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Social innovation for community energy in developing countries – new models and a Mozambican case study

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Abstract—In recent decades, the transition from fossil fuels to the use of renewable energy sources has profoundly changed the world's energy landscape. This in turn has given rise to the concept of energy transition based on the principle of the "three-D's", Decarbonization, Decentralization and Digitalization. The emergence of the concept of community energy suggests a "fourth-D", denoting democratization as a pillar underlying the concept of community energy. This concept is where energy is produced by and for the community, placing the citizen and community at the center as key actors in the entire energy value chain (generation, distribution, consumption, and associated services). This work aims to discuss the social innovation model suitable for the implementation of energy democratization, which leads to the successful penetration of the concept of community energy in developing countries, especially Mozambique, which is a use case study explored in this paper. We explain how this social innovation model can promote socio-economic empowerment, sustainable industrial and human development, and energy inclusion that contributes to environmental balance and social stability in rural communities in Mozambique. The global energy landscape is not uniform in terms of access to energy sources and this debate in developing countries is still relevant and significant, as a considerable number of citizens do not have accessibility to electricity and are still seeking access to it for the first time (energy inclusion). But beyond the social innovation through energy inclusion, we also discuss new innovative modular ways of implementing Distributed Energy Resource (DER) based on typical Photovoltaic (PV) panels and energy storage (batteries). A modular approach for the implementation of smart grids can promote a more cost-effective organic growth, distributing resources more evenly and avoiding oversizing or undersizing of rural electrification systems. Such modularization would also allow new partners or new equipment sets to be added to the infrastructure smoothly. Finally, we suggest the introduction of an AI-based algorithm capable of adapting the smart grid management to new infrastructure modifications (addition of new prosumers or consumers). The algorithm proposed would be able to help control the quality and cost of power for all participants, reduce operation and maintenance costs of the systems, and balance generation and consumption. With that, the suggested modular implementation in conjunction with AI-based smart grid management will provide smart grids that can reduce costs of investment and fair consumption and generation balance that, with time, can promote local sustainable industrial and human development in a virtuous circle to boost social transformation.

Keywords—social innovation, energy inclusion, energy transition, community energy, modular smart grids, energy poverty.

I. Introduction

The International Energy Agency states that access to energy sources is an indispensable condition for sustainable human development [1], [2]. In the modern era, it would be unrealistic to address sustainable industrial and socioeconomic development with very low access to electricity and other clean and Renewable Energy Source (RES) especially in rural areas of developing countries in sub-Saharan Africa [2]. In rural areas of developing countries such as Mozambique, demand for electricity means access to electricity for the first time leading to significant changes in lifestyle and social transformation, and influenced by their traditional values, this access can demand rapid social transformation and the abandonment of secular habits, which can cause a kind of *cultural shock* and consequently *energy rejection*.

The irreversible environmental damage caused by fossil energy sources requires a change in the energy landscape towards the use of clean and RES. The inability of African governments to make significant investments in the sector to ensure energy for all requires a radical change in the approach to the energy sector in Africa. Thus, the concept of Community Energy (CE) would be the right approach for the energy sector in Africa.

This article discusses the concept of social innovation for the democratization of the energy sector in Mozambique as a basic foundation for the successful implementation of the concept of CE to ensure access to clean and RES for developing countries, especially in Mozambique.

II. Research problem description

A. *Context of the search problem*

The global energy landscape is not uniform in terms of access to energy sources. In developed countries, energy access is a normal, unlike developing countries, where access to energy sources is still a relevant and significant discussion due to nonavailability and different desires for access.

The status of full access to energy sources in developing countries allows a progressive transformation and development of the energy sector, giving rise to the concept of CE, where the citizen and the community are no longer simple customers [3]–[5]. In the CE concept, energy is produced by and for the community, placing the citizen and the community as main actors in the energy value chains (generation, distribution, consumption and services) and aiming at energy autonomy, socioeconomic empowerment and human development of local community [6].

In developing countries, the debate is fundamentally focused on access to electricity for the first time, mainly in rural and remote areas where large percentages of the population reside. In this context, the CE concept can be a strategic and critically important solution for energy democracy and accelerate access to clean and RES, however, it is necessary to consider specificity's of the local community. This includes the social transformation necessary for successful implementation to fulfil the CE concept to which this article is addressing as social innovation leading to successful implementation of community energy in developing countries [4], [7].

B. *Research problem statement*

CE rising globally is a useful concept for designing a CE model [8] specifically for developing countries to respond to the UN Sustainable Development Goal (SDG) 7. CE in its genesis, essence and definition is based on the use of locally available clean and RES, which has the potential to transform the energy landscape ensuring energy autonomy and sustainable industrial, socioeconomic, and human development for local communities.

The CE concept discussed in the literature is a generic concept that should consider models and variables for each context (no single model fits all), in this sense, the CE model designed and implemented in developed countries may not be a perfect fit for developing countries [9], as contexts and stages of development of the respective energy sectors are completely different.

In this article, the authors believe that differences in lifestyle and community values, as well as in the level of development of each energy sector, can be unfavourable factors in the successful implementation of CE, especially in developing countries.

Here, the problems and challenges of the energy sector in developing countries are described from the point of view of Mozambique, where the situation is similar to most developing countries in sub-Saharan Africa. In most developing countries, the existing electricity infrastructure does not cover the entire country, and rural and remote communities are badly affected, excluding them from the dynamics of economic development.

Therefore, the approach to clean and RES from the perspective of CE with appropriate models is a significant discussion to promote energy inclusion and autonomy, leading to accelerated access to clean and RES in rural communities [10] of developing countries in accordance with SDG 7. The investment in rural electrification infrastructures based on RES, despite the slow pace, has ensured access to clean and RES for rural communities. However, there are fundamental structural, management and planning challenges to be carefully addressed.

Management and the decision-making processes are centralized at the headquarters located in urban areas where all qualified technical maintenance and repair teams are based [11]. Often, in rural areas there are no local technical teams for minor repairs and routine maintenance due to difficulties in retaining skilled labour who often work in a sub-employment regime with precarious contracts that forces them to relocate to urban areas for better opportunities.

So, maintenance and repair operations require the displacement of technical teams from the headquarters (where "*heavy*" command and decision-making structures result from complex logistical and bureaucratic systems) located in urban areas to rural power systems making small repairs or routine maintenance very expensive and complex.

Operation in its entire chain can often result in frequent and lasting breakdowns, blackouts and inefficiency of power systems due to a lack of qualified local technicians for routine maintenance and repairs, therefore, the quality and cost of power, the operating and maintenance costs of the systems, the balance between generation and consumption, load management, demand and consumption planning over time, become "*time bomb*" challenges [12].

Additionally, the absence of demand forecasting models results in an unbalanced dimensioning between generation and consumption characterized by *undersize*, unexpected demand growth, system overload and collapse, and *oversize*, system sizing with generation capacity above consumption demand, disposal and waste of generated power and, in more serious cases, local systems are abandoned with the arrival of the public power grid. This article discusses social transformations based on social innovation and energy democratization [13] for the successful implementation of the CE concept in developing countries.

C. *Research question*

What model of social innovation must be implemented for the success of the CE concept in developing countries, especially in Mozambique?

The attempt to answer the research question will be based on four concepts namely, energy transition, energy acceptance, social innovation and CE. The main axis to be explored in this article is social innovation leading to a social transformation that favours the successful implementation of the concept of CE in Mozambique and in developing countries.

III. Methodology

We use the Political, Economic, Social, Technological, Environmental and Legal factors (PESTEL) framework to analyse the external factors influencing the project, and the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis approach to describe how internal social aspects can influence or be impacted by the proposed solutions.

A. PESTEL analysis

The PESTEL analysis is used to identify the macro (mostly external) forces facing the project. In the next subsections, we describe the how the PESTEL framework influences the work developed in this paper and are related to developing countries and, more specifically, countries of the Sub-Saharan Africa.

*1) **P**olitical*

The governments in developing countries do not have comprehensive strategies or plans in place to address the development of RES systems and CE initiatives [11], [14]. The lack of RES experts on governmental level [9], [15], clear planning for the power sector and poor institutions coordination [16], [17] lead to low level of stakeholders involvement in decision making [18], [19] and limit the private sector involvement [11], [14]. The result of all that is the lack of effective energy policy and regulatory framework for RES development [15], [17], [20].

*2) **E**conomic*

Economic aspects affect from two different perspectives. Most developing countries have unstable economies [15], [18] which makes it difficult for the development of subsidies or incentives schemes. Also, high taxes and inefficient discount rates for RES [21], [22] can lead to high investment cost and high tariffs [23]–[25]. Limited access to credit facilities and funding mechanisms (and low expected return on investment) [26], [27], lack of viable business models [28], and unclear rules for income generation, limited paying capacity, or poor rural market and low productive use [22], [27], leads to limited investments by the private sector - especially for rural financial institutions [9], [11].

*3) **S**ocial*

Poverty, limited access to rural infrastructure, low household affordability [18], [23], scattered population and resistance to change [16], [28] are commonplace. Local culture (with or without a religious bias) and lower levels of education [14], [20] will definitely lead to a lack of social acceptance of RES policies. The lack of information, low public awareness [15], [29] and community engagement [15], [19] will worsen the energy-related gender issues and discourage local entrepreneurship [9], [18] that would make viable new RES initiatives.

*4) **T**echnological*

There is a structural technological deficiency in developing countries that prevents the progress of RES in general. Deficient or absent technical expertise and skilled personnel [9], [19], [22], and poor Operation & Maintenance (O&M) culture and weak technological knowledge [16], [26] create a big RES adoption barrier. Also, insufficient or obsolete infrastructure – especially in rural areas [15], [22], [26], [28] – associated with poor research and development culture [16], [21] make it nearly impossible to validate resource data and resource assessment [9], [28].

All this can lead to waste of resources and/or bad usage of available resources and investments. For example, the results of bad planning can be seen in under-sized and over-sized minigrids systems [28] that can sometimes be interpreted as low-capacity utilization or having low demand [21], [25] when what is really happening is resources waste.

*5) **E**nvironmental*

RES initiatives can be impacted by environmental disasters (e.g., devastating cyclones [11]) especially when the country lacks resilient systems in the occurrence of natural disasters [9]. Also, as a consequence of the absence of recognition of environmental benefits of renewable mini-grids [21], the resistance on the technology adoption due to its noise or visual impact (e.g., wind energy [16]), and the lack of sustainable use of biomass [16], [18], the consumers can choose more available sources of energy with high levels of Greenhouse gas (GHG) emissions (e.g., fossil fuels [16]).

Additionally, even the use of the available RES can damage the environment if not addressed properly. Examples of it would be the use of mini-grids to power environmentally harmful activities [18] (such as mining and oil drilling) and the poor or absent management of electronic waste (e.g., expired or damaged batteries, and solar panels).

*6) **L**egal*

The lack of a proper legal framework to support RES and CE initiatives – such as Independent Power Producers (IPPs) and Power Purchase Agreements (PPAs) schemes – and regulate the relationship between stakeholders [9], [16], [23] is usually dealt with bureaucracy and lack of transparency in all regulations and policies in place [16], [25], [26]. The usual poor sustainable energy and environmental policies [24] (when not totally absent) and the inadequate planning capacity [11] drive away the expected stakeholders and local communities that should be involved in the whole process [16], [30].

B. SWOT analysis for social impact

In a system, uncertainty grows proportionally with complexity, and in the case of the CE concept, with addition to the intrinsic factors related to the functioning of the system, there are dominant uncertainties related to community behaviour, attitudes and practices which can best be described using SWOT analysis. The SWOT analysis applied to the CE concept should fundamentally focus on innovative social transformation (social innovation) as an essential factor that ensures the successful implementation of CE in developing countries [31].

*1) **S**trengths*

RESs that are consistently available and evenly distributed in most developing countries, especially those in Sub-Saharan Africa, represent an enormous potential for sustainable development of global acceptance confirmed by the Paris Agreement on Climate Change and SDG 7 [32].

Most of the developing countries in Sub-Saharan Africa, for example, have a privileged geographical location that gives them abundant solar radiation and wind speeds, which constitute a huge opportunity to assert themselves in the energy sector based on renewable sources, stimulating the growth of a low carbon economy conducive to sustainable industrial, socioeconomic [33] and human development in line with the Paris Accord on Climate Change.

*2) **W**eaknesses*

Communities in developing countries, especially rural ones in sub-Saharan Africa, have a lifestyle, behaviour, attitudes and practices that are deeply influenced by their cultural habits and traditions, in a context of low or no access to electricity or any source of clean and renewable energy.

The introduction of power systems based on RES, which often provides access to electricity for the first time, can cause cultural clashes, conflicts of interest within the community and compromise the achievement of the Paris Agreement on Climate Change and SDG 7 objectives. In this way, it is important to promote community debate, dialogue and education aimed at the advantages, economic and financial gains arising from access to RES with community participation [32], [33] and ownership over the systems, the so-called CE.

*3) **O**pportunities*

Although most developing countries present a set of deep and structural problems such as economic weaknesses, political instabilities, high rates of poverty and illiteracy, lack of fixed sources of financing for projects, among others [34], these countries have an enormous energy demand market (often for the first time), resulting from very low rates of access to electricity and sources of clean and renewable energy, which represent an enormous opportunity for sustainable public and private investment with return on investment, which, when combined with sound policies and legislation, has the potential to contribute to stimulating emerging low carbon economies, industrial and economic growth, modernization of the residential sector, improvement of living standards for local communities leading to sustainable socioeconomic and human development [35].

*4) **T**hreats*

Ensuring accelerated access to clean and RES in developing countries is a complex task that requires strong private sector investment in electrification infrastructure [36]. This demands an optimal business environment, establishment of factors to stimulate the private sector, guarantee of return and investment based on free trade principles, liberalization of the energy sector and, in particular, demands favourable policy and legislation that are under the full control of government authorities [37], that often act as competing operators to the private energy sector.

IV. Mozambican Use Cases

Government institutions created to promote the development of renewable energy in remote areas are characterized by weaknesses that contribute negatively to the development of renewable energy in rural areas, such as: 1) lack of technical and technological capacity; 2) lack of qualified manpower to design suitable renewable mini-grids; 3) lack of technical skills to evaluate proposals submitted by private companies during the public tender etc; 4) corruption and lack of transparency [38].

The lack of these factors leads to ineffective technical proposals, which culminates in the implementation of poorly dimensioned systems, such as undersized and oversized systems. Therefore, more than 50% of the mini-grid systems in the region, especially in Mozambique, are not working properly and, as a result, the number of people living without electricity is still very high.

In some cases where the demand peaks from 6pm to 8pm are higher than the capacity of the installed system. Other systems are oversized, as the capacity of the installed system can be five or seven times bigger than the current energy demand – and the remaining energy generated is put to waste.

Other commonplace problems are cases where two power generation sources (main grid and local mini-grid) run at the same time and are used in the same village. However, there is no agreement in place for the injection of renewable energy into the main grid. To make matters worse, the remaining energy of the mini-grid is also put to waste.

V. CENTS Platform

The Cooperative ENergy Trading System (CENTS) [39] project coordinated by the International Energy Research Centre (IERC), in collaboration with industry experts (e.g., Smart MPower [40] and mSemicon [41]), academic research centres (e.g., University College Cork (UCC) [42], and National University of Ireland Galway (NUIG) [43]), and CE groups working for sustainable energy (Community Power [44]).

CENTS provides all fundamental hardware requirements, market and regulatory strategies to deliver a blockchain-enabled peer-to-peer energy trading platform. The high-level diagram shown in Figure 1 briefly describes the main components of the platform.

CENTS functionalities provide the means for the establishment of both Peer-to-Peer (P2P) and CE initiatives. That way, CENTS can address one of the most important aspects of CE, i.e., energy democratization. CENTS paves the way for prosumers (individuals or communities that both produce and consume energy) to collaborate by making it possible to trade or donate the energy surplus generation.

By combining several functionalities, CENTS helps the dissemination of RES through a smart grid that can manage the DERs (decentralization) and provides the means for energy digitalization. CENTS also addresses several of the PESTEL and SWOT aspects discussed in Methodology.

Amongst its several components, CENTS offers, in the module "Regulation and Policies" depicted in Figure 1, a "business rules" functionality. It offers ways to customize the relationship between prosumers and consumers to establish the rules that will define a CE, its trading and energy poverty schemes, and the local regulation and policies. That way, CENTS delivers a way to easily create and manage CE groups that can interact internally (with its local participants) and externally (with other consumers, other CE groups and up to the local grid).

Additionally, the module "demand/response and dynamic pricing" provides usage-based information to support the intelligence behind renewable energy pricing and demand.

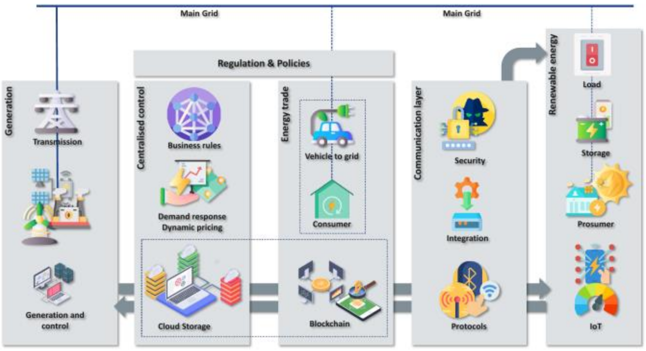

Figure 1. CENTS platform high level diagram [45], [46]

With that, the CENTS platform can develop data-driven support for local policies and optimal operation. This is the core module for the establishment of CE as it provides the information to support local policymakers, energy trading and all business rules that will define the CE behaviour and relationships (both internally and externally).

The remaining CENTS modules cover all the other aspects of CE operation: connecting all prosumers into the system (e.g., Internet of Things (IoT), generation and storage), integration (communication, security), cloud storage and blockchain-based transaction, up to its integration into the traditional energy grid (which can guarantee returns over the investments when the CE connects to the grid and can participate as one of the DER).

VI. Conclusions and Discussion

The CENTS platform offers the flexibility and functionalities for the establishment of dynamic CE implementations. It can overcome several limitations such as the lack of diversified mini-grid ownership models in both community-ownership and government-ownership models. Also CENTS can help improve the dissemination of DER-based mini-grids or micro-grids in developing countries.

The original commonplace problem of insufficient resource assessment to estimate load demand and optimize the CE properly (to avoid undersized and oversized implementations) can be overcome by a modular implementation. This implementation approach allows a more dynamic CE that can grow according to specific demands and/or defined local policies.

However, beyond the scope of the pure technical implementation, there are still local issues that can vary greatly from location to location. For example, developing countries usually have low awareness about DER, a low number of skilled technical manpower and/or a lack of Operation & Maintenance (O&M) culture and spare parts.

But the CE smooth implementation provided by the CENTS platform can bring huge social impact to local communities where it is inserted. Typical examples of such benefits are local economic and job creation boost (both temporary during the construction phase and permanent for operation and maintenance), education improvement (access to electric light and telecommunication), community safety (from improved health care to the existence of street lights), access to telecommunication and improved gender balance (reducing women's burdens).

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ACRONYMS AND ABREVIATIONS

CE	Community Energy. 1–5
CENTS	Cooperative ENergy Trading System. 4, 5
DER	Distributed Energy Resource. 1, 5
GHG	Greenhouse gas. 3
IERC	International Energy Research Centre. 4
IoT	Internet of Things. 5
IPP	Independent Power Producer. 3
NUIG	National University of Ireland Galway. 4
O & M	Operation & Maintenance. 3, 5
P2P	Peer-to-Peer. 4
PESTEL	Political, Economic, Social, Technological, Environmental and Legal factors. 3, 5
PPA	Power Purchase Agreement. 3
PV	Photovoltaic. 1
RES	Renewable Energy Source. 1–4
SDG	Sustainable Development Goal. 2, 4
SWOT	Strengths, Weaknesses, Opportunities, and Threats. 3, 5
UCC	University College Cork. 4