Supporting Information for

Multi-Objective Optimization of an Island Microgrid

Roozbeh Ghasemi[1], Martin Wosnik[2,3,4,*], Diane L. Foster[2,5], Weiwei Mo[1,*]

[1]Department of Civil and Environmental Engineering, University of New Hampshire, NH, 03824, USA

[2]Department of Mechanical Engineering, University of New Hampshire, NH, 03824, USA

[3]Center for Ocean Engineering, University of New Hampshire, NH, 03824, USA

[4]Atlantic Marine Energy Center, University of New Hampshire, NH, 03824, USA

[5]Marine School, University of New Hampshire, NH, 03824, USA

*Corresponding authors:

Martin Wosnik: martin.wosnik@unh.edu;

Weiwei Mo: Weiwei.mo@unh.edu

Section S1: Solar energy supply modeling

Solar generation has been calculated using [1,2] the global horizontal solar irradiation and temperature as the temporal input in each minute:

$$P_{pv,t} = S\beta n f_{pv}\left(\frac{D_t}{D_{STD}}\right)[1 + \alpha(T_t - T_{STD})](1 - f_d)^t$$

Where, $P_{pv,t}$ denotes the kW of solar PV electricity generation at time t, S denotes the solar panel area which equals 1.83 m^2, n is the number of panels installed in the system, $\frac{D_t}{D_{STD}}$ is the incident radiation at time t over the irradiation at standard condition and D_t involves more geometrical calculations that consider panels location, orientation, time of the year, etc. α denotes the temperature coefficient of power that equals -0.0048, $T_t - T_{STD}$ is the temperature difference at each time versus the standard test condition in the unit of degree of Celsius, and f_d denotes the degradation rate of the PV system in each time step (0.5% per year). Parameters used in the solar generation model can be found in the following table:

Table S1: Parameters used in the solar energy modeling

Parameter	Value	Unit
Slope	20	Degree
Azimuth	170	Degree
Latitude	43.01	Degree
Longitude	70.78	Degree
Time zone	-4	Hours
Albedo	0.1	-
Solar system losses	0.15	-
PV derating factor	0.95	-
Incident radiation at standard test condition	1	W/m2

Section S2: Wind energy supply modeling

During the 2019 summer season used as the study period, Shoals Marine Laboratory was using a Bergey Excel 7.5 kW turbine, which was operating at reduced capacity due to storm damage. A modified power curve for this turbine, see section (c) below, was used for calibration of the model.

The damaged 7.5 kW wind turbine was replaced by a Bergey Excel 10 wind turbine in 2021. In the model calculations with the SD model, this replacement wind turbine was used, see sections (a) and (b).

a) Power curve:

The Bergey Excel 10 turbine has a rated power of 8.9 kW at a wind speed of 11 m/s. Peak power of 12.6 kW happens at the wind speed of 16.5 m/s, according to the user manual.

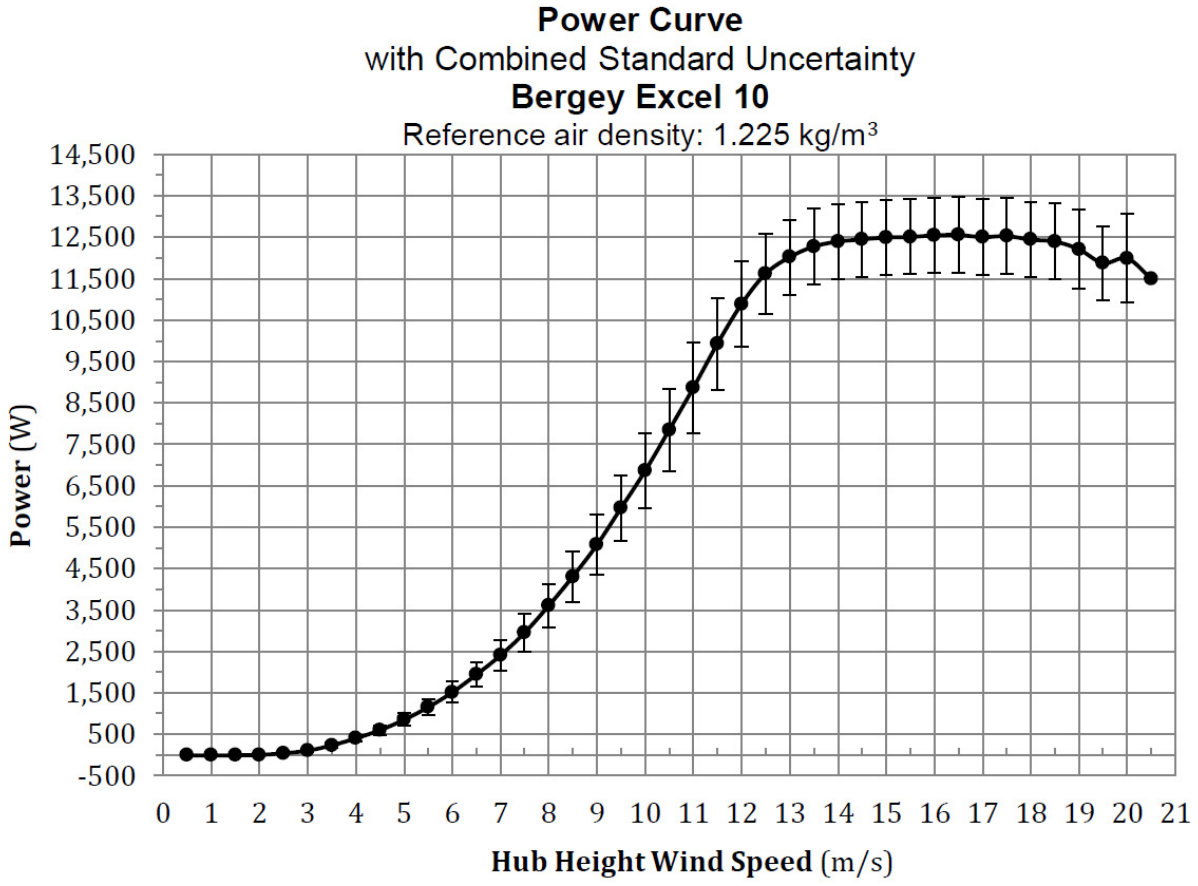


Figure S1: Bergey Excel 10 power curve, for replacement turbine installed at Shoals Marine Laboratory in 2021.

b) Tabulated power data:

In our simulation, we utilized the tabulated data along with an increased resolution of 0.1 m/s for hub-height wind speed. The power output was interpolated using exponential order 4 for wind speeds between 0.5-2.5 m/s, exponential order 10 for wind speeds between 2.5-13 m/s, exponential order 7 for wind speeds between 13.5-17.5 m/s, and a linear interpolation method was employed for wind speeds beyond 17.5 m/s.

Table S2: Excel 10 wind turbine tabulated power data.

Corrected to a sea level air density of 1.225 kg/m3					Category A	Category B	Combined
Bin No.	**Hub Height Wind Speed**	**Power Output**	**Cp**	**1-minute samples**	**Standard Uncertainty, Si**	**Standard Uncertainty, Ui**	**Standard Uncertainty, Ci**
	m/s	***Watts***			***Watts***	***Watts***	***Watts***
1	0.5	-12		158	0.1	0.9	0.9
2	1.0	-12		224	0.3	0.9	1.0
3	1.5	-11		309	0.9	2.9	3.0
4	2.0	0		391	2.1	10.9	11.1
5	2.5	39	0.11	375	2.1	10.9	11.1
6	3.0	102	0.16	661	3.0	20.2	20.4
7	3.5	229	0.23	818	3.4	43.8	43.9
8	4.0	399	0.26	1060	3.2	65.4	65.4
9	4.5	596	0.28	1213	3.0	84.5	84.6
10	5.0	848	0.29	1235	3.7	116.9	117.0
11	5.5	1,151	0.29	1279	4.7	152.6	152.6
12	6.0	1,510	0.30	1250	5.4	195.2	195.3
13	6.5	1,938	0.30	1401	6.0	248.5	248.6
14	7.0	2,403	0.30	1355	7.1	293.3	293.4
15	7.5	2,949	0.30	1014	9.9	362.8	362.9
16	8.0	3,602	0.30	885	12.7	452.4	452.6
17	8.5	4,306	0.30	687	16.8	523.1	523.3
18	9.0	5,071	0.30	736	18.0	604.1	604.4
19	9.5	5,960	0.29	668	19.7	725.9	726.1
20	10.0	6,856	0.29	707	21.4	790.8	791.0
21	10.5	7,849	0.29	650	26.2	912.1	912.5
22	11.0	8,863	0.28	599	28.0	994.0	994.4
23	11.5	9,928	0.28	635	24.3	1098.6	1098.9
24	12.0	10,885	0.27	606	24.8	1105.8	1106.1
25	12.5	11,619	0.25	504	21.7	1044.8	1045.0
26	13.0	12,019	0.23	432	15.0	968.6	968.7
27	13.5	12,276	0.21	337	13.3	906.1	906.2
28	14.0	12,395	0.19	333	7.4	906.0	906.1
29	14.5	12,449	0.17	292	7.2	904.5	904.6
30	15.0	12,495	0.16	279	3.3	907.5	907.5
31	15.5	12,508	0.14	231	10.3	907.4	907.4
32	16.0	12,546	0.13	187	5.4	911.0	911.0
33	16.5	12,555	0.12	165	8.5	910.7	910.8
34	17.0	12,503	0.11	125	24.4	908.8	909.1
35	17.5	12,528	0.10	138	17.8	909.2	909.4
36	18.0	12,442	0.09	98	36.2	908.2	908.9
37	18.5	12,396	0.08	94	36.8	901.0	901.7
38	19.0	12,208	0.08	57	65.2	916.2	918.5
39	19.5	11,878	0.07	39	83.4	960.0	963.6

40	20.0	11,989	0.06	18	130.0	882.0	891.5
41	20.5	11,495	0.06	15	124.6	1066.4	1073.7

c) Calibration using the old wind turbine:

Until July 2020, Appledore Island was powered by a Bergey Excel-R 7.5 kW wind turbine. In May 2019, the wind turbine was damaged during a storm, causing the wind generation to deviate from the power curve of the 7.5 kW turbine. To account for this, an adjusted power curve was interpolated using real data from the damaged turbine. This adjusted power curve was then utilized in the calibration process, as depicted in Figure 2 below. In the calibration process, we applied the adjusted power curve to the SD model and applied a wind energy conversion factor, from 10% to 99% in increments of 1%. The wind energy conversion factor that resulted in the lowest Mean Squared Error (MSE) was selected as the optimal value in our calibrated model.

The damaged 7.5 kW wind turbine was replaced by a 10 kW Bergey Excel wind turbine in 2021. In the model calculations with the SD model, the 10 kW replacement wind turbine was used.

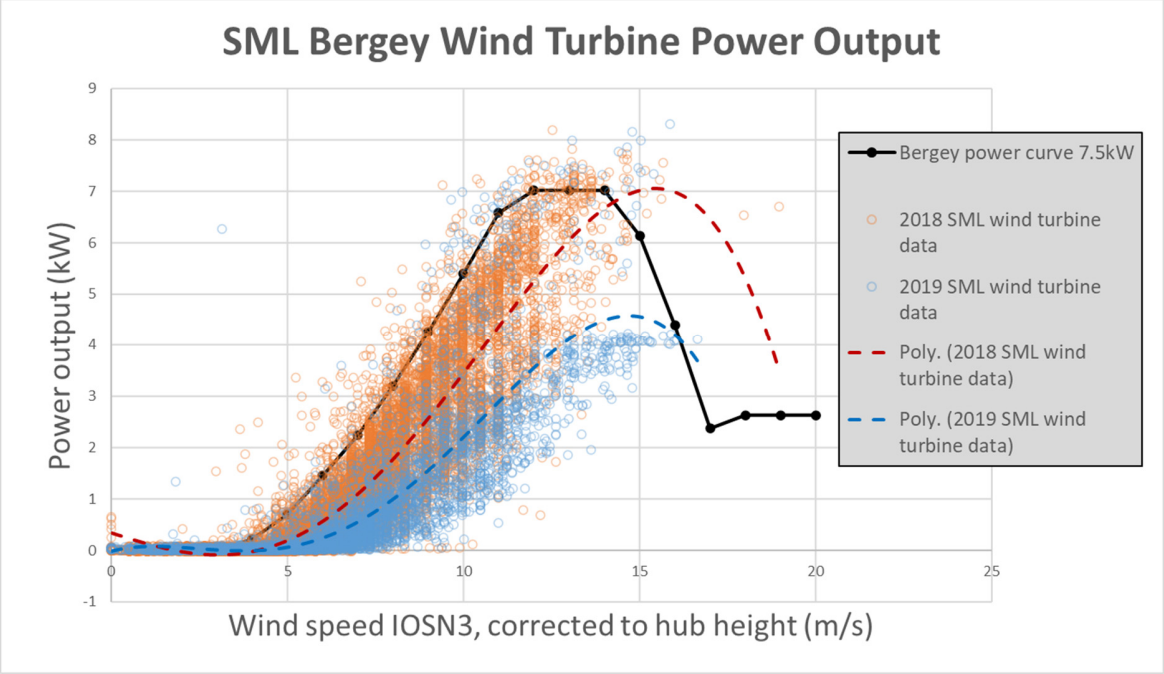


Figure S2: Adjusted 7.5kW wind turbine power curve.

Section S3: SimaPro data entries used for the GHG estimations

For the calculation of carbon emissions associated with each system component, SimaPro 9.4.0.1 was utilized. The IPCC 2021 GWP100 method was adopted to extract the output information related to carbon emissions.

Table S3: SimaPro Items used for environmental impacts.

System component	Item used	Input	Unit	Converted variable used	Unit
Battery storage	{Battery cell, Li-ion {GLO}| market for | APOS, S}.	1	kWh	92.5	kg of CO_{2eq}
Solar panel	{Photovoltaic panel, multi-Si wafer {GLO}| market for | APOS, S}	1.83	M^2	299	kg of CO_{2eq}
Diesel electricity generation*	{market for diesel, burned in diesel-electric generating set, 18.5kW GLO}	1	MJ*	0.0956	kg of CO_{2eq}

Diesel electricity generation carbon footprint has been calculated based on the 1 MJ embodied energy of generating electricity using following conversion factors:

Table S4: Conversion factors to calculate embodied energy.

Input	Conversion rate	Source
1 kWh of diesel electricity generation	0.0903 Gallons of diesel	[3]
1 Gallon of diesel	7.09 lb.	[4]
1 lb.	0.45 kg	
1 kg of diesel	42.8 MJ	SimaPro item description: {Diesel, burned in diesel-electric generating set, 18.5kW {GLO}| market for | Cut-off, U}
Embodied energy of 1 MJ diesel	1.35 MJ	SimaPro item: {Diesel, burned in diesel-electric generating set, 18.5kW {GLO}| market for | Cut-off, U} Method: Cumulative Energy Demand V1.11

Section S4: Equipment's detailed lists

Table S5: The detailed list of panels, wind turbine, diesel generators, and battery storage.

	Building/Site	*Rated Power*	*Unit Count*	*Install Year*	*Type*
Solar PV	Dorm 3	285	16	2007	Mobil Solar Energy GP-50-DG
	Dorm 2	195	15	2009	groSolar's Evergreen ES-A-195W
	ECB	240	36	2014	Canadian Solar CS6P-240
	Solar East Group 1	245	54	2014	Canadian Solar CS6P-245
	Solar East Group 2	245	18	2014	Canadian Solar CS6P-245
	Pole Barn	305	24	2015	Canadian Solar
	Tanks/Gym	305	14	2015	Canadian Solar
	Solar East Group 3	315	56	2016	Solar World SW315
Wind Turbine	-	12.5	1	2014	Burgey Excel 10
Battery	ECB	7.5	40	2014	GNB Absolyte IIP AGM. Model 6-90A15
Diesel Generator	ECB	27	2	2014	N/A

Section S5: Literature review

Table S6: The detailed list of papers used in the literature review section.

Authors	Year	Category	Title	Goal
Raya	2021	Review Paper	Energy management system optimization in islanded microgrids: an overview and future trends	-
Zheng Ma	2018	Review Paper	Solutions for Remote Island Microgrids: Discussion and analysis of Indonesia's remote island energy system	-
Mellouk et al	2015	Review Paper	Overview of mathematical methods for energy management optimization in smart grids	Reviews existing mathematical models used to optimize energy management in smart grid applications.
Ahmad Khan et al	2016	Review Paper	A compendium of optimization objectives, constraints, tools and algorithms for energy management in microgrids	Describes optimization objectives, constraints, and approaches to effectively manage microgrid energy.
Yimmy et al	2019	Review Paper	Energy Management in Microgrids with Renewable Energy Sources: A Literature Review	A literature review of energy management in microgrids, considering renewable sources. The paper also provides a comparison of optimization objectives, constraints, solutions, and simulations in isolated and interconnected microgrid systems. Ultimately describes centralized and decentralized approaches for energy management.
Alireza Askarzadeh	2017	Single objective optimization	A Memory-Based Genetic Algorithm for Optimization of Power Generation in a Microgrid	Proposes a memory-based genetic algorithm that optimally shares power generation tasks among distributed energy resources. MGA is aimed to improve the search capability of genetic algorithms by increasing intensification and amplifying local and global searches.
Iqbal and Siddiqui	2017	Single objective optimization	Optimal configuration analysis for a campus microgrid—a case study	To reduce the dependency on fossil fuels and conventional method of power generation. To make a zero-carbon nature through maximum utilization of renewable energy resources with the help of microgrid. Help government of India and other major stake holder in realizing

				faster adoption of microgrids for ecological and environmental benefits. To reduce the purchases of energy from the grid. To provide a reliable, sustainable, economical, innovative, and optimize power system in the form of microgrid for commercial and residential purposes.
Alramlawi and Li	2020	Single objective optimization	Design Optimization of a Residential PV-Battery Microgrid with a Detailed Battery Lifetime Estimation Model	to determine the optimal number of lead-acid batteries and PV panels, the optimal battery bank depth of discharge (DOD) value, and the optimal tilt angle of the PV panels.
Abdelfatah Ali	2022	Single objective optimization	Optimization of Photovoltaic and Wind Generation Systems for Autonomous Microgrids With PEV-Parking Lots	Find optimal wind and PV size and location in microgrids with PEV-parking lots. Addressing: 1)Stochasticity of generation profile for PV and Wind generation and loads 2) Microgrid constraints 3) DSTATCOM feature of wind and PV generation systems
Amrollahi and Bathaee	2017	Single objective optimization of stand alone microgrids	Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response	this paper seeks to examine and investigate the ability of demand response programming in the case of component size optimization of a micro-grid.
D. I. Papaioannou	2014	Single objective optimization of stand alone microgrids	Optimization & sensitivity analysis of microgrids using HOMER software- A case study	Studied two systems one grid connected the other autonomous; both are located at the pilot site of Meltemi, a seaside camping in Rafina near the Athens coast. The autonomous system under study consists of photovoltaic panels (PVs) combined with a battery stack and a wind generator (WG) combined also with a battery stack. The interconnected system consists of a number of Distributed Generators (DGs) that can partially support the Meltemi camping load in case of islanded Microgrid operation. The Interconnected system includes PVs, WG, batteries and a diesel generator.
Jiang et al	2013	Single objective optimization of stand alone microgrids	Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes	A novel double-layer coordinated control approach for microgrid energy management was proposed in this paper. The proposed approach emphasizes the difference of grid-connected mode and stand-alone mode, and has good convergence in either mode.
Elkadeem et al	2020	Single objective optimization of stand alone microgrids	A systematic decision-making approach for planning and assessment of hybrid renewable energy-based microgrid with techno-economic optimization: A case study on an urban community in Egypt	The study analyses and evalutes various performance investigators by a comparative study of various developed configurations of a microgrid system.
Chen et al	2013	Single objective optimization of stand alone microgrids	Economic analysis and optimal energy management models for microgrid systems: A case study in Taiwan	The purpose of this research is to perform economic analysis, formulate an optimization model, and determine optimal operating strategies for smart microgrid systems. Sensitivity analyses of investment in storage capacity and growth in electricity demand are conducted for the smart microgrid model.
Moradi et al	2018	Single objective optimization of stand alone microgrids	Optimization and energy management of a standalone hybrid microgrid in the presence of battery storage system	Improve energy utilization efficiency, decrease system fuel cost, gas emission reduction through planning energy generation of resources hourly for next day.
Garcia et al	2016	Single objective optimization of stand alone microgrids	Energy management system based on techno-economic optimization for microgrids	Presents a novel control strategy for energy management system using wind, PV, battery, and hydrogen system
Salazar et al	2020	Single objective optimization of stand alone microgrids	Energy Management of Islanded Nanogrids Through Nonlinear Optimization Using Stochastic Dynamic Programming	This work aims at developing and validating a new optimal energy management (EM) algorithm for an islanded NG. The goal of the proposed approach is to ensure the use of maximum available solar power and to achieve optimal battery state of charge. Energy balance approach!
Sayed Mohamed	2019	Single objective optimization of stand alone microgrids	An efficient planning algorithm for Hybrid Remote Microgrids	It presents an efficient planning algorithm for microgrids in remote isolated communities
Hannan, et al	2020	Single objective optimization of stand alone microgrids	Review of optimal methods and algorithms for sizing energy storage systems to achieve decarbonization in microgrid applications	This review paper discusses optimal energy system sizing methods, algorithms, and characteristics. This paper also describes the flaws in energy storage system/decarbonization scenarios applied to microgrids.
Maulik et al	2019	Single objective optimization of stand alone microgrids	Determination of Optimal Reserve Requirement for Fuel Cost Minimization of a Microgrid Under Load and Generation Uncertainties	Economic load dispatch is created by considering load and renewable generation uncertainties, both of which are modeled using triganular fuzzy numbers. Considers reserve requirements for stable operation and uncertainties simultaneously
Jansen and Karki	2017	Single objective optimization of stand alone microgrids	Sustainable Energy Optimization in a Smart Microgrid	determine the most financially economical combination of microgrid technologies with acceptable level of system reliability.
Elgammal et al	2018	Multi-objective optimization of microgrids	Energy management in smart grids for the integration of hybrid wind–PV–FC–battery renewable	Energy management system that can integrate with utility grid, proposed strategy choices courses and power that must be generated by each source and power required from utility network.

			energy resources using multi-objective particle swarm optimization (MOPSO)	
Yimy E, Garcia-Vera	2020	Multi-objective optimization of microgrids	Optimization of isolated hybrid microgrids with renewable energy based on different battery models and technologies	Estimate and optimize the battery lifespan for two types of batteries, lead-acid nad lithium.
Shezan et al	2022	Multi-objective optimization of microgrids	Assortment of Dispatch Strategies with the Optimization of an Islanded Hybrid Microgrid	proper sizing of each element and the steady-state voltage, frequency, and power responses of the microgrid in Kangaroo Island in South Australia.
Hijjo et al	2016	Multi-objective optimization of microgrids	Energy management for islanded buildings integrating renewables and diesel generators	Online energy management system of islanded hybrid pv-battery-diesel microgrid while maintaining efficient operation conditions. Case study: hospital complex in the Middle East
Anglani et al	2017	Multi-objective optimization of microgrids	Optimized Energy Management System to Reduce Fuel Consumption in Remote Military Microgrids	Presents optimized energy management system to control remote microgrid on a temporary military base by considering size of battery storage to minimize fuel consumption.
Zhao et al	2013	Multi-objective optimization of microgrids	Operation Optimization of Standalone Microgrids Considering Lifetime Characteristics of Battery Energy Storage System	This paper discusses the economic optimization problem of a standalone wind–solar–diesel–battery microgrid system in which lead–acid batteries are used. With the full consideration of the lifetime characteristics of lead–acid batteries, a multiobjective optimization problem of minimizing power generation cost and maximizing the useful life of lead–acid batteries has been formulated
Indragandhi et al	2018	Multi-objective optimization of microgrids	Multi-objective optimization and energy management in renewable based AC/DC microgrid	Optimize renewable energy sources and maintaining SOC in batteries to solve the problem of system price and service quality in microgrids and defining the lowest rate of AC/DC exchange.
Mohammad Faisal, et al	2018	Multi-objective optimization of microgrids considering environmental impacts	Review of Energy Storage System Technologies in Microgrid Applications: Issues and Challenges	
El-Bidairi et al	2018	Multi-objective optimization of microgrids considering environmental impacts	A hybrid energy management and battery size optimization for standalone microgrids: A case study for Flinders Island, Australia	1) Designing a multi-objective optimization technique for standalone microgrids which selects the optimal capacity of the storage devices with minimal operation cost; 2) Determining the optimal power generation scheduling for standalone microgrids that aiming to enhance the system performance in both the renewable energy penetration level and economic aspects. Furthermore, minimize the utilization of diesel generators and minimize the CO2 emission levels;
Wu et al	2018	Multi-objective optimization of microgrids considering environmental impacts	Study on distributed generators optimization system in island microgrid	A multi-sources coordinated operation optimization model was built to address the coordinated optimization problem of islanded microgrids to aid in remote power supply.
Kharrich et al	2018	Multi-objective optimization of microgrids considering environmental impacts	Microgrid Sizing with Environmental and Economic Optimization	A hybrid system was designed using MOPSO, two areas in Morocco were observed considering loss of power supply probability and fraction renewable availability
F. A. Mohamed & Koivo	2010	Multi-objective optimization of microgrids considering environmental impacts		optimal operating strategy and cost optimization scheme as well as reducing the emissions of a microgrid (MG).
Negapurkar and Smith	2019	Multi-objective optimization of microgrids considering LCA	Techno-economic optimization and environmental Life Cycle Assessment (LCA) of microgrids located in the US using genetic algorithm	A methodology was developed that assessed the technical, economic and environmental performance of a small scale microgrid composed of seven components, including: PV, WT, LB, BDG, FC, EM and H2 tanks. This novel methodology has been applied to analyze microgrid design in three US cities namely Tucson, Arizona, Lubbock Texas, and Dickenson, North Dakota.

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