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Article

An Environmentally-Friendly Tourist Village in Egypt Based on a Hybrid Renewable Energy System—Part One: What Is the Optimum City?

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Abstract: The main objective of this work is to select the optimum city from five touristic Egyptian cities (Luxor, Giza, Alexandria, Qena and Aswan) to establish an environmentally-friendly tourist village. The selection of the city, according to the economic cost (cost of energy (COE), net present cost (NPC)) and the amount of greenhouse gases (GHG) emitted, is carried out with respect to four cases, based on the effects of ambient temperature and applying GHG emission penalties. According to the simulation results, using the well-known Homer software, Alexandria is the economic city for hybrid photovoltaics (PV)/wind/diesel/battery and wind/diesel/battery systems, while Aswan is the most economic city for a hybrid PV/diesel/battery system. However, for a diesel/battery system there is no significant economic difference between the cities in the study. On the other hand, according to the amount of GHG emitted from a hybrid PV/wind/diesel/battery system, Qena is the optimum city if the effects of ambient temperature are considered. However, if the GHG emission penalties are applied, Aswan will be the optimum city. Furthermore, Alexandria is the optimum city if the effects of ambient temperature are considered and the GHG emission penalties are applied. Additionally, the effects of ambient temperature and applying GHG emission penalties are studied on hybrid PV/diesel/battery, wind/diesel/battery and diesel/battery systems in this study.

Keywords: an environmentally-friendly tourist village; the effects of ambient temperature; GHG emission penalties; cost of energy (COE); net present cost (NPC)

1. Introduction

Tourism is one of the most important sectors in Egypt's economy. At its peak, the sector employed about 12% of Egypt's workforce as well as contributing more than 11% of its gross domestic product (GDP) and 14.4% of foreign currency revenues [1–3]. Figure 1 shows the importance of tourism in Egypt during 2012 [4]. Tourism picked up from 1975 onwards. In 1976, tourism was heavily included in the Five Year Plans of the Government, where 12% of the budget was allocated to upgrading state-owned hotels, establishing a loan fund for private hotels and upgrading infrastructures (including road, rail and air connectivity) in major tourist centers in the coastal areas [1,5,6]. In 1979, tourism experts and specialists brought in from Turkey and several new colleges were established to teach diploma courses in hospitality and tourism management. The number of tourists in Egypt stood at 0.1 million in 1951, with a tremendous rise to 1.8 million in 1981 and then to 5.5 million in 2000. The maximum number of tourists to Egypt rose to 14.7 million in 2010 [1,5,6], as shown in Figure 2.

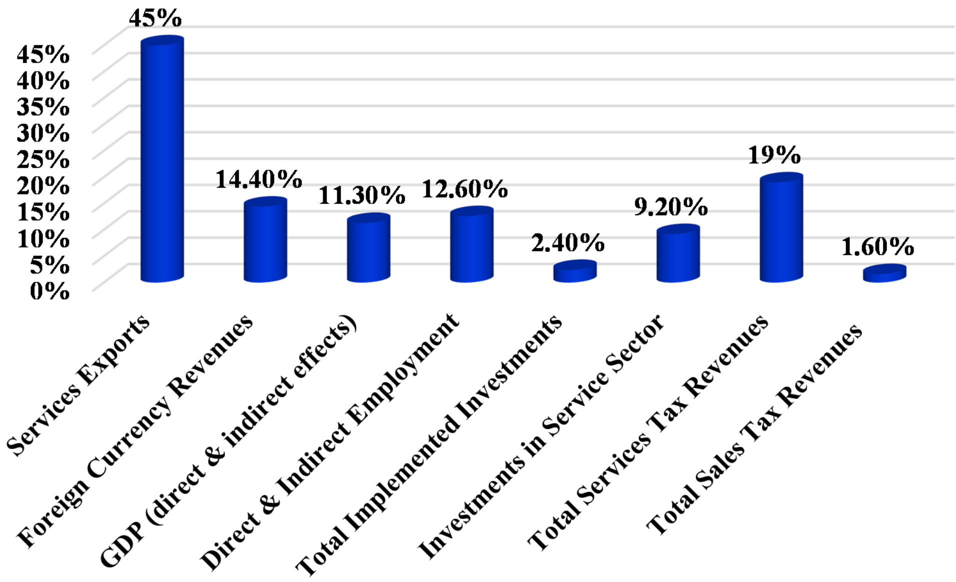


Figure 1. Tourism importance in Egypt during 2012.

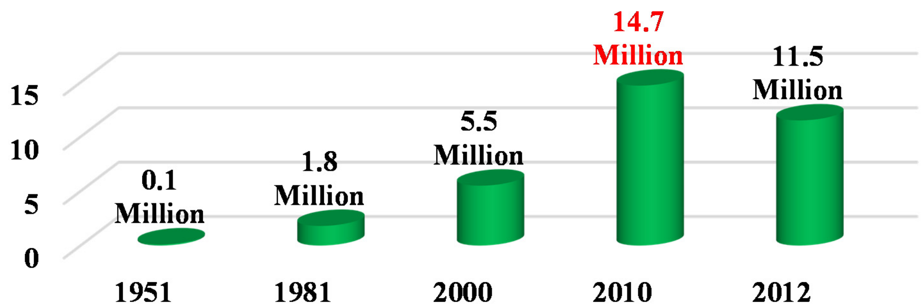


Figure 2. The distribution of number of tourists from 1951 until 2012.

There are many tourist cities in Egypt, five of which were selected for this study: Luxor, Giza, Alexandria, Qena and Aswan. The following are brief highlights of some of the tourist landmarks found in each of the selected cities, to explain why these cities were selected to be under the study.

The first city, Luxor, was the ancient city of Thebes, the great capital of Egypt during the New Kingdom, and the glorious city of the god Amon-Ra [7,8]. It also includes many of the old pharaonic monuments, which are divided between the city's eastern and western mainland's [7,8]. The eastern mainland comprises the Luxor Temple, the Karnak Temple, the Rams Road that links the two temples and the Luxor Museum, and the western mainland comprises the Valley of the Kings, Bahari Temple, Valley of the Queens, Deir El-Medina, and the Temple of the Ramesseum [7,8].

The second city is Giza, characterized by proliferation of ancient pharaonic monuments, making it second most popular for visiting pharaonic monuments after Luxor. Among the most pharaonic monuments in Giza are the great pyramids of Giza, one of the most important of the Seven Wonders of the World, the Sphinx, the Sakkara pyramid, the Cheops Boat Memorial, and an amazing sound and light display project. This is in addition to other medical and historical tourism.

Alexandria, the third city, located on the Mediterranean coast, is named in relation to Alexander the Great, who ordered its establishment in 331 BC, making it the capital of Egypt and the center of Greco-Roman culture and civilization. It is a foremost tourist destination and beach resort throughout the year because of its natural beauty and perfect climate, in addition to many of the historical monuments: the Citadel of Qaitbay, Pompey's Pillar, the Roman Theatre, the library of Alexandria, the Alexandria National Museum and the Museum of Greece, among others.

The fourth city is Qena, located south of the capital Cairo, about 600 km. Dandara, belonging to Qena governorate in Egypt, has one of the most important temples of the ancient Egyptians, called Hathor Temple or the Temple of Dandara. This is in addition to a small temple called the Temple of Isis, which is next to the western corner of the Great Temple.

The last city is Aswan city, located in southern Egypt, and one of the most important tourist landmarks. It has the Abu Simbel Temple, the Nubia Museum and the Temple of Kom Ombo in northern Aswan.

Sustainable tourism or environmentally-friendly tourism are defined as any tourism product that incorporates any green niche product [9,10] or goods, services and or practices considered to inflict little harm on the environment [11]. Since the use of renewable energy offers environmental benefits in the form of CO_2 pollution reduction, combining several renewable energy sources to form hybrid systems, whether off-grid or grid-connected systems, can provide more benefits by reducing CO_2 emissions and providing a reliable supply of electricity in all load conditions [12–18]. In addition, the use of renewable energy sources in remote locations could help reduce the operational cost through the reduction of fuel consumption, increasing system efficiency, and reducing noise and emissions [19].

Fazelpour *et al.* [20] conducted a feasibility study for using various hybrid energy systems: diesel system with battery, wind/diesel system with battery, PV/diesel system with battery and PV/wind/diesel system with battery. The purpose of the assessment was to deliver the electrical power requirements of a 125-room hotel in Kish Island, Güler *et al.* [21] had examined by using four different scenarios: the case of meeting a hotel's electrical energy demand with hybrid systems in Turkey. Dalton *et al.* [22,23] had presented a feasibility analysis for a large-scale stand-alone and grid-connected power supply tourist accommodation operation. The analysis used real load data from a large hotel (>100 beds) located in a subtropical coastal location in Australia. The same author [10] had presented a survey of tourist attitudes to renewable energy supply in Australian hotel accommodation. Bin, Jie and Qiang [24] presented an analysis of the technical and economic feasibility of a renewable energy powered island to determine the optimal renewable energy using hybrid system design that can cover the load for Hainan Island in China. Aagreh and Al-Ghazawi [25] presented a feasibility analysis for renewable energy supply options feeding a small hotel in Ajloun city located in the north part of Jordan. Both technical and economic aspects were investigated for each scenario of the considered supply options. Buonomano *et al.* [26] presented energy and economic analysis of geothermal-solar generation systems in a case study for a hotel building in Ischia, South Italy. Galvão *et al.* [27] presented cogeneration supply from bio-energy for a sustainable hotel building management system in Portugal.

The literature review above shows that several approaches have been discussed regarding environmentally-friendly tourism all over the world. However, there is no published work so far regarding environmentally-friendly tourism in Egypt. Furthermore, Egypt experiences frequent electricity blackouts because of rising demand and natural gas supply shortages, particularly during the summer time. Ongoing political and social unrest in Egypt has slowed the government's plans to expand power generation capacity by 30 GW by 2020 [28].

The potential for using clean energy technologies in Egypt is good given the abundant solar insolation and wind resources. However, so far, uses of renewable energy have been confined to demonstrating projects in which single renewable energy technologies used. No large-scale attempts have been made to use renewable energy. Additionally, hybrid power systems, where more than one power generation technology is used, have also not been employed [29].

The main objective of this work is to select the optimum city from five touristic Egyptian cities (Luxor, Giza, Alexandria, Qena and Aswan) to establish an environmentally-friendly tourist village. Selection of the city is done according to the economic cost (COE and NPC) and the amount of GHG emission, to be studied in four cases with the same load conditions. The first case is considered without taking the effects of ambient temperature into account or applying GHG emission penalties, the second case considers the effects of ambient temperature, while the third case considers the effects of GHG emission penalties and the fourth case combining applying GHG emission penalties and the effects of ambient temperature. Because few researchers in the literature review considered the effects of ambient temperature [30–34] and applying GHG emission penalties of around $20 for each ton of GHG emitted [20,35–37], these four cases will be considered in this study.

Among the nineteen software tools used by Sinha and Chandel [38], Homer was found to be the most widely used tool as it has maximum combination of renewable energy systems and performs optimization and sensitivity analysis that makes it easier and faster to evaluate possible system configurations. Hence, it is used as a software tool in this work.

The remainder of this paper is organized as follows: Section 2 presents the existing load profile, solar energy resource available, wind energy resources available and temperature resources available, which were collected carefully and accurately from accepted sources to run the Homer software, as one of the biggest challenges in using a model like Homer is finding the data to run it. Section 3 shows the different configurations of a hybrid renewable energy power system, under the study, from which the optimum city to be selected. Section 4 discusses the results of selection of the optimum city, according to the economic cost and the amount of GHG emitted in four cases, based on the effects of ambient temperature and applying GHG emission penalties. Section 5 concludes the paper.

2. Data Collection

2.1. Load Profile

The proposed tourist village comprises several units: the hotel building, which consists of 350 bedrooms and has a guest capacity of approximately 1000 guests, in addition to service areas and recreational areas. The scaled total annual energy consumption of the proposed tourist village load is 3650 MWh with peak load demand around 1007.28 kW during the summer period due to the activities of the tourists during that time. The load factor is 0.41, which is equal to the average load divided by the peak load. The baseline average value of the energy is 19,906 kWh/d with peak of load demand around 2005.1 kW as shown in Figure 3. The load conditions are the same for all five cities under the study (Luxor, Giza, Alexandria, Qena and Aswan). Homer is capable of synthesizing the 8760 hourly electrical load values for a whole year, using this hourly load profile and adding random variability factors, known as day-to-day variability and time-step-to-time-step variability [34,39]. In this study, they are taken as 5% for each factor.

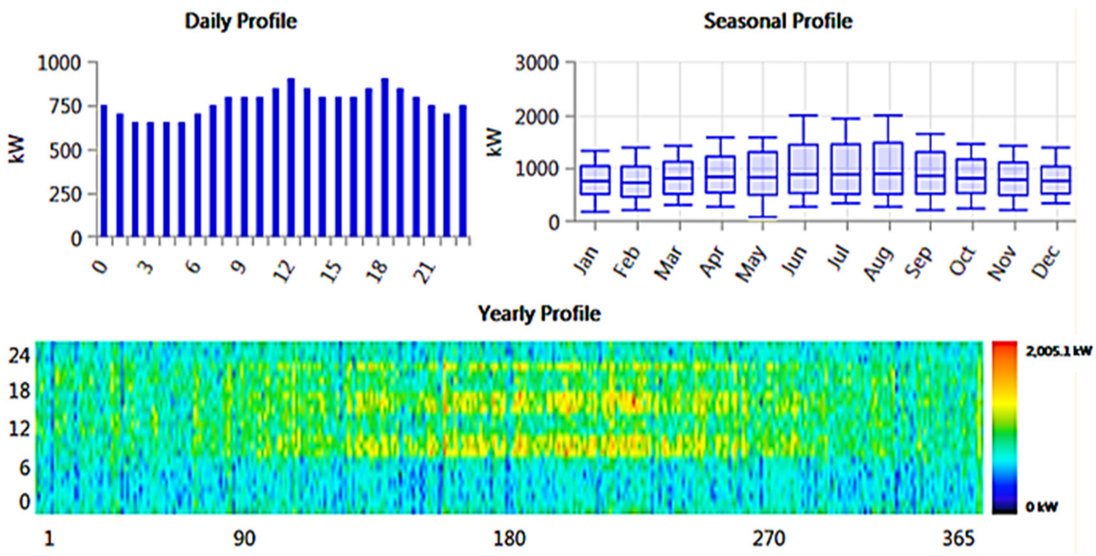


Figure 3. The first day of January, seasonal and yearly baseline load profile.

2.2. Solar Energy Resource

The 22-year (July 1983–June 2005) average monthly solar radiation data of the Egyptian cities (Giza, Alexandria, Qena, Luxor and Aswan), which are located at (30.013 N, 31.21 E); (31.2 N, 29.92 E); (26.16 N, 32.72 E); (25.69 N, 32.64 E) and (24.09 N, 32.9 E) were obtained from NASA (National Aeronautics and Space Administration) database [40]. According to NASA data, which are shown in Figure 4, the average monthly solar radiation data in Aswan is greater than the other cities in eight months (January to April, September to December), but Alexandria has an average monthly solar radiation data greater than the other cities in the summer time (May to August). Moreover, according to the average monthly solar radiation data, Aswan and Alexandria are the selected cities in the study.

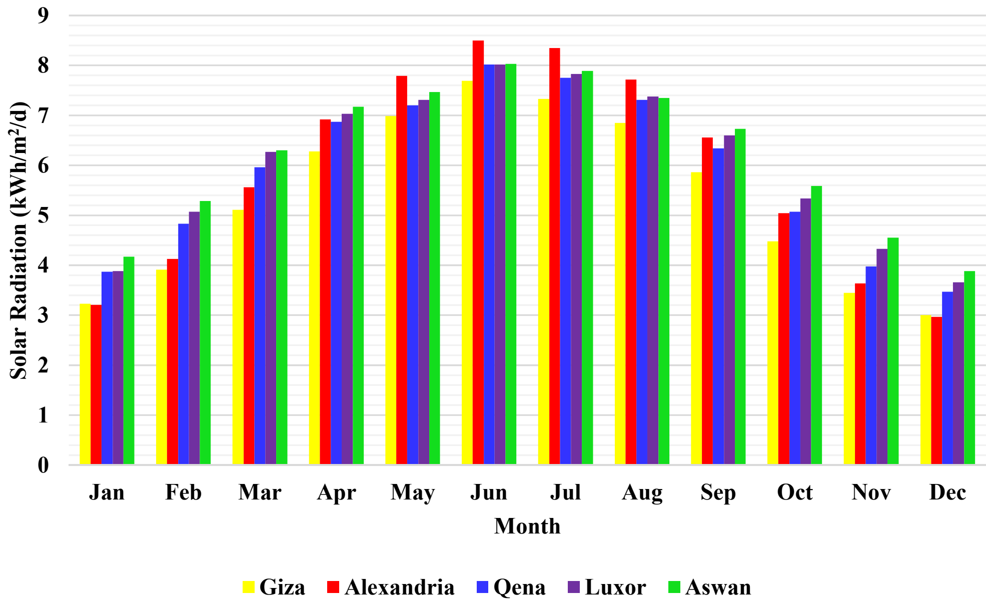


Figure 4. The average monthly solar radiation data in Giza, Alexandria, Qena, Luxor and Aswan.

2.3. Wind Energy Resource

From July 1983 to June 1993, the average monthly wind speed data, measured at 50 m above the surface of the earth of Giza, Alexandria, Qena, Luxor and Aswan, were obtained from the NASA database [40]. Based on NASA data, which are displayed in Figure 5, Alexandria has an average monthly wind speed data greater than the other cities in seven months (January to April, October to December), but the average monthly wind speed data in Qena is greater than the other cities in five months (May to September). Therefore, based on the average monthly wind speed data, Alexandria and Qena are selected from among the other cities for the study. Consequently, according to the average monthly solar radiation data and wind speed data, Alexandria, Aswan and Qena are the selected cities for this study.

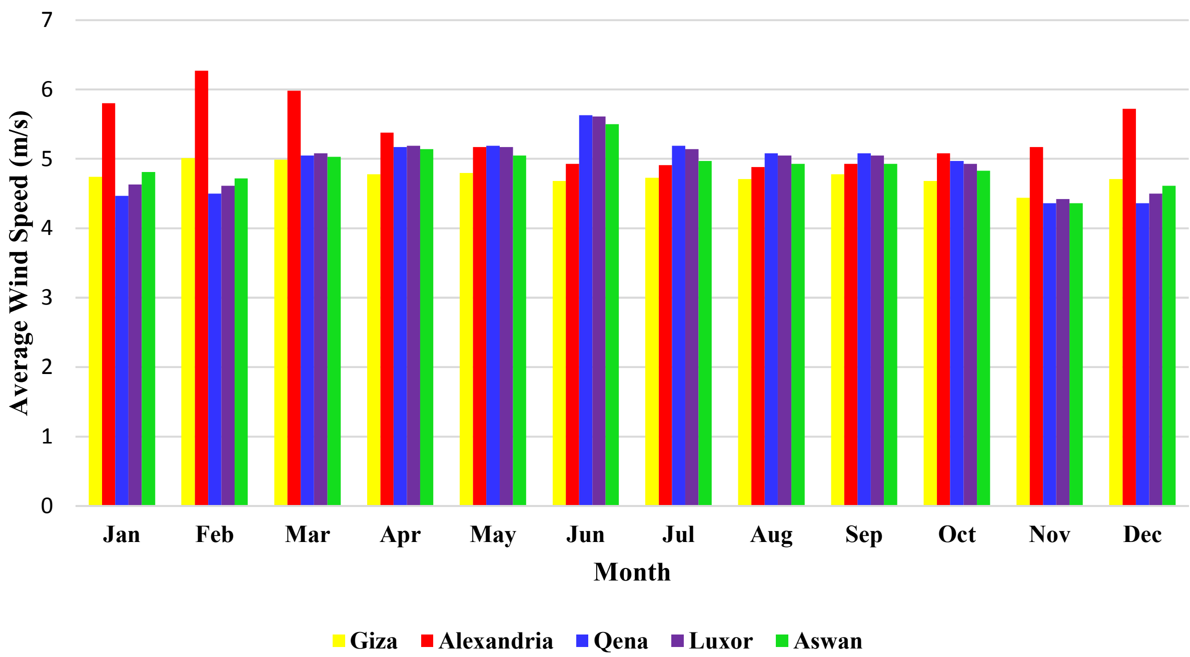


Figure 5. The average monthly wind speed data in Giza, Alexandria, Qena, Luxor, and Aswan.

2.4. Temperature Resource

The same NASA database [40] was used to get the 22-year (January 1983–December 2004) monthly average of the earth's surface temperature in the same previous cities. Figure 6 shows the average monthly temperature data in Giza, Alexandria, Qena, Luxor, and Aswan. The temperature coefficient of power indicates how strongly the PV array power output depends on the surface temperature. It is a negative number because power output decreases with increasing cell temperature. The temperature coefficient of the used PV modules is −0.5%/°C. The nominal operating cell temperature is the surface temperature that the PV array would reach if it were exposed to 1 kW/m^2 of solar radiation and an ambient temperature of 25 °C. The nominal operating cell temperature of the used PV modules is 47 °C.

The power output of the PV module, considering the effects of ambient temperature, can be obtained using the following formula [41]:

$$P_{\mathrm{pv}} = P_{\mathrm{S}} \cdot D_{\mathrm{pv}} \left(\frac{G_{\mathrm{T}}}{G_{\mathrm{S}}}\right) [1 + \alpha_{\mathrm{pv}} (T_{\mathrm{C}} - T_{\mathrm{S}})] \quad (1)$$

where:
D_{pv}, PV derating factor;
G_{T}, solar radiation incident on the PV module at the current time (kW/m^2);
G_{S}, solar radiation at standard test conditions (1 kW/m^2);
P_{S}, power output of the PV module under standard test conditions (kW);
T_{C}, temperature of the PV module at the current time (°C);
T_{S}, temperature of the PV module under standard test conditions (25 °C);
α_{pv}, temperature coefficient of the PV module (%/°C).

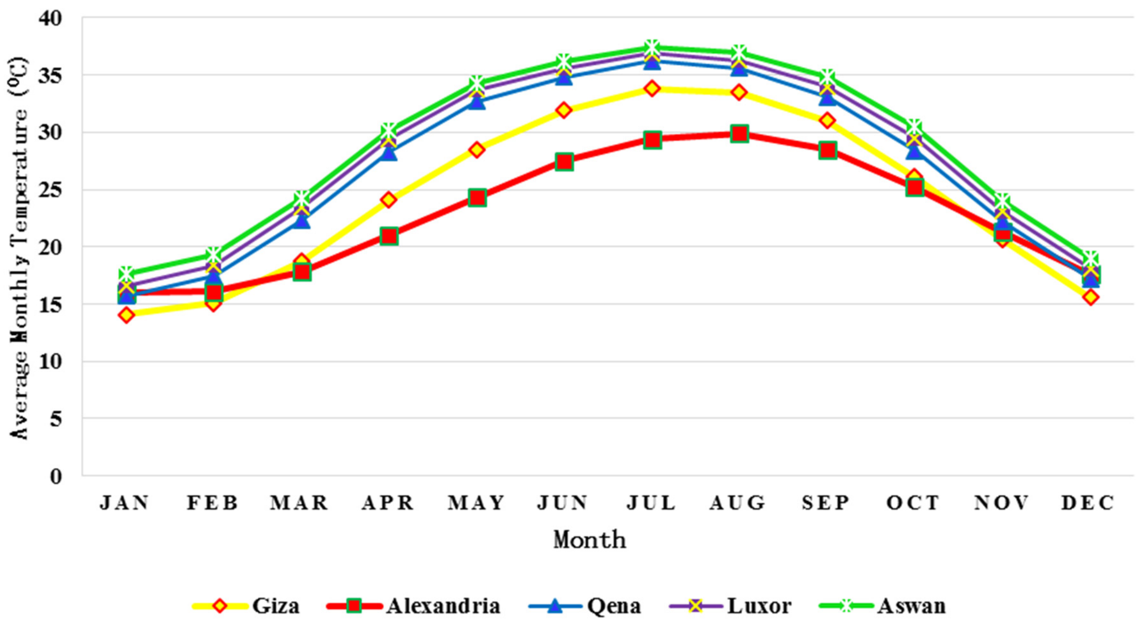


Figure 6. The average monthly earth's surface temperature in Giza, Alexandria, Qena, Luxor, and Aswan.

3. Hybrid System Modeling

The important feature of HRES (hybrid renewable energy power system) is to combine two or more renewable power generation technologies to make the best use of their operating characteristics and to obtain efficiencies higher than that could have been obtained from a single power source. This feature results from the ability of HRES to take the advantage of the complementary diurnal (night/day) and seasonal characteristics of the available renewable energy resources at a given site [18,42]. Figure 7a–d shows the different configurations of a hybrid renewable energy power system (PV/wind/diesel/battery, PV/diesel/battery, wind/diesel/battery and diesel/battery), for this study, among which the optimum city (Luxor, Giza, Alexandria, Qena or Aswan) is to be selected to establish an environment-friendly tourist village for each configuration based on the economic cost (COE and NPC) and the amount of GHG emitted for the same user inputs of the load, components costs, and components technical details.

Tables 1 and 2 highlight the summary of the component costs and technical details of PV, wind, converter, batteries and diesel generators, which are the inputs to Homer software, for a 25-year project lifetime with 8% annual interest rate. In addition, the user inputs of the load, solar radiation, wind speed and temperature are shown, in addition to applying GHG emission penalties of around $20 for each ton of GHG emitted.

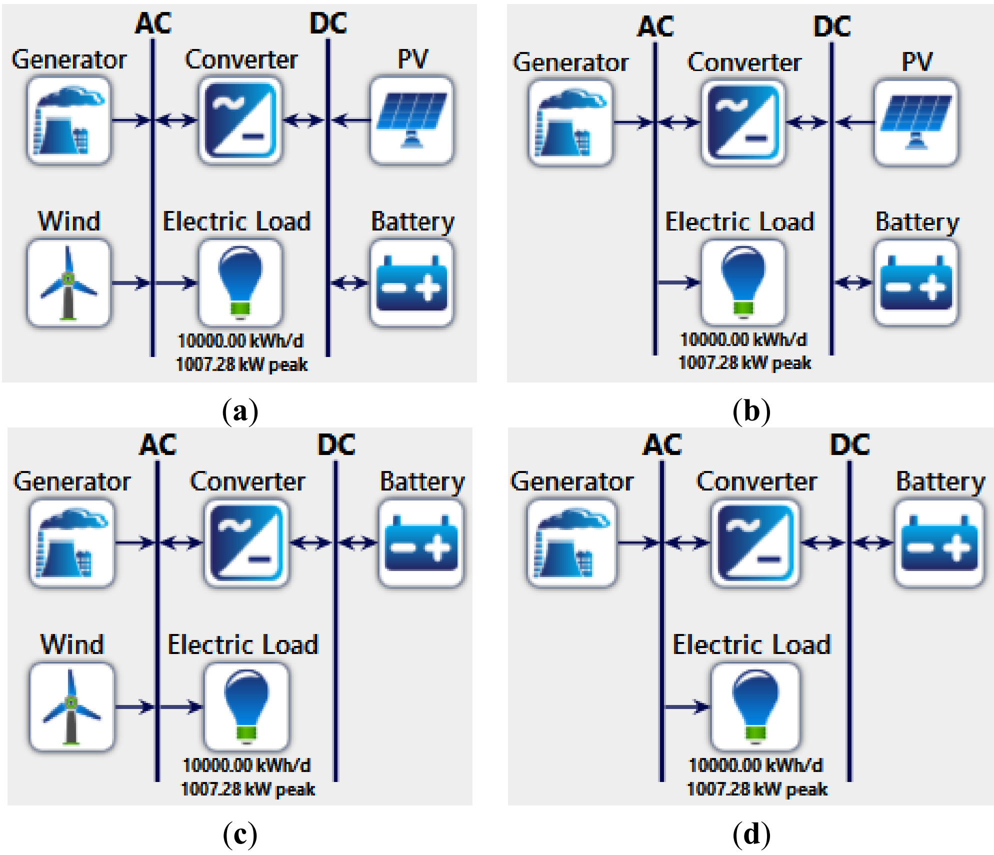


Figure 7. (**a**) Configuration of hybrid PV/wind/diesel/battery system; (**b**) Configuration of hybrid PV/diesel/battery system; (**c**) Configuration of hybrid wind/diesel/battery system; (**d**) Configuration of diesel/battery system.

Table 1. Different costs of the components.

Component	Capital Cost	Replacement Cost	O & M Cost	Life Time
PV module	$3000/kW	$2500/kW	$10/year	20 years
Wind turbine	$4000/kW	$3000/kW	$50/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/hour	15,000 h

Table 2. Technical details of the components.

Technical Details	Value
Derating factor	80%
Ground reflection	20%
Converter efficiency	90%
Fuel cost	$0.24/L
Annual nominal interest rate	8%
Project lifetime	25 years

4. Results and Discussions

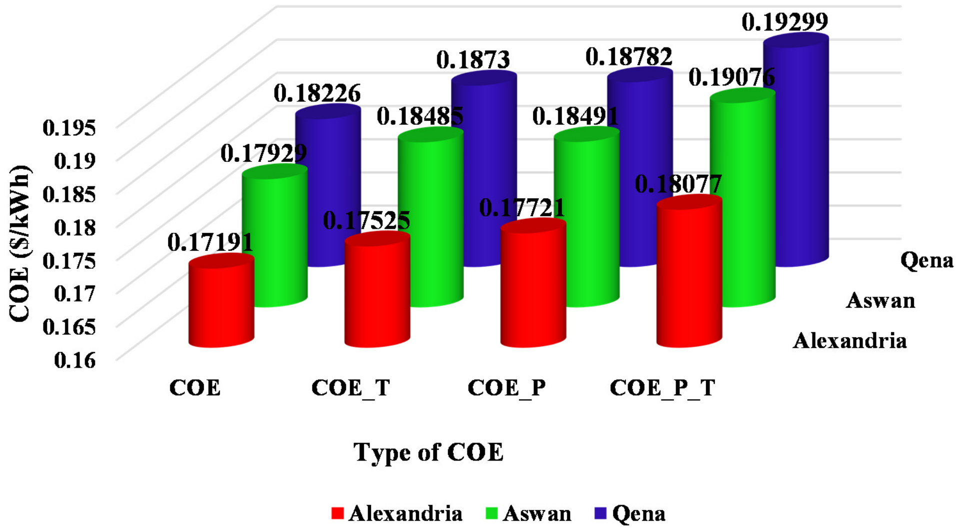
4.1. Selection of the City According to the Economic Cost

The levelized cost of energy (COE) and the total net present cost (NPC) of the system are calculated using the well-known Homer software in four cases:

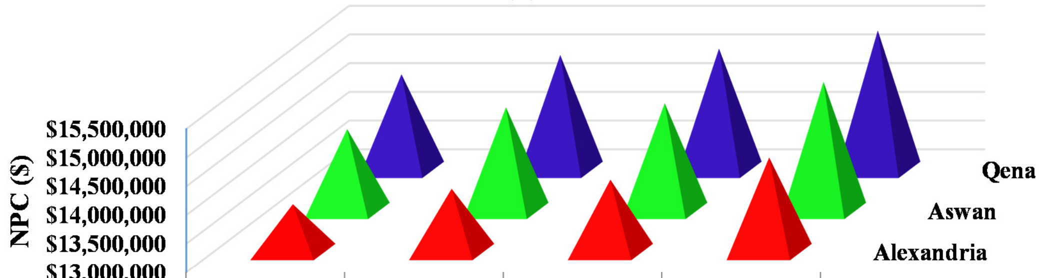
1. COE and NPC represent the levelized cost of energy and the total net present cost of the system without considering the effects of ambient temperature or applying GHG emission penalties.
2. COE_T and NPC_T represent the levelized cost of energy and the total net present cost of the system with considering the effects of ambient temperature.
3. COE_P and NPC_P represent the levelized cost of energy and the total net present cost of the system, taking GHG emission penalties into consideration.
4. COE_P_T and NPC_P_T represent the levelized cost of energy and the total net present cost of the system, taking GHG emission penalties and the effects of ambient temperature into consideration.

4.1.1. Hybrid PV/Wind/Diesel/Battery System

Figure 8a,b shows the different COE and NPC of a PV/wind/diesel/battery system in Alexandria, Aswan and Qena. It is quite clear that Alexandria COE and NPC have the lowest costs compared with the other two cities. In addition, this is achieved in the other three cases, taking the effects of ambient temperature, applying GHG emission penalties and considering the effects of both. The COE and the NPC increase with the effects of ambient temperature and applying the GHG emission penalties in the three cities. In addition, it is quite clear that the gap in COE and NPC between Alexandria and the other two cities is greater than that between Aswan and Qena. Moreover, according to the economic cost, Alexandria is the economic city for a hybrid PV/wind/diesel/battery system, compared to the other two cities, Aswan and Qena.



(a)



	NPC	NPC_T	NPC_P	NPC_P_T
Alexandria	1.38E+07	1.41E+07	1.43E+07	1.46E+07
Aswan	1.44E+07	1.48E+07	1.49E+07	1.53E+07
Qena	1.47E+07	1.50E+07	1.51E+07	1.54E+07

Type of NPC

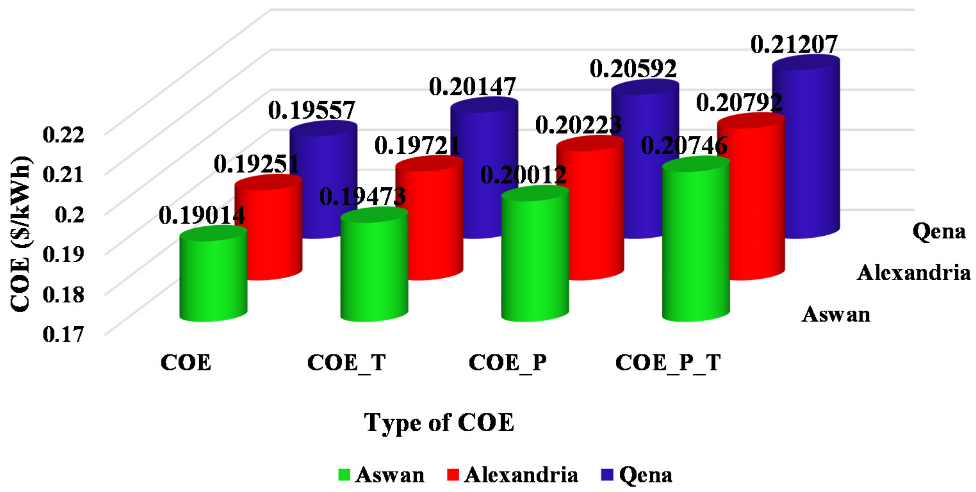
Alexandria Aswan Qena

(b)

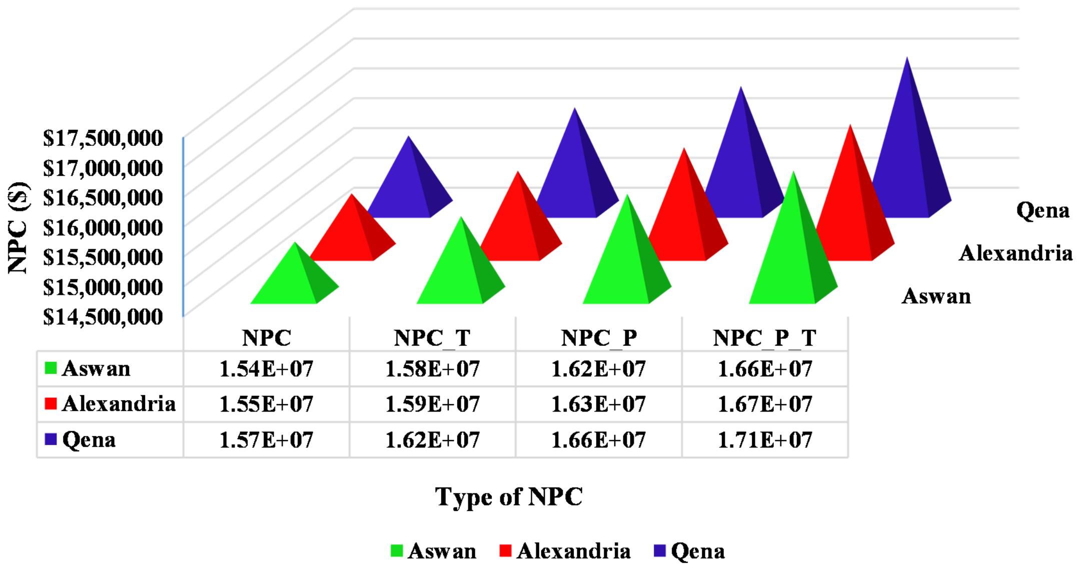
Figure 8. (**a**) The different COE of PV/wind/diesel/battery system in Alexandria, Aswan and Qena; (**b**) The different NPC of PV/wind/diesel/battery system in Alexandria, Aswan and Qena.

4.1.2. Hybrid PV/Diesel/Battery System

Based on the different COE and NPC of a PV/diesel/battery system in Aswan, Alexandria and Qena as shown in Figure 9a,b, we can say that Aswan has the lowest COE and NPC compared with the other two cities, in addition, this is also achieved in the other three cases, taking the effects of ambient temperature, applying GHG emission penalties and considering the effects of both. The COE and the NPC increase with the effects of ambient temperature and applying the GHG emission penalties in the three cities. Additionally, it is quite clear that the gap in COE and NPC between Aswan and Alexandria is not large; this is attributed to the solar radiation data convergence between Aswan and Alexandria as shown in Figure 4. However, according to the economic cost, Aswan is the economic city for a hybrid PV/diesel/battery system, compared to the other two cities, Alexandria and Qena.



(**a**)



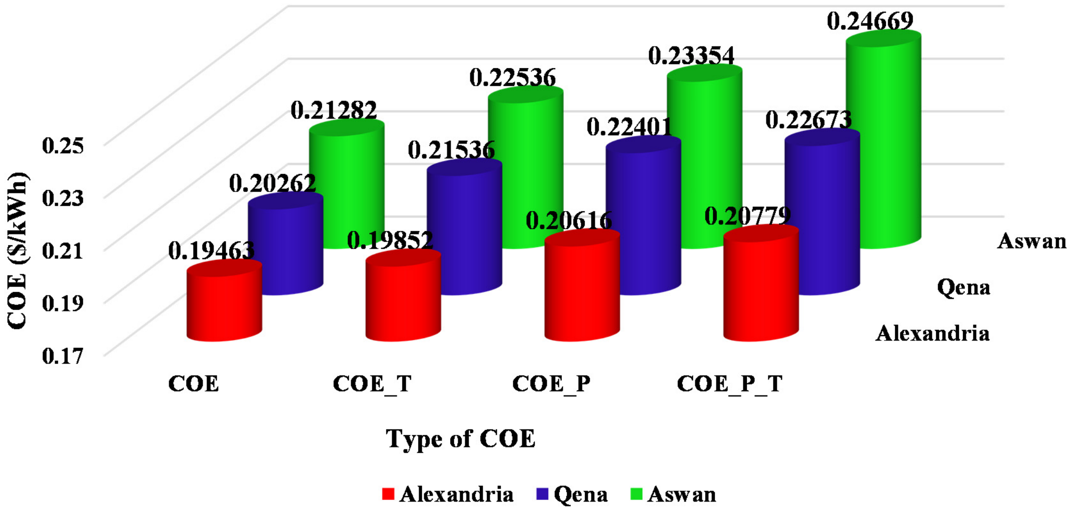
	NPC	NPC_T	NPC_P	NPC_P_T
Aswan	1.54E+07	1.58E+07	1.62E+07	1.66E+07
Alexandria	1.55E+07	1.59E+07	1.63E+07	1.67E+07
Qena	1.57E+07	1.62E+07	1.66E+07	1.71E+07

(**b**)

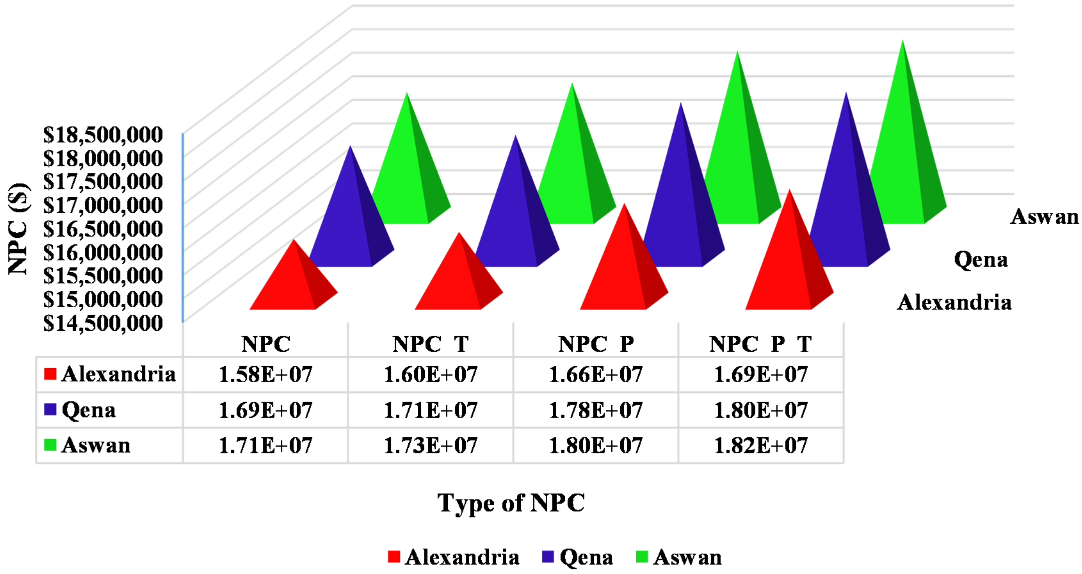
Figure 9. (**a**) The different COE of PV/diesel/battery system in Aswan, Alexandria and Qena; (**b**) The different NPC of PV/diesel/battery system in Aswan, Alexandria and Qena.

4.1.3. Hybrid Wind/Diesel/Battery System

Figure 10a,b shows the different COE and NPC of a wind/diesel/battery system in Alexandria, Qena and Aswan. It is quite clear that Alexandria COE and NPC have the lowest costs compared to the other two cities; in addition, this is also achieved in the other three cases, taking the effects of ambient temperature, applying GHG emission penalties and considering the effects of both. The COE and the NPC increase with the effects of ambient temperature and applying the GHG emission penalties in the three cities. In addition, it is quite clear that the gap in COE and NPC between Alexandria and the other two cities is greater than that between Qena and Aswan. Moreover, according to the economic cost, Alexandria is the economic city for a hybrid wind/diesel/battery system, compared to the other two cities, Qena and Aswan.



(a)

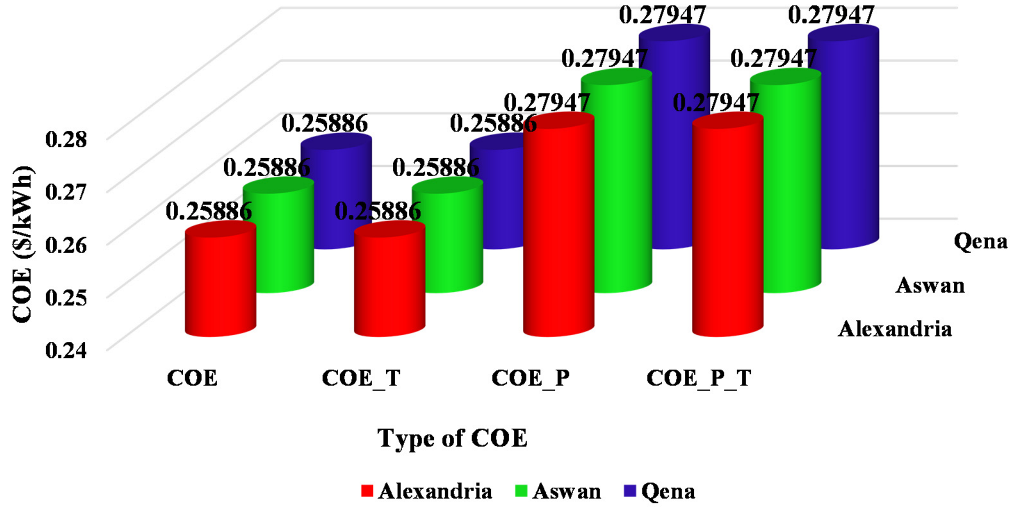


(b)

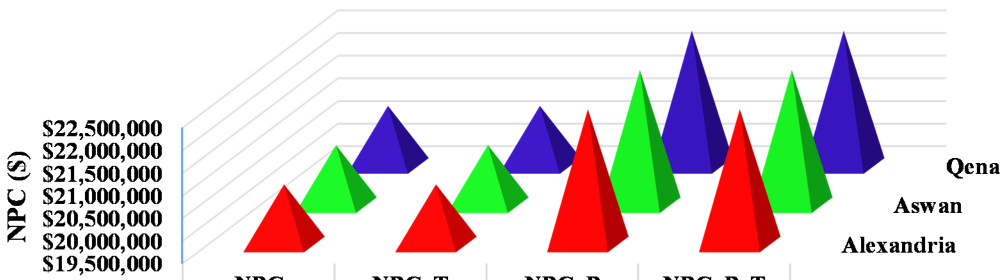
Figure 10. (**a**) The different COE of wind/diesel/battery system in Alexandria, Qena and Aswan; (**b**) The different NPC of wind/diesel/battery system in Alexandria, Qena and Aswan.

4.1.4. Diesel/Battery System

According to the different COE and NPC of a diesel/battery system in Alexandria, Aswan and Qena as shown in Figure 11a,b, it is quite clear that there is no difference in COE and NPC in the three cities regardless of taking the effects of ambient temperature, applying GHG emission penalties or considering the effects of both of the two. The COE and NPC increase with the GHG emission penalties but the effects of ambient temperature are neglected in all three cities. Furthermore, according to the economic cost there is no difference between the three cities in this study for a diesel/battery system.



(**a**)



	NPC	NPC_T	NPC_P	NPC_P_T
Alexandria	2.08E+07	2.08E+07	2.25E+07	2.25E+07
Aswan	2.08E+07	2.08E+07	2.25E+07	2.25E+07
Qena	2.08E+07	2.08E+07	2.25E+07	2.25E+07

Type of NPC

Alexandria Aswan Qena

(**b**)

Figure 11. (**a**) The different COE of diesel/battery system in Alexandria, Aswan and Qena; (**b**) The different NPC of diesel/battery system in Alexandria, Aswan and Qena.

4.2. Selection the City According to the Amount of GHG Emitted

4.2.1. Hybrid PV/Wind/Diesel/Battery System

Figure 12 shows the amounts of GHG emitted from a PV/wind/diesel/battery system in Alexandria, Aswan and Qena. It is quite clear that there is no large difference in GHG amounts emitted from a PV/wind/diesel/battery system in the three cities, ignoring the effects of ambient temperature and GHG emission penalties. However, if the effects of ambient temperature are considered, Qena will be the optimum city for a PV/wind/diesel/battery system according to the amount of GHG emitted compared to the other two cities. On the other hand, if the GHG emission penalties are applied, Aswan will be the optimum city for a PV/wind/diesel/battery system, according to the amount of GHG emitted compared to the other two cities. Furthermore, Alexandria will be the optimum city for the same system according to the amount of GHG emitted compared to the other two cities if the effects of the ambient temperature are considered and GHG emission penalties are applied.

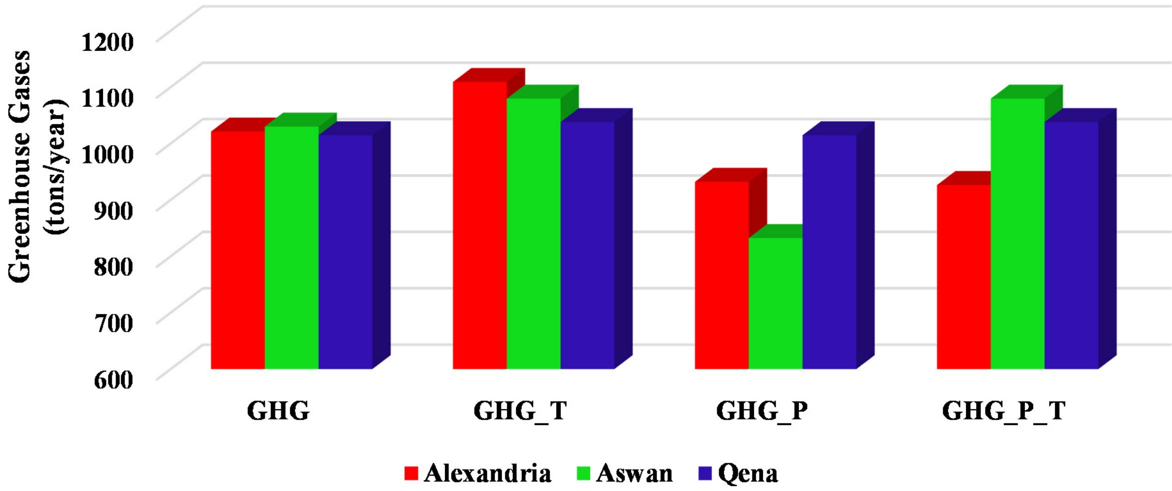


Figure 12. The different amounts of GHG emitted from a PV/wind/diesel/battery system in Alexandria, Aswan and Qena.

4.2.2. Hybrid PV/Diesel/Battery System

According to the amounts of GHG emitted from a PV/diesel/battery system in Alexandria, Aswan and Qena as shown in Figure 13, Alexandria is the optimum city for a PV/diesel/battery system according to the amount of GHG emitted compared to the other two cities, when ignoring the effects of ambient temperature and GHG emission penalties or applying GHG emission penalties. On the other hand, when taking the effects of ambient temperature or both the effects of ambient temperature and GHG emission penalties into consideration, there will be no large difference between Alexandria and Aswan for a PV/diesel/battery system.

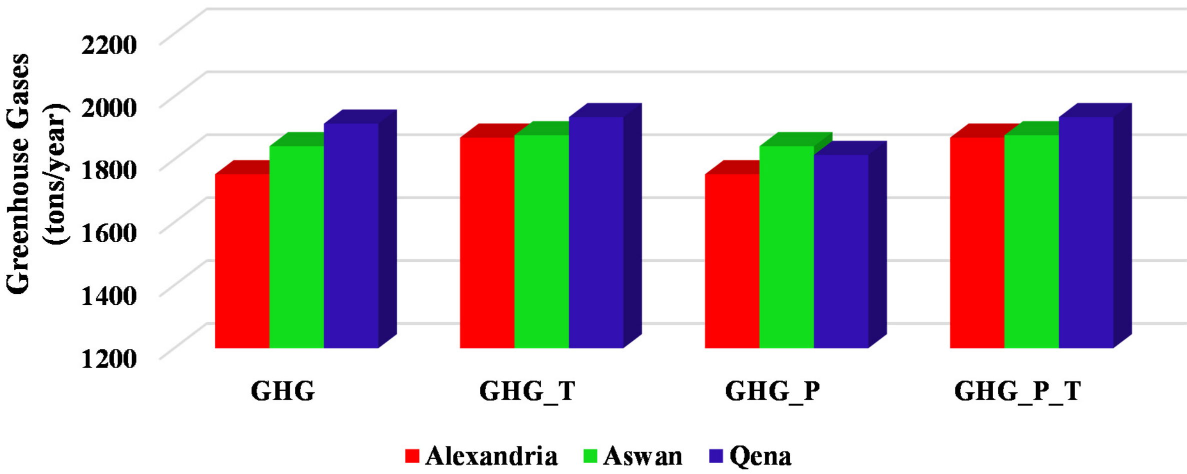


Figure 13. The different amounts of GHG emitted from a PV/diesel/battery system in Alexandria, Aswan and Qena.

4.2.3. Hybrid Wind/Diesel/Battery System

Based on the amounts of GHG emitted from a wind/diesel/battery system in Alexandria, Aswan and Qena as shown in Figure 14, it is quite clear that Alexandria is the optimum city for a wind/diesel/battery system according to the amount of GHG emitted compared to the other two cities, regardless of considering the effects of ambient temperature, applying GHG emission penalties or considering the effects of both.

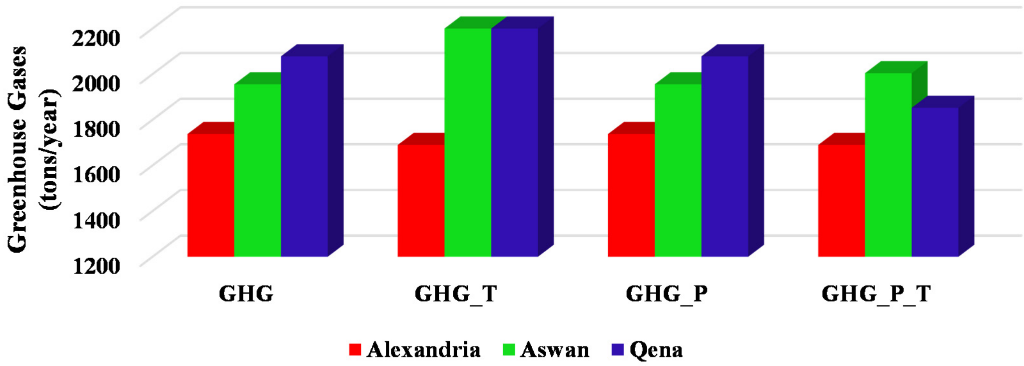


Figure 14. The different amounts of GHG emitted from a wind/diesel/battery system in Alexandria, Aswan and Qena.

4.2.4. Diesel/Battery System

According to the different amounts of GHG emitted from a diesel/battery system in Alexandria, Aswan and Qena as shown in Figure 15, it is quite clear that there is no difference in GHG amounts emitted in the three cities regardless of the effects of ambient temperature, applying GHG emission penalties or considering the effects of both. This is attributed to the fact that the diesel generators have the same operation time to satisfy the required load demand. Moreover, according to the amount of GHG emitted from a diesel/battery system, there is no difference between the three cities in the study.

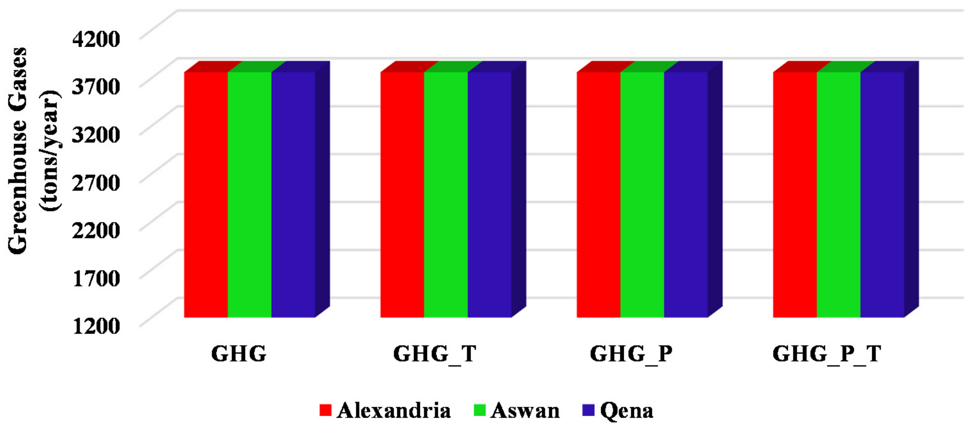


Figure 15. The different amounts of GHG emitted from a diesel/battery system in Alexandria, Aswan and Qena.

5. Conclusions

Based on the simulations and analysis presented in this paper, the following conclusions can be drawn:

1. The selection of the optimum city from five touristic Egyptian cities (Luxor, Giza, Alexandria, Qena and Aswan) to establish an environmentally-friendly tourist village has been carried out according to the economic cost (COE and NPC) and the amount of GHG emitted.
2. The selection of the optimum city has been carried out in four cases based on the effects of ambient temperature and applying GHG emission penalties for different configurations of HRES.
3. Alexandria is the most economic city for a hybrid PV/wind/diesel/battery system in comparison with Aswan and Qena.
4. Aswan is the economic city for a hybrid PV/diesel/battery system compared to the other two cities, Alexandria and Qena.
5. Alexandria is the most economic city for a hybrid wind/diesel/battery system in comparison with Qena and Aswan.
6. For diesel/battery, system there is no difference between the three cities according to the economic cost, but for the same city there is a significant difference according to the economic cost based on applying GHG emission penalties.
7. There is no large difference in GHG amount emitted from a PV/wind/diesel/battery system in any of the three cities, ignoring the effects of ambient temperature and GHG emission penalties.
8. Qena is the optimum city for a PV/wind/diesel/battery system according to the amount of GHG emitted in comparison with the other two cities, if the effects of ambient temperature are considered.
9. Aswan is the optimum city for a PV/wind/diesel/battery system according to the amount of GHG emitted compared to the other two cities, if the GHG emission penalties are applied.
10. Alexandria is the optimum city for a PV/wind/diesel/battery system according to the amount of GHG emitted compared to the other two cities if the effects of ambient temperature are considered and GHG emission penalties are applied.
11. Alexandria is the optimum city for a PV/diesel/battery system according to the amount of GHG emitted compared to the other two cities if the effects of ambient temperature and GHG emission penalties are neglected, or applying GHG emission penalties.
12. There is no large difference between Alexandria and Aswan for a PV/diesel/battery system according to the amount of GHG emitted if the effects of ambient temperature or both the effects of ambient temperature and GHG emission penalties are taken into consideration.
13. Alexandria is the optimum city for a wind/diesel/battery system according to the amount of GHG emitted compared to the other two cities regardless of considering the effects of ambient temperature, applying GHG emission penalties or considering the effects of both.
14. According to the amount of GHG emitted from a diesel/battery system, there is no difference between the three cities under the study.

Author Contributions

All authors contributed to this work. Fahd Diab and Salwa Ali performed the research, discussed the results, and prepared the manuscript; Hai Lan, Lijun Zhang suggested the research idea and contributed to writing and revising the paper. All authors revised and approved the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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