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Sustainable energization of rural areas of developing countries – a comprehensive planning approach

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Abstract

Access to modern energy services in developing countries (DC) is a double-faced challenge. About 1.3billion people do not have access to electricity; 2.6 billion rely on traditional use of biomass for cooking. Solutions to this energy challenge can neither be through isolated promotion of individual technologies nor fuel switching alone. A "system approach" towards a more comprehensive energy access strategy is required. Such access strategy would comprise of the supply of alternative energy carriers and planning of complete energy solutions via a more comprehensive and sustainable Rural Energy Planning (REP) i.e. Sustainable Energization (SE). Existing procedures to SE do not account for the existing energy balance and have not been demonstrated in the context of rural areas. The study aimed to propose and consolidate a more comprehensive REP procedure for SE of rural areas of DC. A seven-step procedure is proposed and its relevance and validity demonstrated through a field case study. The proposed procedure takes into account the existing energy balance and integrates energy drivers in the energy services supply network. Application of the procedure in a rural context showed a great improvement in the quantity, quality, and variety of accessible and affordable energy services for a more sustainable development of rural areas.

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Keywords: Biomass; modern energy access; energy planning; sustainability; sustainable energization.

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1. Introduction

1.1. Scope, problem and objective

The challenge towards the achievement of universal access to modern energy services among other interlinked global energy targets by 2030 is huge. The situation may be more challenging in Sub Sahara Africa (SSA), where more than 650 million people, mostly in rural areas will continue to use traditional biomass for cooking in an inefficient and hazardous manner till 2040 [1]. Improved Biomass Stoves are being promoted as a practical way forward to a more efficient use of solid fuels [1,2]. However, debates still persist as to the efficiencies of these cooking devices. A shift to alternative fuels away from traditional use of biomass is advocated [3].

Within the above context, the issues highlighted can neither be resolved through isolated promotion of individual technologies nor fuel switching alone, but through a "system approach" to a more comprehensive energy access strategy. This will entail the supply of alternative energy carriers and planning of complete energy solutions through a more comprehensive and sustainable Rural Energy Planning (REP).

The objective of this paper is to propose and consolidate a more comprehensive REP procedure for the sustainable energization of rural areas.

1.2. Brief review of the literature

Improving energy access in rural areas of DC can be approached by re-examining the strategies for REP and the concept of energization. Existing approaches to REP include: electrification, integrated energy centres, unplanned energy supply systems, e.g. local firewood markets, isolated energy carrier/technology programs e.g. biogas programs, improved cook stoves, [4–6]. These strategies are often implemented in isolation, hence, have not met the objectives of improving energy access in DC. To improve the situation necessitates a holistic energy system and planning approach. REP models are based on the six-phases Advanced Local Energy Planning (ALEP) process developed by the IEA [7]. The concept of energisation captures very well the issue of energy access for poverty alleviation and sustainable development. The concept has been defined in several ways [6,8,9] however, it has been updated to the theme of Sustainable Energisation (SE) [6]. Within the framework of SE, some gaps have been observed in studies that analysed rural energy systems within the ALEP framework [4,5]. These gaps include: the planning does not consider the sustainability of the energy system, there is a lack of a systematic energy consumption database required for modelling, the studies rarely quantify energy consumption to levels required for realistic modelling, and most models tend to marginalise the multidimensional issues of specific energy supply objectives. These drawbacks are due to the non-integration of SE in the planning process. Nissing et al [4] proposed a six-step procedure in the main study phase of the ALEP process that integrates SE in the REP process. Their procedure does not take into account the energy balance in the existing energy supply system and has been demonstrated only as a theoretical economic model for an urban developmental context.

2. Methods

The objectives of the study were achieved through desktop study of REP process and subsequent formulation of an innovative procedure. The proposed procedure was consolidated through a field study. The study area was Cameroon Protestant College (CPC) Bali located in the rural area of North West of Cameroon. CPC is made up of the following services and facilities: Public Administration, Education, Healthcare, Craftsmanship, dormitories and households, a church, 1179 inhabitants. Considering its organisation and composition, the area was considered a "*micro village*". Various methods and tools were used at each stage of the planning procedure. In particular, in accounting for the existing energy situation of the study area, participant's observations, focus group discussions, direct measurements and survey questionnaires were used to account for the Primary Energy Supply (PES) and Final Energy Consumption (FC) of the study area. For the assessment of local renewable resources, the focus was on biomass for biogas production, hydropower, wind and solar energy. The methods and tools used in the assessment of the locally available renewable energy resources are describe herein below.

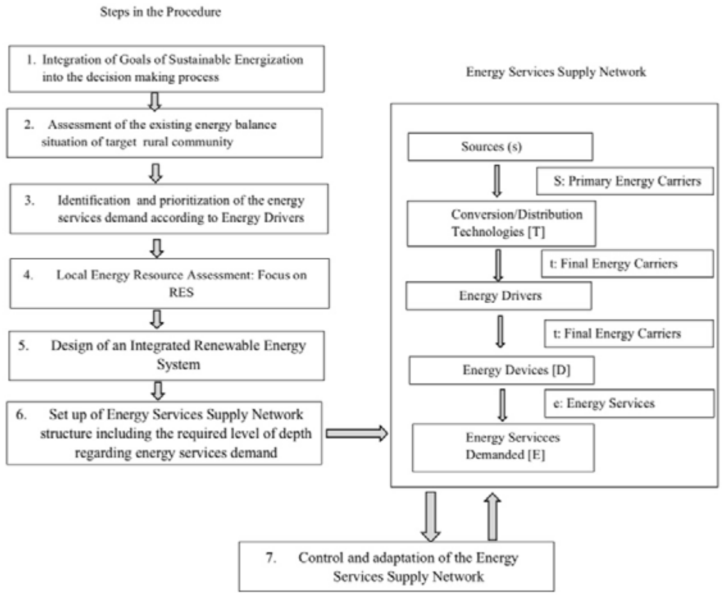

Fig. 1. Steps in the proposed Rural Energy Planning Procedure.

Biomass (for Biogas production): A questionnaire was administered through a face-to-face interview with the households to determine the quantity of monthly production of corn and animal waste. The biogas production potential from these sources were then computed using standard formulae together with biogas yield data and Lower Heating Value (LHV) of biogas obtained from literature [10,11].

Hydropower: Direct field measurements were carried out to obtain the hydraulic head, annual average flow rate and residual flow rate of the river in the study areas. The "Floating Object Test" techniques as suggested in [12,13] and regression techniques using the annual flow rate of the nearby Meché river as reference were used to obtain the flow rate. An altimeter was used to determine the head between the intake and the proposed powerhouse for a micro hydropower scheme. This head was further checked using google maps.

Wind: Direct measurement of wind speed was done from June to October 2014 using a cup anemometer. To characterise the wind regime that reflects seasonal and yearly fluctuations from this limited data, NASA data served as a reference and techniques suggested in [14,15] were used.

Solar: Solar energy potential data were taken from NASA with data for Bamenda, 15 km from study site.

Sankey diagrams were used to visualise energy flows in the energy services supply network before and after the application of proposed planning procedure. HOMER software tool was used to analyse different scenarios to match the electrical energy needs to the local renewable energy resources. Off-Grid and Grid-RES Hybrid scenarios were investigated and optimised from a life cycle perspective. In matching the thermal energy needs to the local renewable energy resources, an ad-hoc solution-focused approach was applied at the level of each energy driver. In setting up of the Energy Service Supply Network (ESSN), the innovation was to consider energy drivers in the network system. This approach enabled a more cost-effective and flexible way to allocate end-use devices to meet the end-use energy services.

3. Results and discussion

3.1. The proposed REP procedure

An extension of the Nissing et al six-step procedure to include an assessment of the existing energy situation resulted in a seven-step procedure. Also at the stage of setting up of the ESSN, energy drivers were included in the

Table 1: Options for meeting Electrical energy needs.

	Off-Grid	Grid – RES Hybrid
Micro Hydropower Plant (MHP)	15 kW	8 kW
Battery (6FM200D)	20 units	N/A
Converter	10 kW	N/A
Net Present Value	US$ 163,088	US$ 132, 791
Levelised cost of Energy (LCOE)	0.18 US$/kWh	0.12 US$/kWh

ESSN model between the conversion technologies and the energy devices (Figure 1). These further extensions of the procedure filled in the observed gaps in the [4] procedure .The strength of the proposed procedure is that it takes into account the energy balance in the existing energy system. The energy balancing allows for the creation of a systematic energy consumption database and quantification of energy consumptions to levels that permit a more realistic modelling. Also, focus on identification and integration of energy drivers at the stage of setting up of an ESSN model allows for flexibility and a more cost-effective way to identify appropriate end-use devices to meet the energy services demanded. Thus, resolving the observed issue of “technology stacking” at household levels. The seven-step procedure was consolidated through a case study in a rural area in Cameroon.

3.2. Energy Planning Solutions

3.2.1. Electrical energy needs

Several scenarios consisting of different combinations of PV, wind and micro hydropower plant and grid power were considered in the HOMER simulations to match the electrical energy needs to the local renewable energy resources were done. Both Off-Grid and Grid-RES hybrid were considered (Table 1).

In both solution options a micro hydropower plant could meet almost all the electrical energy demanded. Sensitivity

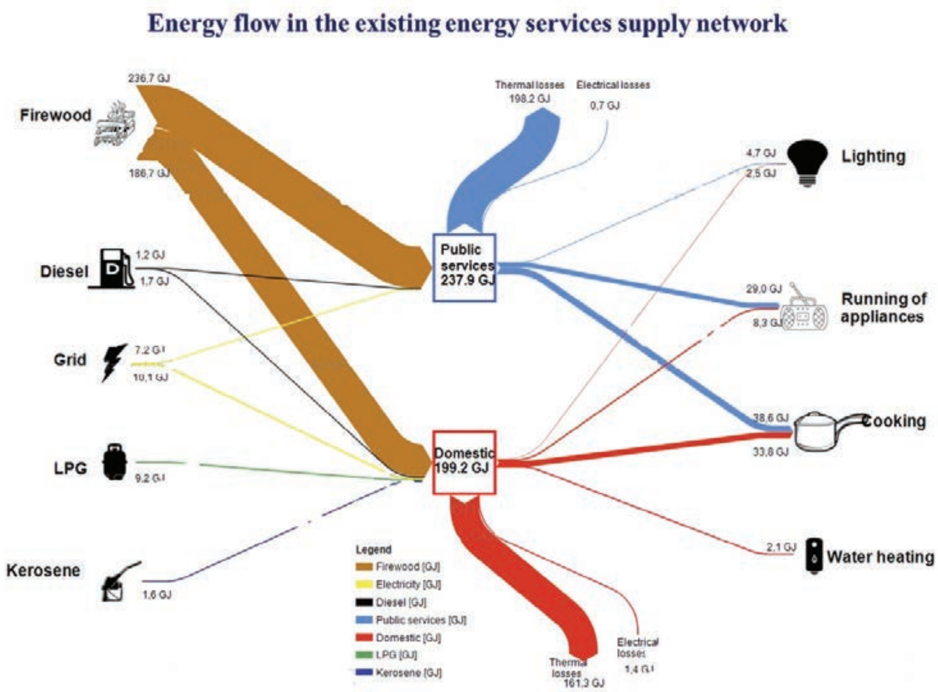

Fig. 2. Energy flow in the existing Energy Services Supply Network.

analyses were investigated for the following changes: (i) a reduction in the cost of hydropower system ranging from 4000 to 1000 US$/kW; (ii) a drop in PV and wind turbine investment costs up to 90 % of the initial value in order to check the competitiveness of the hydropower plant; (iii) a change of 20 % in diesel prices and increase of 5 %, and 20 % unit grid price of electricity. The solution with the micro hydropower plant remained the optimal configuration.

3.3. The Case Study: CPC Bali-Cameroon

3.3.1. Existing Energy situation

The current situation was characterised by heavy dependence on fossil-based fuels and firewood, Primary Energy Supply (PES) of 452 GJ/month and Final Energy Consumption (FEC) of 93 GJ/month. The use of firewood together with low efficiency technologies resulted in huge energy losses (80 %). The energy flow in the existing Energy Services Supply Network (ESSN) is shown in Figure 2.

3.3.2. Local Renewable Energy Resources

Biomass for Biogas production: The measured biogas resource was 354.2 GJ/month. The biogas production from existing biogas system was 8.6 GJ/month.

Hydropower: A potential of 29 kW was estimated at a flow rate of 54 l/s and a head of 55 m. At this fixed flow rate, an average turbine power of 13 kW and a 50 % capacity factor, the hydropower resource was 16.8 GJ/month.

Wind: the average annual wind speed was 3.3 m/s, giving a wind power potential of 10.7 W/m^2, and monthly production of 0,27 GJ/month.

Solar: The daily average irradiation is 5.2 kW/m^2, giving an average gross potential of 0,53 GJ/m^2 per month.

3.3.3. Thermal Energy needs

To reduce the heavy consumption of firewood for cooking in both the public and domestic drivers, more efficient technologies were proposed. Specifically, in the public driver: the ASTRA-type stove which has a thermal efficiency

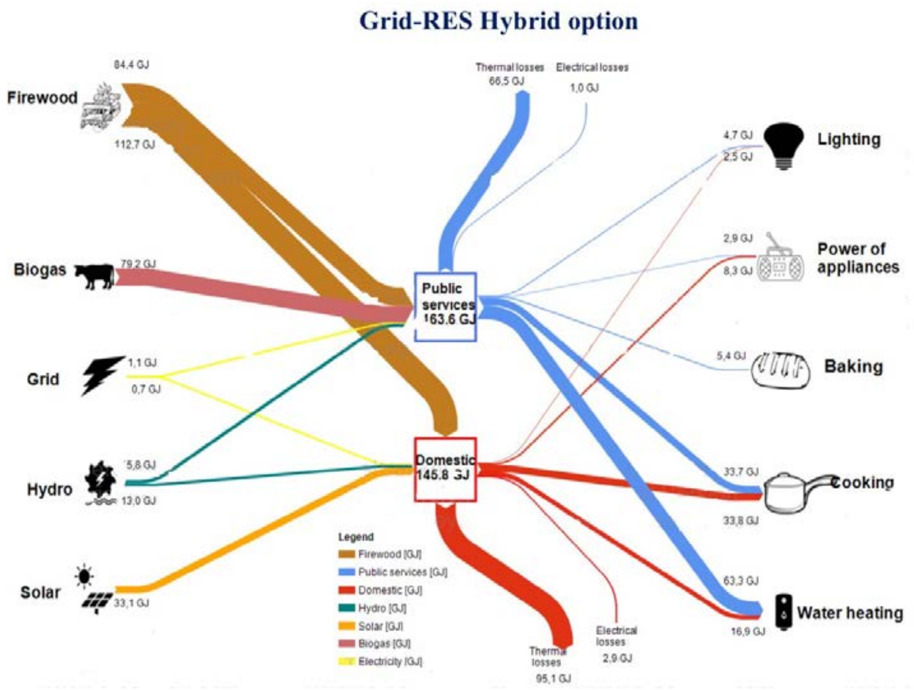

Fig. 3. Energy flow in the resulting Energy Services Supply Network.

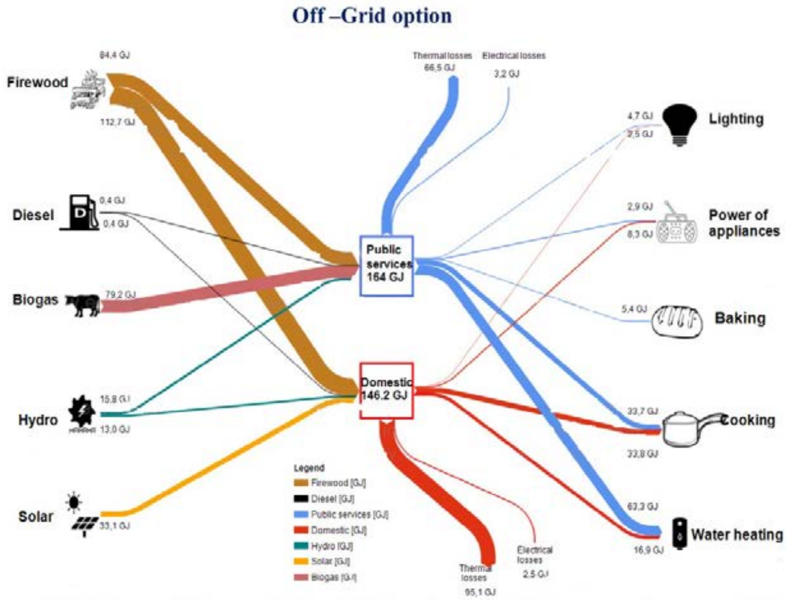

Figure 4: Energy flow in the resulting Energy Services Supply Network -Off-Grid option

of 40 % was proposed to replace the existing less efficient stove which had a thermal efficiency of 24 %, and the replacement of the firewood-powered oven by an electric oven for the baking activities. The replacement of the firewood-power oven by an electric oven had consequences on the capacity of the power plant and load curve both in the Off-Grid and Grid-RES Hybrid options. In both configurations, the capacity of the hydropower increased from 15 kW to 18 kW. However, the LCOE were 0.15 US$/kWh and 0.09 US$/kWh for the Off-Grid and Grid-RES configurations respectively. In the domestic driver: the portable Envirofit G3300 was proposed to substitute the three stone fire. For *Public warm water*, the need of 2.11 GJ/day for warm water was completely unmet. Based on the local renewable energy resources, two solution possibilities existed i.e. use of biogas-fired boilers or solar thermal collectors. Taking the thermal efficiency of 80 % for a biogas boiler into account, the PES required was 2.64 GJ/day. Current biogas production (9.8 Nm^3/day) could meet only 11 % of the existing needs. Considering a flat plate for a SWHS solution and average annual irradiation of 19 MJ/m^3/day, required a collector of 216.6 m^2. This solution option for the provision of public warm water was considered challenging in terms of investment and technical O & M in context of a DC. For the *Domestic warm water*, for a standard of 30 litres per capita per day, the warm water needs were 3.14 MJ. Using a flat plate collector with an efficiency of 60 %, and SWHS efficiency of 85 %, a collector of size 0.42 m^2 per capita was required. For a family of 4 persons and a storage tank of 120 l, a system with 1.64 m^2 could meet the daily warm water needs of the households.

From the above proposed energy solutions, the resulting energy flow in the ESSN was analysed as shown in Figure 3 and Figure 4, respectively. Remarkable in the ESSN is a more diversified energy mix for the study area and a reduction in the PES. There was also a remarkable increase in FC in both the Off-Grid and Grid-RES Hybrid for the same PES. Considering energy supply security and future possibilities to sell electricity through the Grid, the Grid-RES Hybrid option could be recommended for the study area.

4. Conclusions

The relevance and validity of the proposed procedure to REP which integrates the concept of sustainable energization has been demonstrated within the context of a rural area. The demonstration showed that the rural community could have an improved quantity, quality and a variety of accessible and affordable energy services characterised by a more diversified energy supply mix with greater dependence on local renewable energy sources, lower PES, higher FC and reduced energy losses. Thus, the application of this procedure together with careful technology selection and optimisation for SE could improve energy access in rural areas of DC.

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