Smart grid for power generation from renewable energy resources for sustainable energy development in Kanungu district, Uganda

Jane Rose Atwongyeire
Sustainable Energy Management Program, Faculty of Environmental Management, Prince of songkla Universit, Hat Yai, Songkhla, Thailand
roseatwongyeire@gmail.com

Arkom Palamanit
Energy Technology Program, Department of Specialized Engineering, Faculty of Engineering
Prince of Songkla University
Hat Yai, Songkhla, Thailand
arkom.p@psu.ac.th

Adul Bennui
Southern Regional Center of Geo-Informatics and Space Technology, Faculty of Environmental Management
Prince of Songkla University
Hat Yai, Songkhla, Thailand
adul.b@psu.ac.th

Wathanaporn Kraiwan
Hatyai Technical College, Institute of Vocational Education: Southern region 3, Hat Yai, Songkhla, Thailand
wathanapon.k@gmail.com

Abstract

Development of sustainable energy systems involves many energy aspects such as energy technologies and management, energy security, reliability, and sustainability, as well as energy policy and planning. In that regard, smart energy concepts for sustainable energy development are increasingly being recognized and these include smart grids, Internet of Energy (IoT), blockchain-energy among others. These aim to enable a smooth transition from fossil-based energy to clean alternate energy resources. And also, to play an important role in the power generation and distribution from renewable energy resources (RERs) for universal modern energy access. Thus, this study aimed to demonstrate the inclusion of a smart connective concept (smart grid) in power generation and distribution from solar and small hydropower resources in Kanungu district, Uganda. A GIS-based multi-criteria decision-making method was used in the site selection process based on environmental, economic, and technical factors. And, a final resultant map of smart grid suitable sites for distributed power generation from solar and small hydropower RERs was finally generated using GIS.

Keywords: Multi-criteria decision-making; Power generation; Renewable energy; Smart grid

I. INTRODUCTION

Global energy systems are facing many challenges due to the slow-paced transition from fossil-based energy systems to clean energy systems. Yet, the environmental and health impacts of fossil fuel over dependency remain a serious global concern. With the prevailing concerns, to increase the applications of renewable energy resources (RERs) in the power generation sector is one of the solutions. However, power generation and distribution from RERs has its associated limitations such as low energy density of the source, low energy reliability and security by nature, high implementation costs, etc. To overcome these aspects, modern energy technologies combined with smart energy concepts and energy storage need to be applied and emphasized. In the recent years, several energy concepts have emerged towards sustainable energy systems including smart grids, Internet of energy, blockchain-energy, among others. It is, therefore, important for developing countries like Uganda rich with abundant renewable energy resources to consider such smart energy concepts. Uganda for example, has high potential of RERs for power generation, but the electricity access in the country is still low. Thus, one of the solutions to meet the power demand and sustainably exploit the available resource potentials is power generation from RERs combined with the smart energy concept such as a smart grid. Besides, this implementation not only helps to enhance electricity access, but it is also beneficial for energy planning and policy formulation, leading to sustainable energy development and proper management of the resources [2,3].

Smart grid for example is a connective network that is flexible, reliable, and efficient with the ability to monitor, manage and control the power chain from power generation to distribution. However, development and implementation of such systems differ depending on each country's needs and require strategic planning [2]. Most developing countries including Uganda, have not paid much attention to these smart energy systems because of several factors such as poor electricity access, unreliable infrastructure, etc. Nonetheless, planning and implementation of sustainable energy systems that can both combat issues of electricity access as well as provide sustainable smart solutions in the energy sector is key. Moreover, in the study for energy sufficiency, sustainability, and universal access in the sub-Saharan Africa by Gladkykh et al., (2021), it was reported that renewable energy-based power generation is ideal for sustainable solutions [5]. Therefore, this paper presents a site selection study for power generation from solar and small hydropower energy resources on the basis of a smart connective concept (smart grid). Areas suitable for the application of the smart connective concept in a multi-energy power generation

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system were selected using a GIS-based multi-criteria decision-making method. This method is known for site selection and energy planning processes especially a combination of GIS and multi-criteria decision-making method such as fuzzy Analytic Hierarchy Process (AHP) [1,8].

II. METHODOLOGY

The study was done based on qualitative and quantitative data. Survey questionnaires were used to obtain qualitative data while quantitative data was obtained both from online portals and governmental institutions. The data collected and used was based on economic, environmental, and technical factors. These factors included respective sub-factors; (a) Under the economic factor, the sub-factors included distance from transmission lines, topography (elevation and slope), and distance to roads; (b) the sub-factors under the environmental factor included land use, sensitive and protected areas; (c) and under the technical factor, the sub-factors included distance from demand centers, available potential energy resources (solar and small hydropower) and climate (rainfall and sunshine). This is because energy planning such as site selection involves a wide spectrum of decision makers, a survey questionnaire designed according to the mentioned factors and literature was distributed to the experts in different energy fields. This was to obtain opinions from the experts in order to make an informed decision. According to the designed questionnaire, experts were required to rate the significancy of each factor according to AHP Saaty's scale of significance (1 to 9). The scores assigned to each factor by the experts were then transformed into equivalent triangular fuzzy numbers (Table 1).

Table 1. Scale of significance [1]

Significance Intensity	Description	Equivalent Triangular Numbers
1	Equal importance	(1.0, 1.0, 1.0)
3	Moderate importance	(2.0, 3.0, 4.0)
5	Strongly higher importance	(4.0, 5.0, 6.0)
7	Very strong higher importance	(6.0, 7.0, 8.0)
9	Extremely high importance	(9.0, 9.0, 9.0)
2	Intermediary importance	(1.0, 2.0, 3.0)
4		(3.0, 4.0, 5.0)
6		(5.0, 6.0, 7.0)
8		(7.0, 8.0, 9.0)

Using fuzzy Analytic Hierarchy Process (AHP), a multi-criteria decision making-method known for solving complex problems, weight values of the factors were calculated following a similar methodology as [1,8]. The calculated weights were firstly used in a GIS-environment to obtain suitable areas potential for solar power generation using the Global Horizontal Irradiance (GHI) data in ArcGIS 10.5. On the other hand, available data for small hydropower potential sites was obtained from Ministry of Energy and Mineral Development (MEMD), Uganda. Potential sites for solar power generation obtained and small hydropower data were then combined in ArcGIS 10.5 to demonstrate a connective power generation system based on a smart grid concept. The study demonstrates possible power generation from multi-energy sources in a smart connective system for distributed energy resources as illustrated in Figure 1. The illustration demonstrates a possible solar and small hydropower multi-energy power generation system interconnected to transmission, distribution, and consumption. The conceptual design shows interflow of information in the power chain that can be defined as an end-to-end relationship of power supply information. The conceptual design consists of:

A. Power generation control areas (PG-CA)

These are power generation control centers (1, 2, 3, …, n) for monitoring power generation from multi-energy power generation sources within approximate area of the power plants. The conceptualized PG-CAs are in charge of forecasted power generation depending on the season. For example, in the rainy season, more power can be generated from small hydropower plants due to limited solar energy while in hot/dry season, more power can be generated from solar plants to have a balanced sustainable power generation as one of the solutions to sustainable energy management and resource exploitation.

B. Main power generation control area (PG-CA-M)

This is a general power generation control center for controlling, regulating, and monitoring power generation based on the information received from the control centers (PG-CA) as well as the demand and supply situation.

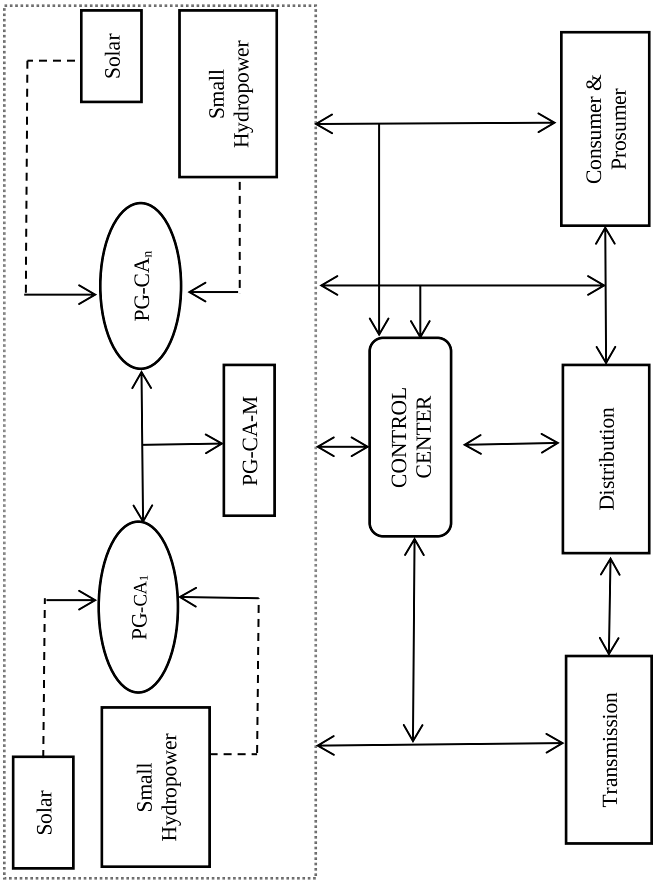
C. Control center

The control center is the overall information flow and interaction center to monitor, regulate, and manage the whole power chain including information of power generation, transmission, distribution, and consumption as well as monitoring the behaviors of both the consumer and prosumer in the power supply chain.

D. Transmission, distribution, and consumption

This section of the conceptual design includes information interaction of transmission, distribution, and end-users (consumers and prosumers).

This conceptual design represents an interactive system of information, communication, and technology in a power chain for sustainable energy management and proper resource exploitation. The system can be manipulatively designed according to the needs of each country and set goals. In this study, the focus is on sustainable exploitation of the available resources to enhance electricity access and sustainable energy management for sustainable development in the study area.



PG-CA Power Generation-Control Area (1,2,3, …n)
PG-CA-M Power Generation-Control Area (Main)

Figure 1. Illustration of a smart connective power system

III. RESULTS AND DISCUSSION: PLANNING A SMART CONNECTIVE POWER SYSTEM

Maier, 2016 reported that in planning an energy system for smart solutions, it is important to integrate energy designs with spatial planning which includes considering factors like system designs, infrastructural and building designs, and evaluation of environmental impacts. And this requires the application of advanced approaches [6]. Several studies have been carried out in the recent years aiming at sustainable energy systems. For example, Stoeglehner, 2011 carried out a study for integrated spatial and energy planning for sustainable energy systems. The author highlighted that some of the important issues to be addressed in planning a renewable energy system on a community scale level is the justification of allocation patterns of energy resources [10]. Gladkykh et al., 2021 carried out a study aiming at the exploration of energy efficiency, sustainability and universal access in sub-Saharan Africa for a social sustainable energy system [5]. Seferlis, 2021 carried out a study for a well sustainably designed and operation energy system to improve power generation and distribution for reduced consumption and emission production [9]. Noorollahi, 2021, carried out a study for renewable energy-based sustainable energy system in Iran contributing to the transition from fossil fuel power generation to renewable energy power generation [7]. Fonseca, 2021 carried out a multi-objective sustainability analysis in designing a distributed energy system focusing on economic, environmental and social aspects [4].

In this study, aiming at sustainable exploitation of energy resources and electricity access, a strategic spatial planning of a smart connective power generation was carried out by selecting suitable sites for a multi-energy resource power generation from solar and small hydropower in Kanungu district, Uganda. As earlier mentioned, suitable sites for power generation from solar were first identified based on the selected factors. Combined with the available data of small hydropower potential sites, suitable areas for a smart connective power generation from both renewable energy resources were obtained. The selection of suitable areas based on a smart connective concept for a smart connective power generation from solar and small hydropower, factors including distance to roads, distance from transmission lines, distance to demand centers and availability of the energy resources were put into consideration. The area consists of four small hydropower feasible sites for power generation which include 0.5 MW Kishamba hydro site, 0.68 MW Birara hydro site, 2.9 MW Mitano hydro site and a 6.7 MW Nengo bridge hydro site according to the data that was obtained from Ministry of Energy and Mineral Development, Uganda. And based on the assumption that 1.4 ha is equal to 1 MW of solar potential, the study area consists of 1,618.95 MW of low suitability, 21,428.08 MW of moderate suitability and 1,350.69 MW of high suitability. As per Figure 2, the resultant map shows suitable areas for smart connective power generation from solar and small hydropower energy resources in Kanungu district, Uganda.

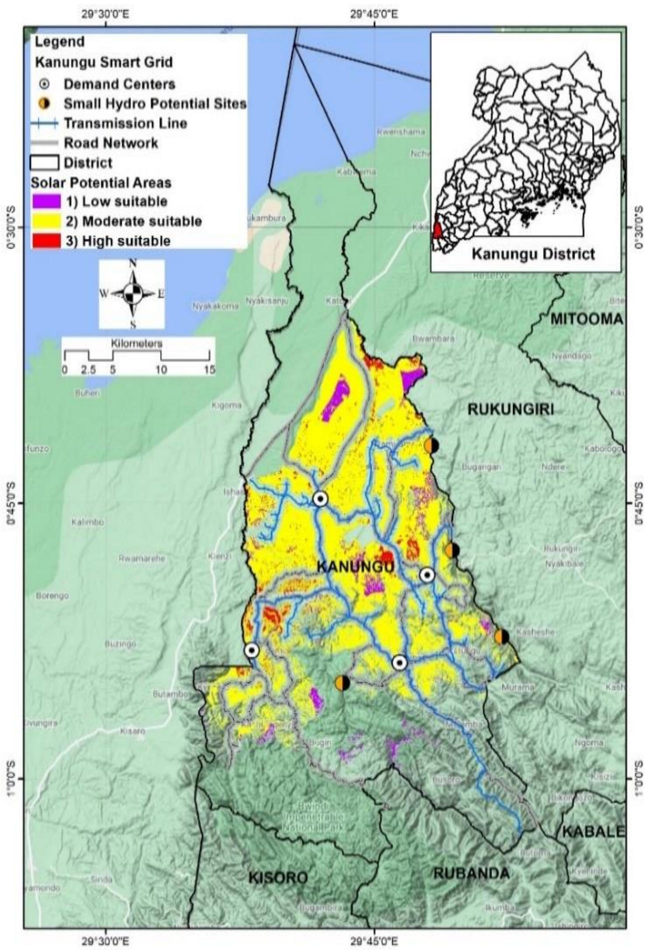


Figure 2. Suitable areas for a multi-energy smart connective power generation system.

IV. CONCLUSION

As the world is moving from fossil-based power generation to clean energy power generation, an emphasis should continue to be put on sustainable, smart, connective, and interactive energy systems. Developing countries like Uganda should consider investing in sustainable smart systems by understanding the need for these smart connective systems. The governments should put in place supportive tools including flexible regulatory frameworks for energy system developments and investments in pilot studies should also be considered for successful implementation of these systems such as smart grids. Most importantly, the countries should make an effort to improve the energy infrastructural systems in order to accommodate the present and future dynamics in the energy sector.

For example, in the case of Kanungu district, Uganda, the study results can be a basis of energy planning, implementation and development in the area for an improved smart connective power generation system.

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VI. REFERENCES

[1] Abbas Asakereh, Mohsen Soleymani, and Mohammad Javad Sheikhdavoodi. 2017. A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran. *Sol. Energy* 155, (2017), 342–353. DOI:https://doi.org/10.1016/j.solener.2017.05.075

[2] Paul Basudde. 2020. *Promoting the Transfer and Development of Climate-Smart Energy Technologies in Uganda*. Elsevier. DOI:https://doi.org/10.1016/b978-0-12-409548-9.12401-7

[3] Zenville Erasmus and Antoine Bagula. 2017. Smart renewable energy systems: A great opportunity for developing countries. *2017 IST-Africa Week Conf. IST-Africa 2017* (2017), 1–16. DOI:https://doi.org/10.23919/ISTAFRICA.2017.8102382

[4] Juan D. Fonseca, Jean Marc Commenge, Mauricio Camargo, Laurent Falk, and Iván D. Gil. 2021. Sustainability analysis for the design of distributed energy systems: A multi-objective optimization approach. *Appl. Energy* 290, March (2021). DOI:https://doi.org/10.1016/j.apenergy.2021.116746

[5] Arnaud Gladkykh, Ganna, Diemer. 2021. When justice narratives meet energy system models : Exploring energy sufficiency , sustainability , and universal access in Sub-Saharan Africa. August 2020 (2021). DOI:https://doi.org/10.1016/j.erss.2021.102075

[6] Stephan Maier. 2016. Smart energy systems for smart city districts: case study Reininghaus District. *Energy. Sustain. Soc.* 6, 1 (2016). DOI:https://doi.org/10.1186/s13705-016-0085-9

[7] Younes Noorollahi, Meysam Pourarshad, and Alireza Veisi. 2021. The synergy of renewable energies for sustainable energy systems development in oil-rich nations; case of Iran. *Renew. Energy* 173, (2021), 561–568. DOI:https://doi.org/10.1016/j.renene.2021.04.016

[8] Penjani Hopkins Nyimbili and Turan Erden. 2020. GIS-based fuzzy multi-criteria approach for optimal site selection of fire stations in Istanbul, Turkey. *Socioecon. Plann. Sci.* 71, May (2020), 100860. DOI:https://doi.org/10.1016/j.seps.2020.100860

[9] Panos Seferlis, Petar Sabev Varbanov, Athanasios I. Papadopoulos, Hon Huin Chin, and Jiří Jaromír Klemeš. 2021. Sustainable design, integration, and operation for energy high-performance process systems. *Energy 224*, 120158. DOI:https://doi.org/10.1016/j.energy.2021.120158

[10] Gernot Stoeglehner, Nora Niemetz, and Karl Heinz Kettl. 2011. Spatial dimensions of sustainable energy systems: New visions for integrated spatial and energy planning. *Energy. Sustain. Soc.* 1, 1 (2011), 1–9. DOI:https://doi.org/10.1186/2192-0567-1-2