energies

MDPI

Article

Multi-Objective Analysis of a CHP Plant Integrated Microgrid in Pakistan

Asad Waqar *, Muhammad Shahbaz Tanveer, Jehanzeb Ahmad, Muhammad Aamir, Muneeb Yaqoob and Fareeha Anwar

Department of Electrical Engineering, Bahria University, 44000 Islamabad, Pakistan;
01-244151-057@student.bahria.edu.pk (M.S.T.); jehanzeb@bahria.edu.pk (J.A.);
muhammadaamir.buic@bahria.edu.pk (M.A.); muneebyaqoob@bahria.edu.pk (M.Y.);
01-244151-005@student.bahria.edu.pk (F.A.)
* Correspondence: asadwaqar.buic@bahria.edu.pk; Tel.: +92-312-517-3920

Received: 15 September 2017; Accepted: 13 October 2017; Published: 17 October 2017

Abstract: In developing countries like Pakistan, the capacity shortage (CS) of electricity is a critical problem. The frequent natural gas (NG) outages compel consumers to use electricity to fulfill the thermal loads, which ends up as an increase in electrical load. In this scenario, the authors have proposed the concept of a combined heat & power (CHP) plant to be a better option for supplying both electrical and thermal loads simultaneously. A CHP plant-based microgrid comprising a PV array, diesel generators and batteries (operating in grid-connected as well as islanded modes) has been simulated using the HOMER Pro software. Different configurations of distributed generators (DGs) with/without batteries have been evaluated considering multiple objectives. The multiple objectives include the minimization of the total net present cost (TNPC), cost of generated energy (COE) and the annual greenhouse gas (GHG) emissions, as well as the maximization of annual waste heat recovery (WHR) of thermal units and annual grid sales (GS). These objectives are subject to the constraints of power balance, battery operation within state of charge (SOC) limits, generator operation within capacity limits and zero capacity shortage. The simulations have been performed on six cities including Islamabad, Lahore, Karachi, Peshawar, Quetta and Gilgit. The simulation results have been analyzed to find the most optimal city for the CHP plant integrated microgrid.

Keywords: combined heat and power plant (CHP); microgrid; multi-objective analysis; waste heat recovery (WHR); HOMER Pro

1. Introduction

During the winter season in Pakistan, natural gas (NG) is used as a primary source to supply the thermal load in the form of heating [1]. However, due to frequent outages of NG during the winter season, consumers tend to switch to electricity to fulfil their heating needs [1]. As there is an average capacity shortage (CS) of around 27% in electricity, the supply of thermal load by electricity puts an extra burden on the grid [2]. In such a situation, a microgrid along with a combined heat and power (CHP) plant represents a sensible solution to utilize the wasted heat and improving the efficiency to 75–88% [3–8]. A conventional thermal generation system has an efficiency of 25–35%, whereas the rest of energy is wasted in the form of unhealthy pollutant emissions [3–5,7]. A CHP plant recovers the wasted heat by using a waste heat recovery (WHR) unit, and therefore helps in controlling the greenhouse gas (GHG) emissions [5,9,10]. A microgrid with a CHP plant ensures the supply of electrical and thermal loads at the same time. Microgrids can range from small units for a single home to larger units for an entire community [4–7,11]. Moreover, a microgrid with a CHP plant can operate both in grid-connected as well as islanded modes [3,7,8]. Currently, CHP plants have broadly grabbed the attention in various countries and pilot projects are being undertaken in Europe, the U.S. and Japan [8,12].

So far, various researchers have investigated the operation of a CHP plant from certain perspectives. Guo et al. [3] have conducted research on an isolated hybrid CHP system consisting of PV/wind/gas turbine generator with vanadium redox flow battery (VRB) for the Qingshan Hu Campus of Hangzhou Dianzi University in China. With the implementation of a CHP system, the efficiency of the gas turbine was significantly improved from 29.5% to 82%. Ebara-Ballard et al. [4] have reported the steady state electrical efficiency of a combined fuel cell/CHP plant operating on NG to be 31%. For this unit, a net increase in fuel consumption and CO_2 emissions was expected. However, 52% of the fuel energy was recollected in the form of heat, which has improved the energy efficiency up to 83%. Boljevic et al. [5,11] have analyzed the impact of CHP plant on thermal and electrical energy supply systems for small and medium sized enterprises. The authors have shown that the mentioned system has improved the overall efficiency of the system to around 77.6% and reduced the emissions to 57.8%. Ivanova et al. [6] have increased the efficiency of a CHP plant integrated with renewable energy sources up to 88%, by proposing a flexible operation algorithm. Bjelic et al. [12] have developed a microgrid with a CHP plant in HOMER to assess the lowest total net present costs (TNPC) under the variation of CO_2 reduction constraint. Ren et al. [13] have evaluated the economic as well as environmental effects of distributed energy resources (DER) on the power system by using a multi-objective linear programming (MILP) technique. An eco-campus in Japan was selected for case study while considering PV, fuel cell and gas turbine for the satisfaction of both electrical and thermal loads. Hossain et al. [14] have improved the efficiency of a diesel generator by utilizing the waste heat of a 4-stroke 4-cylinder water cooled direct injection Hino W04D internal combustion engine (usually known as diesel engine coupled with 50 kVA generator-set considering ammonia and HFC-134a), and finally compared their results with water. Hopulele et al. [15] have worked in the field of combined cool, heat and power (CCHP) plant using genetic algorithm and used HOMER as an optimization tool. The system has fulfilled 90% of electrical load and 75% of thermal load. Surdu et al. [16] have developed an optimization tool which focuses on CHP employment in a competitive energy market context. The authors have minimized the total operating cost by solving the long-term unit commitment involving a CHP plant. Colson et al. [7] have evaluated the benefits of a hybrid solid oxide fuel cell (SOFC) with CHP plant for energy sustainability and emissions control. The hybrid system fulfils the electricity as well as hot water needs for a residential community of 500 homes, more sustainably with less environmental emissions as compared to conventional power plants. Chernyaev et al. [17] have developed a load distribution optimization tool for a CHP plant. The tool optimizes the fuel consumption by using a CHP power plant. Dvorak et al. [18] have scheduled the operation of a CHP plant by using the decomposition methods based on the heat demand, fuel cost and electricity pricing. Sekgoele et al. [8] have carried out the assessment of land filled gas-based CHP plants in South Africa, both technically and economically. The authors have assumed that the stand-alone CHP plant will supply both heat and power to remote communities, while the grid-connected CHP plant will work only during the peak load periods. Chandan et al. [19] have modelled and optimized a CCHP plant to fulfil the cooling, heating and power needs of the University of California, Irvine (UCI) by using cogeneration and thermal storage capabilities. The authors have minimized the operating cost of the plant by forecasting the electrical and thermal loads. Ruieneanu et al. [9] have conducted the parallel operation of a CHP plant with wind farms and have reduced the CO_2 emissions, and therefore have reduced the operating cost of the system. Dai et al. [20] have proposed a new dispatch model for a CHP plant considering the heat transfer process. Boljevic [11,21] has developed a planning algorithm for optimal sizing of CHP plant connected to an urban distributed network with least costs under long term network planning policy. Pierre et al. [10] have technically and economically accessed a flexible CHP plant with carbon capturing and storage. Their work resulted in gaining higher profits by reducing CO_2 emissions. Scholz et al. [22] have evaluated a system consisting of a CHP plant and a conventional gas-fired boiler with a power to heat unit. The authors have evaluated the benefits of the flexibility of power to heat unit to gain the economic incentives during low electricity price hours.

Buoro et al. in [23] have evaluated a distributed energy supply system consisting of a CHP plant with PV and thermal storage by using mixed integer linear programming (MILP). Pareto fronts have been applied to the results to find the most optimized solution. Somma et al. in [24] have investigated a sustainable hybrid CHP-PV system to supply the both electrical and thermal loads. The results have shown that about 21–36% of the total annual costs were minimized with the optimized solution. Somma et al. [25] have developed a multi-objective optimization problem to reduce the energy costs and CO_2 emissions. The authors have considered various thermal energy storage systems to fulfill a time-varying load profile. The results have indicated that a reduction of 27% in costs and 26% in CO_2 emissions was achieved. Zhang et al. [26] have proposed a CHP plant integrated microgrid with energy storage to satisfy the electricity and heat demand. In order to minimize the computational burden, the authors have used a stochastic non-convex optimization which results in minimum operating cost. Ping et al. [27] have proposed a CHP plant dispatch model while considering thermal performance of pipe line and building's inertia. The model is executed by decoupling the electricity and heat supply and in this way the wind penetration is increased. The overall result is saving of operational costs of system. Zidan et al. [28] have proposed a multi-objective optimization problem to minimize the overall costs and CO^2 emissions simultaneously. A genetic algorithm (GA) was applied to find the optimal generation-mix among the CHP plants (with various properties), renewable sources and energy storages. Hussain et al. [29] have proposed a CCHP plant for building microgrids (BMGs) in grid-connected mode. A mixed integer linear programming (MILP) based optimization model to minimize the day to day operational cost has been developed. The cost has been reduced by the energy exchange with the external grid and heat exchange with the prosumer. Alarcon et al. [30] have performed a detailed review of the distributed energy resources integration in distribution networks. Various optimization techniques have been discussed to gain benefits like low operational costs, minimum CO2 emissions, reduction in network losses, enhancement in power quality etc. Moreover, the challenges of grid-integration like voltage regulation, frequency stability, adequacy, system reliability etc. have been investigated. Somma et al. [31] have developed a Pareto frontier based stochastic optimization technique for the daily scheduling of distributed energy resources to minimize the operating costs and CO2 emissions. A sensitivity analysis has been carried out to investigate the impact of high renewable penetration on the economic and environmental aspects. Maroufmashat et al. [32] have proposed a multi-objective optimization based on augmented epsilon constraint technique to minimize the operating costs and GHG emissions.

Most of the abovementioned research has been conducted to improve the efficiency of systems with a CHP plant with waste heat recovery (WHR). This WHR results in minimizing the operating costs. However, from microgrid perspective, there are other parameters like total net present costs (TNPC), cost of generated energy (COE), greenhouse gas (GHG) emissions, WHR and grid sales (GS), which also effect the efficiency of a CHP plant integrated microgrid. Therefore, in this paper the authors have analyzed a CHP plant integrated microgrid considering multiple objectives. The multiple objectives include the minimization of TNPC, COE, annual GHG emissions, and the maximization of the annual WHR and annual GS. Moreover, the CHP plant integrated microgrid has never been evaluated for Pakistan. This multi-objective optimization problem has been simulated for six cities of Pakistan including Islamabad, Lahore, Karachi, Peshawar, Quetta and Gilgit. Different configurations of distributed generators (DGs) like PV/diesel generators with/without batteries have been simulated in both grid-connected as well as isolated modes, to find the optimal configuration. The final optimal solution concludes the most optimum city. These cities are considered for evaluation because these are the most populous cities and provincial capitals [33].

The rest of the paper is organized as follows: Section 2 presents an existing urban community load profile (electrical and thermal), solar energy resource (average monthly solar irradiance) for above mentioned six cities, and temperature resource for same cities. Section 3 shows the microgrid modeling in the form of different DG configurations with/without batteries. Section 4 shows the analysis of results considering multiple objectives. Section 5 concludes the paper.

2. Data Collection

2.1. Load Profile

An urban community identical load profile (electrical and thermal) has been assumed for all the above-mentioned cities. In case of a non-thermal system (without WHR), the scaled annual electrical energy utilization is 13,331.07 kWh/d, peak electric load is 1427.06 kW and an average load is 555.46 kW, as shown in Figure 1. In case of a thermal system (with WHR), the scaled annual electrical energy utilization is 10,911.02 kWh/d, peak electric load is 1073.99 kW and the average load is 454.63 kW, as shown in Figure 2. An equivalent scaled annual thermal energy utilization is 2419.8 kWh/d, peak thermal load is 407.45 kW and an average load is 100.83 kW, as shown in Figure 3.

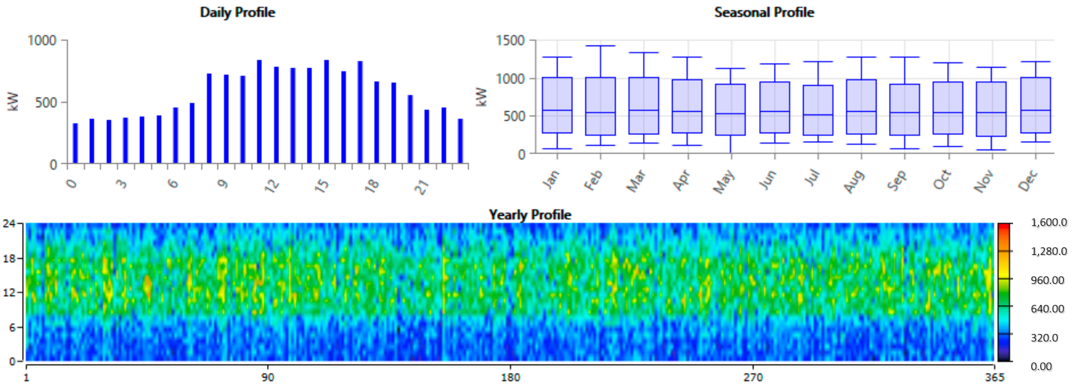


Figure 1. Electrical load in a without thermal system.

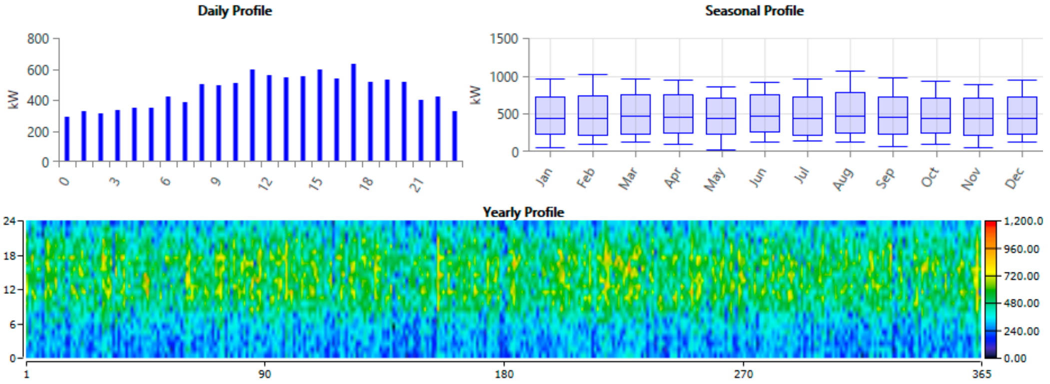


Figure 2. Electrical load in a CHP plant integrated microgrid.

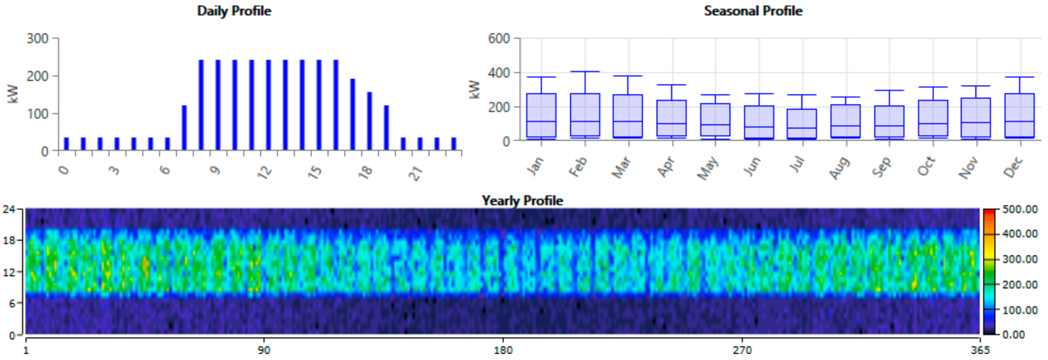


Figure 3. Thermal load in a CHP plant integrated microgrid.

2.2. Solar Energy Resource

The 22-years (from July 1983 to June 2005) average monthly solar irradiance profiles of the Islamabad, Lahore, Karachi, Peshawar, Quetta and Gilgit located at 33°43.8′ N, 73°5.6′ E; 31°33.3′ N, 74°21.4′ E; 24°51.7′ N, 67°0.6′ E, 34°0.9′ N, 71°34.8′ E, 30°11.0′ N, 66°59.9′ E and 35°55.2′ N, 74°18.5′ E respectively, are taken from NASA (National Aeronautics and Space Administration) database [34]. According to the NASA database, as shown in Figure 4, the average monthly solar irradiance in Karachi is greater than other cities during the winter months (January to April, October to December), whereas Peshawar has its peak during the peak summer months of June and July. Quetta has high irradiance in the months of August and September, Lahore has a high irradiance in the month of May.

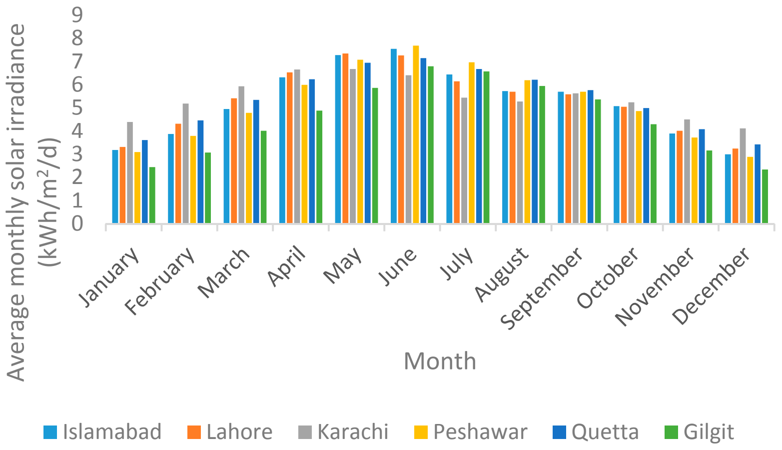


Figure 4. Average monthly solar irradiance data of Islamabad, Lahore, Karachi, Peshawar, Quetta and Gilgit.

2.3. Temperature Resource

The same NASA database is utilized for the 22-year (July 1983–June 2005) average monthly temperature of earth′ surface for the above-mentioned cities, as shown in Figure 5. Karachi has greater average temperature for eight months (January–April, September-December), while Lahore has its peak for four months (May–August). On the other hand, Gilgit has the lowest peak during the entire year.

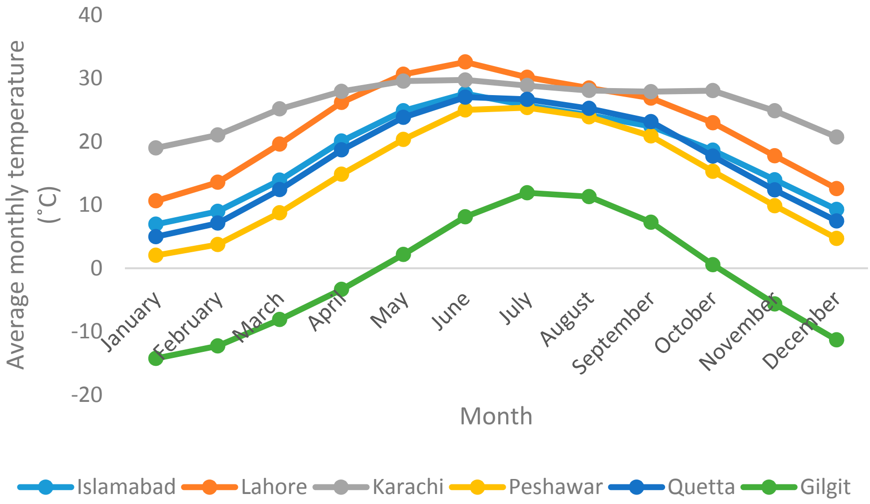


Figure 5. Average monthly earth's surface temperature of Islamabad, Lahore, Karachi, Peshawar, Quetta and Gilgit.

3. Microgrid Modelling

A microgrid introduces the concept of operating the generating sources close to the loads. The generating sources could be thermal or renewable sources, supported by energy storage. This model enhances the efficiency, reliability and cost-effectiveness of the system, which cannot be achieved with a single generating source [25]. In this paper, the microgrid model composes of DGs including PV/diesel generators with/without batteries in both grid-connected as well as isolated modes, with and without considering the effect of WHR. In the context of a grid-connected system, the grid connection is utilized to sale the excess electricity of the microgrid in case of capacity shortage.

In total seventeen different configurations have been analyzed. The conventional diesel generators only system, as shown in Figure 6, has been considered as a first configuration. Among the remaining sixteen configurations, eight are analyzed in isolated mode, as shown in Figure 7a–h and rest of the eight are analyzed in grid-connected mode, as shown in Figure 8a–h. In addition, among the remaining sixteen configurations, eight configurations have been simulated while considering the WHR effect, as shown in Figure 7c,d,g,h and Figure 8c,d,g,h. The PV is the only renewable energy resources used in study (because of the 2.9 million MW solar potential in Pakistan [35]), while batteries are used as the only storage device.

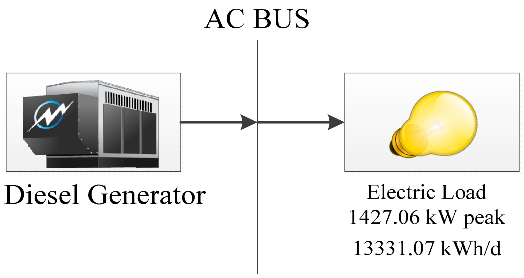
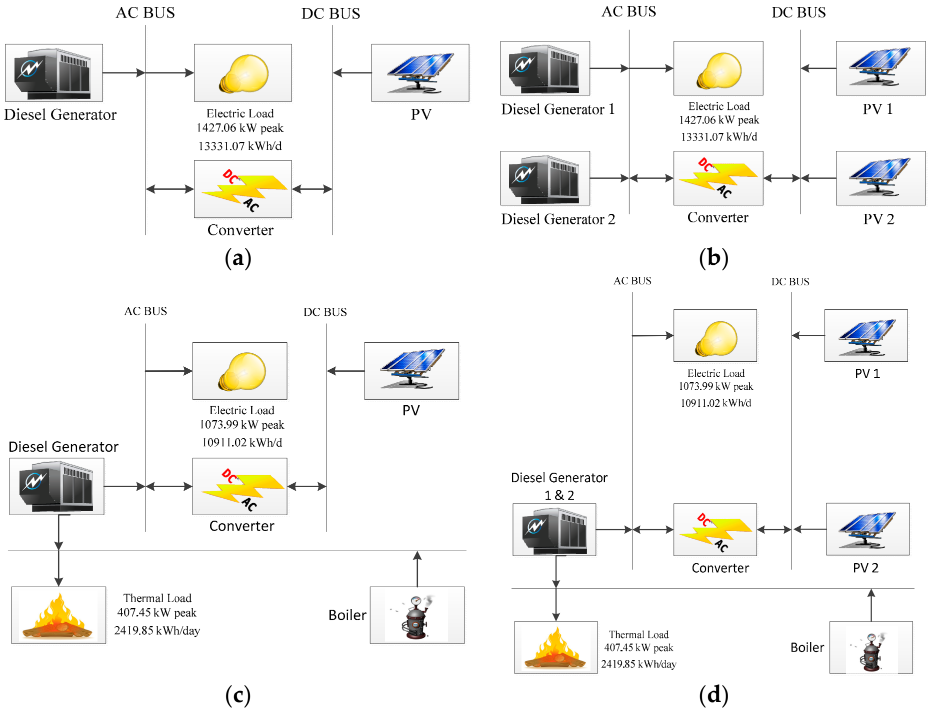


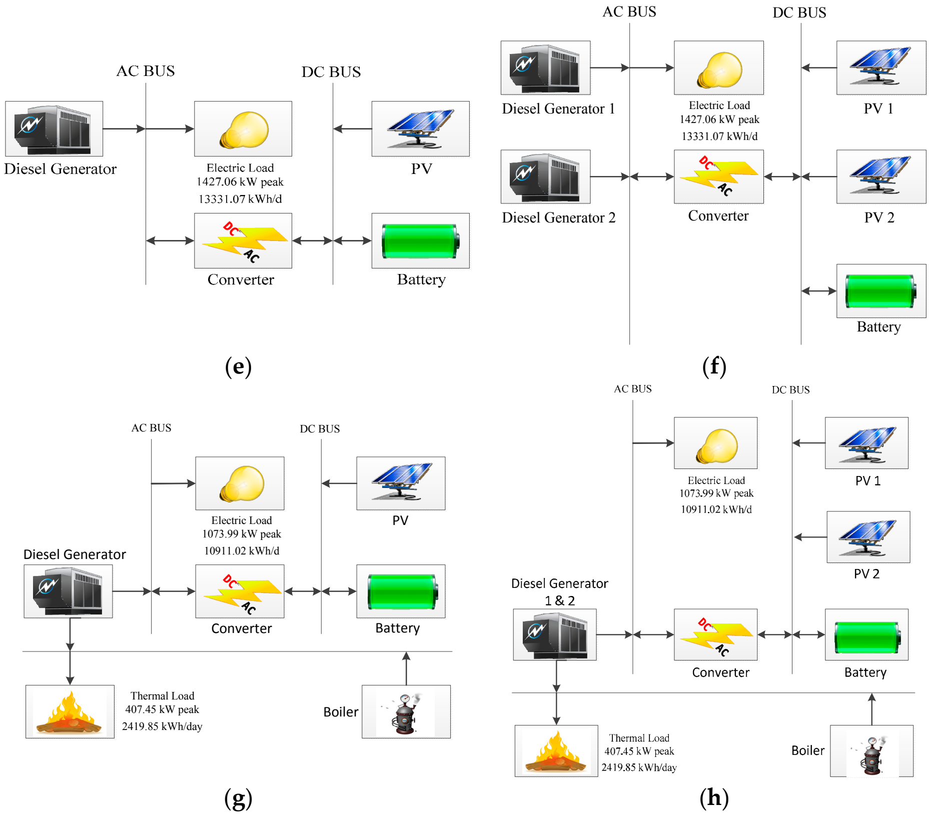
Figure 6. Conventional diesel generators only system.



(**a**) (**b**)

(**c**) (**d**)

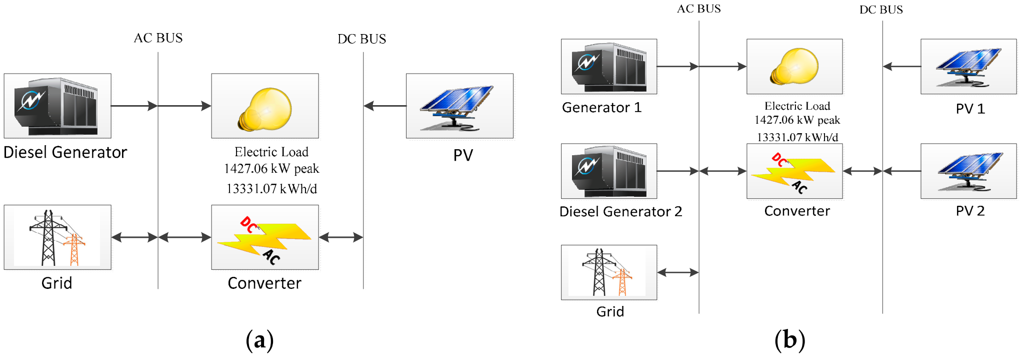
Figure 7. *Cont.*



(**e**) (**f**)

(**g**) (**h**)

Figure 7. (**a**) Isolated single generator (1Gen) and single PV (1PV) without WHR system (**b**) Isolated double generator (2Gen) and double PV (2PV) without WHR system (**c**) Isolated single generator (1Gen) and single PV (1PV) with WHR system (**d**) Isolated double generator (2Gen) and double PV (2PV) with WHR system (**e**) Isolated single generator (1Gen), single PV (1PV) and battery without WHR system (**f**) Isolated double generator (2Gen), double PV (2PV) and battery without WHR system (**g**) Isolated single generator (1Gen), single PV (1PV) and battery with WHR system (**h**) Isolated double generator (2Gen), double PV (2PV) and battery with WHR system.



(**a**) (**b**)

Figure 8. *Cont.*

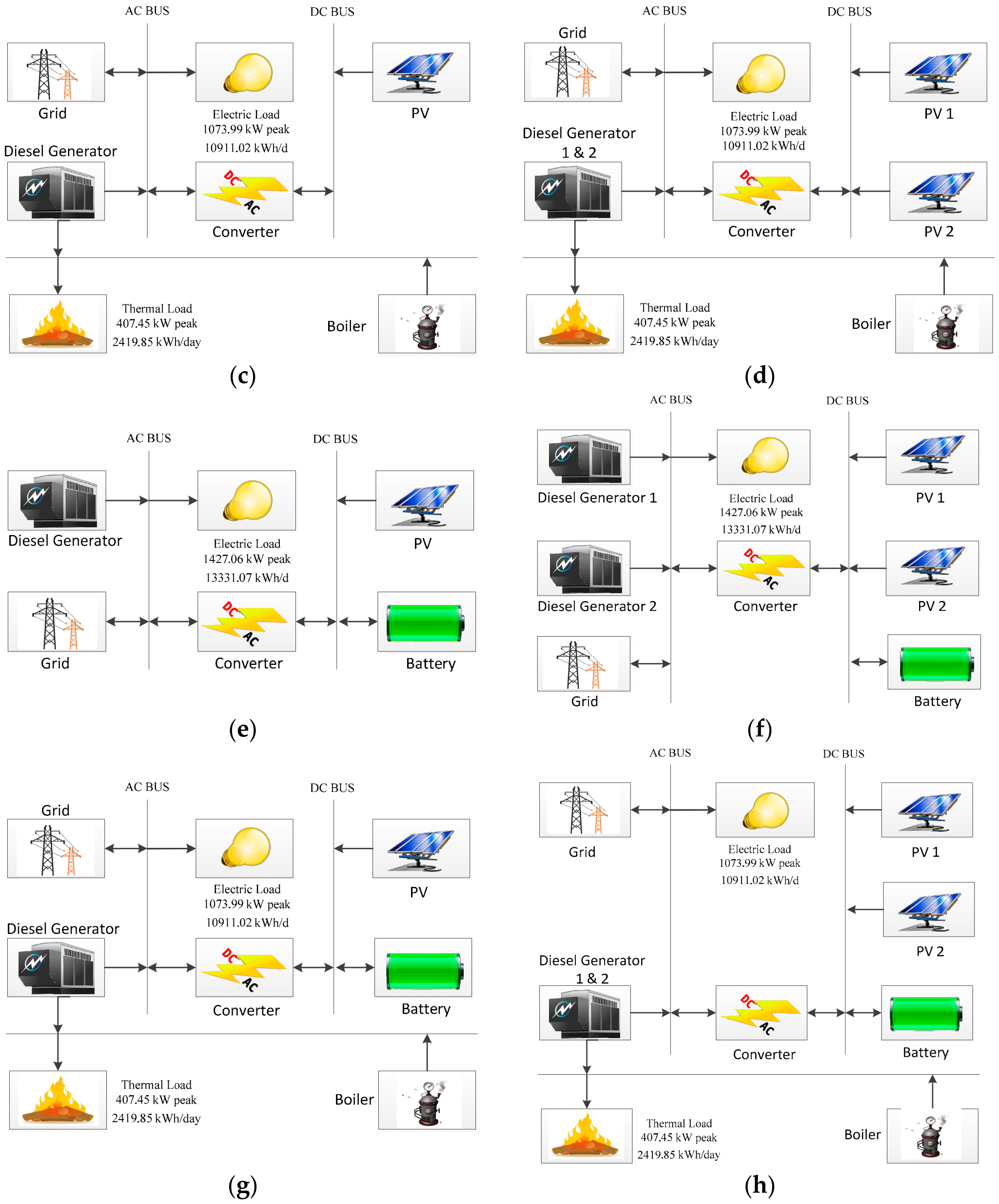


Figure 8. (**a**) Grid-connected single generator (1Gen) and single PV (1PV) without WHR system (**b**) Grid-connected double generator (2Gen) and double PV (2PV) without WHR system (**c**) Grid-connected single generator (1Gen) and single PV (1PV) with WHR system (**d**) Grid-connected double generator (2Gen) and double PV (2PV) with WHR system (**e**) Grid-connected single generator (1Gen), single PV (1PV) and battery without WHR system (**f**) Grid-connected double generator (2Gen), double PV (2PV) and battery without WHR system (**g**) Grid-connected single generator (1Gen), single PV (1PV) and battery with WHR system (**h**) Grid-connected double generator (2Gen), double PV (2PV) and battery with WHR system.

Tables 1 and 2 [36], highlight different costs and technical details of the DGs with/without batteries. These parameters are the input data to HOMER Pro software. The GHG emissions penalty and CS penalty has been set at $20/ton and $20/kWh respectively [36], whereas Pakistan's fuel price has been set at 0.75 $/L [37]. Table 3, highlights the sizes of the DGs with/without batteries taken under consideration.

Table 1. Costs.

Component	Capital Cost	Replacement Cost	O&M Cost	Life Time
PV module	3000 $/kW	2500 $/kW	10 $/year	20 years
Power converter	800 $/kW	600 $/kW	5 $/year	15 years
Battery	300 $/kWh	250 $/kWh	10 $/year	12,600 kWh
Diesel generator	400 $/kW	300 $/kW	0.25 $/h	15,000 h

Table 2. Technical details.

Technical Details	Value
Derating factor	80%
Ground reflection	20%
Converter efficiency	90%
Fuel cost	0.75 $/L
Annual nominal interest rate	8%
Project lifetime	25 years
Emissions penalty	20 $/ton
Capacity shortage penalty	20 $/kWh

Table 3. Sizes.

Component	Range
PV	0–4000 kW
Diesel Generator	0–2000 kW
Battery	0–200 string size
Converter	0–5000 kW

3.1. Multi-Objective Analysis Using HOMER Pro

HOMER is an optimization tool developed by the U.S. National Renewable Energy Laboratory (NREL). HOMER Pro is the latest version. HOMER models the physical behavior and the life-cycle cost of a power system [38,39]. In addition, HOMER allows the user to analyze different configurations of generating and storage units based on their technical and economic benefits. The user provides the resource data like average daily solar irradiance, load profile to be served, generating/storage units to be considered and their costs as input to the HOMER. The software then performs an hourly power balance calculation for each configuration for a year. After simulating all the possible configurations, the infeasible configurations are discarded and the feasible solutions are ranked according to the lowest total net present cost (TNPC).

HOMER uses an optimizer which is based on a derivative free optimization. The optimization algorithm uses a modified grid search algorithm. The user specifies different options (in the form of inputs) related to the generating/storage units in a searchable grid, while the algorithm searches for the optimal solution [40]. The HOMER initially takes input data in a table form, then it performs the simulations on the given data to find out all the possible configurations [40]. These configurations are then analyzed to shortlist the optimal configuration while considering the objectives. Figure 9 shows the flowchart for HOMER Pro.

3.2. Objective and Constraints

The optimal configuration for the CHP plant integrated microgrid is based on multiple objectives. The multiple objectives include the minimization of the, total net present cost (TNPC) of microgrid, cost of generated energy (COE) and the annual greenhouse gas (GHG) emissions, and the maximization of the, annual waste heat recovery (WHR) of thermal units and annual grid sales (GS). These multiple objectives are subject to the constraints of power balance with 25% of operating reserve, battery operation within state of charge (SOC) limits, generation capacity limit and zero capacity shortage.

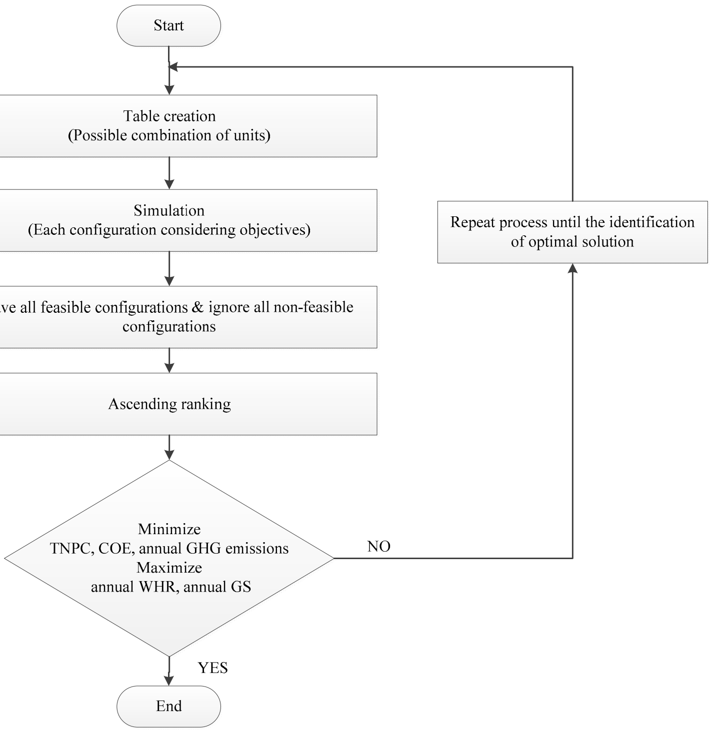


Figure 9. Homer Pro flow chart.

The TNPC of generating/storage unit is the present value of all the costs that it acquires during its lifespan minus the present value of all the revenues that it earns over its lifetime. Revenues include salvage value and grid sales [38]. The COE is calculated based on the total annualized cost and the total load supplied including the grid sales (GS). The GHG emissions include the pollutants like carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (HC), Sulphur dioxide (SO_2) and nitric oxides (NO_x). All emissions are calculated by multiplying the fuel quantity with the emission coefficients [38]. In case of a CHP plant, the generator's heat is recovered to supply the thermal load. Normally the generator's fuel curve is used to estimate the electricity production for a given fuel. It is assumed that the remaining fuel energy will be converted to heat. Waste heat recovery (WHR) is the energy that can be recovered to supply thermal load [38]. Excess of energy that can be sold to the grid is accounted as grid sales (GS). This energy is the difference between total annual load and total annual generation [38].

The power balance with 25% of operating reserve is an equality constraint which not only supplies the load demand, but also ensures 25% additional reserves. Battery operation within SOC limits is an inequality constraint which is maintained to achieve a prolonged battery life. Generator operation within capacity limits is also an inequality constraint to maintain fuel efficiency. Zero capacity shortage is a constraint to ensure the uninterrupted supply of load.

4. Results and Analysis

Tables 4 and 5 indicate the optimal configurations of DGs with/without batteries for each mentioned city individually. The configurations include sizes of diesel generators (kW), PV arrays (kW), batteries (kWh) and converters (kW). Some configurations involve single generator (1Gen) and single PV (1PV), however some configurations involve double generator (2Gen) and double (PV). Tables 6 and 7, show the values of the multiple objectives based on the optimal configurations for each city. Finally, a comparative analysis has been performed to identify best solution in terms of defined objectives. Table 8 shows the most optimal value of each individual objective from different optimal configurations.

Table 4. Optimal configurations for Islamabad, Lahore and Karachi.

City	Sr. No.	DGs' Configuration	DGen1 (kW)	DGen2 (kW)	PV1 (kW)	PV2 (kW)	Battery (kWh)	Converter (kW)
All Cities	CONVENTIONAL DIESEL ONLY SYSTEM							
	1	Diesel only system	1570	-	-	-	-	-
Islamabad	ISOLATED SYSTEM							
	1	1Gen + 1PV + Batt (without WHR)	750	-	1388	-	2112	1179
	2	2Gen + 2PV + Batt (without WHR)	300	550	50	891	816	720
	3	1Gen + 1PV + Batt (with WHR)	600	-	1065	-	1536	889
	4	2Gen + 2PV + Batt (with WHR)	300	500	62.5	910	480	696
	GRID-CONNECTED SYSTEM							
	5	Grid + 1Gen + 1PV (without WHR)	1050	-	2766	-	-	1733
	6	Grid + 2Gen + 2PV (without WHR)	50	1350	644	1405	-	1343
	7	Grid + 1Gen + 1PV (with WHR)	850	-	2366	-	-	1521
	8	Grid + 2Gen + 2PV (with WHR)	50	1000	1053	1269	-	1492
	9	Grid + 1Gen + 1PV + Batt (without WHR)	1050	-	2698	-	1704	1727
	10	Grid + 2Gen + 2PV + Batt (without WHR)	550	1550	1023	1308	240	1110
	11	Grid + 1Gen + 1PV + Batt (with WHR)	900	-	2238	-	1224	1393
	12	Grid + 2Gen + 2PV + Batt (with WHR)	550	500	436	1384	1536	1201
Lahore	ISOLATED SYSTEM							
	1	1Gen + 1PV + Batt (without WHR)	750	-	1502	-	2112	1184
	2	2Gen + 2PV + Batt (without WHR)	250	550	124	860	864	700
	3	1Gen + 1PV + Batt (with WHR)	600	-	1146	-	1560	914
	4	2Gen + 2PV + Batt (with WHR)	350	500	96.9	928	480	698
	GRID-CONNECTED SYSTEM							
	5	Grid + 1Gen + 1PV (without WHR)	1050	-	2889	-	-	1733
	6	Grid + 2Gen + 2PV (without WHR)	50	1300	729	1386	-	1307
	7	Grid + 1Gen + 1PV (with WHR)	850	-	2354	-	-	1468
	8	Grid + 2Gen + 2PV (with WHR)	50	1000	976	1484	-	1515
	9	Grid + 1Gen + 1PV + Batt (without WHR)	750	-	1839	-	2184	809
	10	Grid + 2Gen + 2PV + Batt (without WHR)	400	850	319	1451	2208	1098
	11	Grid + 1Gen + 1PV + Batt (with WHR)	800	-	2133	-	1416	1501
	12	Grid + 2Gen + 2PV + Batt (with WHR)	250	850	2306	265	1032	1444
Karachi	ISOLATED SYSTEM							
	1	1Gen + 1PV + Batt (without WHR)	700	-	1448	-	1896	1233
	2	2Gen + 2PV + Batt (without WHR)	300	550	50	1012	672	743
	3	1Gen + 1PV + Batt (with WHR)	550	-	1169	-	1608	870
	4	2Gen + 2PV + Batt (with WHR)	300	500	160	946	456	750
	GRID-CONNECTED SYSTEM							
	5	Grid + 1Gen + 1PV (without WHR)	1000	-	2930	-	-	1733
	6	Grid + 2Gen + 2PV (without WHR)	50	1250	1316	880	-	1368
	7	Grid + 1Gen + 1PV (with WHR)	800	-	2313	-	-	1425
	8	Grid + 2Gen + 2PV (with WHR)	100	900	919	1533	-	1483
	9	Grid + 1Gen + 1PV + Batt (without WHR)	750	-	1863	-	2352	724
	10	Grid + 2Gen + 2PV + Batt (without WHR)	450	1550	1327	1239	240	1177
	11	Grid + 1Gen + 1PV + Batt (with WHR)	850	-	2280	-	1080	1423
	12	Grid + 2Gen + 2PV + Batt (with WHR)	500	500	804	1198	1192	1154

Table 5. Optimal configurations for Peshawar, Quetta and Gilgit.

City	Sr. No.	DGs' Configuration	DGen1 (kW)	DGen2 (kW)	PV1 (kW)	PV2 (kW)	Battery (kWh)	Converter (kW)
Peshawar		ISOLATED SYSTEM						
	1	1Gen + 1PV + Batt (without WHR)	750	-	1332	-	2160	1187
	2	2Gen + 2PV + Batt (without WHR)	300	550	250	671	744	724
	3	1Gen + 1PV + Batt (with WHR)	650	-	1075	-	1776	932
	4	2Gen + 2PV + Batt (with WHR)	300	500	123	818	552	684
		GRID-CONNECTED SYSTEM						
	5	Grid + 1Gen + 1PV (without WHR)	1050	-	2704	-	-	1724
	6	Grid + 2Gen + 2PV (without WHR)	50	1250	908	1023	-	1322
	7	Grid + 1Gen + 1PV (with WHR)	850	-	2356	-	-	1530
	8	Grid + 2Gen + 2PV (with WHR)	50	1050	1140	1242	-	1532
	9	Grid + 1Gen + 1PV + Batt (without WHR)	1000	-	2746	-	2064	1762
	10	Grid + 2Gen + 2PV + Batt (without WHR)	350	1550	586	1730	240	1123
	11	Grid + 1Gen + 1PV + Batt (with WHR)	850	-	1899	-	1032	1197
	12	Grid + 2Gen + 2PV + Batt (with WHR)	400	500	548	1251	624	957
Quetta		ISOLATED SYSTEM						
	1	1Gen + 1PV + Batt (without WHR)	700	-	1356	-	1920	1087
	2	2Gen + 2PV + Batt (without WHR)	250	550	150	850	672	767
	3	1Gen + 1PV + Batt (with WHR)	600	-	1089	-	1632	941
	4	2Gen + 2PV + Batt (with WHR)	350	500	67.3	937	504	700
		GRID-CONNECTED SYSTEM						
	5	Grid + 1Gen + 1PV (without WHR)	1000	-	2827	-	-	1731
	6	Grid + 2Gen + 2PV (without WHR)	50	1250	571	1503	-	1280
	7	Grid + 1Gen + 1PV (with WHR)	800	-	2313	-	-	1468
	8	Grid + 2Gen + 2PV (with WHR)	50	950	936	1399	-	1463
	9	Grid + 1Gen + 1PV + Batt (without WHR)	950	-	2657	-	1224	1570
	10	Grid + 2Gen + 2PV + Batt (without WHR)	450	1550	688	1688	240	1148
	11	Grid + 1Gen + 1PV + Batt (with WHR)	850	-	2493	-	1032	1573
	12	Grid + 2Gen + 2PV + Batt (with WHR)	450	1500	1631	1979	240	1735
Gilgit		ISOLATED SYSTEM						
	1	1Gen + 1PV + Batt (without WHR)	750	-	1150	-	2160	1189
	2	2Gen + 2PV + Batt (without WHR)	400	550	106	749	672	731
	3	1Gen + 1PV + Batt (with WHR)	650	-	937	-	1704	937
	4	2Gen + 2PV + Batt (with WHR)	300	500	95.5	823	432	750
		GRID-CONNECTED SYSTEM						
	5	Grid + 1Gen + 1PV (without WHR)	1050	-	2386	-	-	1735
	6	Grid + 2Gen + 2PV (without WHR)	50	1350	680	1160	-	1457
	7	Grid + 1Gen + 1PV (with WHR)	850	-	2025	-	-	1510
	8	Grid + 2Gen + 2PV (with WHR)	50	1000	1431	709	-	1574
	9	Grid + 1Gen + 1PV + Batt (without WHR)	1050	-	2225	-	1464	1186
	10	Grid + 2Gen + 2PV + Batt (without WHR)	500	1650	1017	1053	240	1265
	11	Grid + 1Gen + 1PV + Batt (with WHR)	850	-	1867	-	1320	1372
	12	Grid + 2Gen + 2PV + Batt (with WHR)	600	650	1075	1038	1584	1105

Table 6. Multiple objectives for Islamabad, Lahore and Karachi.

City	Sr. No.	DGs' Configurations	TNPC (million$)	COE ($/kWh)	GHG Emissions (tons/year)	WHR (kWh/year)	Grid Sale (kWh/year)
All Cities		CONVENTIONAL DIESEL ONLY SYSTEM					
	1	Diesel only system	50.4	0.9700	3595.017	-	-
Islamabad		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.4	0.315	886.650	-	-
	2	2Gen + 2PV + Batt (Without WHR)	10.8	0.209	2694.932	-	-
	3	1Gen + 1PV + Batt (With WHR)	13.8	0.317	1014.785	904,483	-
	4	2Gen + 2PV + Batt (With WHR)	9.42	0.214	2112.380	1,056,847	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	19.4	0.164	2145.700	-	6,239,867
	6	Grid + 2Gen + 2PV (Without WHR)	7.25	0.056	6902.004	-	7,289,230
	7	Grid + 1Gen + 1PV (With WHR)	15.6	0.155	1905.514	976,228	5,245,573
	8	Grid + 2Gen + 2PV (With WHR)	6.29	0.055	5078.612	1,676,691	6,255,967
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.3	0.180	2010.973	-	5,677,536
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	8.95	0.070	6844.752	-	7,114,622
	11	Grid + 1Gen + 1PV + Batt (With WHR)	16.3	0.161	2068.991	987,366	5,259,435
	12	Grid + 2Gen + 2PV + Batt (With WHR)	8.77	0.097	3860.661	1,211,317	4,188,724
Lahore		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.6	0.321	875.618	-	-
	2	2Gen + 2PV + Batt (Without WHR)	11.0	0.211	2712.651	-	-
	3	1Gen + 1PV + Batt (With WHR)	13.9	0.319	1000.214	904,691	-
	4	2Gen + 2PV + Batt (With WHR)	9.62	0.2190	2102.363	1,056,003	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	20.0	0.169	2154.424	-	6,231,266
	6	Grid + 2Gen + 2PV (Without WHR)	7.56	0.059	6783.642	-	7,081,981
	7	Grid + 1Gen + 1PV (With WHR)	16.1	0.162	1935.756	976,475	5,140,511
	8	Grid + 2Gen + 2PV (With WHR)	6.70	0.058	5069.349	1,677,087	6,258,396
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.6	0.278	1608.812	-	2,079,787
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	9.16	0.089	5361.747	-	6,769,393
	11	Grid + 1Gen + 1PV + Batt (With WHR)	16.9	0.183	1860.616	961,111	4,310,902
	12	Grid + 2Gen + 2PV + Batt (With WHR)	8.89	0.083	4817.334	1,538,487	5,688,099
Karachi		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.9	0.325	925.864	-	-
	2	2Gen + 2PV + Batt (Without WHR)	11.1	0.214	2692.043	-	-
	3	1Gen + 1PV + Batt (With WHR)	14.2	0.325	1024.433	900,601	-
	4	2Gen + 2PV + Batt (With WHR)	9.81	0.223	2108.410	1,061,929	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	20.2	0.175	2115.538	-	5,941,478
	6	Grid + 2Gen + 2PV (Without WHR)	8.03	0.064	6708.314	-	6,969,520
	7	Grid + 1Gen + 1PV (With WHR)	16.4	0.173	1893.449	965,763	4,733,953
	8	Grid + 2Gen + 2PV (With WHR)	7.26	0.067	4838.588	1,591,449	5,736,755
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.9	0.278	1688.857	-	2,197,825
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	9.64	0.074	6944.456	-	7,296,741
	11	Grid + 1Gen + 1PV + Batt (With WHR)	17.0	0.176	1976.607	970,729	4,358,460
	12	Grid + 2Gen + 2PV + Batt (With WHR)	9.57	0.107	3840.075	1,210,031	4,071,456

Table 7. Multiple objectives for Peshawar, Quetta and Gilgit.

City	Sr. No.	DGs' Configurations	TNPC (million $)	COE ($/kWh)	GHG Emissions (tons/year)	WHR (kWh/year)	Grid Sale (kWh/year)
Peshawar		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.4	0.316	905.329	-	-
	2	2Gen + 2PV + Batt (Without WHR)	10.8	0.208	2689.675	-	-
	3	1Gen + 1PV + Batt (With WHR)	13.8	0.318	1005.361	910,638	-
	4	2Gen + 2PV + Batt (With WHR)	9.40	0.213	2116.130	1,056,336	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	19.2	0.162	2151.258	-	6,222,348
	6	Grid + 2Gen + 2PV (Without WHR)	7.15	0.057	6680.821	-	6,909,362
	7	Grid + 1Gen + 1PV (With WHR)	15.4	0.153	1901.308	976,348	5,260,739
	8	Grid + 2Gen + 2PV (With WHR)	6.20	0.052	5210.133	1,724,241	6,547,619
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.0	0.179	1979.710	-	5,564,821
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	8.67	0.068	6833.651	-	6,738,256
	11	Grid + 1Gen + 1PV + Batt (With WHR)	16.2	0.171	2008.673	968,185	4,119,405
	12	Grid + 2Gen + 2PV + Batt (With WHR)	8.41	0.099	3744.682	1,199,142	3,658,048
Quetta		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.4	0.317	924.143	-	-
	2	2Gen + 2PV + Batt (Without WHR)	10.9	0.209	2663.564	-	-
	3	1Gen + 1PV + Batt (With WHR)	13.9	0.319	1011.226	905,825	-
	4	2Gen + 2PV + Batt (With WHR)	9.54	0.217	2112.711	1,059,623	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	19.3	0.167	2064.567	-	5,966,449
	6	Grid + 2Gen + 2PV (Without WHR)	7.44	0.059	6693.132	-	9,879,361
	7	Grid + 1Gen + 1PV (With WHR)	15.7	0.163	1841.852	965,224	4,852,982
	8	Grid + 2Gen + 2PV (With WHR)	6.59	0.059	4939.342	1,634,352	5,962,893
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.0	0.182	1801.340	-	5,405,521
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	9.12	0.069	6917.252	-	7,241,042
	11	Grid + 1Gen + 1PV + Batt (With WHR)	16.6	0.174	2004.305	987,894	4,592,684
	12	Grid + 2Gen + 2PV + Batt (With WHR)	8.92	0.069	6041.482	2,040,282	8,322,268
Gilgit		ISOLATED SYSTEM					
	1	1Gen + 1PV + Batt (Without WHR)	16.3	0.314	959.355	-	-
	2	2Gen + 2PV + Batt (Without WHR)	10.7	0.207	2669.885	-	-
	3	1Gen + 1PV + Batt (With WHR)	13.7	0.315	1040.364	910,025	-
	4	2Gen + 2PV + Batt (With WHR)	9.28	0.211	2107.538	1,055,539	-
		GRID-CONNECTED SYSTEM					
	5	Grid + 1Gen + 1PV (Without WHR)	19.2	0.163	2214.816	-	6,178,188
	6	Grid + 2Gen + 2PV (Without WHR)	6.60	0.050	6922.720	-	7,330,439
	7	Grid + 1Gen + 1PV (With WHR)	15.2	0.152	1969.277	975,359	5,193,023
	8	Grid + 2Gen + 2PV (With WHR)	5.79	0.049	5116.636	1,673,369	6,337,434
	9	Grid + 1Gen + 1PV + Batt (Without WHR)	20.0	0.205	1936.572	-	4,230,165
	10	Grid + 2Gen + 2PV + Batt (Without WHR)	8.57	0.062	7096.481	-	7,514,326
	11	Grid + 1Gen + 1PV + Batt (With WHR)	15.9	0.168	1952.439	962,808	3,895,477
	12	Grid + 2Gen + 2PV + Batt (With WHR)	8.30	0.088	4349.394	1,329,160	4,719,079

Table 8. Most optimal values of each objective in different optimal configurations.

City	Sr. No.	Optimal Configuration	Objectives				
			TNPC (million$)	COE ($/kWh)	GHG Emissions (tons/year)	WHR (kWh/year)	Grid Sales (kWh/year)
Gilgit	**1**	Grid + 2Gen + 2PV (With WHR)	**5.79**	**0.049**	5116.636	1,673,369	6,337,434
Lahore	**2**	1Gen + 1PV + Batt (With WHR)	13.9	0.319	**1000.214**	904,691	-
Quetta	**3**	Grid + 2Gen + 2PV + Batt (With WHR)	8.92	0.069	6041.482	**2,040,282**	**8,322,268**

Table 8 indicates the optimal solutions considering the objectives. Table 8 further shows that all the objectives are not pertaining to a single city. Gilgit has the most optimum values for TNPC and COE. However, its other three objectives are not optimum. Lahore has the most optimum value for annual GHG emissions. Similarly, Quetta has the most optimum values for annual WHR and annual grid sales.

4.1. Graphical Representation

4.1.1. Total Net Present Cost

Figure 10 shows the comparative analysis of TNPC for different DG configurations for the six cities. Gilgit has the lowest TNPC among all DG configurations. In grid-connected mode, double diesel generator (2Gen) and double PV (2PV) with WHR system costs about 5.79 million$, which is the lowest TNPC.

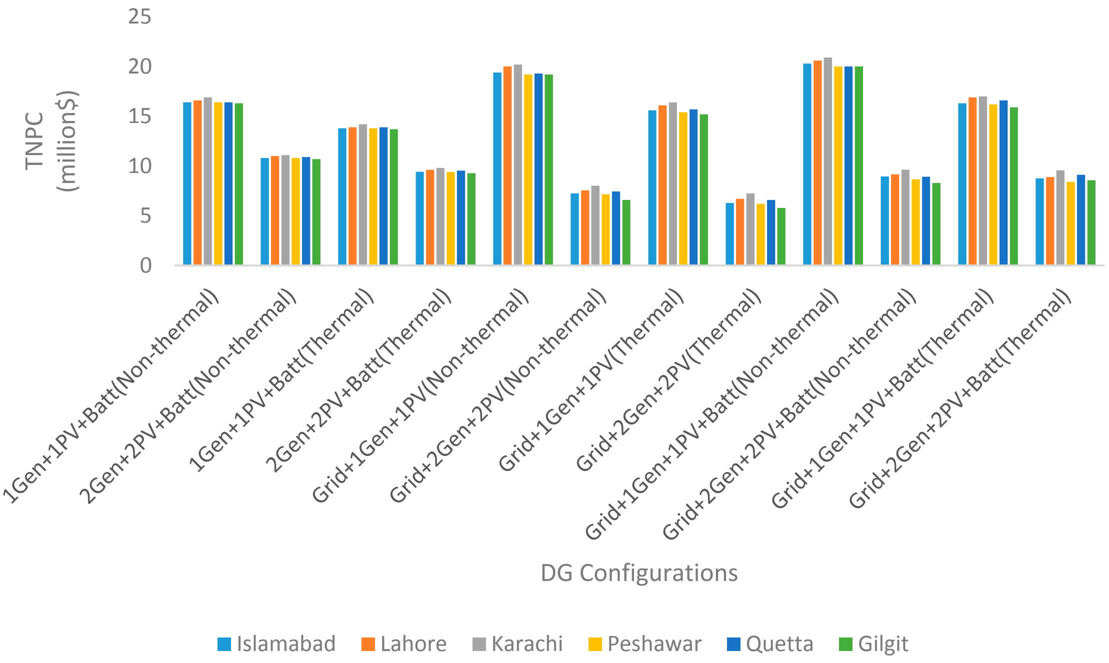


Figure 10. TNPC comparison.

4.1.2. Cost of Generated Energy

Figure 11 shows the comparative analysis of COE for different DG configurations for the six cities. Gilgit has the lowest COE among all DG configurations. In grid-connected mode, double diesel generator (2Gen) and double PV (2PV) with WHR system costs about 0.049 $/kWh.

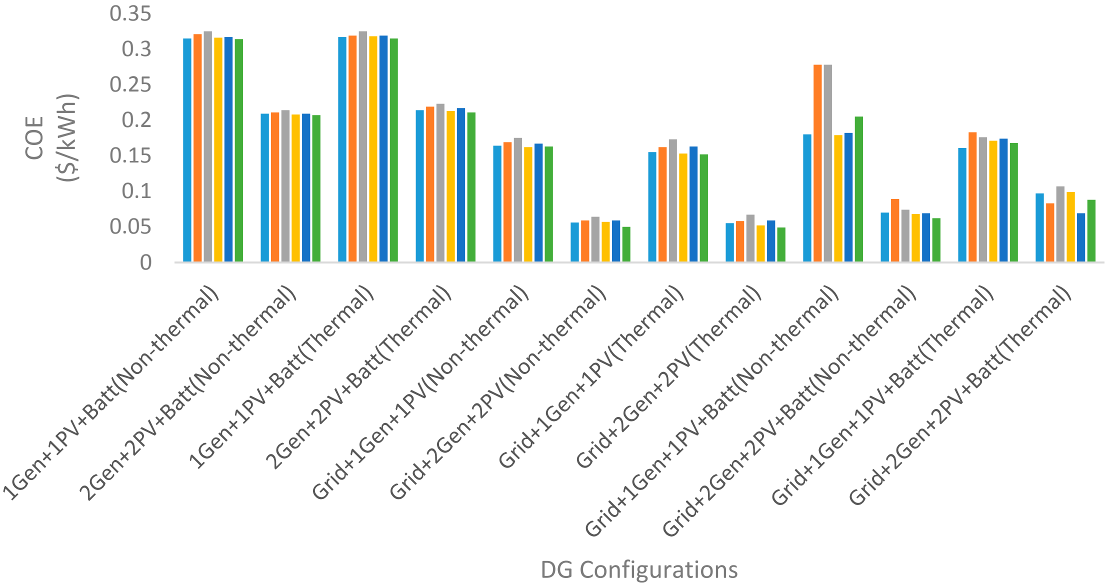


Figure 11. COE comparison.

4.1.3. Greenhouse Gas Emissions

Figure 12 shows the annual GHG emissions for different DG configurations for the six cities. The DG configurations without WHR have lower GHG emissions. However, these configurations are excluded due to zero WHR. Lahore has the lowest annual GHG emissions among all DG configurations. In isolated mode, single generator (1Gen), single PV (1PV) and battery with WHR has the lowest GHG emissions of about 1000.214 tons/year.

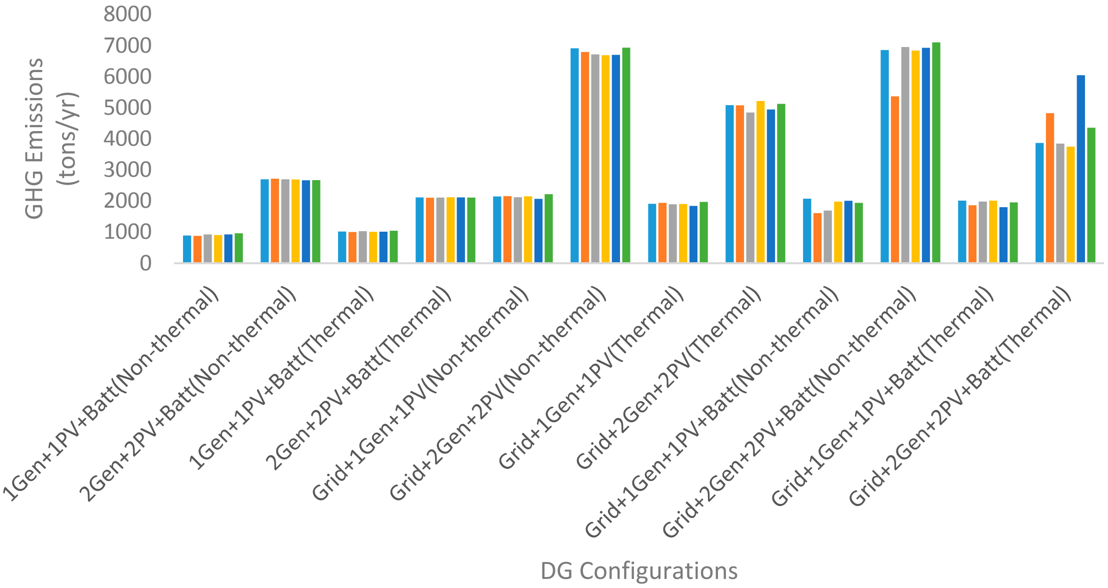


Figure 12. GHG emissions comparison.

4.1.4. Waste Hear Recovery

Figure 13 shows annual WHR for different DG configurations for the six cities. Configurations with WHR are only considered. Quetta has the highest annual WHR among all DG configurations.

In grid-connected mode, double diesel generator (2Gen), double PV (2PV) and battery has the highest annual WHR of about 2,040,282 kWh/year.

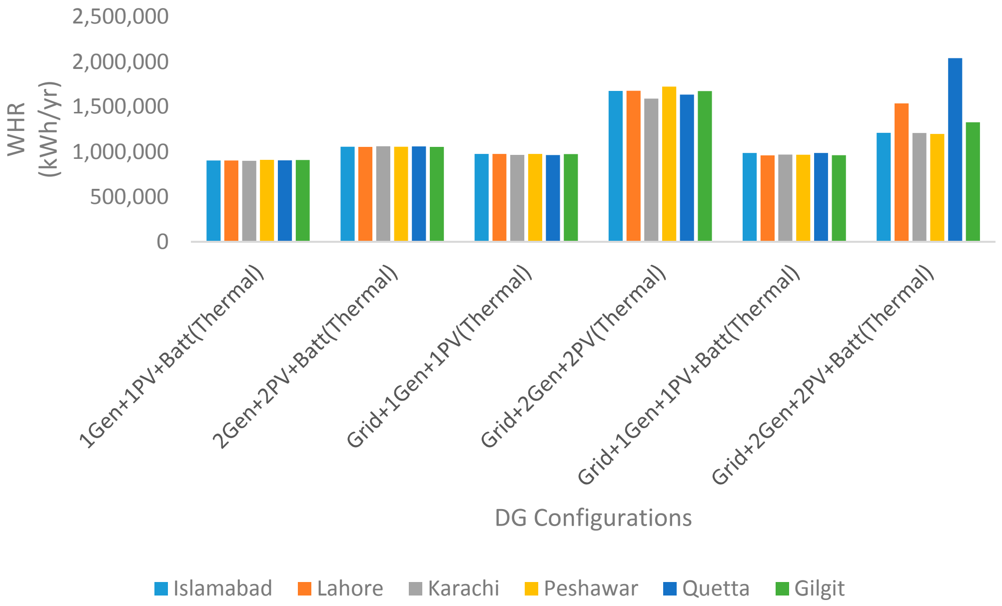


Figure 13. WHR comparison.

4.1.5. Grid Sales

Figure 14 shows the annual grid sales for different DG configurations for the six cities. Quetta has the highest annual grid sales among all DG configurations. In grid-connected mode, double diesel generator (2Gen) and double PV (2PV) and battery with WHR has the highest annual grid sales of about 8,322,268 kWh/year.

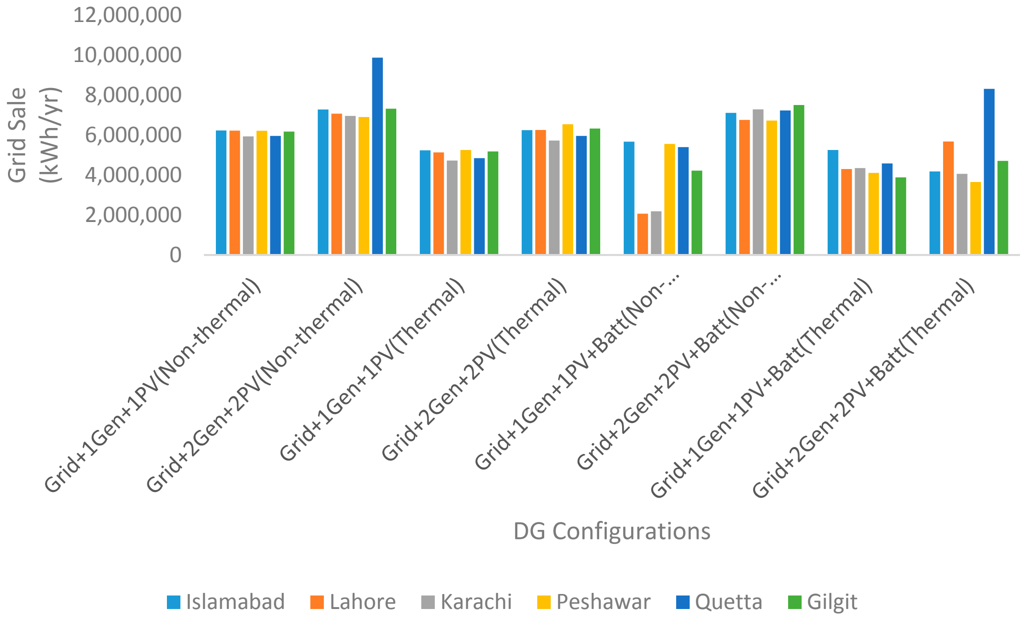


Figure 14. Grid sales comparison.

5. Conclusions

In this research authors have demonstrated the use of CHP plant when the consumers of NG start using electricity due to outage of natural gas. This supply of thermal load by the electricity was putting an extra burden on the electricity grid. The authors have proposed a solution in the form of a CHP plant integrated microgrid to supply both electrical and thermal loads simultaneously. In this aspect HOMER Pro software has been used to simulate a CHP plant integrated microgrid. Different configurations of the DGs with/without batteries were evaluated considering multiple objectives, including the minimization of TNPC, COE and annual GHG emissions as well as the maximization of annual WHR and annual GS. These multiple objectives were subject to the constraints of power balance, battery operation within state of charge limits, generator operation within capacity limits and zero capacity shortage. The multi-objective analysis shows that a single city does not meet all the objectives in a single configuration. However, Gilgit and Quetta are two cities which satisfy more than one objective in a single configuration.

Gilgit has the lowest TNPC, in both grid-connected and isolated modes. It is because the temperature profile of Gilgit is very contented for solar PV power generation. As the operating cost of renewable energy is very low, and this in return makes the TNPC low. The value of TNPC is lower in configurations where double generators (2Gen) and double PV (2PV) systems of different ratings are used as compared to configurations with single generators (1Gen) and single PV (1PV) systems. This is because a single generator may operate inefficiently during low loads. A single generator (1Gen) with WHR has lower TNPC than a single generator (1Gen) with no WHR. It is because, a single generator (1Gen) with WHR supplies both the electrical as well as with WHR loads. Same is true for double generators (2Gen) with WHR. Among all the cities Gilgit has the lowest TNPC, followed by Peshawar, Islamabad, Quetta, Lahore and Karachi respectively.

Gilgit also has the lowest COE. It is because the temperature profile of Gilgit is very contented for solar PV power generation. As the operating cost of renewable energy is very low, and this in return makes the COE low. Authors concluded that the value of COE is lower in grid-connected configurations as compared to isolated configurations. This is due to the fact that the excess electricity could be sold to the grid. Furthermore, the value of COE is lower in double generator (2Gen) configurations as compared to single generator (1Gen) configurations, as during light loads, a single generator (1Gen) may operate inefficiently.

Lahore has the lowest annual GHG emissions. This is because the DG configuration in isolated mode (1Gen) with single generator has the lowest annual GHG emissions. It is concluded that GHG emissions are higher in grid-connected configurations as compared to isolated configurations. The configurations without battery have low GHG emissions as compared the configurations with battery. This is because battery charging from the generators results in higher GHG emissions. The configurations without WHR have lower GHG emissions as compared to the configurations with WHR. It is concluded that a configuration with double generator (2Gen) have more GHG emissions than configurations with single generator (1Gen).

Quetta has the highest annual WHR. A double generator (2Gen), double PV (2PV) and battery with WHR, recover the maximum heat in grid-connected mode.

Quetta also has the highest annual grid sales. A double generator (2Gen), double PV (2PV) and battery with WHR, sales maximum electricity to the grid on yearly basis.

The decision for selection of final most optimal city for the CHP integrated microgrid is left to the state authorities and the planning commission. In future work the authors expect a more detailed analysis on the effect of WHR on TNPC by varying the heat recovery ratio. Moreover, a more detailed analysis is expected by changing the generator fuel to biomass or natural gas.

Author Contributions: All authors have contributed to this work. Asad Waqar proposed the research idea and contributed to writing the paper. Shahbaz Tanveer, Fareeha Anwar performed the simulations. Jehanzeb Ahmad, Muhammad Aamir and Muneeb Yaqoob contributed to the analysis of results. All authors have approved this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Diversifying Pakistan's Energy Needs. Available online: http://naturalgasglobal.com/2016/06/20/diversifying-pakistans-energy-needs-a-case-of-natural-gas-lng (accessed on 20 June 2016).
2. Dunya News. Available online: http://dunyanews.tv/en/Pakistan/285583-Electricity-shortfall-reaches-5500-MW-in-Pakistan (accessed on 18 December 2016).
3. Tengfei, G.; Qiuxuan, W. Optimal design and feasibility analysis of a stand-alone hybrid CHP system-based on PV/Wind/gas turbine generator/VRB for a university in Hangzhou city. In Proceedings of the 2016 Chinese Control and Decision Conference (CCDC), Yinchuan, China, 28–30 May 2016; Volume 28, pp. 6187–6191.
4. Adrain, B.D. Integration of Combined Heat and Power Generators into Small Buildings. Master's Thesis, University of Waterloo, Waterloo, ON, Canada, 2006.
5. Sreto, B.; Barry, N. Impact of combined heat and power plant on thermal and electrical energy supply for small and medium size enterprises. In Proceedings of the 42nd International Universities Power Engineering Conference, Brighton, UK, 4–6 September 2007; Volume 42, pp. 17–20.
6. Plina, I.; Antans, S.; Olegs, L.; Maris, B. Combined heat and power plants towards efficient and flexible operation. In Proceedings of the IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, 7–10 June 2016; Volume 16.
7. Colson, C.M.; Nehrir, M.H. Evaluating the Benefits of a hybrid solid oxide fuel cell combined heat and power plant for energy sustainability and emissions avoidance. *IEEE Trans. Energy Convers.* **2011**, *26*, 140–148. [CrossRef]
8. Alexey, C.; Vladimir, M.; Alexander, A. Combined heat and power plants load distribution optimization. In Proceedings of the 45th International Universities Power Engineering Conference UPEC2010, Wales, UK, 31 August–3 September 2010; Volume 45.
9. Michal, D.; Petr, H. Decomposition methods for operations scheduling problem in a combined heat and power plant. In Proceedings of the 10th International Conference on Environment and Electrical Engineering, Rome, Italy, 8–11 May 2011; Volume 10, pp. 1–4.
10. Sekgogele, K.; Chowdhury, S.; Chowdhury, S.P. Technical and economic assessment of landfill gas-based CHP plants in South Africa. In Proceedings of the 46th International Universities' Power Engineering Conference (UPEC), Soest, Germany, 5–8 September 2011; Volume 46, pp. 1–5.
11. Vikas, C.; Anh-Tuan, D.; Baoduo, J.; Faryar, J.; Jack, B.; Ioannis, A.; Amit, C.; Andrew, A. Modeling and optimization of a combined cooling, heating and power plant system. In Proceedings of the 2012 American Control Conference (ACC), Montreal, QC, Canada, 27–29 June 2012.
12. Ilija, B.B.; Rade, M.C. Optimal distributed generation planning at a local level—A review of Serbian renewable energy development. *Renew. Sustain. Energy Rev.* **2014**, *39*, 79–86.
13. Liviu, R.; Mihai, P.M. Parallel operation of combined heat and power plants and wind farms. In Proceedings of the 2012 International Conference on Applied and Theoretical Electricity (ICATE), Craiova, Romania, 25–27 October 2012; pp. 1–4.
14. Yuanhang, D.; Lei, C.; Yong, M.; Qun, C.; Kang, H.; Junhong, H.; Yiwei, Z.; Fei, X. Dispatch model of combined heat and power plant considering heat transfer process. *IEEE Tarns. Sustain. Energy* **2017**, *8*, 1225–1236.
15. Ren, H.; Weisheng, Z.; Ken'ichi, N.; Weijun, G.; Qiong, W. Multi-onjective optimization for the operation of distributed energy systems considering economic and environmental aspects. *Appl. Energy* **2010**, *87*, 3642–3651. [CrossRef]
16. Sreto, B. Planning algorithm for optimal combined heat & power generation plant connection in urban distribution network (UDN). In Proceedings of the 11th International Conference on the European Energy Market (EEM14), Krakow, Poland, 28–30 May 2014; Volume 11, pp. 1–7.
17. Shekh, N.H.; Saiful, B. Waste heat recovery from exhaust of a diesel generator set using organic fluids. In Proceedings of the 10th International Conference on Mechanical Engineering, Dhaka, Bangladesh, 20–22 December 2013; Volume 10, pp. 439–444.

18. Sreto, B. Combined heat & power plant connection into urban distribution network according to least cost technically acceptable principle. In Proceedings of the 50th International Universities Power Engineering Conference, Stoke on Trent, UK, 1–4 September 2015; Volume 50, pp. 1–6.
19. Saint-Pierre, A.; Pierluigi, M. Techno-economic assessment of flexible combined heat and power plant with carbon capture and storage. In Proceedings of the 2014 Power Systems Computation Conference, Wroclaw, Poland, 18–22 August 2014; pp. 1–7.
20. Constantin, S.; Nouredine, H.; Christophe, K.; Raphael, C. Combined heat and power plant optimization tool in a competitive energy market context. In Proceedings of the CIRED 2005—18th International Conference and Exhibition on Electricity Distribution, Turin, Italy, 6–9 June 2005; Volume 18.
21. Eugen, H.; Mihai, G. Optimization of a combined cool, heat and power plant based on genetic algorithms and specialized software. In Proceedings of the 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, Romania, 16–18 October 2014; Volume 8, pp. 1030–1033.
22. Daniel, S.; Felix, M. Increasing flexibility of combined heat and power plants with power-to-heat. In Proceedings of the 12th International Conference on the European Energy Market (EEM), Lisbon, Portugal, 19–22 May 2015; Volume 12, pp. 1–5.
23. Buoro, D.; Casisi, M.; Nardi, D.A.; Pinamonti, P.; Reini, M. Multicriteria optimization of a distributed energy supply system for an industrial area. *Energy* **2013**, *58*, 128–137. [CrossRef]
24. Somma, D.M.; Yan, B.; Bianco, N.; Graditi, G.; Luh, P.B.; Mongibello, L.; Naso, V. Multi-objective design optimization of distributed energy systems through cost and exergy assessments. *Appl. Energy* **2017**, *204*, 1299–1316. [CrossRef]
25. Marialaura, D.S.; Bing, Y.; Nicola, B.; Peter, B.L.; Giorgio, G.; Luigi, M.; Vincenzo, N. Multi-objective operation optimization of a distributed energy system for a large-scale utility customer. *Appl. Therm. Energy* **2016**, *101*, 752–761.
26. Zhang, G.; Cao, Y.; Cao, Y.; Li, D.; Wang, L. Optimal Energy Management for Microgrids with Combined Heat and Power (CHP) Generation Energy Storages and Renewable Energy Sources. *Energies* **2017**, *10*, 1288. [CrossRef]
27. Li, P.; Wang, H.; Lv, Q.; Li, W. Combined Heat and Power Dispatch Considering Heat Storage of Both Buildings and Pipelines in District Heating System for Wind Power Integration. *Energies* **2017**, *10*, 893. [CrossRef]
28. Zidan, A.; Gabbar, H. DG Mix and Energy Storage Units for Optimal Planning of Self-Sufficient Micro Energy Grids. *Energies* **2016**, *9*, 616. [CrossRef]
29. Hussain, A.; Bui, V.; Kim, H.; Im, Y.; Lee, J. Optimal Energy Management of Combined Cooling Heat and Power in Different Demand Type Buildings Considering Seasonal Demand Variations. *Energies* **2017**, *10*, 789. [CrossRef]
30. Alarcon-Rodriguez, A.; Ault, G.; Galloway, G. Multi-objective planning of distributed energy resources: A review of the state-of-the-art. *Renew. Sustain. Energy Rev.* **2010**, *14*, 1353–1566. [CrossRef]
31. Di Somma, M.; Graditi, G.; Heydarian-Forushani, E.; Shafie-khah, M.; Siano, P. Stochastic optimal scheduling of distributed energy resources with renewables considering economic and environmental aspects. *Renew. Energy* **2018**, *116*, 272–287. [CrossRef]
32. Maroufmashat, A.; Sattari, S.; Roshandel, R.; Fowler, M.; Elkamel, A. Multi-objective optimization for design and operation of distributed energy systems through the multi-energy hub network approach. *Ind. Eng. Chem. Res.* **2016**, *55*, 8950–8966. [CrossRef]
33. Pakistan Bureau of Statistics. Available online: http://www.pbscensus.gov.pk/content/area-population-aadministrative-units (accessed on 23 August 2017).
34. NASA Surface Meteorology and Solar Energy. Available online: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov (accessed on 2 January 2017).
35. Tribune. Available online: https://www.tribune.com.pk/story/1357453/going-green-pakistan-1-9mw-solar-energy-potential/ (accessed on 17 March 2017).
36. Fahd, D.; Hai, L.; Lijun, Z.; Salwa, A. An Environmentally-Friendly Tourist Village in Egypt Based on a Hybrid Renewable Energy System—-Part One: What Is the Optimum City? *Energies* **2015**, *8*, 6926–6944.
37. PAkBIZ. Available online: http://www.pakbiz.com/finance/petroleumprices/ (accessed on 3 January 2017).
38. Pavan, Y.V.; Ravikumar, B. Renewable energy based microgrid system sizing and energy management for green buildings. *J. Mod. Power Syst. Clean Energy* **2015**, *3*, 1–13. [CrossRef]

39. Tom, L.; Paul, G.; Peter, L. Micropower system modeling with HOMER. *Integr. Altern. Sour. Energy* **2006**, 379–418. [CrossRef]
40. Homer Microgrid NEWS and Insight. Available online: http://microgridnews.com/homer-optimizer-a-faster-path-to-finding-least-cost-microgrid-options/ (accessed on 23 August 2017).