshao, village councillors and residents it was agreed that the community required assistance in the establishment of a reliable electricity service. Hence, the villagers agreed that they would facilitate in the piloting of the CARES method. Prior to the visit the University of Canterbury Ethics Committee approved the CARES method [63].

The characteristics of the built environment were established, see Figure 4. Residents valued electricity services (VES) were captured during the informal interviews see Figure 5. After meeting with residents from the different areas a preliminary report on the findings and a draft of ‘power’ was created. During October of 2017, a two-day workshop was conducted. The workshop was organized by the Toshao and consisted of 30 representatives from the different parts of Kabakaburi.

During the workshop community members engaged in discussions of what is most important, what they do best, and how they do it. The ‘level of necessity’ was discussed using an analogous approach of the basket: a common village item representative of the different levels of necessity—‘essentiality’, ‘importance’ and ‘optionality’, see Figure 6 .

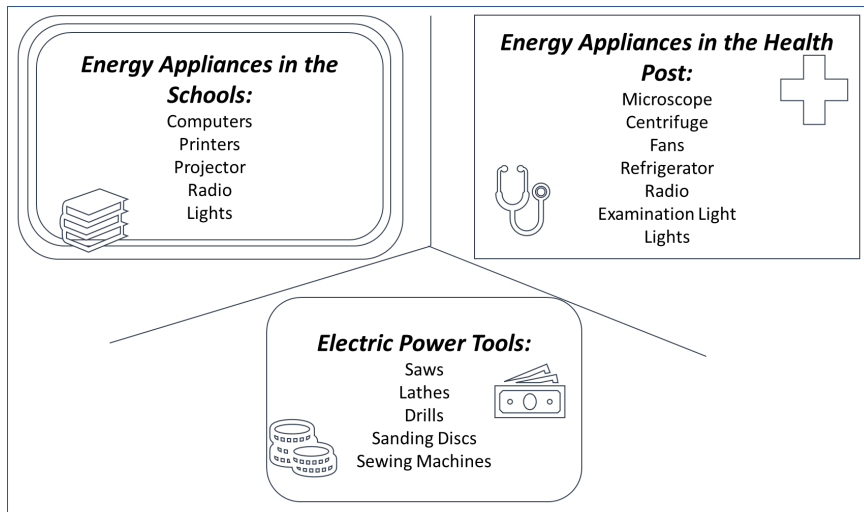


Figure 5. The Valued Electricity Services (VES) identified by residents of Kabakaburi. (Top left) Appliances in the school that will require electricity. (Top right) Appliances at the health post that will require electricity. (Bottom) Electrical appliances that will boost the local economy.

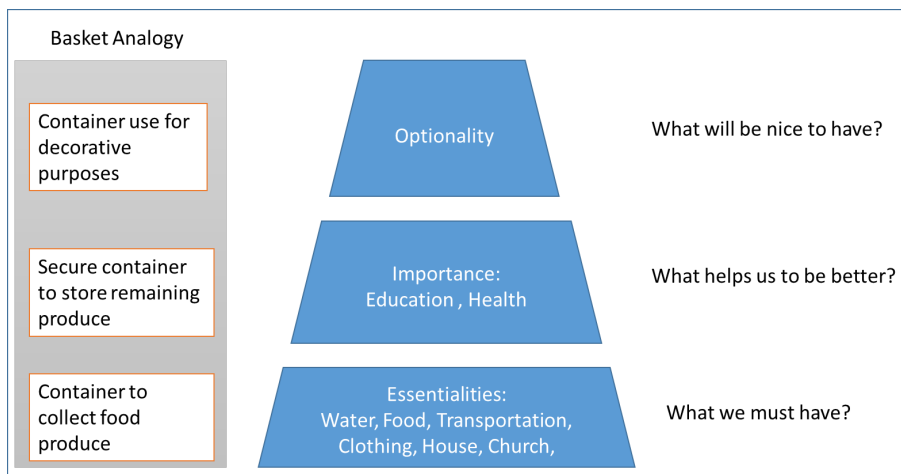


Figure 6. Diagram expressing Kabakaburi’s levels of necessity and basket analogy applied to establish common understanding.

The basket analogy was used to help participants identify their levels of necessity in a manner that was common and well understood by everyone. The residents contemplated on their essential needs and what additional support would be helpful. Each resident reflected on their average day to see what they did most of the time and what activities were most time-consuming. They identified the main contributors to lengthy and challenging activities and what improvements can be made. All activities were classified into time of day events (morning, mid-day, afternoon and evening) see Table 3.

**Table 3.** Table indicating the time of day and different activities completed in Kabakaburi.

<b>Morning 6 a.m.–1 p.m.</b>	<b>Afternoon 1 p.m.–6 p.m.</b>	<b>Night 6 p.m.–6 a.m.</b>
Tidy	Farming	Homework
Wake-up	Football/cricket/volleyball	Dinner
Prepare to go to farm	Picking up children	Cooking
Bath	Tidy up children	Work planning/writing
Washing	Relax watch movie	Ironing
Cooking		Dish washing
Making calls		Reading
Prepare for school		Church meeting
Transport children to school		Relaxing
Work on Farm, school, church, clinic		Fishing
Craftwork		
Devotions		
Praying		

The CARES questionnaire was completed and the individual discussion making tendencies, attitudes, and behaviours towards electricity, system sensitivity, and costs completed. Participants reviewed and compared the preliminary findings (pre-workshop—informal interviews and documents reviewed) with the findings from the CARES workshop ('level of necessity' and questionnaire exercises). Ambiguous responses were discussed, and the findings validated. Participants voluntarily placed themselves into groups to discuss three priority optional VES. These activities were examined using the Intime analysis (there impacts 100 years into the future). The groups created shift projects briefs which supported their shared vision. 'Power Kabakaburi' was adjusted to reflect the findings from the CARES workshop and the members asked to play through 'Power Kabakaburi' (see Figure 7 and Tables 4 and 5).

Power Kabakaburi consists of a visual display of the community in the form of a board game. The board consists of four major dynamic areas of interest. The population and household, resources reserve, community aspirations, and the resource consumption consisting of energy supply options, see Figure 7.

The wealth of the community is reflected in the resource reserves. Power Kabakaburi provides some assurances that food production will not be affected given the population remains within 10% of year 0's population. Reflective of the gaming system members are presented with avatars representative of key roles in the community and a dice to provide players with an opportunity for cards selection. Besides the board, avatars and cards 'Power' facilitates more of a means for members to discuss various choices and together select best possible options that fit with a means of generating real-time consequences and feedback. Only power systems options applicable to the community are considered. The order of play consists of the following steps:

1. Selecting of an electricity service option.
2. Select one VES option.
3. Select a dilemma card.
4. Select an opportunity card,
5. Review the 100 years from now impact then move on to the next round.

The rolling of the dice is used to determine who selects the card and is responsible for reaching consensus on decisions. This simulates a situation of a new leader each time.

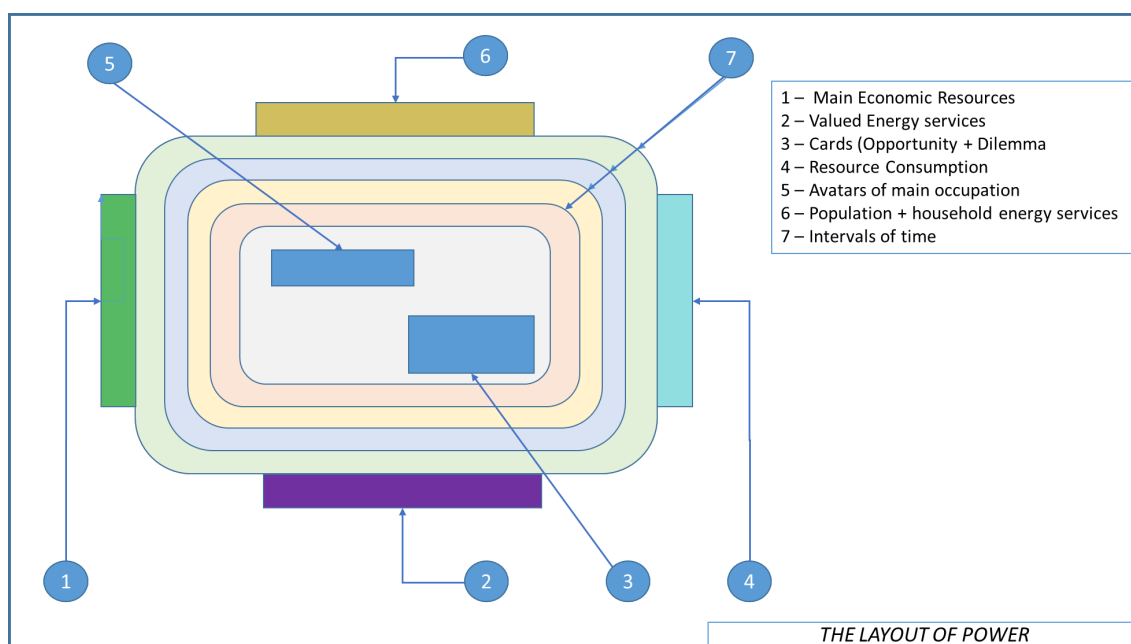


Figure 7. The gamified board of 'Power'.

Table 4. Table presenting the responses of the energy choices opportunities and threats at the different times in the life of the Solar Home System.

Solar Home Systems (SHSs)			
Rounds	Opportunities	Threats	Responses
Solar Home Systems (SHSs) is 8 years Old			
1—Year 0	Secure a new system since local supplier can deliver at an affordable rate	Battery system fails, and the battery type is not available. Battery disposal required.	Will not acquire a new system if old one is fine. Seek external aid for new battery or substitute. Bury old battery
Solar Home Systems (SHSs) is 13 years Old			
2—Year 5	SHS is working well no changes required. Batteries become readily available.	Small components fail; however, they can be replaced with alternatives.	Will not acquire spare batteries. Earn monies and replace small components.
Solar Home Systems (SHSs) is 13 to 23 years Old			
3—Year 5 to 15	Government awards all new buildings an upgraded SHS.	Solar panels get damaged resulting in insufficient battery charging. Disposal of panels are required.	Seek support in replacing with advanced systems. Bury damaged panels.
Solar Home Systems (SHSs) is 28 years Old			
4—Year 20	Local supplier has a supply of SHSs, but they are expensive and require individual investment.	Battery supply is limited, and batteries are becoming increasingly expensive.	Will find a way to purchase new system when needed. Try to extend the life of the battery as much as possible.

**Table 5.** Table presenting the responses of the Dual Electricity System (DES) opportunities and threats for the VES.

School and Health Post			
Rounds	Opportunities	Threats	Responses
Power systems at School and Health Post inoperable			
1—Year 0	Designed a system to be implemented.	Finance for developing this system is not locally available	Willingness expressed in financing the operation of the system with 10% of income. Preference expressed for system to managed by a separate group.
Solar Lighting System Installed in School and Health Post			
2—Year 5	Solar Lighting operational. Light at school facilitates evening cultural activities.	Building require renovation and systems may need to be removed and replaced.	Cultural activity can allow for fund raising and during installation of new system potential repairs could be addressed.
Gasoline generator installed; DES fully functional Solar Lighting 5 to 10 years old			
3—Year 5 to 15	An upgrade for the new lighting system is available.	Batteries and small components need replacing. Disposal of batteries required.	Health budget to supply funding for health post and school to fund replacement through fund raisers. Bury discarded batteries.
DES in place Gasoline generator 10 years, Lighting 15 years			
4—Year 20	Local supplier has lighting systems, but they are expensive.	Battery supply is limited, and batteries are becoming increasingly expensive. Fuel price increasing.	Management team will find a way to purchase new system when needed. Try to extend the life of the battery as much as possible. Reduce on the use of diesel

The results of Power Kabakaburi played with five (5) community avatars namely teacher, nurse, farmer, housewife, and priest (all randomly selected) is presented in Table 4 through to Table 5. The community had the option to select from the very beginning if the school and health post should remain in the VES. Table 4, presents the responses concerning the residential VES.

Table 5 present the responses of the dual systems applicable for the VES for the school and the health post. The results highlight what challenges could be associated with the VES and ascertains from residents what their corrective measures will be.

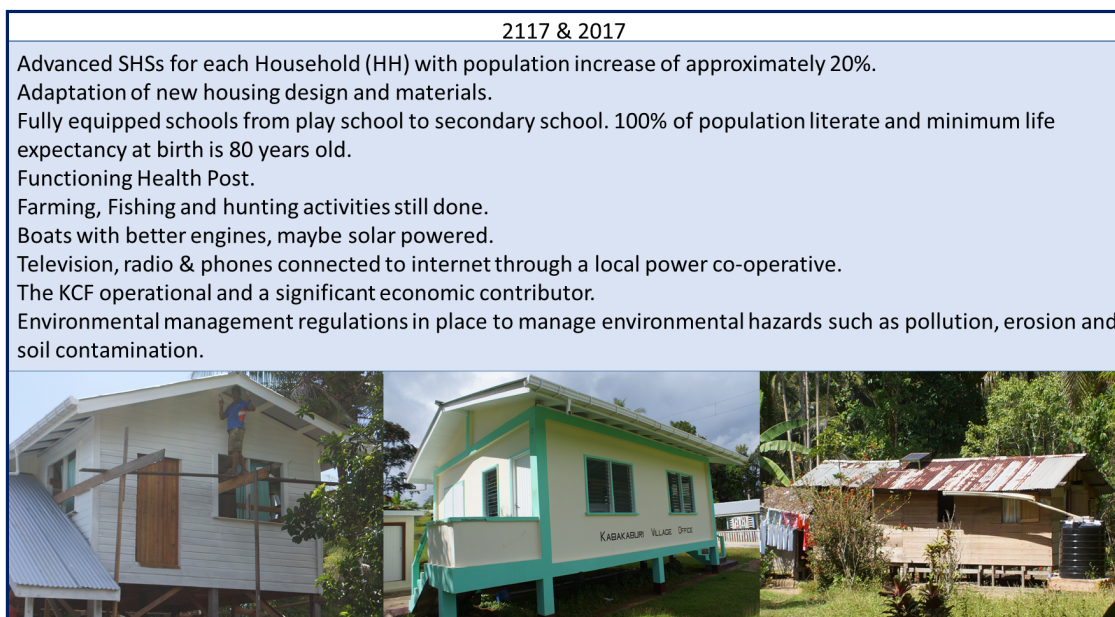
The 'power Kabakaburi' (PK) community selected the sawmill as the priority economic VES and discussed the equipment required for setting up this operation. During the discussion several issues were raised such as: deforestation and reforestation, sales, price and costs, dispersing of wealth among residents, management, impact of deforestation on surrounding vegetation, erosion, and soil fertility. Participants agreed with developing the sawmill but still had some lingering doubts. As depicted in Figure 7, the soonest possible time for the sawmill to be operational will be within year 5 to 15. The electricity services will be delivered using fuel oil.

The second choice was the Kabakaburi Cassava factory (KCF). This was to be in operation by year 5, since the building had been completed and some equipment were to be purchased. However, PK reflects a conservative view of KCF being fully operational in Year 5. The technicalities and functionalities of this facility was not common among players. Consequently, issues such as market competition, local supply chain raw materials and distribution and sale of products were expressed.

The final of three choices was the eco-tourism option. This option is an aspiration for the most distant future and was identified to be in place by year 20. Given the long-term deadline, no major short-term activities of establishing this activity were detailed.

It was required for the community apply Intime and detail the consequences after each round. However, the participants were anxious in completing the review of the VES from year 0 to year 20. After working through the 20 years period Figure 8 highlights the  $\pm 100$  years discourse.

The future picture of Kabakaburi is based on the view of the 5 participants. The consequences of the VES selected during the 20 years period is reviewed. Members agreed that the building structures may evolve to something new comparing what it is now see Figure 8 to 100 years ago.



**Figure 8.** (Top) Participants summary of Kabakaburi 2117 when the VES they selected are implemented. (Bottom) Buildings in Kabakaburi today.

## 5. Findings

The CARES approach was piloted in Kabakaburi. This approach facilitated the specification of the local resources capacity and human activity system, extracted the core community VES, reviewed the implications of their future aspirations and determined where and how will electricity supply fit. The community has never been involved in such an activity. While the community and the approach are new, the experience provided much-needed areas for improvement. This approach provided for community participation in designing their power system, which is unlike the contemporary utility, top-down power system design applied in non-remote areas.

### 5.1. Cultural Values

The approach supported the considerations of the behaviour and attitudes of local resident decision-making. The decision-making biases help to provide an indication on how a system must be designed for it to be successful. It is important for the designer to understand the technical specifications of a system as it is equally important for the individual and shared behaviour towards the system to be acknowledged. The research captured decision-making by directly asking persons to select from three options, their most applied behaviour when in a position of moral dilemma. Despite most persons identified with the deontological ethics which allowed for adhering to preset rules; a considerable portion of persons choose to support a system that will allow the greater gain for the greater amount of people; or a system that was right for them. Given the almost even spread of ethical biases, more than 80% of the respondents supported the nationally agreed target to reduce diesel consumption. Nevertheless, a large majority of persons are very much in support of developing a fuel oil power plant despite the risks of cost increases or shortages. The benefit of economic expansion is more attractive than limiting investments due to environmental threats. Individuals also seemed more comfortable using the resources they can today, instead of forgoing and/or extending its use.

### 5.2. Resource Values

The attitudes and behaviour identified suggests that given the opportunity then the residents may be inclined to invest whatever resources if they find it absolutely necessary to achieve the intended VES. The built environment analysis suggests that the major economic resource that the community has is the forest. Guyana has a deforestation rate of 0.048% [64] and the major contributor to deforestation



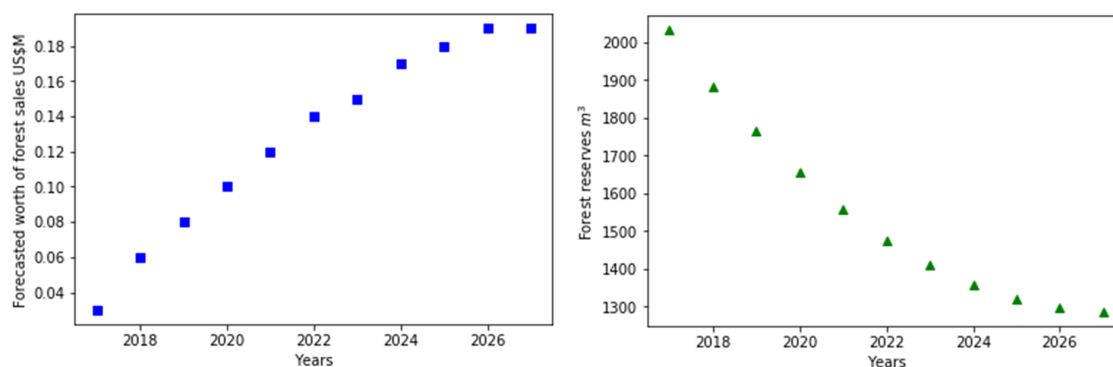
is the mining sector [65]. Kabakaburi also has deposits of bauxite in some areas. The almost 100 km<sup>2</sup> portion of lands allocate to the Amerindian village may look significant; however, it only represents a mere 0.05% of the 18.4 million forest cover of Guyana [65].

Therefore, resource values of the community were assessed by liquidating the major resource option—the forest lands. To generate greater monetary value for the timber, the export prices from 2013 to 2017 are inflated to 2017 price and the forecast of exports developed, allowing for a portion of Kabakaburi's forest of 0.1% [66] to be exported, see Figure 9. However, with the Low Carbon Development Strategy (LCDS) and the sustainable forest management practices (SFMP), measures have been implemented to control deforestation and hence curtail any opportunities for exploitation. If this was ignored then the trend of exports suggests that export is reducing at a polynomial rate expressed as:

$$y = -0.00134x^2 - 2.9639x + 055.878 \quad (1)$$

resulting in a point where timber exports may no longer be a contributor to the economy. Hence, the need to exploit the forest for the satisfaction of the VES was not adopted. This analysis supported many of the trends that have been seen in the development of sawmills in Guyana. Hence, the aspiration of creating a sawmill for producing timber was not a lucrative idea. In light of this, the cassava factory option was examined.

Cassava factories have been implemented in rural Nigeria [67], Tanzania [68] and Cambodia [69]. These large-scale entities offer to be major contributors to rural employment and require a high capital investment. Small-scale developments have also been sited across Ghana [70,71] and Nigeria [72] and have been credited with increasing household income and ousting poverty [70,72]. In Kabakaburi, cassava is one of the staple diets along with rice and corn. So, despite there is not that huge demand for garri (“A coarse-grained roasted, grated fermented flour, made from cassava and used as a staple food in a similar way to ground rice” [73]) as in Africa; Kabakaburi is seeking to use cassava as a major economic contributor. Kabakaburi residents do not use cassava to produce garri instead it is used to produce cassava bread (“A flat bread, as hard and thin as a cracker, made from cassava flour” [74]) and cassareep (A thick brown liquid made from the juices of the bitter cassava root, with additional spices [75]). To this end some of the equipment have been purchased and the building completed. The scale of production is expected to provide employment opportunities for approximately 5 persons. The main products from the Nigerian factories has been garri, starch, and feed stock, with garri being the major product with the greatest return. The main products from the KCF are cassava and cassareep. KCF will have a production of 160 cassava breads per week completed over two 8-h days. The two days operation method will require an annual cassava harvest from 0.15 hectares. However, with need for crop rotation [76] a total area of 0.5 hectares may be needed to accommodate the production volumes. The current analysis looks at the production of cassava bread only. The production of cassareep and feed stock is not yet considered due to confirmation for market demand. These opportunities if required in considerable quantities may require full 40 h per week operation at the KCF with the potential to generate more revenues. PK, presented the KCF as a lucrative investment to boost employment and assist with the villages transition into the cash economy; generating an average of approximately US\$ 0.12M yearly over the 20 years life span of the facility. The continued operation of KCF will require establishing of quality management systems (QMS) that will safe guard both the employees, customers, and community. Such considerations will impact KCF greatly.



**Figure 9.** (Right) The expected monies earned from sales forecast (inflated to 2017 value). (Left) Forecast of volume of reserves remaining.

### 5.3. Perceived Value

Tourism in Guyana has experienced a considerable increase in the recent years and Kabakaburi is hoping to share its space with curious and inquiring individuals. A small-scale tourism facility with the capacity to accommodate 10 persons per month would require a major capital investment and a minimum cost of no less than US\$300 per person per night. Most importantly this facility will be expected to cater to the needs of the tourists and such information is not yet available.

### 5.4. Important VES

Education and health are the areas of importance and required electricity services. Residents participated integrally in the configuration of the electricity system, by identifying what equipment will be satisfactory. They developed load flow diagrams and selected electricity generation sources.

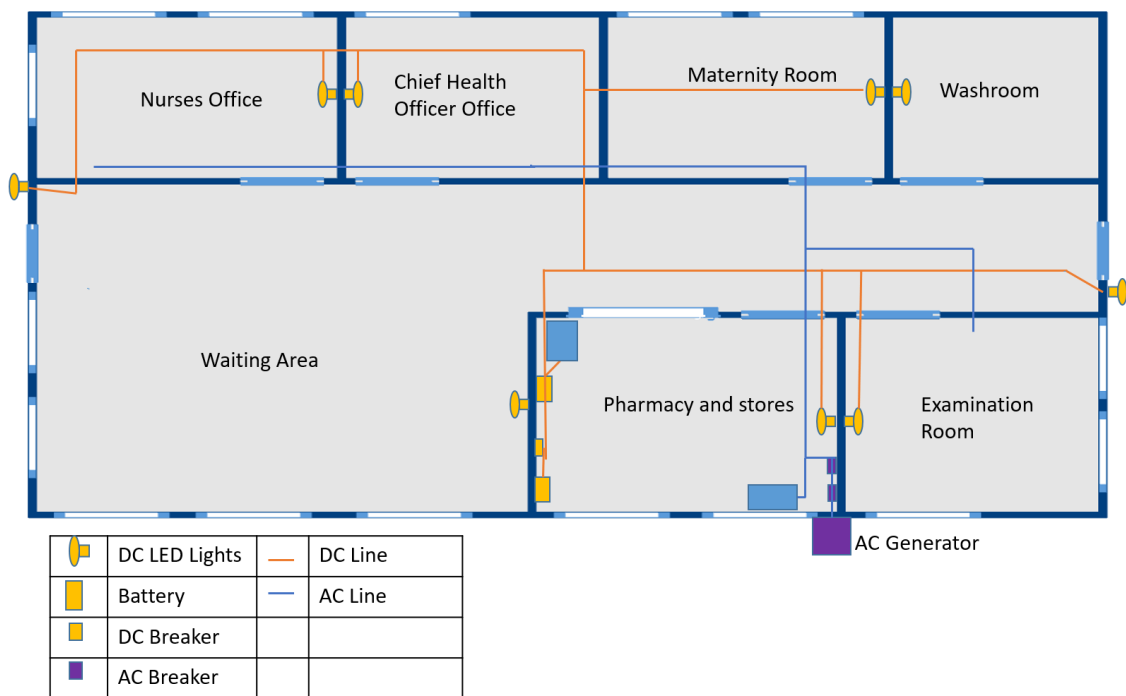
Dual-power systems for the school, health post, and the KCF were selected. These systems consisted of PV-DC lighting, and diesel generation for the AC loads. These systems are not connected, see Table 6.

**Table 6.** Table showing the electricity requirements and cost for the various VES.

Buildings	DC Lighting (\$US/W)	AC Loads (\$US/W)
Kabakaburi Cassava Factory (KCF)	8	3
Primary School	9	5
Health Post	6	4

A PV-DC lighting system and gasoline generator system for AC supply was designed for the school and the health post, see Figure 10 showing the health post design. Unlike the school the health post was equipped with a solar direct-drive vaccines refrigerator. The solar direct-drive vaccines refrigerator with a compressor applies internal thermal storage instead of batteries and is directly coupled to the PV array. Hence, no charge controller is required, and the system combines good thermal insulation together with a phase change material as storage offering 101 h of autonomy [77].

To deliver electricity for the school required each student to contribute in the vicinity of US\$7.50 to US\$10.00 per term (three months). Some parents showed willingness to pay. However, it would still be quite an expense for households that have more than 3 children attending school. The cost for the health post was calculated based on an average number of 320 patients contributing within US\$5 to US\$10 annually.



**Figure 10.** A PV-DC lighting and refrigeration system and AC gasoline generator system for the health post.

### 5.5. Current System Improvements

Despite residents expressed satisfaction with the current lighting model; they do aspire to have 24 h electricity. Delivering 24 h, 7 days a week electricity will not be without its challenges and as residents played through the game they suggested responses to anticipated dilemmas and opportunities, which showed some commitment to accepting SAIDI and SAIFI of approximately 0.8 and 0.7, respectively.

“System Average Interruption Duration Index (SAIDI) indicates the total duration of interruptions for the average customer across the electric system during a predefined period of time such as a month or a year. It is commonly measured in minutes or hours of interruption. Mathematically it is the total number of customer-minutes of interruption divided by the total number of customers on the system. As an example, a SAIDI of 100 means the average customer on the electric system over a period of a year would experience a total of 100 min of power interruption. System Average Interruption Frequency Index (SAIFI) indicates how often the average customer experiences a sustained interruption over a predefined period of time, typically a year. It is derived by dividing the total number of customers interrupted in a year by the total number of customers served. As an example, a SAIFI of 1.00 means the average customer over a year would experience one single outage” [78].

The cost of developing such a system will be in the vicinity of US\$ 40M more than they expected it to cost. Irrespective, of members demanding a ‘utility-like’ system they do not support a private operator. Instead, members discussed what a co-operative venture would entail and how should it be adopted. This is in keeping with the discoveries of Van Gevelt et al. [79].

### 5.6. Resilience and Essential Needs—What Are You Good at and Want to Keep Doing?

The essential services identified by the village do not depend on electricity. This clearly demonstrates the resilience of residents in Kabakaburi. The current electricity system enhances their standards of living by delivering social benefits. The social benefits consist mainly of lighting after dark and entertainment. Resident expend approximately US\$0.003 and US\$2.7 for lighting and entertainment, respectively see Kabakaburi electricity ‘costometer’ Figure 11. We suggest further work

in examining the electricity resilience. The residents in Kabakaburi have a minimum annual expense from US\$3550 to US\$10,375, see Figure 12.

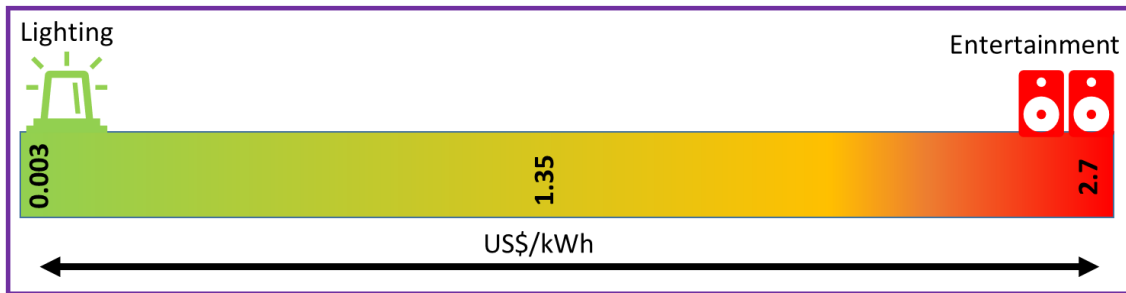


Figure 11. Kabakaburi electricity 'costometer' highlighting the range of the cost of electricity.

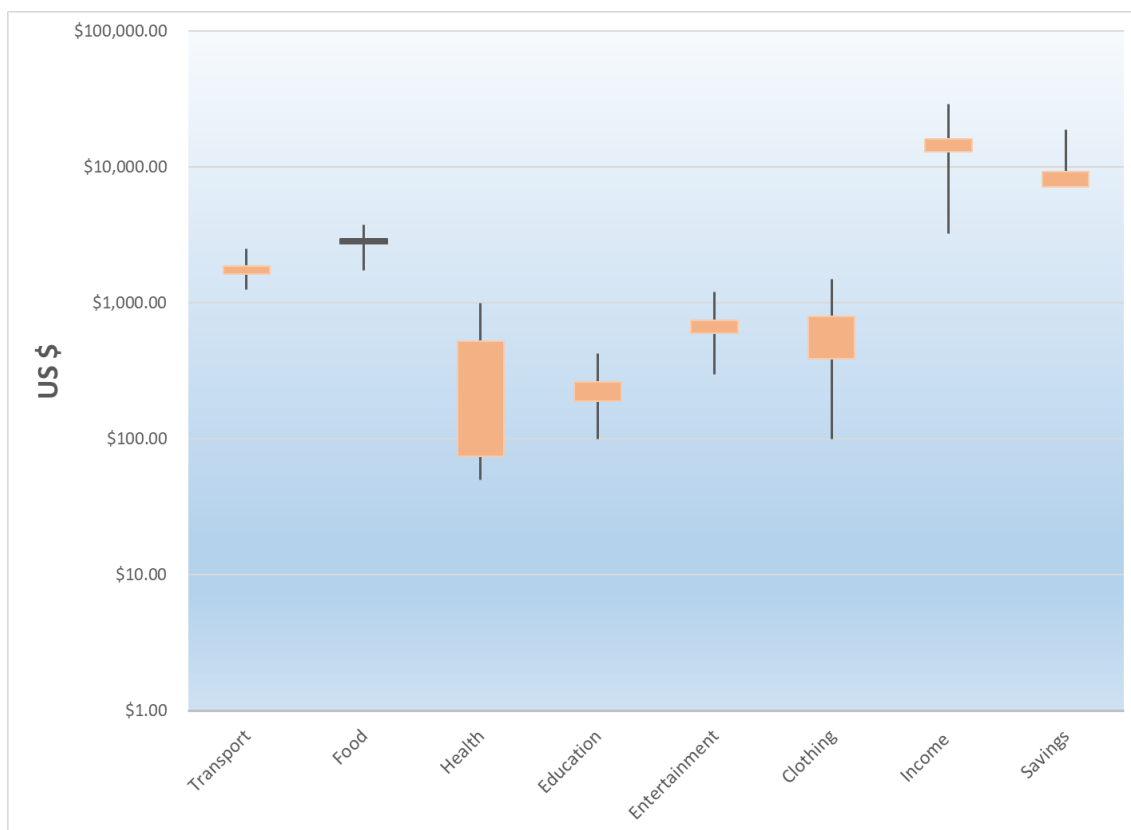


Figure 12. The annual expenses of residents in Kabakaburi expressed as log<sub>10</sub> in US\$.

The Intime analysis, while creating a moment for reflection and imagination did manage to stir up a sense of inter-generational consideration, respect, and responsibility. Participants compared living conditions 100 years ago to the conditions now and anticipate even better conditions in 2117. Despite houses are built differently, the attires are more conservative, transport is less laborious, people live longer, and the village has expanded, still the community will continue to farm, fish, and hunt. For these activities they will need the forest. Removal of the forest within the next decade see Equation (1) and Figure 9, will rob the generation in the next 90 years of their identity, even livelihood, and, to a point, existence. Hence, the group concluded that it will be wise to ensure the life of the forests is maintained hence, safeguarding the flora and fauna for generations to come.

Initially, there is no mention of sustainable development (“developments that meets the needs of the current generation without compromising the abilities of future generation to meet their needs and aspirations” [80] and “development that improves the quality of human life while living within the

carrying capacity of supporting ecosystems" [81]). The intent of this was for the community to take a simplistic view at assessing their demand and supply mechanisms. To echo the views of Vogt [82], this approach demonstrated, "*man as part of his environment, what he is doing to that environment on a world scale, and what the environment is doing to him.*"

Hence, this method of identification and quantification of VES presented two phenomena of sustainability: weak and strong sustainability. Weak sustainability is the human capital consisting of infrastructure, labour, and knowledge which can be substituted for natural resources such as fossil fuels, minerals and trees [83]. Strong sustainability consists of natural capital providing some functions that are not substitutable by man-made capital. Hence leaving the future generation a natural capital reserves similar to what is available today [84].

Care for the environment was a significant concern; however, it was about potential options of transitioning into the cash economy that took precedence. The value of the natural capital goes beyond money [85]. Hence reducing the intended man-made capital reserve. Gowdy and McDaniel [86], presented the case of weak sustainability on the island of Nauru, where despite residents enjoyed a high gross national income per capital  $GNI_{pc}$  in approximately 90 years, 80% of the island was biologically impoverished. Additionally, due to Asian financial crisis and other factors, the interest from the US\$ 1 billion trust fund, required to maintain the steady income of Nauruans, did not materialize. The case of Nauru, presents a compelling argument against weak sustainability, substituting natural resources for human capital. In a similar manner, this story presents a picture of what can happen should Kabakaburi concede to investing their forests for VES.

The essential services consisting of water, food, transportation, clothing, housing and church see Figure 6, are not directly affected by electricity except for providing fresh water during the dry season. Water actually covers (drinking, cooking, cleaning, and transport). The fresh water supply is hampered due to the receding salt water levels during the dry season. Residents noted that the (salt water) sea water often comes into the river. When the sea water comes into the river this presents a threat to the supply of fresh water. Notwithstanding this, the sea water also brings with it a new variety of fishes which they can have for food. To maintain the fresh water supply, villagers must travel closer to the river's source which can be time-consuming and expensive. Alternatively, PV power is used for pumping fresh water during the dry season. Interestingly, resident-expressed interests in understanding biophysical economics and ways of transitioning to a cash economy, a green economy, and social happiness were also discussed.

## 6. Discussion

### 6.1. CARES Contribution

Although in the world of international cooperation it is well known that a bottom-up approach is needed the application of this method is challenging since these decisions are made on a global scale with no direct representations from rural villages. Identifying and satisfying rural community electricity needs has been a global challenge, because it requires understanding the value systems of rural communities. The empirical evidence has shown that rural electrification projects have failed to deliver sustained economic prosperity and enhanced human development [87]. In this article, we examined the values in a gamified manner to verify and validate the electricity system design for appropriateness. In accordance with previous studies [88–90] our results showed that after the VES were identified, the load curves developed, and the system designed to satisfy those needs, up to this point, everyone was confident in the suitability of the system. This is quite similar to what happens when the rural electrification projects are completed and commissioned. The philanthropist fund and builders implement the projects then retreat and leave the system to operate. Our results showed that with the Intime analysis of the gamified system participants were enlightened about the system impacts on their resource and cultural values. Moreover, participants discussed during the game not only to avoid exploitation of their resources, but also decide on what would be the

most lucrative productive activity that will deliver a sustainable electricity system beyond their basic lighting needs. Participants also cooperated to decide for themselves what will be the most appropriate development initiatives that will provide win-win circumstances, delivering a clear signal for future sustainability of rural electrification. In addition, we observed that the principles of ethical dilemmas played a major role in prioritizing the VES choices. Furthermore, the gamified depiction of the VES showed that despite there was unanimous agreement to incorporate various streams of resources into economic activities, participants were reluctant to do so at the detriment of the ecology and would prefer the sustained basic electricity needs be equitably distributed. Specifically, economic development choices were motivated by the perceived value options, but in the end decision-making was influenced by the rapid depletion of resources and subsequent erosion of traditional practices. Our findings clearly illustrate a model of how policy-makers, engineers, development workers and rural communities can work together with rural community being the principal decision makers for implementation of rural electricity services; and highlights the role of rural community values in the rural electrification solution.

As with the work of Domenech et al. [91] the delivery of electricity to residents of Alto Peru via the Program for Rural Electrification and Access to Renewable Energies in the Andean Zone, the households are widely dispersed in Kabakaburi with the mission “Kabakaburi” composed of the schools, market, church, and 25 households. The demand assessment of the residents was representative of the residents’ real needs taking into account the consumption habits, future increases in demand, current generation assets and electricity tolerances contributing to the final demand. The development of the demand curves was done in unison with the residents so the villagers could immediately validate the system specifications and understand/appreciate the design process. In addition, this led to enhancing the technical capacity of the residents. CARES approach unlike Serpa and Zilles [92] initiates the capacity-building early on in process and not just at the implementation stage. We believe that the involvement of the end user in the initial design will not only eradicate unnecessary rework and reduce costs, it will also provide an opportunity for educating all parties involved. Moreover, the participation in the load development and analysis puts in motion what Serpa and Zilles [92] calls an irreversible social-cultural change, which the community should be well aware of and if possible identify variables of reversibility should that be the optimal choice. Fuentes et al. [93] have identified an extensive list of failure of PV systems which were not representative of any technical problems in Kabakaburi; meanwhile some residents did replace light bulbs no major replacements had been done to the 8 years old system. However, the threats of the system were incorporated into the game for residents to become aware of and to identify ways of addressing them should they occur. The conditions that existed in Kabakaburi and that in the Saharawi [93] accommodations were very different. The difference in environmental, social, cultural, and financial practices among rural communities globally are diverse. No one solution fits all. Rural electrification systems must be customized to needs and undeniably requires an approach that is adaptive, flexible, and participatory. The adaptive, flexible, and participatory characteristics are lacking in the top-down approaches. So, while the sustainability experts are all cognizant of this the customized efforts that rural electrification needs is quickly substituted with a standardized, quick, and prefabricated solutions that experts believe will achieve an implementation deadline. One response to the true sustainable development of the local community is to create a system that is developed *by* the peoples, *for* the people and *with* the people.

Kabakaburi has experienced forms of irreversible socio-cultural impacts of electricity use locally in the community via the installation of SHSs and the residents’ interaction with the urban way of life. The installation of the current solar systems followed the top-down approach and over the life of the asset the community has adopted the new technology as valuable. The value derived from the SHSs has motivated residents to further explore more productive VES. The experiences of electricity may have created an expectation that needs to be managed if these services are to be transferred to productive uses. It is here that CARES seeks to examine the opinions, ideas, and needs to characterize designs,

of systems, programs, and policies that will fit. It is the hope that given the emergent viewpoint that the community can have a plan and in so doing can access the necessary funding for projects. This emergent approach allows for co-education of the facilitator and the community and alleviates ignorance in various areas arising as the plans for development emerges.

Alvial-Palavicino et al. [94] have recognized the need for trust similar to CARES it is an integral aspect in the initial stages of the development, which is the basis of CARES and is applied sooner in the development process. Meanwhile Alvial-Palavicino et al. [94] incorporates the vision of all stakeholders for consensus building it lacks the involvement of the members in the design. CARES offers co-design and co-development which includes co-construction and cooperation until the community has achieved the social transition. The (Electrificación Sustentable Cónдор, Condor Sustainable Electrification Project in English) ESUSCON project appeared to be more or less patronizing since the donor is motivated to deliver a service in support of corporate responsibility and the local residents are not providing major financial support or their need to resist isolation through communication with the rest of the world was not cause for the intervention. Inadvertently, the resources from which the finances are generated from is within the local community and can be considered their wealth. Nevertheless, CARES depicts what Alvial-Palavicino et al. [94] considers to be the path for evolution strengthening of the sociological system by incorporating the opinion and ideas of the community to develop guidelines for projects.

The current study contributes to creating a general understanding of the mechanisms underlying the success of rural electrification. The results demonstrate that our participants considered the continued preservation of the ecology as priority over economic development, and these convictions were in accordance with the findings of Gibson et al. [95], which cautions that “material gains are not sufficient measures or preservers of human well-being” [95]. The importance of the environment to rural residents did not require intense and complex scientific calculations, merely, a simple input-output analysis and evaluation of the system during its’ lifetime and at end-of-life. This also provides a supplementary explanation as to why after rural electrification systems reach their end-of-life or even after they experience a system failure they are abandoned. A program that will seek to maintain standards and support adequate replacement will be required. A system that will be locally accessible and can deliver technical advice will also be beneficial. Hence, CARES allows for communities to voice their local perspective in the electricity debate so that external aids can be better channeled to the areas of need preventing what Coppock [96] calls a broken system with little hope to impact the community. The plan that will result from the CARES approach further informs funding agents on the time and cost requirements and allows for the aid to be better fit for purpose. Moreover, our findings agree with various other findings regarding weak and strong sustainability [97–99], which the community identified just after completing the game. An understanding of weak and strong sustainability was not explicitly expressed prior to playing the game. In short, the mere exposure to an emergent participatory approach to rural electrification has empowered rural members to contribute to rural electrification solutions in a meaningful and sustainable manner and achieve mutual learning.

## 6.2. Delivering on the Community's Needs

The Kabakaburi’s case study has demonstrated that the CARES can add value not only to electricity design process in rural communities but rural development as whole. It is apparent that the economic feasibility is minimal for the areas of importance and optionality. This further highlights the trade-offs that apply to weak and strong sustainability. CARES presents a visual image and virtual interaction of what happens when community consider weak sustainability instead of strong sustainability. Hence, unlike the present model of power system design done to facilitate ambitious forecasts due to ever increasing production rates CARES demonstrates that this may not work in subsistence communities, should they agree to participate in the cash economy. Notwithstanding, the cities and towns of today have grown out of subsistence living to what they are now and while they do deliver economic opportunities they lack the physical components of rural villages that are of importance to resilient rural lifestyle. Such opportunities include the vast expanse of farm lands,

unpolluted air, a rich community spirit, and happiness. The latter two are difficult to quantify with conventional methods of economic decision-making. However, they have been cited as delivering more satisfaction to living than wealth and can contribute to eradicating many global challenges [100].

The VES of the community resides not in their essentialities. Rural communities require energy services that deliver much required assistance in improving the already functional operations and delivering potential value adding characteristics which simultaneously supports human development (education, health, and comfort). The PV system is operational because it delivers a VES, it requires little from that community upfront, low operating support, and lasts a considerable length of time.

We developed the following complex cost benefit analysis (CCBA) to account for the resource use and electricity consumption trade-off for a community. CCBA is a composite statistic combining reserves, expected returns and asset life based on the resource that may be expended to achieve productive electricity benefits. The specific focus of the CCBA is to shift the focus of analysis of financial indicators which deliver weak sustainability to resource and time measurements that support strong sustainability. CCBA is a new tool for understanding the economics of rural electrification sustainability. The CCBA combines three factors:

- Reserves of resources to be used productively for economic gains,  $m^3$
- Expected returns from the use of the resources,  $EROI_{soc}$
- The life time of the asset and its contributions,  $t$

The indices are transformed into unit less quantities between 0 and 1 using, Equations (3)–(5). CCBA is generated from the geometric mean of the indices, see Equation (6)

$$CCBA = \prod R_i \times R_{ei} \times L_{fi} \quad (2)$$

where:

CCBA is the complex cost benefit analysis,

$R_i$  is a reserve index,

$R_{eri}$  is the expected returns index, and

$L_{fi}$  is the life index of the asset.

And

$$R_i = \left( \frac{x_r - \min_r}{\max_r - \min_r} \right) \quad (3)$$

where:

$x_r$  is the reserve used (previous reserve plus amount to be used)

$\min_r$  is the minimum reserve that must remain

$\max_r$  is the maximum reserve that existed or can be calculated from past records

And

$$R_{eri} = \left( \frac{x_{er} - \min_{er}}{\max_e - \min_{er}} \right) \quad (4)$$

where:

$x_{er}$  is the energy of the system

$\min_{er}$  is the minimum energy the system can deliver

$\max_e$  is the average maximum energy of the system at final manufacture

And

$$L_{fi} = \left( \frac{R_l - e_l}{R_l} \right) \quad (5)$$

where:



$R_l$  is the average time required for the acquiring of the resource (time of existence plus extraction through to point of delivery)

$e_l$  is the lifetime of asset to be invested in

Hence,

$$CCBA = \sqrt[3]{R_i \times R_{ei} \times L_{fi}}. \quad (6)$$

### 6.3. Implications for Design

This approach has extended the design process of power system to incorporate a greater input from the end user. Ultimately, this design approach not only captures the voice of the customer (VOC) it allows the customer to confirm that their needs were well interpreted and that the intended deliverable will be better engineered. This allows for more efficient design by eradicating unnecessary waste in prototyping by providing a virtual context for end-users to interact with both a product, its corresponding services, and challenges in use. This has the potential to reduce customer complaints and instead creates an atmosphere where the customer can apply a sense of ownership and provide constructive improvements. The customer may be more appreciative of the service and the design process is extended beyond the experts and design offices.

### 6.4. Limitations

The limitations of our work are evident in the single case application. CARES delivers a flexible structure and while this application may be responsive in some environments, in others it might present challenges.

Aspects in values assessment may be extended beyond VES and can present underlying reasons for systems failure. Such aspects of personality and local politics were exempted from this analysis since the primary focus was to establish the VES that were directly related to the residents. While 'Power' attempts to deliver a visual representation of the real-life operations with a dynamic perspective it lacks the political ingredient. In developing countries politics can have an impact on development.

Adaptation of CARES in a rural setting is likely to be affected by the literacy levels of participants. This was not a problem at Kabakaburi but in situations with a high percentage of illiteracy CARES may require modifications.

The internal social and political issues were not examined in detail since the focus was on the needs. Many members were intermarried and people identified more as a community than as a tribe. No focus was placed on the intrinsic tribal differences. Furthermore, CARES will require an adequate amount of time, which may not necessarily synchronize with the time-frame of development projects. Maybe local NGOs can be tasked to deliver the needed assistance given the full complement of an equipped multi-disciplinary team that will effectively aid in the emergent development process given the consent of the community. One key note is that CARES does not seek to develop an electricity system. However, given the role that electricity plays in human development it is inevitably an unsuspecting characteristic that is bound to reveal itself. Moreover, the risks of participation are worth the benefits and can complement the application of scientific research methods.

### 6.5. Potential Future Research Directions

A potential future line of research could be to explore the political and tribal value systems, to see how they affect the local identify of the community. This may be able to bring out nuances that might not be captured by the CARES approach as documented. This might usefully be approached using an ethnographic type of study.

Another potentially interesting research question could be to examine the effect of people coming into and exiting the community. Sub-questions in this area could be how the value systems change, how knowledge changes, how exposure to modern communication changes expectations. This raises the question of how world-views change, and psychology research methods may be appropriate.

Also, there is the children's perspective. The present study was limited to representing the adult's perspectives. However, children may have different perspectives, and it may be worthwhile finding ways to include their views earlier in the process.

We hope to return to the community to further examine the findings and explore avenues for national or regional funding. Since the council members would have received training in areas of leadership we intend to also work with them to create final proposals for funding.

## 7. Conclusions

The CARES approach is a rural community participatory approach for the identification of the types of values from the end-user perspective that may guarantee a successful rural electrification design that fits the needs, with assistance of a facilitator. It consists of seven steps all hinged on local community participation and effective communication. It encourages experts or anyone willing to assist in development of rural communities, to approach it in a more structured way with the main focus being from the bottom-up and with an invitation from the community for support. We found that rural residents could identify areas for improvement and just required some support in facilitating prudent decision-making. The application of gamification allowed for the participants to better explore the consequences of their electricity options from design to its end-of-life and to tailor their aspirations (perceived values) so as not to exploit the resource limitations and surrender cultural practices.

We propose the application of CARES approach to policy development so that policies can be better streamlined to fit local requirements. We have identified a new CCBA for determining project feasibility that is not directly linked to money.

The CARES methodology provides a mechanism whereby *important innovations and changes normally start from [the] tiny minorities of people who.. use their creative freedom [101]*.

This paper makes the following contribution to the body of knowledge:

- A novel approach, CARES has presented a visual depiction of a dynamic system and has facilitated local participation from resident in the design of their VES.
- We have applied the gamified approach towards power system learning and knowledge sharing that has not been done before.
- We have applied gamification to aid in real-life decision-making there by empowering rural communities to contribute towards their development and to identify areas where they need assistance
- A novel way of rural community participation is proposed that supports the implementation of policies which can fit rural systems.
- A new CCBA is proposed for evaluating rural electrification investments.

This study and its methodology make a potential contribution to policy frameworks for rural electrification at both the regional and global scale. In particular, it admits the community perspective into the design process, thereby helping to create an energy system that the community can own and sustain.

The most important steps that all major stakeholders involved in rural electrification should adopt is to approach rural communities as a facilitator willing and able to help communities to help themselves. Helping rural residents to recognize their local values, needs, challenges, and how to wisely address their needs would help them to attain the ultimate goal of sustainability.

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## Abbreviations

The following abbreviations are used in this manuscript:

PREA	Pennsylvania Rural Electric Association
USA	United States of America
CARES	Community Access Resource for Electricity Sustainability
TES	Typical Electrification System
GDP	Gross Domestic Product
SAM	Strategic Analysis Method
MGK	Micro-Grid Kit
EEM	Essentiality Electricity Model
BABSTER	Bottom-up Agent-based Strategy Test-kit for Electricity Renewables
HOMER	Hybrid Optimization of Multiple Energy Resources
ETAP	Electrical Power System Analysis and Operation Software
PSS	Power System Simulator
UAEP	Unserved Area Electrification Programme
PV	Photo-Voltaic
DC	Direct Current
AC	Alternating Current
Ah	Ampere hour
kW	Kilowatt
SHS	Solar Home Systems
VES	Valued Electricity Services
PK	Power Kabakaburi
DES	Dual Electricity Systems
LCDS	Low Carbon Development Strategy
SFMP	Sustainable Forest Management Practices
KCF	Kabakaburi Cassava Factory
WHO	World Health Organization
PRA	Participatory Rural Appraisal
ESUSCON	Electrificación Sustentable Cóndor, Condor Sustainable Electrification Project in English
VOC	Voice of the Customer

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