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THE TECHNO-ECONOMIC EVALUATION OF THE BETWEEN A GRID EXTENSION AND HYBRID RENEWABLE SYSTEMS CONSIDERING DEFERRABLE LOADS

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ABSTRACT

The rapid depletion of fossil energy resources significantly increases the need for renewable energy resources (RES) in electricity production. Hybrid power systems (HPS) are a promising solution for rural electrification where grid extensions are uneconomical. This study investigated the technical, economic, and environmental aspects of on-grid or off-grid HPS performance for optimal rural electrification. In addition, the effects of different deferrable load values on grid extension distance (GE) and optimal off-grid system sizing were investigated. Sensitivity analyses were conducted to evaluate the effects of variations in solar irradiation potential, diesel fuel costs, and discount rates on optimal HPS sizing. In scenarios where the deferrable load is above 9%, the GEs were zero, while below 5%, they increased to 24.2 km. In contrast, when the diesel generator (DG) was integrated into HPS, the photovoltaic (PV) and energy storage system (ESS) capacities were reduced by half in the optimal scenarios, and it was found that the GE was zeros regardless of the deferrable load. In the case of the highest deferrable load, the NPC is 22.6% lower than when there is no deferrable load. NPC surpasses the energy cost in the grid-only condition when solar irradiation is less than 4 kWh/m2/day, and ESS cost multipliers are greater than 2. This study will help researchers find optimal electrification solutions that support hybrid renewable energy and environmentally friendly options.

Keywords: Hybrid Power System, Grid Extension, Rural Electrification, Sensitivity Analysis, Solar Photovoltaic

1. INTRODUCTION

Global population increase and the development of industry are causing a significant increase in energy consumption. Today, more than 50% of this energy consumption is met by traditional energy sources Indragandhi et al. (2017), World Energy Outlook (2020) . The increasing use of traditional energy sources causes many environmental problems Zhu et al. (2021). In order to reduce the use of fossil fuels and to mitigate climate change, the trend towards renewable energy sources (RES) has increased significantly in recent years Maisanam et al. (2019), Marefati et al. (2019) . On the other hand, sustainable development scenarios include sustainable energy and environmental goals, including energy access and clean air targets Dhabi (2020). Countries are aiming for net-zero emissions by the middle of the century. Policies set by governments in line with sustainable environmental goals have made the use of RES energy important Bhattacharyya (2013). The primary sources of these resources are solar and wind energy, but they have many disadvantages, such as investment costs, intermittent energy structures, and efficiency problems Maisanam et al. (2019), World Energy Outlook. (2020). For sustainable energy and environment, grid-supported or off-grid installations of renewable energy HPS can provide many technical, economic, and environmental advantages Manju & Sagar (2017). On-grid or off-grid HPS installations can provide many technical, economic, and environmental benefits for sustainable energy and the environment Panda et al. (2023). The grid extension distance is a metric in km that balances the cost of grid extension and the cost of off-grid electrification Ortega-Arriaga et al. (2021). This distance provides the cost of grid extension to a remote area to be the same as investing in an off-grid power system Ozturk and Demirci (2023). Many studies are investigating the performance of HPS in rural areas, considering sustainable energy and environmental targets. In Africa, the solution of the rural energy problem with HPS has been investigated and it has been found that rural electrification rates are below 40% Antonanzas-Torres et al. (2021). The economic and environmental impacts of GE and off-grid HPS have been reviewed to inform the appropriate electrification strategy in regions without access to electricity Kemausuor et al. (2018) . A model is presented to determine the least-cost strategy for rural electrification. A combination of GE and off-grid generation was identified in the lowest-cost strategy for universal electrification. For villages with different climatic characteristics and load profiles, the GE cost accounts for 43% of the NPC Mousavi et al. (2021). In the feasibility of off-grid HPS proposed for a small community in Bangladesh, the GE was found to be 8-12 km Nandi & Ghosh (2010). It has also been emphasized that if the government develops supportive policies through incentives and subsidies, it can contribute to the social and cultural development of the respective regions and a sustainable environment and energy Baldwin et al. (2015) . With the HPS analysis, energy costs were reduced by about 27% and 77% of the required energy was provided by RES Robert & Gopalan (2018). Sensitivity analyses were performed by considering variations in inflation and discount rates to increase energy reliability and continuity, and unit energy costs ranged between 0.085-0.238 $/kWh Kasaeian et al. (2019). The techno-economic feasibility of an off-grid HPS proposed for the electrification of a remote village was studied Oladigbolu et al. (2020). It was emphasized that financing rural electrification is challenging, and innovative business models should be developed El-Kharouf et al. (2020). The study was focused on finding an optimal HPS to supply the load of a small village in Iran that faces frequent power outages with RES. It was found that adding fuel cells to the HPS increases the unit energy costs by 37% yet improves the system flexibility Motjoadi et al. (2020). The potential of DG, alternative energy source HPSs, and centralized GE options for the electrification of off-grid areas with the lowest unit energy cost was evaluated Moner-Girona et al. (2019). This study investigated the potential of satisfying consumer energy demands with grid extension or off-grid HPS. In addition, sensitivity analyses were performed considering different deferrable load rates, solar radiation potentials, diesel fuel costs, and variations in discount rates.

2. METHOD

Table 1 shows the primary and deferrable load variations of the total electrical load of 2500 kW for each analyzed scenario. Table 2 shows the costs of the components in HPS International Renewable Energy Agency (IRENA). (2021), Dhabi (2020), World Energy Outlook (2020). Analyses were carried out in Izmir province with a solar radiation potential of 4.68 kWh/m²/day.

Table 1

Table 1 Scenarios

Load Type	S1	S2	S3	S4	S5
Primary Load (kWh)	2000	2125	2250	2375	2500
Deferrable Load (kWh)	500	375	225	125	-

Table 2

Table 2 Hybrid Power System Component Costs

HPS Components	Capital Cost	Replacement Cost	O&M Cost
Photovoltaic panel (PV)	1000 $/kW	950 $/kW	10 $/year
Energy storage system (ESS)	250 $/kWh	225 $/kWh	2 $/year
Converter	300 $/kW	300 $/kW	0,02 $/year

Photovoltaic panels (PV) have an important place in renewable energy sources. Equation (1) shows the output power rating of a PV panel. Where, Y_{PV} is the nominal capacity of the PV array [kW], f_{PV} is the PV depreciation factor [%], G_t is the solar radiation incident on the PV array at the current time [kW/m²], α_P is the temperature coefficient of the power [-0.20 to -0.60 %/°C] and T_c is the PV cell temperature [⁰C].

$$P_{PV} = Y_{PV} \,.\, f_{PV} \,.\, G_t \,.\, [1 + \alpha_P \,.\, (T_c - 25)] \quad [kW] \tag{1}$$

Equation (2) describes the power of the inverter [kW] while Equation (3) gives power of the rectifier [kW]. According to the given, $P_{DC}(t)$ is the total power at the DC bus [kW], $P_{AC}(t)$ is the total power at the AC bus [kW], η_{inv} is the inverter efficiency [%] and η_{rec} is the rectifier efficiency [%].

$$P_{inv}(t) = P_{DC}(t) \,.\, \eta_{inv} \quad [kW] \tag{2}$$

$$P_{rec}(t) = P_{AC}(t) \,.\, \eta_{rec} \quad [kW] \tag{3}$$

Power lines are essential for the transportation of electricity from generation to consumers. However, many factors, such as high investment costs of transmission and distribution systems, long grid extension distance, and climatic variations, create problems for the lines. Therefore, grid extension cost is defined as the cost per km of the user's distance to the nearest access point to the central grid. The critical distances to existing lines are calculated as in Equation (4). GE is the grid extension distance [km], NPC is the total net present cost HPS [$], $CRF(i, N)$ is the capital recovery factor, GP_{price} is the cost of power received from the grid

[$0.12/kWh], E_{load} is the electricity demand of the load [kWh/year], GE_{CAPEX} is the capital cost of grid extension [$12000/km] and GE_{OPEX} is the operation and maintenance cost of grid extension [$ 200/year/km] (Ozturk et al. (2021)).

$$GE = \frac{NPC \cdot CRF(i,N) - GP_{price} \cdot E_{load}}{GE_{CAPEX} \cdot CRF(i,N) + GE_{OPEX}} \quad [km] \tag{4}$$

The total net present cost (NPC) of the system is the present value of all costs (capital, replacement, O&M, etc.) over the life of the project divided by the present value of all revenues earned (recovery, etc.). The formulas for NPC are given in Equation (5), capacity capital factor in Equation (6), nominal real interest rate in Equation (7), and unit energy cost in Equation (8) Ozturk et al. (2021). According to the given formulas, $C_{ann,total}$ is the total annual cost value [$/year], N is the project life [20 years], i is the annual real discount rate [%], i' is the nominal discount (borrowing) rate [%], f is the expected inflation rate [%] and COE is the unit energy cost [$/kWh] Terkes et al. (2023).

$$NPC = \frac{C_{ann,total}}{CRF(i,N)} \quad [\$] \tag{5}$$

$$CRF(i,N) = \frac{i \cdot (1+i)^N}{(1+i)^N - 1} \tag{6}$$

$$i = \frac{i' - f}{1+f} \quad [\%] \tag{7}$$

$$COE = \frac{C_{ann,total}}{E_{load}} \quad [\$/kWh] \tag{8}$$

This study utilizes HOMER ® PRO software from HOMER Energy. This software creates optimal system models by analyzing multiple renewable energies, batteries, power grid, and other energy sources over the project lifetime according to the electrical load requirement Ozturk and Demirci (2023) . Figure 1 shows HPS model: Diesel generator (DG), photovoltaic panel (PV), AC/DC converter, energy storage system (ESS), primary and deferrable loads and grid.

Figure 1

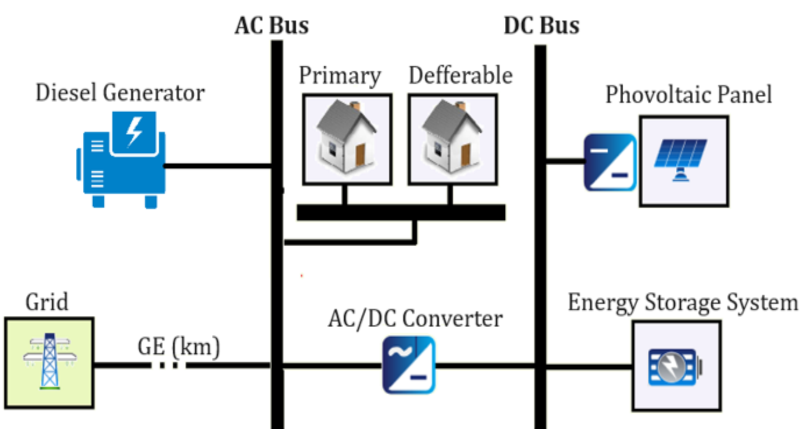

Figure 1 HPS Model

3. SIMULATION RESULTS AND DISCUSSIONS

Table 3 shows the optimal system sizing results for different deferrable loads.

Table 3

Table 3 Optimal System Sizing Results for Different Deferrable Loads

	Off-Grid HPS (on DG)				
	S1	S2	S3	S4	S5
Solar PV (kW)	1317	1195	1392	1390	1452
Lithium-ion ESS (kWh)	3817	3545	4412	4471	4877
Converter (kW)	409	430	443	487	512
Diesel Generator (DG)	600	600	600	600	600
	Optimal Results				
Grid Distance (km)	< 0	< 0	< 0	< 0	< 0
NPC (M$)	2.91	3.14	3.29	3.43	3.57
COE ($/kWh)	0.064	0.069	0.072	0.075	0.078
RF (%)	98.1	94.5	98.0	97.7	98.0
Diesel Fuel Use (L/year)	5,355	12,910	5,601	6,354	5,670
Clipped Energy (%)	51.1	46.8	53.6	53.6	55.4
CO_2 (kg/year)	14,016	33,793	14,661	16,632	14,842

In the case of supplying energy demand from the only grid, the NPC increases up to 5.52 M$. Total CO_2 in this scenario is 576.8 tons/year. HPSs with off-grid PV-ESSs with a deferrable load above 9% gave optimum results. In the scenarios with a deferrable load of 125 kWh and below (S4 and S5), the GEs extended up to 7.89 km and 24.2 km, respectively. Moreover, in HPS scenarios where the deferrable load is below 5%, the NPC is 8% higher than in the only-grid system. ESS capacity is up to 50% lower than the other scenarios in the S1 scenario. The analysis shows that off-grid HPSs are optimum for a deferrable load above 10% and solar radiation potential above 4.5 kWh/m^2/day. Moreover, in scenario S1, where the deferrable load is set at 20%, solar radiation above 4.0 kWh/m^2/day is sufficient for GE to be zero. On the other hand, in scenario S5, where the deferrable load is zero, the only grid system provided optimal results up to a solar potential of 6.0 kWh/m^2/day. In these scenarios, the GE, which extends up to 141.0 km for a solar potential of 3.0 kWh/m^2/day, is zero only if the solar potential is above 5.5 kWh/m^2/day. The variation of the deferrable load extends the GE up to 52 km. Thus, in S1, optimal results were achieved with off-grid HPS, while in the S5 scenario, the on-grid system provided the best NPC up to 10.2 km due to the non-availability of a deferrable load option. The results show that increasing the proportion of deferrable load by up to 20% can reduce the NPC by up to 30%, depending on the solar potential. By integrating the diesel generator into the HPS, PV-ESS capacities are halved, and economic results are obtained, as shown in Table 3. On the other hand, DG integration in HPSs reduced RF by up to 4.5%. This resulted in a fuel use of 12,910 L/year and CO_2 emissions of 33.8 tons/year. In the S1 scenario, where the deferrable load is the highest, the NPC drops to 2.91 million dollars. Similarly, in the S5 scenario with no deferrable load, NPC increases by 22.6% to $3.57 million.

Figure 2 shows the technical, economic, and environmental results of the variation in solar radiation and ESS costs for the S1 scenario. The increase in solar radiation potential towards 7 kWh/m^2/day reduces the optimal PV installed capacities by more than 50%. The rise in costs caused ESS capacities to decrease from 4500 kWh to 1000 kWh. Optimal system configurations varying depending on solar radiation and ESS costs resulted in a wide range of NPC from 1 M$ to 7M$. In scenarios with solar radiation below 4 kWh/m²/day and ESS cost multipliers above 2, NPC exceeded the energy costs in the only grid scenario. On the other hand, in scenarios where the ESS cost multiplier is below two and the solar radiation potential is above 4 kWh/m²/day, NPC is economical with a cost reduction of up to 1M$. For scenarios above 4 kWh/m²/day, a slight decrease of 5% in RF is realized. In scenarios with low solar radiation and high ESS costs, CO_2 increased up to 70 tonnes/year. In scenarios with high solar potential and low ESS costs, this decreased to less than 10 tonnes/year, resulting in a more environmentally friendly outcome.

Figure 2

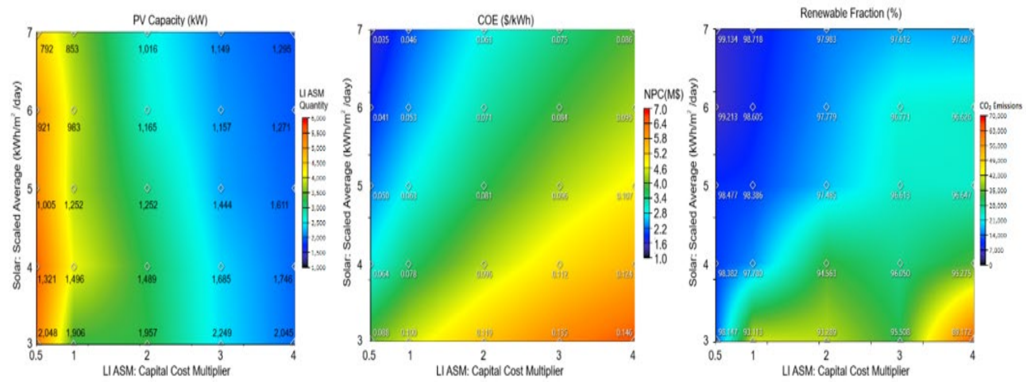

Figure 2 HPS Optimal System Configuration Considering Different Solar and Capital Cost for S1

Figure 3

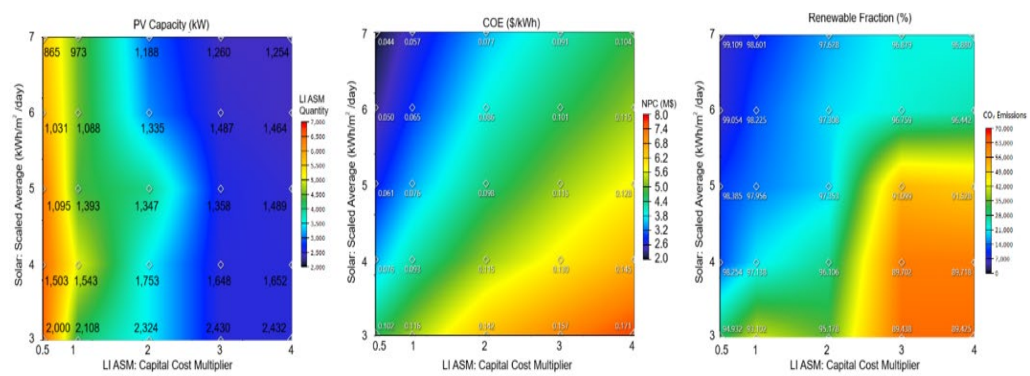

Figure 3 HPS Optimal System Configuration Considering Different Solar and Capital Cost for S5

Figure 3 shows the technical, economic, and environmental results of the variation in solar radiation and ESS costs for the S5 scenario. With the increase in solar radiation potential towards 7 kWh/m²/day, the optimal PV capacity is realized as 865 kW. This value is 10% higher than in the S1 scenario, where the deferrable load is maximized. Moreover, the no deferrable load in the S5 scenario caused the optimal ESS capacities to be larger than in S1. Depending on the solar radiation and ESS costs, the optimal system configurations resulted in a range of NPC between 2M$-7M$. In scenarios where solar radiation is below 4 kWh/m²/day, and ESS cost multipliers are above 2, NPC exceeds the energy costs in the only grid scenario. On the other hand, in scenarios with ESS cost multipliers below two and a solar radiation potential above 4 kWh/m²/day, NPC decreased up to 2M$.

Figure 4 shows the optimal system configurations for various GE and discount rates in the S1 and S5 scenarios. Optimal economic results are realized in the HPS with PV/ESS, where the discount rate is below 8%. On the other hand, for the S1 scenario, when the discount rate is 8-11%, and the GE is above 40 km, the best results are obtained in DG/PV/ESS/GRID. The optimal HPS model above an 11% discount rate is realized as DG/PV/ESS. Although similar HPS configurations are recognized in the S5 scenario, especially the DG/PV/ESS/GRID configuration, shown in red, is realized when GE is more than 60 km.

Figure 4

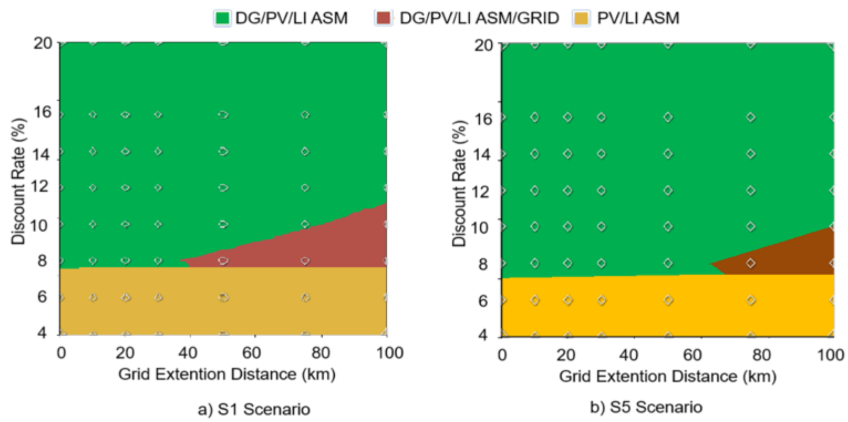

Figure 4 HPS Optimal System Configuration for S1 and S5 Scenario

Figure 5

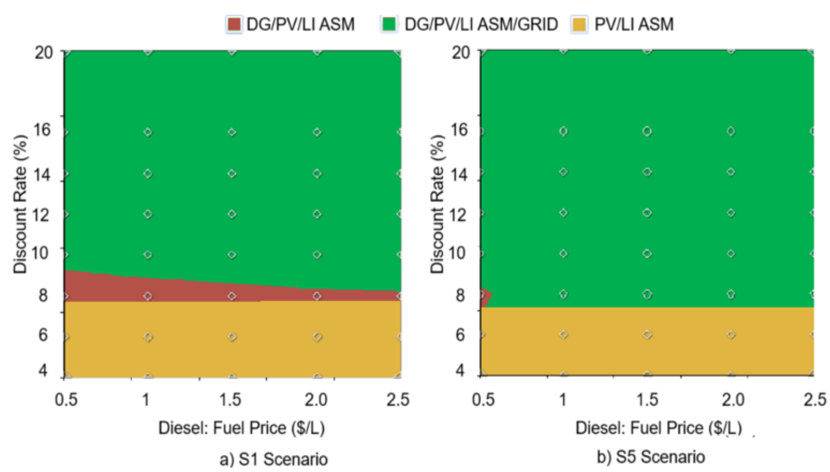

Figure 5 HPS Optimal System Configuration for 50 Km Grid Extension Distance

The optimal HPS configurations based on fuel costs and variations in discount rates are shown in Figure 4. While the optimal systems vary depending on the variation in discount rates, HPS with off-grid PV/ESS under an 8% discount rate yielded the most economical result. In the S1 scenario where the deferrable load is maximum, optimal results are obtained in DG/PV/ESS/GRID when the DR is between 8-10%. On the other hand, in the S5 scenario, where there is no deferrable load, this scenario is realized in a very limited region for the case where the diesel fuel cost is 0.5 $/L. Moreover, optimal results for scenarios S1 and S5 are obtained for HPS with DG/PV/ESS/GRID at DRs above 10% regardless of diesel fuel costs.

4. CONCLUSION

This study investigates the effects of different deferrable load grid extension distances and off-grid optimal system sizing for optimal rural electrification. Sensitivity analyses consider variations in solar radiation potential, diesel fuel costs, ESS costs, and discount rates. Optimum results are obtained for off-grid HPSs in scenarios with a deferrable load above 9%. On the other hand, in scenarios where the deferrable load was below 5%, the GE increased to 24.2 km. With the use of DG, RF decreased to 5.5%, and 33.8 tons/year of CO_2 emissions were realized. In the scenario with the highest deferrable load, NPC decreased by 2.91 M$, while in the scenario with no deferrable load, it increased by 22.6%. In scenarios with solar radiation below 4 kWh/m^2/day and ESS cost multipliers above 2, NPC exceeded energy costs in the only grid scenario. Moreover, in scenarios with low solar radiation and high ESS costs, CO_2 increases up to 70 tons/year. On the other hand, the optimal PV capacity is 10% higher in the non-deferrable load. Moreover, optimal results are obtained for DG/PV/ESS/GRID at discount rates above 10% regardless of diesel fuel costs. This study is expected to help researchers find optimal solutions for stand-alone rural electrification supporting hybrid renewable energy and environmentally friendly options.

CONFLICT OF INTERESTS

None.

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REFERENCES

Antonanzas-Torres, F., Antonanzas, J. & Blanco-Fernandez, J. (2021). 'State-of-the-Art of Mini Grids for Rural Electrification in West Africa'. Energies, 14(4). https://doi.org/10.3390/en14040990.

Baldwin, E., Jennifer, N. Brass, C. S., & Lauren, M. M. (2015). 'Electrification and Rural Development : Issues of Scale in Distributed Generation'. WIRES Energy and Environment 4(2). https://doi.org/10.1002/wene.129.

Bhattacharyya, S. C. (2013). 'Rural Electrification Experience from South-East Asia and South America'. https://doi.org/10.1007/978-1-4471-4673-5_7.

Demirci, A., Ozturk, Z., & Tercan, S. M. (2023). 'Decision-Making Between Hybrid Renewable Energy Configurations and Grid Extension in Rural Areas for Different Climate Zones'. Energy 262 (August 2022) : 125402. https://doi.org/10.1016/j.energy.2022.125402.

Dhabi, A. (2020). Renewable Power Generation Cost.

El-Kharouf, A., Soyhan, H. S., Al Qubeissi, M. (2020). Renewable Energy - Resources, Challenges and Applications. Eds. Intechopen.

Goel, S., & Sharma, R. (2017). 'Performance Evaluation of Stand Alone, Grid Connected and Hybrid Renewable Energy Systems for Rural Application : A Comparative Review'. Renewable and Sustainable Energy Reviews, 78. https://doi.org/10.1016/j.rser.2017.05.200.

Indragandhi, V., Subramaniyaswamy, V., & Logesh, R. (2017). 'Resources, Configurations, and Soft Computing Techniques for Power Management and

Control of PV/Wind Hybrid System'. Renewable and Sustainable Energy Reviews, 69, 129-43. https://doi.org/10.1016/j.rser.2016.11.209.

International Renewable Energy Agency (IRENA). (2021 October 24).

Kasaeian, A., Rahdan, P., Rad, M. A. V., & Wei-Mon Yan. (2019). 'Optimal Design and Technical Analysis of a Grid-Connected Hybrid Photovoltaic/Diesel/Biogas under Different Economic Conditions : A Case Study'. Energy Conversion and Management, 198. https://doi.org/10.1016/j.enconman.2019.111810.

Kemausuor, F., Sedzro, M. D., & Osei, I. (2018). 'Decentralised Energy Systems in Africa : Coordination and Integration of Off-Grid and Grid Power Systems-Review of Planning Tools to Identify Renewable Energy Deployment Options for Rural Electrification in Africa'. Current Sustainable/Renewable Energy Reports 5(4), 214-23. https://doi.org/10.1007/s40518-018-0118-4.

Maisanam, A. K. S., Podder, B., Biswas, A., & Sharma, K. K. (2019). 'Site-Specific Tailoring of an Optimal Design of Renewable Energy System for Remote Water Supply Station in Silchar, India'. Sustainable Energy Technologies and Assessments, 36. https://doi.org/10.1016/j.seta.2019.100558.

Manju, S., & Sagar, N. (2017). 'Progressing towards the Development of Sustainable Energy : A Critical Review on the Current Status, Applications, Developmental Barriers and Prospects of Solar Photovoltaic Systems in India'. Renewable and Sustainable Energy Reviews, 70, 298-313. https://doi.org/10.1016/j.rser.2016.11.226.

Marefati, M., Mehdi, M., and Mousavi, S. A. (2019). 'Introducing an Integrated SOFC, Linear Fresnel Solar Field, Stirling Engine and Steam Turbine Combined Cooling, Heating and Power Process'. International Journal of Hydrogen Energy 44(57) : 30256-79. https://doi.org/10.1016/j.ijhydene.2019.09.074.

Moner-Girona, M., Bodis, K., Morrissey, J., Kougias, I., Hankins, M., Huld, T. & Szabo, S. (2019). 'Decentralized Rural Electrification in Kenya : Speeding up Universal Energy Access'. Energy for Sustainable Development, 52. https://doi.org/10.1016/j.esd.2019.07.009.

Motjoadi, V., Bokoro, P. N., & Onibonoje, M. O. (2020). 'A Review of Microgrid-Based Approach to Rural Electrification in South Africa : Architecture and Policy Framework'. Energies, 13(9). https://doi.org/10.3390/en13092193.

Mousavi, S. A., Zarchi, R. A., Astaraei, F. R., Ghasempour, R., & Khaninezhad, F. M. (2021). 'Decision-Making between Renewable Energy Configurations and Grid Extension to Simultaneously Supply Electrical Power and Fresh Water in Remote Villages for Five Different Climate Zones'. Journal of Cleaner Production, 279, 123617. https://doi.org/10.1016/j.jclepro.2020.123617.

Nandi, K. S., & Ghosh, H. R. (2010). 'Prospect of Wind-PV-Battery Hybrid Power System as an Alternative to Grid Extension in Bangladesh'. Energy, 35(7), 3040-47. https://doi.org/10.1016/j.energy.2010.03.044.

Oladigbolu, O. O., Ramli, M. A. M., & Al-Turki, Y. A. (2020). 'Feasibility Study and Comparative Analysis of Hybrid Renewable Power System for Off-Grid Rural Electrification in a Typical Remote Village Located in Nigeria'. IEEE Access 8. https://doi.org/10.1109/ACCESS.2020.3024676.

Ortega-Arriaga, P., Babacan, O., Nelson, J., & Gambhir, A. (2021). 'Grid Versus Off-Grid Electricity Access Options : A Review on the Economic and Environmental Impacts'. Renewable and Sustainable Energy Reviews, 143. https://doi.org/10.1016/j.rser.2021.110864.

Ozturk, Z., Demirci, A., Tosun, S., & Ozturk, A. (2021). 'Technic and Economic Effects of Changes in the Location of Industrial Facilities in Industrializing Regions on Power Systems'. In 2021 13th International Conference on Electrical and Electronics Engineering (ELECO), IEEE, 11-17. https://doi.org/10.23919/ELECO54474.2021.9677827.

Ozturk, Z., Tosun, S., & Ali Ozturk. (2021). 'Comparative Evaluation of Stand-Alone Hybrid Power System with Different Energy Storages'. Fresenius Environmental Bulletin, 30, 10908-24.

Ozturk, Z., and Demirci, A. (2023). 'Optimization of Renewable Energy Hybrid Power Systems Under Different Penetration and Grid Tariffs'. Journal of Polytechnic. https://doi.org/10.2339/politeknik.1246418.

Panda, A., Dauda, A. K., Chua, H., Tan, R. R., & Aviso, K. B. (2023). 'Recent Advances in the Integration of Renewable Energy Sources and Storage Facilities with Hybrid Power Systems'. Cleaner Engineering and Technology, 12. https://doi.org/10.1016/j.clet.2023.100598.

Robert, F. C., & Gopalan, S. (2018). 'Low Cost, Highly Reliable Rural Electrification through a Combination of Grid Extension and Local Renewable Energy Generation'. Sustainable Cities and Society, 42. https://doi.org/10.1016/j.scs.2018.02.010.

Stritzke, S., & Jain, P. (2021). 'The Sustainability of Decentralised Renewable Energy Projects in Developing Countries : Learning Lessons from Zambia'. Energies, 14(13). https://doi.org/10.3390/en14133757.

Terkes, M., Ozturk, Z., Demirci, A., & Tercan, S. M. (2023). 'Optimal Sizing and Feasibility Analysis of Second-life Battery Energy Storage Systems for Community Microgrids Considering Carbon Reduction'. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.138507.

World Energy Outlook. (2020).

Zhu, Q., Li, X., Wu, J., & Sun, J. (2021). 'Analyzing the Sustainability of China's Industrial Sectors : A Data-Driven Approach with Total Energy Consumption Constraint'. Ecological Indicators, 122, 107235. https://doi.org/10.1016/j.ecolind.2020.107235.