Efficiency Assessment of Oasis Hotel in Utilizing a Hybrid Solar Energy System

A Case Study
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1 INTRODUCTION

Income generated from tourism has long been a pillar of the Egyptian economy. The World Travel and Tourism Council estimates that in 2016, the direct contribution of travel and tourism was EGP87.4 bn (USD8.7 bn), equivalent to 3.2% of Egypt's total GDP.[1] In that same year, the tourism industry supported around 773,000 jobs, constituting approximately 2.9% of total employment in the country.[2] 2017 saw an estimated 5.5 million international tourist arrivals and the sector is expected to continue to be a key source of national revenue, foreign currency and employment in the following years.[3]

Tourism and associated travel, however, are also extremely energy-intensive activities. Egypt's current energy mix is heavily dependent on oil and gas, and has experienced an increase in overall CO2 emissions.[4] The reliance on fossil fuels in the tourism sector is expected to become increasingly costly for businesses in upcoming years, and cause serious environmental damage to the wider ecosystem. The effects of this are not directly felt by companies, but contribute to the destruction of tourist destinations.[5] The sector is highly climate sensitive, with climate influencing environmental conditions that encourage or discourage visitors.[6] While it is difficult to gauge to what extent benefits from income and employment will offset these indirect losses, the sustainability of the sector is crucial, given its critical contribution to the economy.[7]

It is in this context that this case study investigates the efficiency of a hybrid solar energy system at Oasis Hotel in Marsa Alam, a tourist destination located on the southern end of Egypt's Red Sea coast. The case study aims to investigate the economics behind the implementation of solar energy, in the hope that the experience of Oasis Hotel will incentivize other companies in the tourism sector to invest in renewables. The study will document the hotel's collaboration with KarmSolar, a pioneer in Egypt's solar energy sector, to integrate solar energy into their energy mix, detailing the rationale and process of the transition. While resource efficiency was a primary motive for the hotel's integration of renewable energy, Oasis Hotel were also keen to decrease their reliance on the central grid or the purchase of diesel fuel and achieve self-sufficiency. The wider issue of sustainable tourism is also touched upon in this study.

The study proceeds in four substantive sections. The first explores the tourism sector in Egypt, with a focus on sustainable tourism and the integration of solar energy. The second section details the set-up of the micro-grid and associated challenges. The specific framework of the grid necessitates the use of diesel generators, but the balance between diesel and solar has not been optimized by means of data analysis. The third and fourth sections analyze available data on the use of both energy sources and offer suggestions for a more efficient use of diesel generators. The case study is both quantitative and qualitative, aiming to present a complete picture of the hotel's transition to renewable energy.

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[1] Travel and Tourism Economic Impact 2017, Egypt, (The World Travel and Tourism Council, 2017). https://www.wttc.org/-/media/files/reports/economic-impact-research/regions-2017/world2017.pdf.

[2] Ibid.

[3] Ibid.

[4] M. Georgei and H. Bombeck, "Energy Use in Sharm El-Sheikh Resort in Egypt", International Journal of Sustainable Development and Planning, 7, no.1 (2012): 412-427. https://www.witpress.com/elibrary/sdp-volumes/7/4/646.

[5] Oshani Perera, Stephen Hirsch, Peter Fries, Switched On: Renewable Energy Opportunities in the Tourism Industry, (United Nations Environment Programme, 2003).

[6] UNWTO Backgound Paper, From Davos to Copenhagen and Beyond: Advancing Tourism's Response to Climate Change, (World Tourism Organization, 2009). http://sdt.unwto.org/sites/all/files/docpdf/fromdavostocopenhagenbeyondunwtopaperelectronicversion.pdf.

[7] Ahmad Muhammad Ragab and Scott Meis, "Developing Environmental Performance Measures for Tourism Using a Tourism Satellite Accounts Approach: a Pilot Study of the Accommodation Industry in Egypt," Journal of Sustainable Tourism, 24, no. 7, (2016):1007-1023. https://doi.org/10.1080/09669582.2015.1107078.

Popular tourist sites in Egypt are diverse, ranging from the major urban cities of Cairo and Alexandria to the beaches along the Red Sea, and the Nile River in Luxor and Aswan. While still best known for its archaeological sites, the sector has grown to include more leisure-orientated mass tourism, with an associated boom in the hotel industry in the early 2000s.[8]

As Eman Helmy, associate professor at Helwan University, points out in her 2004 study of sustainable tourism in Egypt, a synergy between sustainability and tourism ensures the protection of natural resources while developing local businesses and populations. The term 'sustainability' here encompasses both ecological conservation and planning strategies that ensure the longevity of the sector. She argues that, although it may seem paradoxical in the context of development, sustainable development, efforts to combat poverty, and policies that encourage tourism all complement one another.[9] Policy-making should aim to mitigate tourism's negative impacts and ensure positive outcomes are inclusive of local populations.

Marsa Alam, where Oasis Hotel is situated, is popular among Red Sea destinations for its coral reefs and marine fauna, which depend on the upkeep and protection of natural resources. A number of conservation initiatives have emerged in the area, the most prominent of which is the Red Sea Sustainable Tourism Initiative (RSSTI) supported by the United States Agency for International Development (USAID) and led by the Egyptian Tourism Development Authority (TDA). The initiative documents best practice, assesses and monitors its impact, and raises awareness on sustainability.[10]

For some businesses, sustainability is a concept that can be profitably promoted to tourists. This 'green' marketing projects a positive relationship to the environment and local community, which is appealing to certain consumer bases.[11] Indeed, sustainable tourism has grown in popularity in the last decade. Egypt too has seen increasing interest in sustainable tourism in recent years, leading to the development of 'eco-lodges,' small-scale facilities and associated nature-based activities.[12]

Sustainable tourism does not, however, require the construction of entirely new facilities along eco-lodge lines, but can simply mean the more efficient use of locally available resources. The United Nations World Tourism Organization considers reduced energy use as the starting point in mitigating the effect of tourism on climate change.[13] This includes improving energy efficiency and integrating renewable energies, both of which were key factors in Oasis's switch to renewable energy.[14]

A resource-efficient approach can have the positive effects of reducing both costs and detrimental effects on the environment. In particular, the solar energy facilities installed at Oasis capitalize on Egypt's geographic positon on the global sunbelt, which consists of areas that experience high solar radiation.[15]

Best known for its intensive coastal coral reefs and colorful sea life, Marsa Alam attracts divers from around the world. The opening of its own international airport in 2003 placed the small coastal town on the map for investors, with the construction of several resorts and hotels that cater to divers — Oasis Hotel being one of them.[16] The hotel was founded in 2010, roughly 20 kilometers north of Marsa

[8] Leïla Vignal, "The New Territories of Tourism in Egypt: a Local-global Frontier?" Cybergeo: European Journal of Geography, 509, (October 2010). http://journals.openedition.org/cybergeo/23324.

[9] Eman Helmy, "Towards Integration of Sustainability into Tourism Planning in Developing Countries: Egypt as a Case Study," Current Issues in Tourism, 7, no.6, (2004): 478-501. https://doi.org/10.1080/1368350050408668199.

[10] Egypt: Red Sea Sustainable Tourism, PDF (USAID), accessed 21 December 2017. http://pdf.usaid.gov/pdf_docs/PDACH397.pdf.

[11] Mohammed El Dief and Xavier Font, "The Determinants of Hotels' Marketing Managers' Green Marketing Behaviour," Journal of Sustainable Tourism, 18, no.2: 157-174. https://doi.org/10.1080/09669580903464232.

[12] Ashraf Salama, "Sustainable Tourism: Exploring the Fragile Environment in Egypt," The Big Project, 2008, 40.

[13] UNWTO Background Paper, From Davos to Copenhagen.

[14] Samir Hammam (HCHTech), interview with Nancy Salem and Youmna Hashem at HCHTech office in Cairo, November 13, 2017.

[15] Isabel Bottoms, 80 Gigawatts of Change (The Egyptian Center for Economic and Social Rights and Heinrich Böll Stiftung, 2016): 91, http://ecesr.org/wp-content/uploads/2016/03/80-Gigawatts-of-Change-En-Pages.pdf.

[16] "Marsa Alam travel," Lonely Planet, accessed December 10, 2017. https://www.lonelyplanet.com/egypt/red-sea-coast/marsa-alam.

Alam proper. With access to an expanse of the Red Sea, Oasis has established itself as a diving lodge, with little else in the way of recreational activities. The hotel caters to both local and international visitors, and plans to open a second hotel of a similar capacity nearby are currently underway.

Fig. 1: Oasis Hotel, Marsa Alam

In 2014, Oasis began a transition to solar energy, integrating this renewable source into the mix with diesel-run generators. Solar energy for Oasis is provided through a micro-grid installed and maintained by KarmSolar, which is also expected to provide energy to the second hotel. On average, solar energy accounts for the majority of energy generated and consumed by the hotel during the day. Alongside solar panels, the hotel also utilizes solar water heaters, a technology that is already widespread in the tourism sector.[17] As is the case in many hotels, most electricity goes toward heating; another significant portion of the electricity is consumed by water purification processes.

While solar energy already makes up a sizeable segment of the energy mix, the hotel still depends on diesel generators, which are both costly and detrimental to the environment. The generators are controlled manually and are always running. Using data provided by Oasis, this case study projects the most efficient use of the diesel generators to capitalize on solar energy production. Prior to this case study, a cost efficiency of the hybrid system had not been assessed.

2.1. Off-Grid Solar Energy

Electricity in Egypt is mainly supplied through a centralized national grid operated by the state. The number of electricity consumers increased by 2.6%, from 30.6 million in 2014 to 31.4 million in 2015, according to the 2014/2015 annual report produced by the Egyptian Electricity Holding Company.[18] The same report estimates Egypt's energy mix to be 91% oil and gas, 8% hydropower and 0.8% renewables.[19] In 2008, the Supreme Council of Energy announced that renewable energy would meet 20% of Egypt's energy demand by 2022.[20]

Even in places that are connected to the grid, diesel-run generators are often used as a supplementary power source. Nearly 70% of all diesel fuel is imported.[21] An alternative is off-grid solar energy systems, which reduce the cost of imports on the national budget, as well as reducing the environmental and health hazards associated with diesel fuel pollutants.[22] While solar energy cannot be generated throughout the night, it is highly predictable and — as the case of Oasis demonstrates — can be augmented by diesel generators in a hybrid system.

The Regional Center for Renewable Energy and Energy Efficiency (RECREE) identifies three main challenges to the wide-scale adoption of off-grid solar

[17] Oshani Perera, et al., "Switched On: Renewable Energy Opportunities."
[18] Ministry of Electricity and Renewable Energy, Annual Report 2014-2015, (Egyptian Electricity Holding Company, 2014-2015): 42, http://www.moee.gov.eg/english_new/EEHC_Rep/2014-2015en.pdf.
[19] Ibid., 20.
[20] Ministry of Electricity and Renewable Energy, "Annual Report 2015/2016" (Egyptian Electricity Holding Company: 2016).
[21] RECREE, Diesel to Solar Transformation: Accelerating Achievement of SDG 7 on Sustainable Energy - Assessing Untapped Solar Potential in Existing Off-grid Systems in the Arab Region (RECREE, 2016), 7, accessed October 15, 2017. http://rcreee.org/sites/default/files/d2s_rep_v7.1-31.3.16_web.pdf.
[22] Dalia Sakr, Joern Huenteler, Matsuo Tyeler, Ashish Khanna, Scaling up distributed solar in emerging markets: the case of the Arab Republic of Egypt. Policy Research working paper; no. WPS 8103. Washington, D.C.: World Bank Group, 2017, Accessed October 15, 2017. http://documents.worldbank.org/curated/en/815911497878875622/Scaling-up-distributed-solar-in-emerging-markets-the-case-of-the-Arab-Republic-of-Egypt.

energy systems: low levels of awareness, insufficient implementation capacity, and a perception of high risk among the banking and financing sector;[23] meaning that there are not many well documented success stories of solar projects available to the banking sector. These challenges combine to make finding appropriate financing difficult, making upfront costs high. However, solar energy systems may be profitable in the long term, especially with the gradual removal of diesel subsidies, which for now remain a critical barrier to the adoption of renewable energies in Egypt.[24]

Off-grid technologies such as solar energy decentralize energy supplies, and allow the sector to make more efficient use of available resources. They are also built to scale, and can be expanded and integrated as required.[25] In 2016, RECREE identified Marsa Alam as an ideal candidate for the introduction of off-grid solar energy, not least because it was found to be completely dependent on diesel for electricity generation. It was estimated that the resort's 56-plus hotels, with around 12,500 hotel rooms, consumed approximately 60,000 tons of diesel per year, creating 200,000 tons of CO2 emissions.

The following section outlines the experience of integrating solar energy in Oasis and challenges faced in the process.

[23] RECREE, "Diesel to Solar Transformation: Accelerating Achievement of SDG."
[24] Dalia Sakr, et al., "Scaling Up Distributed Solar," 9.
[25] Oshani Perera, et al., "Switched On: Renewable Energy Opportunities."

3 THE HYBRID SYSTEM

In 2015, Oasis signed on with KarmSolar to install a solar energy station on site. By late 2016, the company had fully integrated their solar system with Oasis' existent energy system. The hotel has derived its energy from a hybrid system of solar and diesel since. With a current capacity of 50 rooms, the hotel's average occupancy during high seasons reaches 80%. Hotel management plans to open a second hotel in the coming year that will also use the energy generated by the solar station. KarmSolar's solar station was therefore sized to generate enough energy for both hotels. The second hotel is currently in the final phases of construction and is set to open its doors in the coming year.

Fig. 2: Solar panels at Oasis Hotel

Prior to the installation of the solar station, Oasis ran on two diesel generators that provided power to the entire resort: a Cumin generator with a capacity of 176 kW and a Caterpillar generator with a capacity of 256 kW. The generators were used interchangeably depending on the demand.

Fig. 3: Diesel generators at Oasis Hotel

Alongside the generators, a handful of rooms, both guest and staff, were installed with solar water heaters when the hotel first opened in 2010, and are still in use to this day. During a visit to Oasis, the site manager explained that of the 70 water heaters installed, solar heaters account for roughly 40-45. The heaters run automatically, heating water during the day and storing it for use within tanks. These tanks require regular maintenance and are replaced every two years or so as a result of corrosion. Although these solar heaters fulfil their function well, their impact in relieving the load on generators is minimal — given Marsa Alam's year-round warm weather, hot water consumption is not very high at the hotel. The site manager explained that the majority of the electricity generated goes toward air conditioning and the hotel's kitchen, since the hotel's activities are relatively limited.

In addition, 700 KarmSolar photovoltaic (PV) panels were installed on Oasis' grounds and are visible from the hotel gates. Each panel can generate up to 250 W of energy, with a cumulative capacity of 175 kW. The solar station was integrated into Oasis' existing generator station, and is capable of functioning autonomously alongside the generators.

This hybrid system's set-up follows a multistep process, most of which is automated. The PV panels function during the day, converting sunlight into direct current (DC) electricity, and an inverter converts this to alternating current (AC) to be fed into

3 THE HYBRID SYSTEM

Fig. 4: Solar water heaters at Oasis Hotel

the electric grid for commercial consumption. Once the energy has been converted to AC, it is sent to the hotel's power grid. A controller, a device that automates and manages the output of the solar station, is installed at the point where the solar and generator outputs are connected. Preconfigured with the generators' sizes, capacities and minimum loads, it simultaneously measures the hotel's energy demand and the amount of energy being produced by them, and runs the solar energy system accordingly.

According to Omar Hosny, chief technical officer at KarmSolar, diesel generators have a recommended minimum load at which they must run in order to maintain their efficiency.[26] For Oasis' generators, that minimum is 30-40% of total capacity. One of the main functions of the solar energy system is to alleviate the burden on the generators, while ensuring that the minimum load is being met in order to safeguard the generators' longevity. At 20-millisecond iterations, the controller measures energy demand and, depending on which generator is in use, determines the solar energy output accordingly.

The controller also plays a pivotal role in preventing a reverse flow of electricity from the panels to the generators, which can occur if the hotel's energy demand declines and the solar station's output remains constant. In this instance, the controller's 20-millisecond iteration measurements are crucial in ensuring that the output of the solar station matches the hotel's required load, so as not to damage the generators. Although the station is on site, Oasis plays no part in the management of the system, or upkeep of the panels. Hosny explains that KarmSolar is responsible for the maintenance of all parts of the system.[27] A technician from KarmSolar is regularly present at the site, tasked with monitoring the system and its performance, as well as undertaking maintenance and servicing.

Fig. 5: Controller at Oasis Hotel

Since the installation of the solar station, Oasis has modified the way that the generators run in order to accommodate the new system, and has invested in a third, smaller Cumin generator with a capacity of 130 kW. Technicians at the hotel set the generators' runtimes according to a variable schedule, since the sun sets almost two hours earlier during the winter than during the summer. The 176 kW Cumin gener-

[26] Omar Hosny (KarmSolar), telephone interview with Youmna Hashem, December 14, 2017.
[27] Ibid.

ator runs during the late hours of the night and into the early hours of the morning. As this is the time when the majority of guests are in their rooms, the generator mainly supplies the hotel's air conditioning system. During the day, when there is plenty of sunlight, the 130 kW Cumin generator runs, allowing for the solar station to carry the majority of the load. The 256 kW Caterpillar generator — the largest of the three types — runs from sunset and throughout the evening. The generators' fuel consumption is thereby reduced, helping to decrease expenditure on purchasing and transporting diesel, while wear and tear on the generators is also minimized, resulting in lower maintenance costs and longer lifespans.

The installation and integration process was not without its challenges. Hosny explained that this is common when integrating solar systems into an existing energy system, particularly if the existing energy system is primitive or outdated; rarely are existing systems equipped with the means to accommodate future integration of different systems.[28] When this is the case, it becomes difficult for installers like KarmSolar to trace the layout of the set-up in order to connect their own. Oasis' set-up required KarmSolar to upgrade several of the enclosure's components, such as cabling.

Although Oasis runs on a hybrid system of diesel and solar, Hosny clarified that this is not the only option available to those interested in transitioning to solar energy.[29] Each instance requires a thorough assessment of energy needs, budget, and existing set-up. In theory, it would be possible for Oasis to completely overhaul their generators and operate purely on solar energy. However, budget constraints are significant. The components required to store solar energy — solar batteries — are still prohibitively expensive, rendering them unattractive to interested parties in comparison to alternative methods available. As long as storage remains costly, and viable solutions such as hybrid systems exist, it is unlikely that those with limited capital will be interested in investing in standalone systems.

The installation and integration of solar into the hotel's energy supply doubtless contributes to a more sustainable use of energy in the long run. However, in the short term, the question of the most efficient use of resources stands: can the use of generators be optimized in a way that further capitalizes on solar energy production? The following sections critically assess the efficiency of the hybrid system, discussing the analysis carried out on the available data for both the generators and solar, and providing recommendations based on the findings.

[28] Ibid.
[29] Ibid.

4 DATA ANALYSIS

The following section outlines the data analysis undertaken to assess the efficiency of the hybrid system at Oasis Hotel. This includes a detailed exploration of the data sources, historical and projected energy consumption, assumptions, and observations from the analysis. The data depicts the energy consumed by the hotel over the 2016-2017 period, and is broken down by energy source (solar versus diesel). Based on this data, projections can be made for the opening of a second hotel with a 40-room occupancy.

The data utilized in the case study was collated from a number of sources. Data methodology and presentation differed, as outlined in the following section.

4.1. Data Sources

Audit reports provided by Oasis Hotel contained data on energy consumption during winter and summer months, diesel prices, energy production by diesel generator, energy production by solar panels, capacity of generators and daily usage, related expenses, and maintenance fees. In 2013, Energy and Environmental Consultants (ERCC), an engineering and consulting firm based in Cairo, conducted an energy audit for the hotel. The audit, which was published in early 2014, recommended the use of a hybrid solar energy system instead of dependence on generators alone. The report provided this case study with critical data that enabled comparison of the energy set-up before and after the installation of solar panels.

This case study also utilizes data, accessed through an online PV monitoring system, on the hotel's solar energy consumption. The online portal monitors the consumption and production of energy by the solar panels. Through analyzing the performance of the panels, the system then identifies losses and savings in energy, and visualizes it with graphs and tables.

In addition to these datasets provided, two interviews were conducted by the A2K4D team with Samir Hammam, the managing director of Oasis Hotel, and Omar Hosny from KarmSolar. These interviews provided key context and details that allowed researchers to construct a timeline of the installation process. Finally, a site visit was conducted, with a guided tour by the site manager, who provided further technical information on the set-up of the solar station.

4.2. Historical Energy Consumption

In order to accurately analyze the current energy system's efficiency and make projections about its future, valuable context is provided by past data. The following subsection looks at the key historical data.

The current hybrid system of diesel generators and solar energy fulfills Oasis' energy needs. As solar energy service provider, KarmSolar is responsible for providing the hotel with a portion of energy in daytime hours only. The hotel depends on diesel generators for the remaining portion of energy during the daytime and throughout the night.

4 DATA ANALYSIS

Capacity	Number of units	Operating hours	Period of day
256 kW	2	6	6 pm-12 am
176 kW	1	9	12 am-9 am
130 kW	1	9	9 am-6 pm

Fig. 6: Operating schedule of diesel generators at Oasis Hotel

As outlined in Figure 6, Oasis depends on four diesel generators with different capacities, each following different schedules throughout the day.

Utilization	Jan 17	Feb 17	Mar 17	Apr 17	May 17	Jun 17	Jul 17	Aug 17	Sep 17
Solar energy	2,999	1,966	3,499	4,824	6,040	9,847	14,832	14,870	15,967
Diesel generators	35,859	41,227	40,345	40,890	45,898	48,209	51,533	54,612	47,958
Total kWh	38,858	43,194	43,844	45,714	51,938	58,056	66,365	69,482	63,926

Fig. 7: Total kWh consumed from January 2017 to September 2017

Total energy consumption between January and September 2017 is presented in Figure 7. The figures for solar energy generated were extracted from invoices issued by KarmSolar, while the figures for energy generated from diesel generators come from estimates based on the schedule detailed in Figure 6. It is worth noting that, regardless of the actual amount of solar energy utilized per month, the hotel is required to pay a minimum monthly utilization fee that entitles it to 20,000 kWh of energy per month.

As displayed in Figure 8, the use of solar energy increased steadily from January 2017 to September 2017, while the total consumption of diesel decreased.

Actual percentage of total consumption	Jan 17	Feb 17	Mar 17	Apr 17	May 17	Jun 17	Jul 17	Aug 17	Sep 17
Solar	22%	13%	23%	30%	33%	48%	64%	61%	71%
Diesel	78%	87%	77%	70%	67%	52%	36%	39%	29%

Fig. 8: Actual percentage of total consumption of solar and diesel energy

Total	Jan 17	Feb 17	Mar 17	Apr 17	May 17	Jun 17	Jul 17	Aug 17	Sep 17
Utilization of diesel generators (kWh)	35,859	41,227	40,345	40,890	45,898	48,209	51,533	54,612	47,958
Liters of diesel	14,599	14,310	14,945	14,877	15,074	18,075	18,321	19,390	18,764
Actual kWh produced/li ter	**2.46**	**2.88**	**2.70**	**2.75**	**3.04**	**2.67**	**2.81**	**2.82**	**2.56**

Fig. 9: Actual kWh produced per liter from January 2017 to September 2017

The total quantities of diesel fuel purchased by the hotel from January 2017 to September 2017 are presented in Figure 9. By dividing the total amount of energy produced by the diesel generators (Fig. 7) by the total quantity of diesel liters, the energy produced per liter of diesel by the generators was calculated. The calculations, illustrated in Figure 9, indicate that the generators produced an average of 2.74 kWh/liter during the period. This data is later used to assess the efficiency of the diesel generators.

According to ERCC's audit report, throughout 2013, the generators produced an average of 1.88 kWh/liter. The report further stated that, data from the manufacturer put the generators' average operational efficiency at 3.33 kWh/liter — a figure almost double that of the generators' actual production.[30] A comparison of pre- and post-solar installation averages indicates that the hybrid system has helped increase the generators' operational efficiency. In doing so, the system helps extend the lifespan of the generators, as operating below recommended capacity is considered detrimental to diesel generators. The average kWh produced per liter of diesel is a vital conversion factor for our analysis, which will be used to estimate the number of liters of diesel required.

4.3. Future Energy Consumption

Figure 10 presents the monthly energy consumption for Oasis' existing 40 rooms and, based on these figures, makes projections for future energy consumption once the new hotel begins to operate.

	40 rooms	80 rooms
During summer	65,000 kWh/month	130,000 kWh/month
During winter	40,000 kWh/month	80,000 kWh/month

Fig. 10: Estimated energy consumption for 40 and 80 rooms during winter and summer

[30] ERCC, "Energy Audit Report For Oasis Marsa Allam Resort" (Cairo: ERCC, 2017) 6.

The allocation of energy consumption over the course of the day is as follows, based on rough estimates provided by the site's manager:

Period of day	(%) of kWh consumed
6 pm-12 am (Night)	45%
12 am-9 am (Night)	20%
9 am-6 pm (Daylight)	35%

Fig. 11: Energy consumption during the day

Solar Station Assumptions

The solar station is able to supply the hotel with a total capacity of 153 kW. As outlined in Figure 12, the solar station generates a monthly average of 25,347 kWh, whereby one kWh is sold for EGP1.35/kWh. As previously noted, regardless of the amount of solar energy consumed per month, Oasis Hotel is required to pay for a minimum monthly utilization of solar energy, which is fixed at 20,000 kWh.

Solar power capacity (kW)	153
Average solar peak (hours/day)	5.52
Total operating days	360
Average annual production (kWh)	304,164
Average monthly production (kWh)	25,347
Minimum monthly consumption (kWh)	20,000
Selling price (EGP/kWh)	1.35

Fig. 12: Solar station assumptions

4.4. Comparative analysis between diesel generators and the hybrid system

The model presented in this analysis compares two approaches taken to produce energy during daylight hours. The first approach looks at the monthly cost of using diesel generators alone, and the second looks at the monthly cost of using the hybrid system. The amount of energy produced during the day is calculated by multiplying the energy consumed per month for the given season (summer or winter) shown in Figure 10 by 35% (the percentage of energy consumed during daylight) shown in Figure 11.

Approach 1: The first approach is based on assuming the quantity of diesel by dividing the amount of energy produced during daylight hours by the conversion factor (energy produced per liter of diesel) in the two scenarios illustrated above, using average rate and historical rate. Then, by multiplying the cost of diesel — EGP3.95/liter — by the number of liters of diesel required to meet energy needs during daylight hours. This calculation provides a total cost of the first approach.

Approach 2: The second approach — using a hybrid system — combines the use of diesel generators and solar energy, whereby solar energy provides the largest share of energy during the daytime. While there is no exact measurement, solar energy is estimated to contribute around two thirds of total output. The share of energy produced by the diesel generator (one third of energy required during daylight hours) will be calculated using the same methodology as the first approach, outlined above. The remaining two thirds will be calculated by multiplying the price of energy (i.e. EGP1.35/kWh) by the amount of solar energy produced, given a minimum monthly consumption of 20,000 kWh and maximum of 25,347 kWh. Any consumption over the maximum will be supplied through diesel generators on the same basis as the first approach.

4 DATA ANALYSIS

Using Diesel Generators	
Total Power Required	22,750
Total Diesel Liters Consumed	8,295
Total Cost	**32,767**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	15,167
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	7,583
Total Diesel Liters Consumed	2,765
Total Cost of Diesel	**10,922**
Total Cost of Hybrid System	**37,922**
Summer Total Savings	**-5,156**

Using Diesel Generators	
Total Power Required	14,000
Total Diesel Liters Consumed	5,105
Total Cost	**20,164**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	9,333
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	4,667
Total Diesel Liters Consumed	1,702
Total Cost of Diesel	**6,721**
Total Cost of Hybrid System	**33,721**
Winter Total Savings	**-13,557**

Fig. 13: The monthly cost of diesel generators versus a hybrid system for 40 rooms during summer and winter, based on an average rate of 2.74 kWh/liter

Using Diesel Generators	
Total Power Required	22,750
Total Diesel Liter Consumed	12,101
Total Cost	**47,799**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	15,167
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	7,583
Total Diesel Liter Consumed	4,034
Total Cost of Diesel	**15,933**
Total Cost of Hybrid System	**42,933**
Summer Total Savings	**4,866**

Using Diesel Generators	
Total Power Required	14,000
Total Diesel Liters Consumed	7,447
Total Cost	**29,415**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	9,333
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	4,667
Total Diesel Liters Consumed	2,482
Total Cost of Diesel	**9,805**
Total Cost of Hybrid System	**36,805**
Winter Total Savings	**-7,390**

Fig. 14: The monthly cost of diesel generators versus a hybrid system for 40 rooms during summer and winter, based on a historical rate of 1.88 kWh/liter

Using Diesel Generators	
Total Power Required	45,500
Total Diesel Liters Consumed	16,591
Total Cost	**65,533**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	30,333
Total Solar Power Consumed	25,347
Total Cost of Solar System	**34,218**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	20,153
Total Diesel Liters Consumed	7,348
Total Cost of Diesel	**29,026**
Total Cost of Hybrid System	**63,245**
Summer Total Savings	**2,289**

Using Diesel Generators	
Total Power Required	28,000
Total Diesel Liters Consumed	10,210
Total Cost	**40,328**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	18,667
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	9,333
Total Diesel Liters Consumed	3,403
Total Cost of Diesel	**13,443**
Total Cost of Hybrid System	**40,443**
Winter Total Savings	**-115**

Fig. 15: The monthly cost of diesel generators versus a hybrid system for 80 rooms during summer and winter, based on an average rate of 2.74 kWh/liter

Using Diesel Generators	
Total Power Required	45,500
Total Diesel Liters Consumed	24,202
Total Cost	**95,598**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	30,333
Total Solar Power Consumed	25,347
Total Cost of Solar System	**34,218**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	20,153
Total Diesel Liters Consumed	10,720
Total Cost of Diesel	**42,343**
Total Cost of Hybrid System	**76,561**
Summer Total Savings	**19,037**

Using Diesel Generators	
Total Power Required	28,000
Total Diesel Liters Consumed	14,894
Total Cost	**58,830**
Using Hybrid System	
Dependency on Solar Power	0.67
Total Solar Power Required	18,667
Total Solar Power Consumed	20,000
Total Cost of Solar System	**27,000**
Dependency on Diesel Generators	0.33
Total Power Required by Generator	9,333
Total Diesel Liters Consumed	4,965
Total Cost of Diesel	**19,610**
Total Cost of Hybrid System	**46,610**
Winter Total Savings	**12,220**

Fig. 16: The monthly cost of diesel generators versus a hybrid system for 80 rooms during summer and winter, based on a historical rate of 1.88 kWh/liter

Figure 17 outlines the results of the comparative analysis, showing potential savings or losses per month for each scenario. This is calculated by applying each approach during summer and winter, with both the existing and the potential number of rooms, using the conversion factor for both scenarios (average rate of 2.74 kWh and historical rate of 1.88 kWh). Summer runs from April to September and winter runs from October to March.

Number of rooms	40 rooms				80 rooms			
Season	Summer		Winter		Summer		Winter	
kWh produced per liter of diesel	2.74	1.88	2.74	1.88	2.74	1.88	2.74	1.88
Savings/(losses) in EGP	(5,156)	4,866	(13,557)	(7,390)	2,289	19,037	(115)	12,220

Fig. 17: Results of the comparative analysis

4.5. Outcomes

With Oasis Hotel's current capacity of 40 rooms, using the average amount of energy produced per liter by the diesel generator (2.74 kWh), it can be observed that, during the summer, the total cost of using the diesel generators is EGP32,767, as opposed to the total cost of the hybrid system (EGP37,922), a difference of EGP5,156. In the winter, the total cost of the hybrid system is EGP13,557 more than that of diesel generators alone.

However, for a projected 80 rooms, the outcome is different. If the hybrid system is used during the summer months, it could save Oasis Hotel a total of EGP2,289. If used in the winter months, it could save a total of EGP155.

The observations differ when using the historical rate of energy produced per liter by the diesel generator. If the generators produce 1.88 kWh per liter of diesel, using the hybrid system would be beneficial for Oasis. It could potentially save EGP4,866 in summer for 40 rooms and EGP19,037 for 80 rooms. It would still lose EGP7,390 in winter for 40 rooms, but it would save EGP12,220 for 80 rooms.

12 am-9 am (Night)	20%
9 am-6 pm (Daylight)	35%
6 pm-12 am (Night)	45%
Average Consumption in Summer (40 Rooms)	65,000
Average Consumption in Winter (40 Rooms)	40,000
Average Consumption in Summer (80 Rooms)	130,000
Average Consumption in Winter (80 Rooms)	80,000
Average kWh produced/liter	2.74
Historical kWh produced/liter	1.88
Price of Diesel/Liter	3.95

Fig. 18: Energy Consumption Figures

One of the main observations is that there is a large variance between the historical average of the energy produced per liter by the generators (1.88 kWh), the average calculated over the last nine months (2.74 kWh) and optimum production (3.33 kWh). It is crucial to identify the reasons as to why optimum production is not being reached. Increasing the production output of the generators may help reduce the number of generators, or enable Oasis Hotel to use smaller generators. The difference between the historical rate (1.88 kWh/liter) and the average rate (2.74 kWh/liter) already affects the efficiency of the generators when used alongside the solar panels.

Solar power capacity (kW)	153
Average solar peak (hours/day)	5.52
Total operating days	360
Average annual production (kWh)	304,164
Average monthly production (kWh)	25,347
Minimum monthly consumption (kWh)	20,000
Selling price (EGP/kWh)	1.35

Fig. 19: Energy production figures

The conversion factor is vital in the presented analysis. For instance, assuming the average rate is 2.74 kWh/liter, the hybrid system is inefficient during summer and winter for generating energy for 40 rooms, while partially efficient for generating energy for 80 rooms (but only during the summer), as shown below in figures 20 and 21.

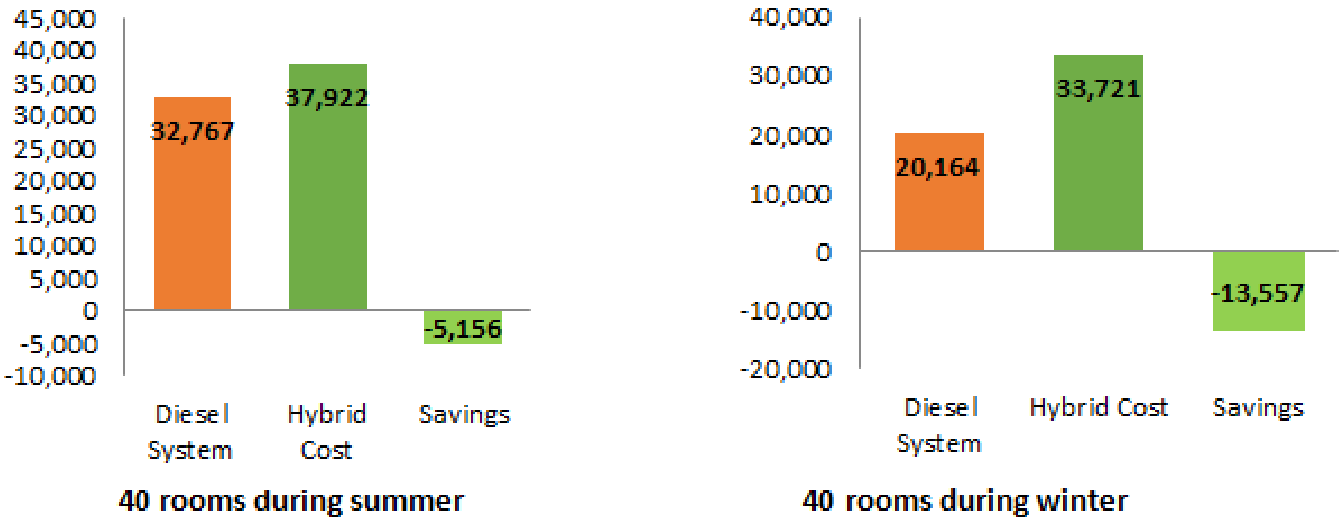


Fig. 20: Scenario 1 — 40 rooms during summer and winter, using an average rate of 2.74 kWh/liter

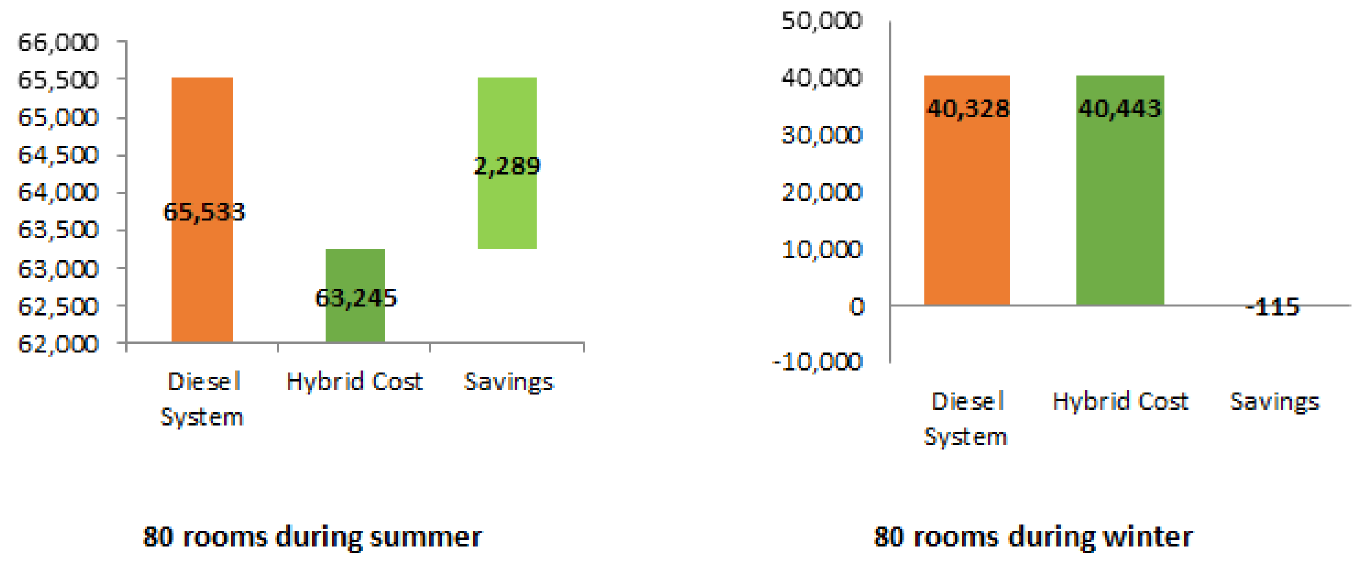


Fig. 21: Scenario 2 — 80 rooms during summer and winter, using an average rate of 2.74 kWh/liter

Using the historical rate (1.88 kWh/liter), the hybrid system is only inefficient when generating energy for 40 rooms during winter. It is efficient, however, during summer for generating energy for 40 rooms, and when generating energy for 80 rooms during both summer and winter, as shown in figures 22 and 23.

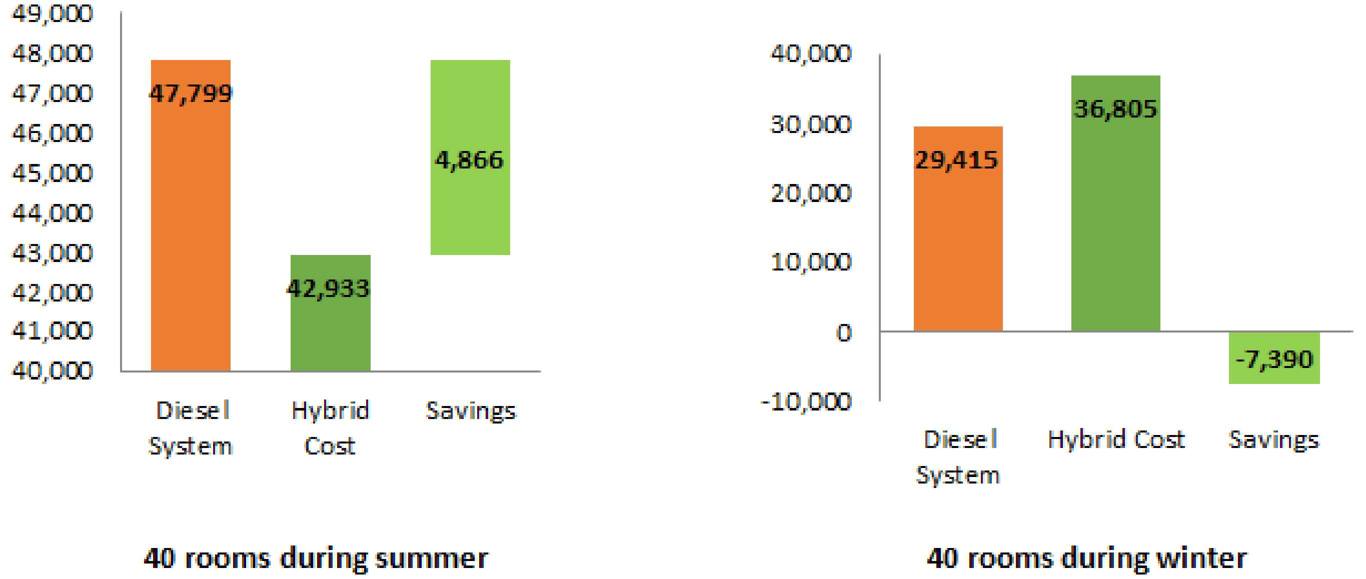
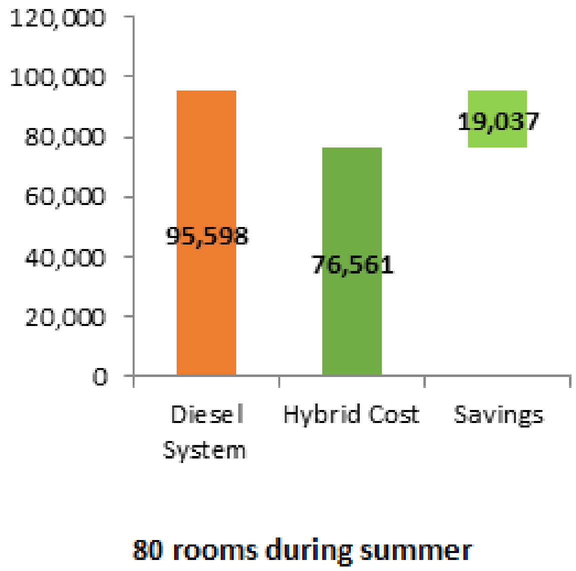


Fig. 22: Scenario 1 — 40 rooms during summer and winter, using a historical rate of 1.88 kWh/liter



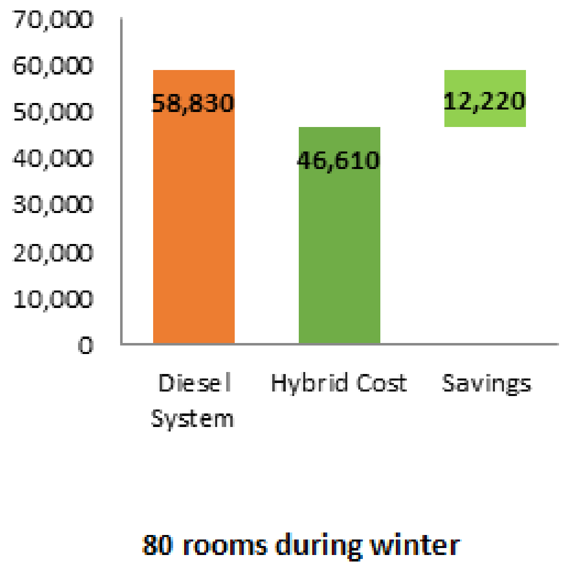


Fig. 23: Scenario 2 — 80 rooms during summer and winter, using a historical rate of 1.88 kWh/liter

5.1. Recommendations

The recommendations below take into account the following:

1. During daylight hours, the hybrid system derives one third of its energy from diesel generators, and two thirds from solar energy.

2. A generator is assumed to work on average half a load for nine hours per day for 30 days (see Annex for data sheet).

3. Two different conversion factors were used in these calculations, the historical rate and the average rate (1.88 and 2.74 kWh per liter, respectively).

Accordingly, based on the total energy required to be produced by diesel generators, Oasis Hotel could run more efficiently by reducing the capacity of their generators as detailed in the following:

A) Using average kWh/liter = 2.74

Number of rooms	40 rooms		80 rooms	
Season	Summer	Winter	Summer	Winter
Total energy required to be produced by generator (kWh)*	7,583	4,667	20,153	9,333
Recommended generator capacity (kW)	40-60	30	40-60 and 135	75

Fig. 24: Recommended generator capacities at average rate of 2.74 kWh/liter

As shown in the table above, to make the hybrid system more efficient, Oasis should purchase smaller generators than the four they currently possess. A smaller generator with a capacity of 40-60 kW would be sufficient to cover the needs of 40 rooms in summer, and another one with a capacity of 30 kW in winter. To provide energy for 80 rooms, the hotel would need two generators in summer with capacities of 40-60 kW and 135 kW, and one with a capacity of 75 kW in winter.

B) Using historical rate of 1.88 kWh/liter

Number of rooms	40 rooms		80 rooms	
Season	Summer	Winter	Summer	Winter
Total energy required to be produced by generator (kWh)[31]	7,583	4,667	20,153	9,333
Recommended generator capacity (kW)	100	40-60	125 and 135	125

Fig. 25: Recommended generator capacities at average rate of 1.88 kWh/liter

If the average production of the generators is 1.88 kWh/liter, generator capacity will need to increase to cover the hotel's needs. For 40 rooms, one generator with a capacity of 100 kW for summer and one with a capacity of 40-60 kW for winter will be efficient. The projection for 80 rooms identified a need for two generators with capacities of 125 kW and 135 kW respectively in summer, and one with a capacity of 125 kW in winter.

[31] These figures were arrived at by comparing the energy required to be produced by generators with the expected output of each generator. The total energy generated was calculated by multiplying three factors by one another: the diesel consumed in liters, by the generator when operating at half-load capacity; the energy produced per liter consumed; and the generator's total operating hours per month. These figures are shown in the Annex.

6 REFLECTION

This case study was undertaken with two objectives: firstly, to document the experience of Oasis Hotel in transitioning to a hybrid solar energy system, and secondly, to quantitatively analyze the efficiency of the system. The study was compiled in cooperation with the hotel management, who provided researchers with audit reports and data, and partially sponsored a site visit. While Oasis has operated using this hybrid system since 2014, the question of the most efficient use of the system becomes pertinent in light of the planned establishment of a second hotel nearby.

The solar station at Oasis was installed by KarmSolar. The off-grid system currently provides energy to the first Oasis Hotel with a capacity of 40 rooms, and is expected to provide energy to the second hotel at the same capacity. The transition to solar energy began in 2014, when solar energy was integrated into the energy mix alongside diesel-run generators. The hotel had previously been entirely dependent on the use of diesel fuel. The use of this fossil fuel has adverse effects on the environment and is closely linked to climate change.

One of the main motivations for this transition was the appeal of resource efficiency. Solar energy is both an abundant and non-depletable resource. The installation would ideally allow Oasis Hotel to both curb its dependency on diesel, and mitigate harmful effects on natural resources. Businesses and policymakers who wish to encourage sustainable tourism in Egypt must aim to both protect natural resources and develop local enterprises and communities.

This case study investigates the economics behind installing solar energy, providing preliminary research and evidence for other companies in the tourism sector looking to invest in renewables. Currently, the diesel generators contribute around one third of the hotel's energy needs, while solar energy contributes two thirds, during the daytime only. This changes between summer and winter months. A total of four generators of different capacities are used to power the hotel. Due to the set-up of the original diesel system, a full transition to solar energy was not considered to be a viable option for Oasis.

The study focuses specifically on two questions: whether the hybrid system would save the hotel money, and if there is a more efficient way to depend on generators, either through lower usage, or the use of smaller generators. This was calculated for two scenarios, the first being the current capacity of one hotel (40 rooms), and the second the projected capacity of two hotels (80 rooms).

The findings of the case study indicate that, as it stands, the hybrid system is costlier than the use of diesel generators alone, but could allow for marginal savings for the scenario in which two hotels are attached to the same grid. The study found a potential source of inefficiency: the output of generators running below optimal levels, which could affect the outcome. This variable warrants further investigation. Another option would be to purchase smaller generators, lowering overall costs in both scenarios.

There are, of course, limitations to these findings. Possible environmental costs or benefits of installing this system was not accounted for, and could potentially sway any decision regarding the merits of installing off-grid solar energy systems. Additionally, it is difficult to predict future changes in diesel prices in Egypt, which could likewise affect the profitability of a hybrid system.

Nonetheless, the study engages with an important conversation taking place around the potential for sustainable tourism to contribute to Egypt's economic and environmental development. Environmental degradation is of particular concern for tourist destinations, like Marsa Alam's Oasis Hotel, which depend on the beauty of their surroundings for income. Furthermore, diesel, which is imported to Egypt, was always a consistent monthly expense for the hotel; its price is likely to increase in coming years. Sustainability, in both the business and environmental sense, is a crucial direction for future research, and one to which this case study hopes to have contributed.

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ANNEX

Operating Hours per day (daylight)	9
Number of days	30
Average energy produced (kWh/liter)	2.74
Historical energy produced (kWh/liter)	1.88

Number of liters consumed per kWh based on generator size and load.

Generator size (kW)	Liters/hour			
	1/4 load	1/2 load	3/4 load	Full load
20	2.28	3.41	4.93	6.06
30	4.93	6.82	9.09	10.98
40	6.06	8.71	12.12	15.15
60	6.82	10.98	14.39	18.17
75	9.09	12.88	17.42	23.1
100	9.85	15.53	21.96	28.02
125	11.74	18.93	26.88	34.45
135	12.5	20.45	28.77	37.1
150	13.63	22.34	31.8	41.27
175	15.53	25.75	36.72	48.08
200	17.8	29.15	41.64	54.51
230	20.07	33.32	47.32	62.84
250	21.58	35.97	51.49	68.14
300	25.75	42.78	60.95	81.39
350	29.91	49.59	70.79	95.02
400	33.7	56.41	80.63	108.27
500	41.64	70.04	99.94	135.14
600	49.97	83.28	119.24	162.02
750	61.70	103.72	148.77	202.14
1000	81.76	137.79	197.22	269.14
1250	101.83	171.48	246.05	336.14
1500	121.89	205.55	294.50	403.15
1750	141.95	239.24	343.34	470.15
2000	162.02	273.31	391.79	537.15
2250	182.08	307.00	440.62	604.15

ANNEX

Half load	
Average rate	**Historical rate**
2,525	1,731
5,050	3,462
6,450	4,421
8,130	5,573
9,537	6,538
11,500	7,883
14,017	9,609
15,143	10,380
16,542	11,340
19,067	13,071
21,585	14,797
24,673	16,913
26,635	18,258
31,678	21,715
36,720	25,172
41,770	28,634
51,863	35,552
61,666	42,272
76,802	52,648
102,029	69,942
126,976	87,043
152,203	104,336
177,150	121,437
202,377	138,730
227,324	155,832