Household Energisation in Rural South Africa: A Systems Approach Towards Energy Access

T. Makonese, and J. Meyer

Abstract— In South Africa, household electrification has improved significantly since the dawn of independence, with the current national electrification rate at 87%. However, poor households in rural communities, informal urban settlements and low-income urban Townships still rely heavily on traditional fuels to meet their basic energy needs. The majority of these households are energy poor, as they tend to expend a higher proportion (> 10%) of their disposable income on energy services. The continued use of traditional fuels is associated with health challenges including asphyxiation, upper and lower respiratory complications, and mortality. Notwithstanding the benefits of household electrification in rural areas, there is a great need to consider other cheaper alternative energy sources, as the cost of electricity tends to limit its use. Household "energisation" instead of "electrification" has the potential to provide households with access to clean renewable energy sources at minimal cost. Effective household energisation employs a systems approach towards a more comprehensive energy access strategy of meeting households' energy needs using a suite of locally available renewable energy carriers. Energy options available for rural communities are assessed using a 'systems thinking' approach.

Index Terms— **Access, energy options, electrification, renewable energy, systems thinking, energy poverty**

1 INTRODUCTION

The majority of households in sub-Saharan Africa (SSA) lack access to clean energy sources. It is estimated that more than 650 million people in SSA, mostly those residing in rural areas, rely on traditional fuels and combustion devices to meet their basic energy needs [1]. This trend is expected to continue into the near future, past the year 2040 [1]. Improved cookstoves (ICS) and cleaner fuels have been promoted as a way of increasing the sustainable utilisation of biomass fuels for purposes of cooking and heating [2]. The continued use of solid fuels has been associated with morbidity and mortality, especially in the developing world [3]. However, there have been debates about the effectiveness of ICS in addressing household air pollution (HAP) and related diseases as well as reduced fuel consumption [1]. A 'complete' shift from biomass fuels to cleaner alternatives of energy such as LPG and electricity has been advocated [4].

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In rural communities of South Africa, biomass is the primary source of energy for cooking and space heating. Over the years, rural development has been provided through increased mechanisation and agricultural productivity, improvement of road infrastructure, education and health [5]. Rural electrification has been suggested as a policy instrument for improving energy access. However, studies carried out in South Africa have revealed that most rural households that are connected to the grid continue to use traditional fuels for cooking and space heating. The electricity is used for lighting, refrigeration and entertainment [6]. The cost of electricity and related technologies have been pointed out as the major impediments to the uptake of the energy source. The majority of these households are energy poor, as they tend to expend a higher proportion (> 10%) of their disposable income on energy services [7]. In other studies, it has been argued that the erratic nature of electricity supply leaves households without a choice; they revert to traditional fuels for purposes of cooking and heating [8].

Notwithstanding the benefits of household electrification in rural areas, there is a great need to consider other cheaper alternative energy sources as the cost and availability of the energy source tends to limit its use. According to Lloyd [7], a focus on household "energisation" instead of "electrification" alone is needed to alleviate the ongoing trap of poverty. It should be noted that electrification is included in the energisation process, together with other alternative energy carriers including solar, biogas, biomass, wind, hydro etc. Household energisation has the potential to provide households with access to clean renewable energy sources at minimal cost [7].

According to Mungwe et al. [1], "…*the issues highlighted can neither be resolved through the isolated promotion of individual technologies nor fuel switching alone, but through a "systems approach" to a more comprehensive energy access strategy*." Effective household energisation employs a systems approach towards a more comprehensive energy access strategy of meeting households' energy needs using a suite of locally available renewable energy carriers. There is, therefore, a need to understand the dynamics of household energy in rural communities and factors influencing sustainable energy development. This paper aims to interrogate household energisation using a systems approach. Results from this study can be useful for rural energy policies and strategies in South Africa.

2 SYSTEMS APPROACH

A systems approach is an interdisciplinary method that is applied to situations to understand complex inter- and intra-cyclical effects between variables in a system, unlike linear approaches that deal with cause-and-effect relationships [9]. Causal-loop diagrams are used to give feedback from interrelationships that exist between variables in a system [11].

Systems approach thinking is not a new approach, but it has been employed in many studies including drought resilience [9], agriculture [10],[11], transport and accidents [12], and public governance [13], to mention a few. However, there is limited information on the use of systems dynamics to understand rural household energisation. Mungwe et al. [1] attempted to address the issue of household energisation by integrating available renewable energy technologies including wind, solar, biogas, and hydropower. A systems thinking to rural household energisation is needed as most of the factors affecting the uptake, and use of energy carriers and related technologies are becoming increasingly covariant. Health outcomes of "business as usual" approaches to household energisation can be assessed by applying systems thinking thereby giving multiple perspectives and scales considering the larger system of determinants [9]. According to Béné et al. [14] as cited in Mavhura et al. [9], "…*each level and, or scale has unique influences on* energisation *while cross-level and cross-scale interactions reflect changes in capacities and outcomes related to the unique e□ects of one level/scale of measure on another*".

There is, therefore, a need to analyse the levels at which factors influence household energisation. At the community level, it becomes possible to analyse interactions between shocks, stresses, vulnerability, resilience and the well-being of households [15]. We also note that households are a part of broader complex and interconnected sub-systems that interact with shocks and stresses [9],[15]. According to Mavhura et al. [9], "…*it is possible to account for the feedbacks in the processes a□ecting population groups and their environments; and understand the nature and determinants of the absorptive, adaptive and transformative capacities of social systems"*.

3 METHODOLOGY

3.1 Case study area

Gwakwani is a small, rural village in the Northern part of the Vhembe district of the Limpopo province in South Africa. The population density of the Gwakwani area can be classified as less than 10 – 25 people per square kilometre [4] with approximately 70 people residing in the village. The village is approximately 17 km from the nearest town and closest petrol filling station. Due to the isolated location of the village, it is deprived of supplied grid electricity, direct mobile cellular connection as well as municipal water supply or sanitation services. The connection of the village to these services was denied in the past as it is financially unviable and outweighs the advantages of connecting this small rural community to these services. The villagers mainly survive on subsistence farming whose income is supplemented by government grants of approximately R300 per month. Some households receive contributions from breadwinners who migrate to urban centres.

3.2 Scoping study

A three-year (2014 – 2017) planning and scoping study was carried out and identified the benefits of a systems perspective towards household energisation in rural and marginalised communities of South Africa. This was done with the aim of improving access and promoting rural development. During the scoping period, the project team organised a series of technical workshops and informal focus group meetings to gather evidence and views from the all stakeholders (including companies, academics, technical personnel, and end users) concerning the integration of energy systems using a systems approach.

Similar to van Gevelt et al. [16], sets of questions were addressed at each workshop and focus group meetings. The questions focused on identifying the potential and barriers of alternative energy carriers to energise households in the Gwakwani village. At the end of the discussions, recommendations were postulated concerning how the barriers could be overcome and the potential realised. These discussions were augmented by issues identified through questionnaires administered in the village, which focused on water supply, sanitation, health, food, energy, and STEM (i.e. science, technology, Engineering and mathematics).

3.3 Systems dynamics

For the assessment of renewable energy technologies, the focus was on woody biomass, biogas, and solar. Causal loop diagrams were employed to ascertain the levels of association between variables in the system. A Vensim® PLE 7.2 desktop software was used to generate the causal loop diagrams.

4 RESULTS AND DISCUSSION

4.1 The rural household energy matrix

Results from the planning and consultative meetings, as well as questionnaire administration, showed that bioenergy remains the most dominant energy carrier in the Gwakwani rural village. Energy carriers such as hydropower remain unsuitable for rural communities given the dispersed nature of the communities. Bioenergy will remain a survival commodity, into the near future, for most rural communities in the developing world [17]. Fig. 1 shows a matrix of potential energy sources for a typical rural village in South Africa.

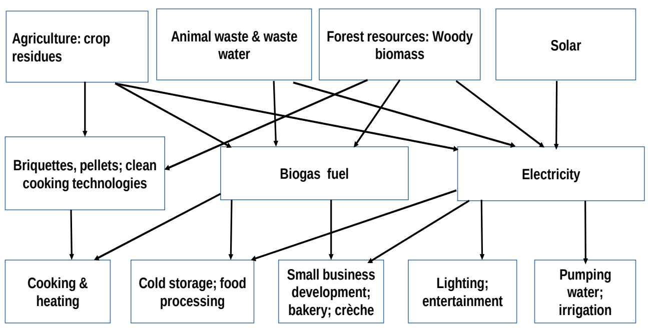

Fig. 1: A matrix of rural energy carriers, conversion and user needs in Gwakwani village

The matrix shows that bioenergy has the potential to be converted into different forms of energy carriers including briquettes and pellets (for cooking and heating), biogas, and electricity. However, there is a great need to promote bioenergy technologies within a focused policy framework and financial support scheme to that adopted for large-scale applications [17]. Locally available bioenergy sources, when hybridised with solar, have the potential to meet a large part of the rural households' energy and development needs into the near future.

4.2 System components of energy and rural development

A gap was identified in the manner in which the issue of household energisation has been handled in past projects and programmes. There is a great need to plan rural household energisation projects holistically. Such a plan requires the provision of efficient modern technologies and integrating these with needs and resources to promote value addition and to create jobs that can improve the socio-economic outlook of the village dwellers. Fig. 2 shows a simplified causal loop diagram for household energisation and rural development in Gwakwani village.

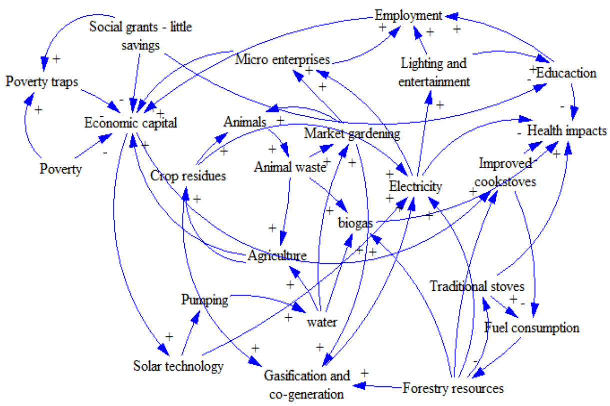

Fig. 2: simplified causal loop diagram for household energisation and sustainable development of Gwakwani

Selected components/ variables of the system are described in detail in the sections below.

4.2.1 Water, health and food security in Gwakwani

A safe, clean, affordable and easily accessible water supply is imperative for good health [18]. The Millennium Development Goal (MDG) 7 aimed at ensuring environmental sustainability through the provision of safe drinking water and basic sanitation by 2015, thereby reducing the proportion of people without access by half [19]. Clean water should be available for drinking, food preparation, personal and home hygiene – a move from the general notion that when there is adequate clean drinking water only the community is purported to have access [18].

In light of this, the University of Johannesburg went into Gwakwani to provide clean, safe, easily accessible and dependable running water for the villagers. The researchers realised that in off-grid communities such as Gwakwani, energy is also a critical input to the water supply. Before the University went into Gwakwani, the households in village depended on water supply from the nearby river. They did not have access to a running water supply. The river is infested with crocodiles, and there have been reports of crocodile attacks on livestock during water drinking episodes. As such, wealth has been lost resulting in those affected households sinking deeper into poverty and being entangled further in poverty traps. The water from the river was used for drinking, washing, bathing, cooking and water small vegetable gardens.

Gwakwani had a high prevalence of malaria infections. Malaria is caused by the protozoan parasite *Plasmodium*, which enters the blood through the bite of a female *Anopheles* mosquito. The disease causes symptoms such as fever, fatigue, loss of appetite, nausea, anaemia, and can lead to severe complications and even death. Malaria is prevalent in Limpopo because the area has extremely high temperatures in the summer (excess of 34°C), which allows mosquitoes to proliferate. The villagers reported being excessively bit by mosquitoes as they walked back and forth the river to fetch water for domestic and agricultural needs.

During the initial focus group interviews with the community leaders, they pointed out the need for clean running water supply in the village. The University of Johannesburg researchers then put in motion a plan to drill boreholes and install solar water pumps (Fig. 3a). The solar pumps would draw water from the borehole and pump it to Jojo tanks/ containers (Fig. 3b) that are located close to a small plot (Fig. 3d) that was adopted for use for cooperative agro-business. The plot uses drip irrigation from the Jojo tanks. About four solar water heaters (Fig. 3c) were strategically built around the village to provide hot water for bathing to households. This removes the need for heating water for personal and home hygiene using traditional solid fuels such as wood and crop residues.

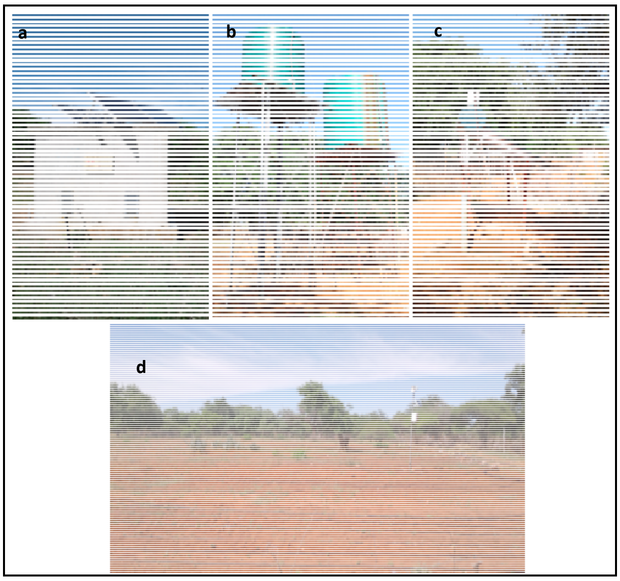

Fig. 3: Photographs of (a) solar water pump, (b) storage tanks for drip irrigation, (c) running cold and hot water provision, (d) drip irrigation setup and a weather station in Gwakwani village.

Since the establishment of the solar borehole scheme, villagers have reported reduced incidences of malaria, and livestock loss in the village. The provision of running water has removed the need for households to go to the river; the livestock is given water from the tapped water supply in the village. These interventions proved to improve the health, the social and economic stature of the village as a sustainable source of clean water close to the community members' dwellings promoted the cultivation of crops for subsistence and commercial purposes. The increase in subsistence farming meant that the villagers were dependent less social grants for buying basic food items. On the other hand, the increased production enabled community members to sell excess produce at the local market. For example, the drip irrigation farm was used to grow chillies, which were sold to the local market. Because the village has been energised, there is a potential for growing a chilli processing plant in the village. The production process requires clean water, hot water for sterilising the containers, and energy for cooking the mixture of chillies and herbs. The energy to power such a micro-industry is already available in the village. Such processed agro-products can be sold to local markets and supermarkets in nearby towns including Polokwane, thereby increasing the economic capital of the villagers.

4.2.2 Establishing micro-enterprises for rural development

Over the years, the main drivers for renewable energy and related technologies were the need to protect the environment and energy security, while the economic benefits were overlooked. Economic development is imperative for ensuring the sustainability of renewable energy in short to medium term. As part of the household energisation programme and the need to establish micro-enterprises in Gwakwani, an off-grid solar bakery was supplied to the village (Fig. 4). About eight locals were taught how to operate the bakery and to bake bread and buns. The bakery is registered as a cooperative and has a company bank account; profits are deposited into this account on a weekly basis. Follow up visits revealed that as the people became more specialised and accumulated baking skills in this new micro-industry, their capacity to innovate was enhanced. The bakery staff now bakes a wide selection of baked products including white and brown bread, rolls (hamburger and hot dog), and Chelsea buns.

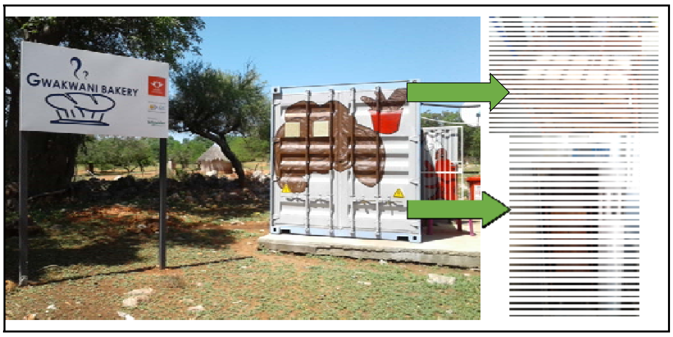

Fig. 4: A photograph showing micro-enterprise development using solar energy – a modern bakery for Gwakwani village.

The Gwakwani bakery supplies bread to the local market and nearby villages including Mbodi and Matatane and produces between 120 – 160 loaves of bread per day. This is, however, dependent on the weather patterns and the season (e.g. in winter months and rainy days when the skies are overcast, the number of loaves of bread produced decreases significantly). The bakery makes a profit of approximately of R14 000 per month. Each baker gets a monthly income of about R600, more than the money a household get as part of a government grant.

4.2.3 Education, Lighting and Entertainment

Grid electrification by a power utility of the Gwakwani rural village was not seen as a financially viable option as the villages are dispersed far apart. Based on impact and needs assessments with the community, the University of Johannesburg found that a promising method for sustainable education development in the community was through the implementation of renewable energy resources. The University built a solar-powered crèche made from donated storage tanks. A TV set connected to a DStv satellite dish was also provided, which opened up the world to the children in the village. The TV is used as a media tool to educate the children through channels such as SABC, Mind-Set, History, Discovery, National Geographic, Animal Planet etc. Information Communication Technology (ICT) has the potential to enhance and support the development of quality education in off-grid rural communities. The South African Constitution stipulates that all South African learners should have access to the same quality of learning and teaching, similar facilities and equal educational opportunities [20]. However, this is not the case for Gwakwani as the village did not have access to a crèche for the children and the nearest primary school is 8 km away, with the secondary school about 4 km further.

Fig. 5: A photograph illustrating education development – (a) establishment of a solar-powered crèche, (b) equipped with a TV set on a DStv subscription.

It is acknowledged that lighting for extending working and learning hours improves enhances education in marginalised communities. Every household in the Gwakwani village was installed with a photovoltaic solar lamp for extended lighting. School going children in the village acknowledged that the solar lanterns were important to help them study at night. They also cited that ever since they started using solar lanterns for lighting during study times at night, they have experienced fewer eye irritations and respiratory tract infections. Some households were using paraffin lamps for lighting at night as the candles were used up quickly. These symptoms were attributable to the soot and vapours from paraffin lamps. In homes that could not afford to light for extended periods in the night, the children were disadvantaged as some failed to complete homework and assignments. With the introduction of the solar lanterns, all these challenges became a problem of the past. Effective services and maintenance support for the solar lighting systems have been established in the village. Due to the difficult terrain and dispersed nature of the village, it is imperative that the maintenance services be established in the village. If the services were to be supplied outside the village, the user would be forced to wait for the infrequent visit of the maintenance contractor for simple procedures.

4.2.4 Energy efficient, clean cooking solutions in Gwakwani

There is a great potential for biogas generation and utilisation in Gwakwani village. Biogas is a natural gas produced by the anaerobic digestion of biodegradable materials (human waste, animal waste, and green waste) and contains mainly methane and other inert gases such as carbon dioxide and nitrogen. Biogas fuel burns with fewer pollutant emissions compared to wood, crop residues and dried animal waste. The effluent sludge from biogas plants, when treated, becomes a source of nutrients for the soil in the form of bio-fertilisers. In Gwakwani village, each household has a pit latrine (Fig. 6). These toilets can be utilised as a source of raw materials for biogas plants. Again, households have livestock including cattle and goats that can provide fresh animal waste for use in biogas plants. The methane from the biogas plants is useful for cooking and heating, reducing risks associated with smoke emissions from solid fuel combustion. The produced biogas fuel can also be used as a clean fuel for small internal combustion engines for mechanical or electrical applications [17].

Fig. 6: A photograph image showing pit latrines. There is a pit latrine for each compound or household.

Considering that the majority of households in Gwakwani need a cleaner fuel for cooking, caution should be taken not to build many small biogas plants for each family unit. For sustainable utilisation of the fuel, it may be better to build and strategically position some moderate-sized biogas plants around the village ensuring that more than three households share the fuel from a specific plant allocated to them. This is because individual units tend to suffer from lack of maintenance especially when the economic capital of households improve [17].

In Bihar, India, a pilot plant has been built with two digesters, one linked to the pit latrine and another fed with normal animal waste. The slurry from the pit latrine is pasteurised and mixed with the slurry from the normal digester. The mixed, treated slurry is sold as bio-fertiliser, enhancing the economic capital of the community. The biogas produced from the two digesters is first mixed, and cleaned before it is used in internal combustion engines. The biogas is also used as a fuel for domestic cooking and heating activities [17]. However, in informal interviews carried out in the Gwakwani village, some respondents seemed to be apprehensive about the use of biogas and bio-fertilisers produced from human waste – anything made from human faecal matter is considered a cultural taboo. Such misconceptions need to be addressed before the technology is rolled out into the community.

There also exists an opportunity for efficient and less polluting improved biomass cookstoves. The community uses biomass as their primary energy for cooking. The cooking activity is normally done outside on a three-stone fire outside. The villagers cited the smoke from biomass burning as hazardous to health for their reason to cook outside. However, they have challenges in the rainy season when they are forced to cook indoors during incessant rains. Efficient biomass burning forced-draft cookstoves, especially those burning pelletised or briquetted fuels can be used indoors as they produce fewer emissions of noxious pollutants. Again, the continued use of traditional stoves has negative socio-economic impacts. Women and children have to spend more time collecting fuel, when they can be using that time to venture into other productive activities such as education and cooperatives to enhance their economic capital. On the other hand, improved cookstoves can improve the socio-economic welfare of women, children and other vulnerable groups.

4.3 Barriers to systems integration

Systems theory has been developed and studied extensively especially for problems related to social-ecological systems. However, there is still sparse information in the open and grey literature concerning empirical work on modelling the relationships between social and ecological factors [15]. The same is true for the relationships between variables in household energisation systems. Systems thinking methods are only applied to developing conceptual frameworks and have not been used to analyse data or for monitoring and evaluation exercises [15].

Mixed methods are needed in the analysis of household energisation, and such methods should include panel data that includes all variables in the system (i.e. social capital; human capital, economic capital, ecological factors, health impacts etc.) as well as high-frequency shock monitoring at every level. According to Mock et al. [15], most of the work carried out in resilience measurements relied on household surveys and quasi-experiments using household data. As such, this limited the ability to synchronise conceptual frameworks and empirical observations – more work is needed to address this gap.

5 Implications for Rural Energisation

Renewable energy supply in remote villages such as Gwakwani can reduce the “energy poverty” that is a common feature in rural communities in developing countries. Rural energisation allows off-grid communities to produce their energy to meet their demand and needs rather than importing expensive conventional fuels.

The development of off-grid renewable energy systems, especially for water pumping, cooking and heating, micro-enterprise development is needed to address issues related to diseases, food security, and poverty traps. This is because when a remote village has access to clean, safe and dependable alternative solutions, this triggers economic and social development. If hybrid systems are introduced in the villages, there is an opportunity of attracting energy-intensive sub-macro manufacturing and processing industries such as agro-food processing, smelting, etc. Integrated systems based on renewable energy has the potential of freeing rural communities on over dependence on woody biomass and grid electricity (in parts were rural households are connected), and provide them with more stable and cheap power supply. Such a system could attract new businesses that range from accommodation to restaurants, leading to the development of self-contained, modern and smart rural villages.

Renewable energy strategies and projects for rural development should be contextually appropriate – they should not be driven by national policies but by local concerns or demands. Local networks including cooperatives and any other relevant structures or institutions in that community must manage such projects. When local demand has been met, then there are opportunities to export the energy to other areas or feeding excess electricity into the main electricity grid (feed-in tariffs). Chaurey et al. [21] argued that provision of electricity through off-grid renewable energy might not significantly raise living standards unless it enables income generation.

The role of intermediate institutions such as Universities and local governments in the dissemination of renewable energy technologies should not be undermined. The involvement of the University of Johannesburg in the Gwakwani renewable energy project is key to the development of renewable energy in the area by promoting social acceptance. The University disseminated information to the local community, and with the help of the local Chief, they put in place democratic mechanisms that allowed the locals to coordinate activities and to influence key decisions about renewables. It is also possible for intermediate institutions to mirror national renewable energy policies to local needs.

6 Conclusion

The research has demonstrated that there is a need for systems thinking in addressing rural household energisation issues. The study has shown that rural communities could benefit immensely from locally available renewable energy sources for health, education, social and economic development. However, results have pointed out that rural economic development is not an automatic outcome of renewable energy provision. Jobs are created when there are linkages with core rural businesses such as agriculture, agro-businesses, and food security.

Future research has to focus on the development of an optimisation model for rural households in South Africa, considering the suite of renewable energy carriers at their disposal. The model will then be validated with real-world scenarios to provide solutions related to the selection of the renewable energy carrier, related technologies, and the amount of energy to be produced and stored. Such results may be useful for sustainable rural energy development..

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