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Systems analyses and the sustainable transfer of renewable energy technologies: A focus on remote areas of Africa

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ABSTRACT

Sustainable energy provision is regarded as one of the most significant challenges facing the realm of development, especially in Africa where large proportions of the population still lack access to energy services. Although there have been much efforts to address these problems with renewable energy technologies, there have also been substantial failures and problems. The Intermediate Technology Development Group (ITDG) has developed a manual that seeks to address these implementation issues. The Renewable Energy for Sustainable Rural Livelihoods workgroup has also developed such a framework, termed SURE, which is a multi-criteria decision analysis modelling tool. Both of these frameworks rely heavily on the Sustainable Livelihoods Approach and emphasise the need to rigorously analyse the sub-systems where technologies are to be introduced. These two frameworks have been integrated and assessed in terms of their applicability for the South African rural renewable energy landscape through a Delphi study conducted with several experts in the energy sector. The results indicate that the integrated framework is suitable for the South African context, with additions to the ITDG and SURE frameworks suggested. Finally the paper highlights a potential concern in the South African renewable energy industry in that technology assessment methods that are utilised in practise do not incorporate the concepts of sustainability science adequately; this must be addressed through further case study research efforts.

1. Introduction

In light of the almost universal acceptance of the Millennium Development Goals (MDGs) [1], the growing awareness of climate change [2], and an increasing concern of an oil peak as oil prices continue in a general upward direction [3], the search for renewable energy (RE) has become increasingly important [4]. Especially in rural areas of Africa, where the bulk of the continent's poor still find themselves, the potential of RE to address the challenges of energy poverty and meeting the 2015 targets of the MDGs, has been highlighted [5]. In South Africa, for example, the national government views RE as a means to reach its constitutional commitments made through the mechanism of human rights in terms of access to electricity for all citizens [6], whilst alleviating the perceived enormous costs involved with utility-based grid provision in rural areas [7]. Also, a target of 10,000 GWh of energy to be produced from renewables by 2013, has been set [8].

Despite this enormous drive for renewable energy, literature suggests that renewable energy projects are rather prone to failure, especially in remote areas [9]. The international experience of the World Bank Group [10] highlights the fact that the interaction between society and renewable energy technology is one of the critical factors of success that needs to be actively managed if sustainable energy development is to be achieved. Some of the prevailing challenges listed include: "…perceived financial and political risks, insufficient institutional capacity to implement projects, weak or inadequate regulatory frameworks, and limited understanding of what is feasible on the ground". An in-depth study of renewable energy models in Southern Africa confirms this realisation [11], and highlights that socio-political factors are on par with economic and technical aspects when it comes to the sustainability of renewable energy projects. These, and other studies [12], suggest that there are truly significant challenges to transferring renewable energy to rural areas. A holistic, integrated approach to rural renewable energy delivery is subsequently needed. Identifying what such an approach may look like was the

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purpose of a literature study. The primary objective of this paper is to identify a framework of such an approach. The paper further evaluates the framework through a Delphi methodology that engaged experts from across the South African renewable energy landscape.

2. Decision-making frameworks to facilitate the sustainable transfer of renewable energy technologies (RETs) in rural areas

A comprehensive literature review of rural development, and the role of renewable energy for such development, is summarised elsewhere [13]. The literature review concludes that the integration of renewable energy into the rural development paradigm is of great importance to the sustainability of technology transfer in particular, and sustainable development in rural settings in general. A rural energy implementation framework should therefore not only be based on the lessons learned from the failures of previous rural energy projects [12], but should also incorporate the current theories found within rural development thinking [14].

The "Energy for Sustainable Rural Livelihoods" manual of the Intermediate Technology Development Group (ITDG) [15] is such a framework. As the product of practical experience in technology related development, the manual serves in pragmatically integrating all spheres of the rural developmental process in a very flexible, people-based manner. As such, the social and institutional spheres of sustainable development receive a great deal of attention, not for a moment relegating them to anything less than the technological, ecological and economic spheres.

The social sphere primarily focuses on using participatory techniques to gain indigenous knowledge as well as to determine the possible impacts of technology choices. It also places people and their needs in the centre of the rural renewable energy process. The institutional sphere is mainly concerned with the creation of supportive institutions. This is not restricted to any level of government or organisation, but is a cross-cutting call for meaningful institutional transformation in the face of the need for rural energy. The choice of technology is a product of the careful analyses of demand and supply, required and available skills, and the standards and quality control measures in place.

Another framework is based on a multi-criteria decision-support system that utilises a large amount of technical and non-technical information collected in a variety of ways to determine the most appropriate energy choice [16]. The software used by the Sustainable Rural Energy Decision-Support System (SUREDSS) was developed by the Renewable Energy for Sustainable Rural Livelihoods (RESURL) project, which is funded by the UK Department for International Development (DFID) [17]. SURE was tested in a remote Colombian rural community, who were already making use of a diesel generator, but required additional energy.

2.1. Structure of the introduced frameworks

The discussion of the proposed frameworks for rural energy provision needs to first address the characteristics, similarities and differences between the two frameworks, after which they will be combined into one framework. The flowcharts of Figs. 1 and 2 are useful as basis for this discussion.

The analyses methods that the ITDG manual and the SURE tool utilise are not vastly different. However, there are two important differences between the approaches, which are made clear by the two diagrams. The first is that all of the analyses of the SURE tool fed into a computer model that eventually derives an appropriate technology choice. In other words a hierarchy is established with technology occupying the top position when it comes to sustainable energy provision for rural communities. This, however, brings about the second important difference. Whereas the ITDG manual has a whole section/chapter devoted to institutional analysis and development, this is noticeably absent from the SURE system of analysis. The ITDG manual partly addresses this problem by focusing on the development of, for example, institutions in addition to their analysis. What their experience has taught them is that rural energy is not just about technology choice, but also about development.

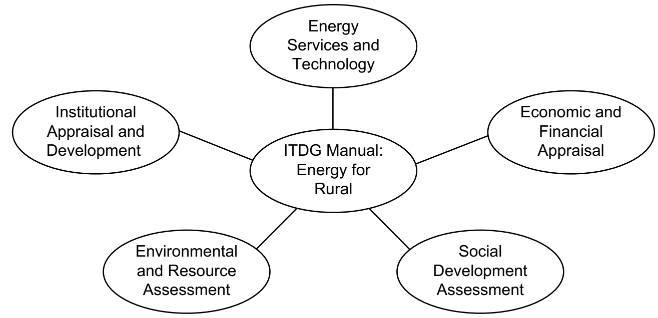

Fig. 1. The ITDG manual framework.

In essence, it is about the balance between a choice and a strategy, where the former is the result of the SURE decision-support system and the latter the result of the ITDG manual. Although the SURE decision-support system does not provide an appropriate "strategy" for the implementation of rural energy technology, it does enhance the chances of success of the strategy produced by the ITDG manual. This is achieved by promoting the technology that is sure to be the best option for the community concerned. The rest of the strategy surrounding this technology can now be developed, in partnership with the community, around this technology.

Fig. 3 illustrates how the two different approaches may be reconciled by integrating the SURE tool in the ITDG manual. The decision-support provided by SURE greatly enhances the efficiency of the ITDG manual by providing a more robust technology choice system without undermining the other four spheres in terms of their contribution to the strategy. The functional detail of the two systems will be discussed in the broad framework of the different stages of a project, allowing for an increased understanding of the interaction between these two.

Table 1 provides a summary of the abovementioned methods, analyses and frameworks, allowing one to gain a more thorough understanding of the eventual product or integrated framework that is being proposed for further evaluation. As may be observed, a major part of this overall framework revolves around comprehensive analyses, allowing for the proper assessment of all major areas of the context where a technology will be introduced. Much of the analyses are reliant on the communities themselves and requires their continued involvement, since the analyses methods are technologically neutral and aim to deliver a solution that is acceptable to the community. The implementation and monitoring and evaluation stages are also created in such a way that they are community led and motivated, which not only has sustainable technology implementation, but also empowerment in mind. The details of how the analyses may be executed, and associated indicators calculated, are provided elsewhere [13].

3. Research design and methodology

The Delphi technique was selected for the study. The versatility of the technique to produce generalisable results [18] was the main basis for the selection. The Delphi technique is also particularly well suited to situations where those with the expert knowledge on the particular problem are geographically dispersed, as is the current

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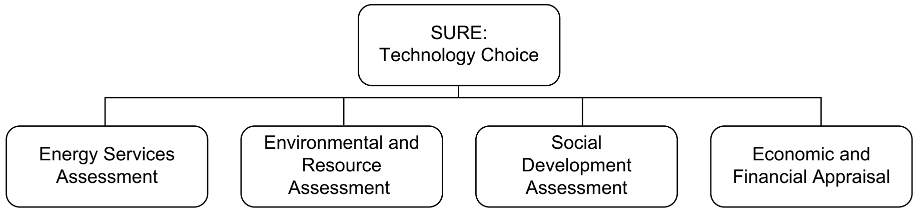

Fig. 2. The SURE decision-support system framework.

case with rural renewable energy experts in South Africa. Additionally, the relatively low cost and effort required from participants ensures that these professionals will be much more inclined to share their experiential knowledge. The research process that was followed is summarised in Fig. 4 [13].

3.1. First questionnaire

The Delphi study consisted of two rounds: the first round tested the ITDG and SURE frameworks making use of an online survey tool (www.surveymonkey.com). Multiple choice questions were mostly employed, coupled with explanatory spaces that allowed for respondents to comment or add imperative information, from their perspectives. Respondents were also expected to justify the majority of their choices in comment boxes that were provided. Possible participatory candidates were identified by the South African Council for Scientific and Industrial Research (CSIR), and were contacted via e-mail and telephone. Seven candidates agreed to participate that represent 7.7% of the list of possible candidates.

The first two parts of the survey provided introductory information, and ascertained the demographic profiles of the participants, establishing them as experts in the field of rural renewable energy in South Africa. From there on the survey was framed according to the different stages of a project cycle (see Table 1). Accordingly, the next section dealt with preparatory analysis, testing both the need for and methods used for this analysis. It then proceeded to baseline analysis, analysis and decision-support, implementation strategy, and monitoring and evaluation, testing each section in more or less the same manner.

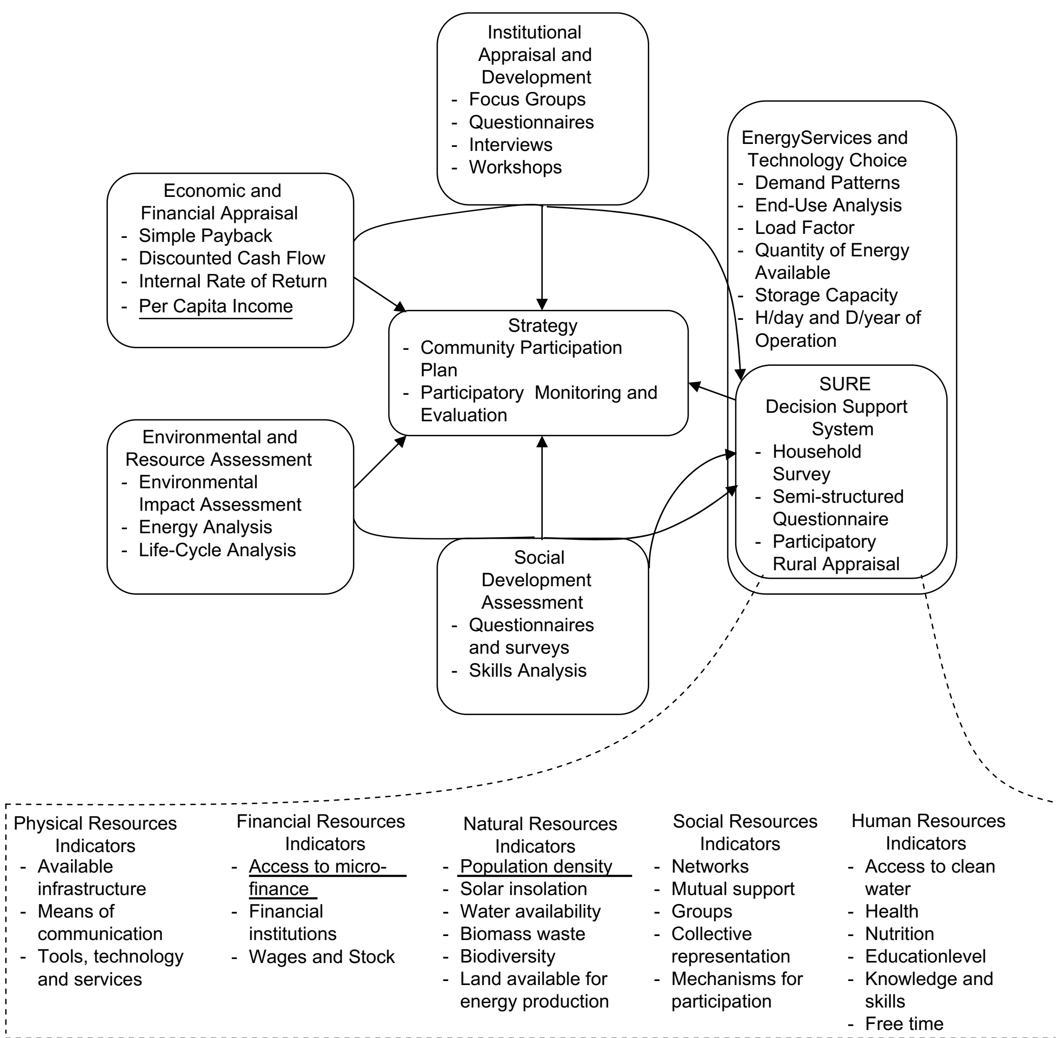

Fig. 3. The proposed integrated ITDG–SURE-DSS framework.

Table 1
Framework summary.

Project section	Proposed methods
Preparatory Analysis	Policy Environment Analysis
	Community Stakeholder Analysis
Baseline Analysis	*SURE*
	Physical Resources
	Financial Resources
	Natural Resources
	Social Resources
	Human Resources
	Energy and Technology Analysis
	Skills Analysis
Implementation	Community Action Plan
Monitoring and Evaluation	Participatory Monitoring and Evaluation

3.2. *Second questionnaire*

The results of the first round of testing were assimilated from the different respondents and reworked into a feedback document that was sent out to respondents along with the second round questionnaire. This particular questionnaire strove to test the stability of responses, especially in areas where there seemed to be radically divergent views or a lack of clarity. Additional ideas, methods, definitions and indicators that arose as a product of the first round were also tested with the group.

The main aim of the questionnaire was not consensus, but rather gathering relatively stable responses that may provide answers that expose the underlying inconsistencies and assumptions that make up the frameworks.

4. Research findings

4.1. *Sample profile*

The participant profile was homogenous in the sense that all of the respondents are engaged in renewable energy in one way or another, whether this is through design, technology dissemination,

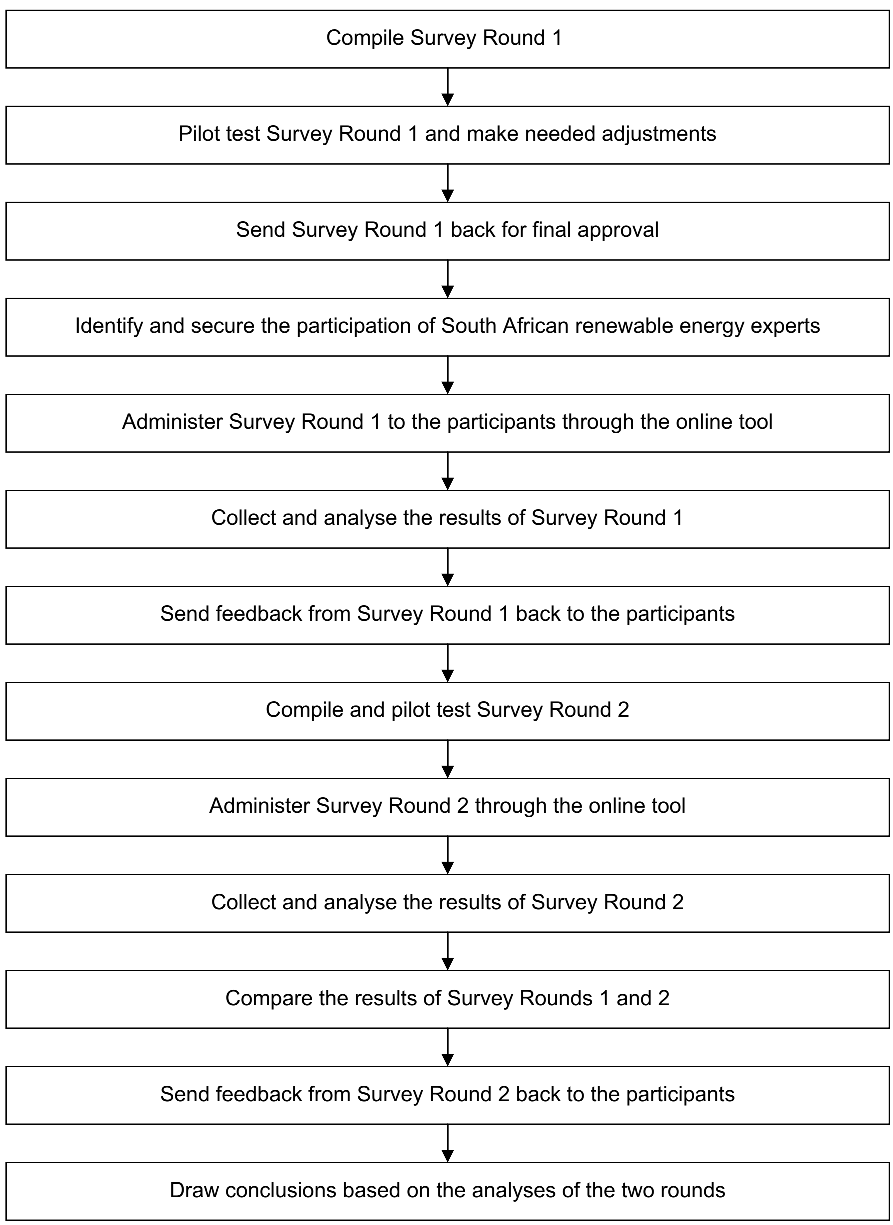

Fig. 4. The research process.

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rural implementation, or research. Other than that there were not much corresponding features between participants. They are from all over South Africa, involved in a number of different renewable energy technologies and/or activities, with very different levels of experience and educational backgrounds. However, there seems to be two general "trends" in the respondents' profiles. The one is that most of them, except for one, have been involved in renewable energy for less than ten years. The exceptional participant has been involved for more than double that amount of time, even though he has the lowest level of education in the group. The other "trend" is that five of the seven respondents were either educated in engineering or seem to have received relevant vocational training. The remaining two participants are from the social sciences, an area greatly removed from the world of engineering. This interaction of the different knowledge fields within the realm of renewable energy highlights the necessity of transdisciplinariy in dealing with renewable energy systems.

Another point of similarity is the fact that most of them, except one, is working in the private sector. Some of these companies directly interact with the public sector due to the fact that they are operating as concessionaires, while others do not seem to interact with government on such a direct level at all. The only participant not directly working for the private sector seems to be caught somewhere in between since he is employed by a para-statal organisation that aims to benefit both the public and private sectors. Unfortunately, there are no respondents directly employed by the public sector, which may prove to be one of the major shortcomings of the study, especially when it comes to the generalisability of the results.

4.2. General analyses of the responses

The analyses of the responses identified key aspects that are summarised in Table 2. Not all of these comments are necessarily relevant to the study at hand, yet they provide an important glimpse into some of the possibly dominant mindsets in the renewable energy and development sector in South Africa.

Table 2
Noteworthy comments made by participants of the Delphi study.

General area of contribution	Comments
Policy	Can be both enabling and constraining.
Community	Involvement and acceptance very important.
Practicality of certain analyses/Methods	*Baseline Analysis*: Only practical if need exists for later impact assessment. However, another point is that most energy projects have a big enough impact to warrant an impact assessment. *Per Capita Income*: Difficult to gather information in rural areas. *Policy Environment Analysis*: Large amount of policy may result in "paralysis". *Community Action Plan*: May only serve as a method of ensuring community participation in something they don't need/want. Also, this kind of action usually requires large amounts of funding.
Indicators	There seems to be a need for/inclination towards meta-indicators.
RE reputation	Poorly planned and executed renewable energy projects seem to cause much harm to the industry.
Ownership vs. Project-based provision	Project-based provision destroys the need, therefore also the industry. Temporary nature of projects automatically means that maintenance and assistance may disappear once a project is finished.
System design	All factors of the end-user community need to inform the design.
Financial resources	In South Africa it is very difficult for the poor to access financial institutions. Micro-finance and co-operatives are therefore very important.
Social resources	Seen as inherent yet very important part of (poor) rural communities.
Technological ignorance (from the community)	Seen as a possible significant hindrance to the sustainability of energy implementation.
Product/Project vs. People orientation	Most answers on this issue reflect the fact that project success is dependent on people; therefore you must get people to accept the project. "…get buy-in…" and "…if you want the project to work you must involve the people…" are two significant examples of comments that support this. Also see Practicality: Community Action Plan comments.
SURE	Format of output is very helpful, especially for product comparison.
Financial assessment tools	No definite favourites, very context-dependent.
PM & E	Proponents feel quite strongly about the need for and importance of participatory monitoring and evaluation.
Private vs. Public RE	Strong minority antagonism towards any renewable energy provision that isn't market-led.

5. Discussion

5.1. Responses to the ITDG and SURE frameworks

The two identified frameworks, according to this study, pass the applicability test with great success. Not only do they line up with the most authoritative studies on rural development and rural renewable energy, but they have also proven to be acceptable to experts within the renewable energy realm in South Africa.

From a sustainable development perspective, the frameworks are perceived to pave the way forward to a sustainable future as they facilitate increased complexity. Not only is this done through a technology neutral approach, which opens up a world of energy possibilities to the end-users, but the SURE decision-support approach is founded upon the Sustainable Livelihoods perspective, according to which the appropriateness of energy interventions is measured based on their effect on the five capitals of a community (see Fig. 3) [13]. The most appropriate energy option will obviously increase those capitals most important to the community, thereby increasing the number of options of the community; this again translates into increased complexity.

The Sustainable Livelihoods decision-support approach is also impossible to use without proper participatory practises being in place. This can be found throughout the proposed frameworks, from the preparatory analysis through to the monitoring and evaluation. The results of the Delphi study also reveal that interactive methods of analyses and information gathering were constantly among the highest scoring. The community-based decision-making, implementation, and monitoring and evaluation methods proposed by the ITDG also received strong support from respondents, in that social learning and empowerment are facilitated through the delivery of energy to rural communities.

The interactive nature of the proposed methods also allow for easier technology transfer as knowledge of, and experience with, the proposed energy technologies increase through participation in all stages. The skills analysis proposed by the ITDG framework furthermore significantly increases the chances of successful technology transfer in that, as was proposed by the respondents, it allows for decision-making around the technical maintenance ability of the community. Coupled with the community-based strategy development, the practise of successful technology transfer becomes much more of a tangible reality. This strategy, designed around the sustainable livelihood capitals and capital-needs of the community, is also a key in enabling effective poverty reduction in the targeted communities.

The developers of the SURE decision-support approach argue that "…it is a valuable contribution to the project of bringing

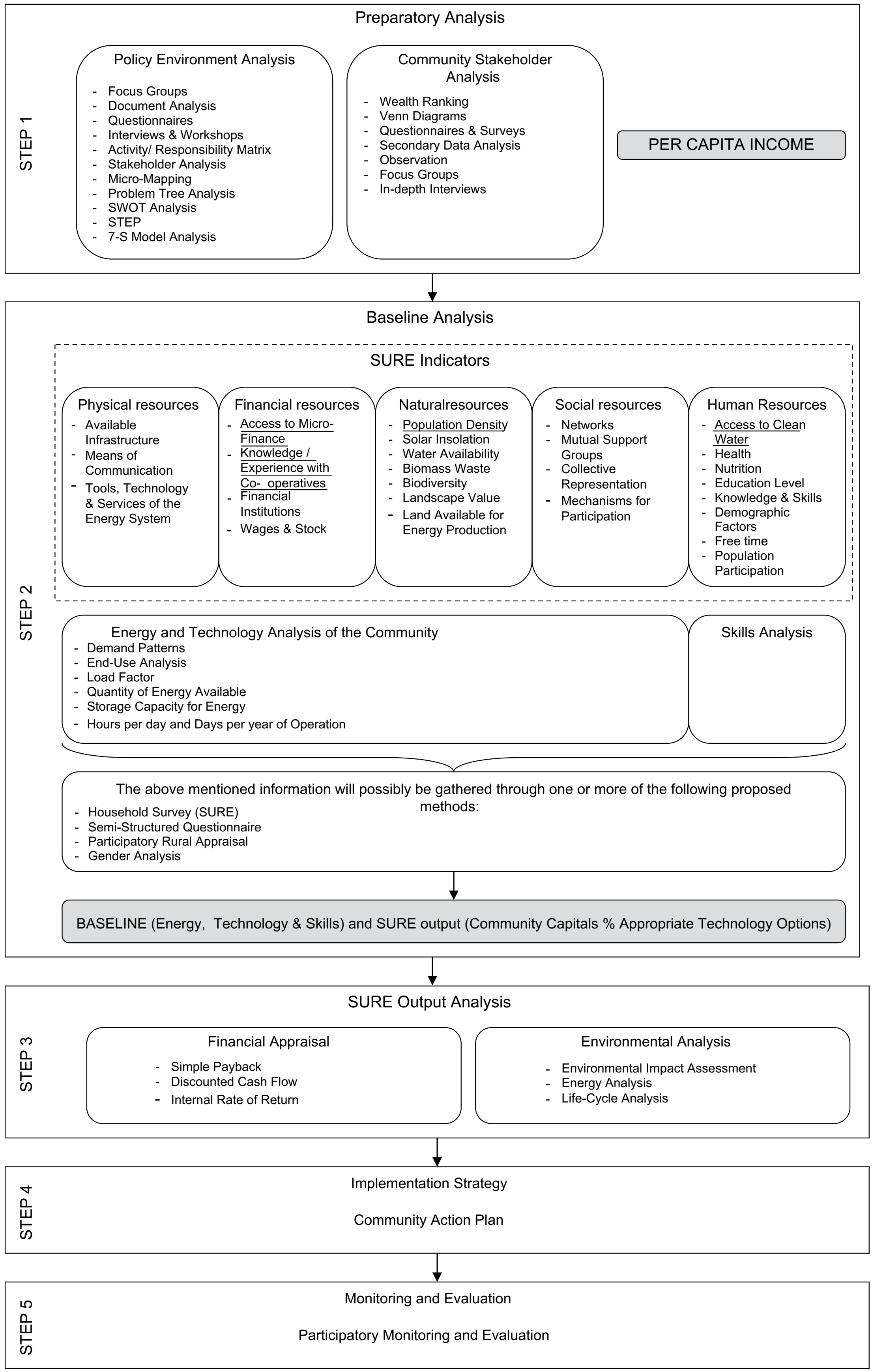

Fig. 5. a. Breakdown of the methods and indicators of the framework (Steps 1 and 2). b. Breakdown of the methods and indicators of the framework (Steps 3–5).

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affordable, sustainable energy to poor rural communities in the developing world. This information can be crucial for a community searching for feasible solutions to concrete problems as well as for national government programmes targeting sustainable rural development in specific areas'' [16]. The validity of this argument has increased as a result of this study, not only because of the fact that their model has achieved positive results from renewable energy experts in a developing country, but also because it has been combined with the ITDG manual that allows for the utilisation of the information provided by SURE to create a robust, community-based implementation strategy.

Not that the two frameworks were accepted unanimously, or without reservations. The struggle that was observed in the literature review between the forces of the market and the state in development [13] also played out in the results of the Delphi study; the intensity of this struggle proved to be rather strong in some cases (refer to the last comment in Table 2). These differences in opinion prove that utilising experienced individuals in this research does not rule out the need for practical testing, as was initially thought. Instead, reservations about the practical executability of a number of analyses and indicator-type assessments merely served to prove that the frameworks definitely need to be tested further through additional case studies.

Another aspect that needs to be considered is that the participant profile is skewed towards the private sector and technology supply. This has had a definite effect on the results; the most blatant example is the market-fundamentalist that to a large degree undermined much of the consensus around the framework. However, the remaining results are almost perplexing when one considers the fact that a very large percentage of the responses are in line with what is being propagated in rural renewable energy literature and public rhetoric. This is quite possibly the result of the fact that most large-scale renewable energy undertakings are funded and run by the state, NGO's and/or other international organisations and is geared, especially in South Africa, towards development.

Still, most of the participants responded distinctly more confidently when it comes to issues of finance and technology. This is not at all surprising when one considers the fact that these are the two factors that most technology suppliers deal with on a day to day basis. Effectively, it is only those implementing and using the technology, which in a lot of cases are the clients of these technology suppliers, that are expected to take cognisance of the additional dimensions such as environmental, social and human resources.

This exposes a possible significant flaw in the South African renewable energy industry. The private sector, which is to a large degree responsible for a majority of renewable energy research and development, is still designing systems with only financial and technological considerations in mind.

5.2. Integration of the ITDG and SURE frameworks

Fig. 3 shows the integrated framework, with the priority indicators and methods also listed; these are the indicators and methods that scored above 65% in the second round of the Delphi study. For the further clarity, Fig. 5 provides a step-by-step breakdown of the proposed sequential framework with the additional methods and indicators that were proposed by the respondents. Most significant are the importance of the indicators Access to Clean Water, Population Density, Access to Micro-Finance, and Knowledge/Experience with Co-operatives, which were highlighted by the respondents.

In general, however, and as discussed in Section 5.1, there seems to be a definite bias towards the economic and technological sectors of the framework; this is evident from the fact that both of these sectors have the largest number of appraisal methods that scored above 65%. Energy Services & Technology Choice is indeed the section with the highest amount of votes, with six methods scoring above 65%.

These results point towards a possible deficiency in terms of knowledge in the South African renewable energy industry concerning environmental and social/human issues. It seems that technological development and provision are mainly governed by financial and technical issues, which does not necessarily make for holistic sustainable rural development driven by renewable energy.

This deficiency points towards a deeper cause in the technological management value chain. It is therefore proposed that this deficiency be addressed through the introduction of the concepts of sustainability science into the arena of technology assessment in general [19], but especially as it relates to the research and development of renewable energy systems for rural areas [20].

6. Conclusions

Rural poverty remains an important undeniable part of African society. Energy, in all of its forms, is needed to alleviate the rural poverty characteristics of the region. However, a literature review has revealed that the actual delivery of energy to those most in need of it is a very complicated matter, more often than not leading to trust-shattering failures. A study, summarised in this paper, subsequently set out to assess the ITDG and SURE frameworks that have been introduced to facilitate the sustainable implementation of renewable energy technologies in rural areas, but in the South African context.

The study utilised experienced individuals in the South African renewable energy industry through the Delphi research methodology. The responses ascertain that the systems analysis approach, that is the Sustainable Livelihoods foundation of the frameworks, is indeed fundamental to the sustainable transfer of renewable energy technologies into remote areas of Africa. By integrating these two frameworks then more robust, community-based implementation strategies may be formulated.

The study confirmed the struggle between the forces of the market and the state in development, which has been identified in literature. This may be assigned to the profiles of the study participants that represented the private sector more, i.e. a market-fundamentalist perspective. Thereby the study highlights a potential concern in that renewable energy systems are still most often designed with only financial and technological considerations in mind. Because renewable energy projects, in Africa, are largely influenced by governments, NGO's and/or international agencies, the responses from the Delphi participants were mostly in line with what is being propagated in rural renewable energy literature and public rhetoric, but analyses methods in the Energy Services & Technology Choice section of the integrated framework were favoured by those that often drive these projects.

It is therefore concluded that much is still required to enhance sustainability science thinking in renewable energy technology research and development, and specifically in technology assessment methods that are appropriate to the research and development phases of technology management value chains in general. Additional cases studies are required to refine and verify systems analyses and technology assessment frameworks.

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