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A Feasibility Study on CHP Systems for Hotels in the Maltese Islands: A Comparative Analysis Based on Hotels' Star Rating

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Abstract: In Europe, the energy consumed for heating and cooling purposes by the hospitality sector is significant. In island economies such as that of the Mediterranean Island of Malta, where Tourism is considered essential to the local economy, energy consumption is perhaps even more significant, and energy-efficient systems, or the use of renewable energy, are often listed as possible solutions to counter this. Based on this premise, the research contained in this paper presents an investigation on the technical and financial feasibility of using Combined Heat and Power (CHP) and Combined Cooling, Heating, and Power (CCHP) systems for the hospitality sector in Malta. Using a supply–demand design methodology, the research made use of the software package RETScreen to model the electrical and thermal demand of a number of hotels ranging from 3- to 5-star hotels. Based on these modelled hotels, different scenarios were simulated to analyze the technical and financial implications of installing a CHP in these modelled hotels. A number of parameters, including thermal size matching, presence of financial grants, electricity tariffs, feed-in tariffs, and fuel prices, were tested out for a total of 144 scenarios. Results showed that the parameters having the highest impact were those of a financial nature. Specifically, the study showed that the 4-star hotels considered were the hotels which would benefit the most from having such systems installed.

Keywords: combined heat and power; hospitality; feasibility; sensitivity analysis; simple payback

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Citation: Magro, B.; Borg, S.P. A Feasibility Study on CHP Systems for Hotels in the Maltese Islands: A Comparative Analysis Based on Hotels' Star Rating. *Sustainability* **2023**, *15*, 1337. https://doi.org/10.3390/su15021337

Academic Editors: Oz Sahin and Russell Richards

Received: 17 December 2022
Revised: 2 January 2023
Accepted: 9 January 2023
Published: 10 January 2023

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1. Introduction

The Energy Performance of Buildings Directive (2012/27/EU) [1], and subsequent revision (2018/844/EU) [2], highlight the fact that around 40% of the EU's final energy consumption is used for building space heating and cooling.

Hotels are no different from any other building, in so far as energy requirements go, and they require energy commodities such as space heating and cooling, domestic hot water, and electricity, and often this energy requirement is significant. In fact, given the building typology and the type of activity going on in hotels, various authors have highlighted how, compared to other buildings, hotels are significant energy consumers. Pérez-Lombard et al. [3], for example, highlighted how in 2003 the energy consumed by hotels as a percentage of the total energy consumed by the commercial sector varied between a minimum of 14% in the USA and a maximum of 30% in Spain. Likewise, Smitt et al. [4] describe hotels as very energy-intensive buildings whose market, at least until the onset of COVID-19 in 2020, experienced a significant annual growth of between 7–13%.

In response to this, on a national level, various countries have placed emphasis on reducing energy dependency, especially where heating and cooling are involved, and a number of legislative, technical, and academic documents encourage the introduction of measures that promote energy-efficient systems, such as cogeneration installations as an alternative to traditional heating and cooling.

The Mediterranean Islands of the Maltese Archipelago are no different from any other developed country, and the fact that the country heavily relies on tourism [5] makes this aspect even more important. The National Energy and Climate plan of Malta, for example, states that Malta needs to achieve an energy saving of 0.24% of the annual final energy consumption each year for the next 10 years until 2030 [6]. As is to be expected, in the hospitality sector heating and cooling are the predominant energy loads, with the plan highlighting that the main consumer of fuel-based spatial heating is the hospitality sector.

Based on this context, the scope of this paper is to present a holistic feasibility study on the use of Combined Heat and Power (CHP) and Combined Cooling, Heat and Power (CCHP) systems in hotel buildings in Malta. Contrary to most studies, however, rather than focusing on one type of hotel and its specific energy demands and commodity costs, this study takes into consideration a more high-level approach to cover a wider spectrum of hotels with their energy demands and boundary conditions. The objective of this study is therefore to observe the potential energetic and financial impacts that a CHP and a CCHP system has on a hotel, based on its star rating and eventually on its characteristics.

2. The Maltese Hotel Industry, Its Energy Consumption, and the Use of Cogeneration

2.1. Tourism in Malta—The Hotel Industry and Its Classification

According to Maltese legislation, Legal Notice 351 of 2012 (Tourism Accommodation Establishments) [7], hotels in Malta are classified into five classes (or stars), with the classification being based on several criteria which licensed hotels must abide by in order to get classified. Such criteria include aspects such as cleanliness, general impression, reception, room equipment, noise control and air conditioning, sleeping comfort, public areas, facilities, etc. Based on these criteria, each hotel is given points and ranked according to the standard achieved. Focusing particularly on the three- to five-star hotel range, for which this research is intended, given that this industry segment equates to almost 83% of the total beds in serviced accommodation, a 3-star hotel has to obtain 250 points, a 4-star hotel has to attain 380 points, while a 5-star hotel has to attain and maintain 570 points.

Based on this classification, and considering only the three- to five-star hotel range, the market size is as shown in Figure 1 [5].

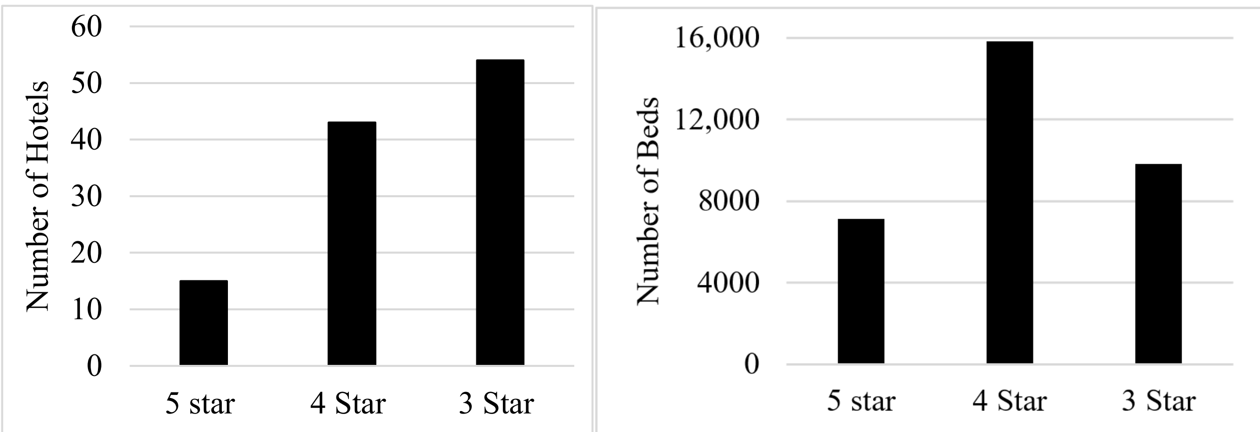

Figure 1. Number of Hotels (**left**), Number of Beds (**right**) in the three- to five-star hotel range.

2.2. Energy Consumption in the Hotel Industry in Malta

Although it is often thought that the energy consumption of a hotel is directly related to the respective hotel's classification, it is in fact more complex than this, and there are several factors impacting the energy consumption of hotels. Such factors often include occupancy rate, building typology, facilities within the hotel such as laundries and spas, etc. Whereas one manages to find the energy consumption of certain specific hotels, it is often difficult to find comprehensive studies studying the energy consumption of a range of hotels, often because such studies are expensive and cumbersome to make given the huge variety. In fact, it has been only recently that large hotels in Malta started being requested to produce energy audits in line with Legal Notice 196 of 2014 (Energy Efficiency and

Cogeneration Regulations) [8]. Since then, a benchmarking scheme has been established for the Maltese hospitality sector, and this has provided a good insight as to the energy consumption of hotels in Malta. This will be discussed in detail in Section 3.1.

2.3. CHP—Combined Heat and Power

One of the measures which is often brought forward to address energy-efficiency is the use of Combined Heat and Power. CHP, or cogeneration, is the simultaneous production of thermal and electrical energy, with the former being a utilized form of the waste energy stream of the latter [9]. The system takes the form of a prime-mover which produces electricity, from where waste heat can be recovered and utilized for multiple purposes, including water and space heating. With the addition of thermally activated chilling systems, the waste stream from cogeneration systems can also provide space cooling, and become known as trigeneration systems or Combined Cooling, Heat, and Power [10,11].

There are different prime-mover options available on the market which can be used as CHP systems, including fuel cells, reciprocating internal combustion engines, micro-turbines, gas turbines, and steam turbines. Whereas fuel cells are still not commercially competitive to satisfy the energy demands required, gas and steam turbines are only typically commercially competitive when required to satisfy energy demands, which are above what is typically required to satisfy the energy demands of a hotel [12]. Reciprocating internal combustion engines, on the other hand, are very flexible systems offering a wide range of power capacities, the possibility of heat being recovered at different locations and temperatures, and the possibility of using different types of fuels [12]. Based on this premise, and as will be discussed later, the prime mover which was considered for the purpose of this study was the reciprocating internal combustion engine.

Other than the energetic and environmental performance, the principal benefit of using a CHP system is economic, either through saved fuel costs [13] or through fiscal incentive schemes such as electricity feed-in tariffs (FIT) [14,15]. Various case studies have shown that savings created over the lifetime of such systems are enough to offset the total lifetime operating cost, including capital costs, running costs, and maintenance costs, and leave enough profitable margin to invest in the system [16–19]. Generally, most systems are used to reduce electricity costs, either as a base load system or else as an electricity peak shaving device, whichever makes most economic sense [16]. CHP systems also offer increased power reliability since power interruptions would have less of an impact [11]. Since CHP systems are more energy-efficient, a reduction in emissions such as CO_2, NOX, and SO_2 per kWh generated is also to be expected when compared to systems which generate heat and power separately. Additionally, grid-related benefits can be also obtained. These can include reduced grid congestion, reduced peak power requirements, and less transmission and distribution losses [12]. It is therefore no surprise that cogeneration accounts for more than 8% of the total electricity generation [20].

Notwithstanding this, many challenges keeping cogeneration and trigeneration units from reaching high market penetration levels remain. Such challenges are often associated with the financial risk inherent to an investment, which is considered as a significant upfront expenditure, coupled with the requirement of specialized technical knowhow, which must guarantee an optimized design for the specific circumstances where the investment is being made [21].

2.4. Cogeneration in the Hotel Industry

Literature is full of examples of cogeneration and trigeneration systems being integrated in hotels, either through simulation or as field studies of real case scenarios. Some such as Salem et al. [13] and Rotimi et al. [22] use an existing hotel for the optimum sizing of a CHP system using software. Others such as Galvao et al. [23] and Smith et al. [24] are more specific in their analysis of cogeneration in the hotel industry, focusing on bioenergy and thermal storage, respectively.

The focus, however, is always on individual case scenarios, targeting one hotel with its specific energy characteristics. The reason for this is that, as pointed out earlier, apart from the climatic conditions, there are several factors impacting the amount of energy which a hotel uses. These include physical parameters, such as the building footprint and construction typology, and the efficiency of the systems installed, and operational parameters such as the presence of catering facilities, laundries, swimming pools, spas, seasonality, and occupancy levels. All these contribute differently to the heating and cooling demand of a hotel.

Given this diversity, matching the CHP to the energy demand of a specific hotel is often a laborious task. Depending on whether they are thermally or electrically matched, CHP systems can perform at a loss if they are oversized, as there would be significant instances in time when they would be idle, unless of course heat is dumped or the system is made to work for a significant portion of time at part-load. Likewise, undersizing a system typically, though not always, does not allow the full potential of a CHP design to be obtained [25]. A financial analysis carried out on a number of UK hotels showed that the payback period for differently sized systems was typically in the order of 2.5 years when the CHP system was appropriately sized, whereas for smaller systems, although less expensive than the larger systems, the payback period was longer due to less savings [26]. It is, however, only fair to point out that such results have to be seen in the context of the fiscal environment where the CHP is operating.

Having a perfectly supply–demand matched CHP system is nonetheless important for the success of any project, and typically detailed studies are required for each specific hotel before any system is financed or given the go ahead. In this context, research [24] investigating the use of trigeneration systems for the hotel industry in North Cyprus found that when sizing the trigeneration system for the minimum base load, the system was more feasible than when sizing it for the maximum value of the base electrical load. In the cases investigated where the minimum base load was met, the simple payback period was between one to four years. For the trigeneration systems which were sized for the maximum electrical load, the simple payback period was between one to six years for systems connected to the grid [26].

3. Methodology

The paper hereby being presented makes use of a supply–demand design methodology, whereby the thermal and electrical characteristics of a number of representative hotels were first modelled using the software package RETScreen [27], for the results then to be subsequently used in a series of parametric sensitivity studies conducted to understand the effect of a number of parameters on the feasibility of a CHP or CCHP system deployed in a particular hotel typology.

Given that as discussed in the introduction the purpose of the analysis was a holistic, high-level approach to analyze the feasibility of CHP and CCHP systems in different hotel typologies in Malta, the software RETScreen was chosen, as it is a purposely designed tool aimed specifically at assessing the feasibility (both technical and financial) of clean or alternative energy technologies, such as cogeneration [28], under a variety of scenarios.

3.1. Modelling the Demand

The methodology made use of data measured and collected from six different hotels operational in the Maltese Islands. The data set was derived from surveys conducted for the BEST (Benchmarking Energy and Sustainability Targets) program [29], a benchmarking program initiated in 2016 aimed at monitoring energy consumption in hotels and putting forward simplified calculations for energy savings based on the use of energy-efficiency technologies. In this regard, Figure 2 shows a part-screenshot of some of the technologies which can be studied within the BEST platform, whilst Figure 3 shows the portal where the data can be inserted by the user.

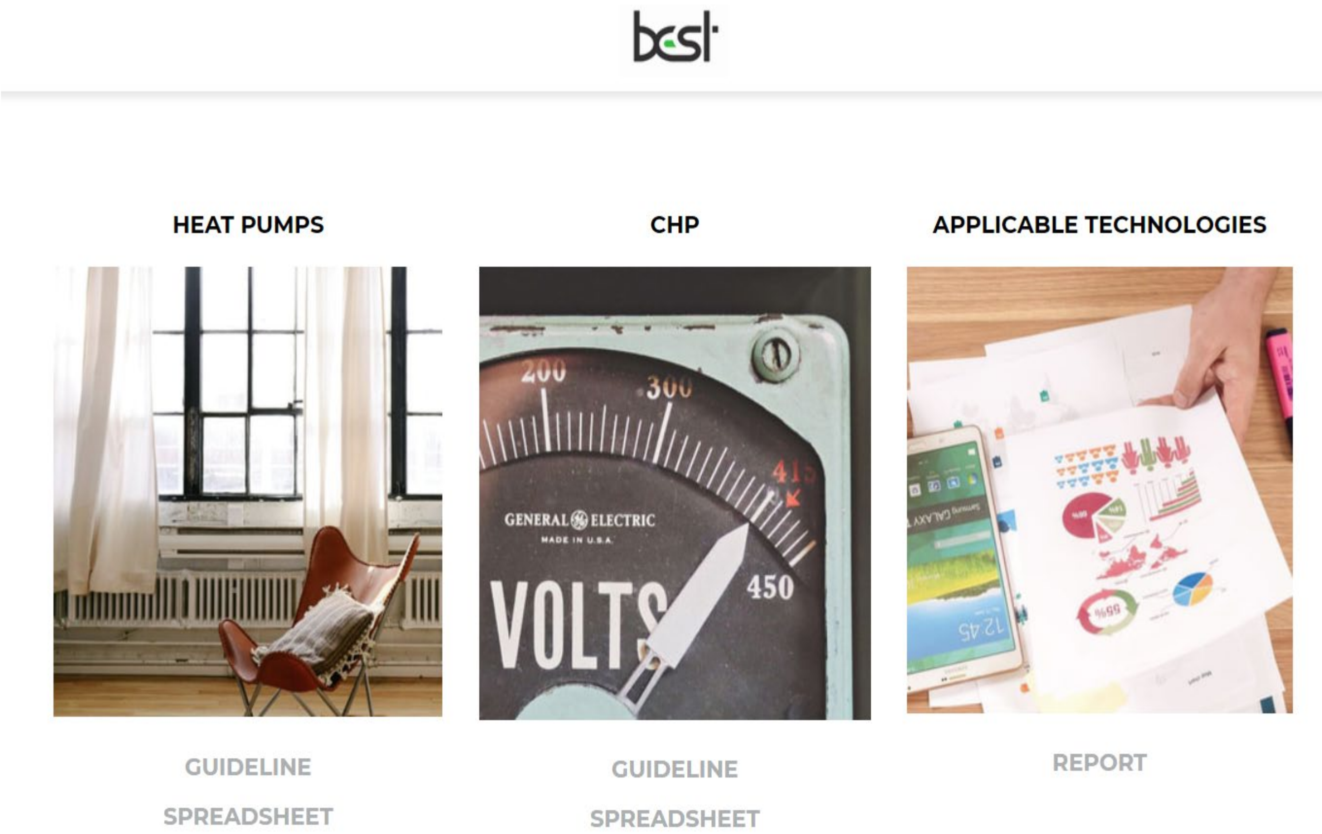

Figure 2. BEST platform showing some of the technologies which can be studied.

BEST Total Energy Show as Graph

Sector	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Amount kWh
Electrical Consumption (GRID Bought)	167 453	155 688	163 742	172 536	194 468	237 128	265 246	265 532	245 064	237 490	177 996	180 758	**2 463 101**
Fuel Consumption	116 421	88 993	124 860	110 208	90 020	105 204	74 471	81 546	64 459	86 570	100 750	151 667	**1 195 167**
Water Consumption	4 938	6 863	4 303	7 106	5 830	9 548	9 127	10 283	9 649	9 868	8 517	6 580	**92 612**
Total	**288 812**	**251 544**	**292 905**	**289 850**	**290 318**	**351 880**	**348 844**	**357 361**	**319 172**	**333 928**	**287 264**	**339 005**	**3 750 880**
Results per denominator													
Per m2	8,882	7,736	9,008	8,914	8,929	10,822	10,729	10,991	9,816	10,27	8,835	10,426	115,358
Per m2 * degree day													0,112
Per occupied room	120,943	98,375	92,897	79,848	75,722	95,88	105,55	88,324	79,893	81,486	81,632	139,222	92,318
Per occupied room * degree day													0,09
Per guest nights	74,667	63,457	58,336	50,655	45,172	54,725	59,196	46,531	46,304	47,272	51,731	79,992	54,556
Per guest night * degree day													0,053

Figure 3. BEST platform showing the energy input portal.

The data utilized in this study primarily consist of monthly electrical energy, water, fuel consumption data, and relative guest occupancy. The monthly data related to energy is subdivided into energy consumed, renewable energy generated, and heat produced. Other operational data, such as footprint and conditioned area, were also collected through this program. To create a diverse enough spectrum of hotels, the data of six different hotels were chosen. Two of the hotels had a 5-star rating, two had a 4-star rating, and two had a 3-star rating. Since the study is related to CHP systems, the heat demand was considered based on the fuel consumed for heating. Therefore, the 5-star hotels chosen had a despairing fuel consumption, with one higher than the other. The same reasoning was applied for the choice of the 4- and 3-star rated hotels. Although the physical size of the hotel was not the only factor impacting the electrical and/or fuel consumption, as the facilities offered also played a role, it was noted that the hotel with the higher energy consumption in each category was always practically double in size in terms of heated floor area (m^2). The data shown in Table 1 below is the data that was collected and used for the simulations. Given the financial nature of the data, only a limited amount of data is disclosed in this paper.

Table 1. Raw data used for the simulations.

	Hotel 1	**Hotel 2**	**Hotel 3**	**Hotel 4**	**Hotel 5**	**Hotel 6**
Star Rating	5-Star	5-Star	4-Star	4-Star	3-Star	3-Star
Current Fuel Type Used	Propane	Propane	Propane	Propane	Diesel	Diesel
DHW Heating Base Demand (%)	38	27	50	65	78	35
Total Propane Consumed (kg)	67,498	34,850	29,832	17,931	-	-
Total Diesel Consumed (l)	-	-	-	-	56,721	10,204
Power Gross Average Load (kW)						
January	624	177	55	46	89	31
February	666	181	77	68	90	31
March	660	176	79	65	92	26
April	690	199	84	64	96	21
May	751	230	93	69	99	27
June	940	308	109	97	143	31
July	1029	369	124	126	170	49
August	1083	368	122	124	179	52
September	1006	357	118	102	139	43
October	940	316	112	87	147	37
November	733	227	88	66	115	31
December	651	202	74	73	114	37

3.2. Paramters Investigated

Based on their technical and financial importance in conducting such a feasibility study, for this study five parameters were chosen, namely:

- the size of the CHP system—whether the system matched the heating demand of the hotel, or if it was undersized or oversized. The over- and undersizing was 20%.
- the availability of a financial grant—the presence of a financial grant covering 65%, 55%, and 45% of the capital cost. An analysis was also carried out without the assistance of any financial grant.
- the cost of fuel—For propane (5-star rated and 4-star rated hotels) (*hotel 1*–*hotel 4*), three fuel prices were considered, specifically: €0.6/kg, €0.5/kg, and €0.4/kg. For the 3-star rated hotels (*hotel 5* and *hotel 6*), the diesel prices considered were €1.212/l, €1.010/l, and €0.808/l. For both cases, the prices include an average middle price and a higher and lower price [30].
- the feed-in tariff—for the feed-in tariff, three levels were considered, namely, €0.11/kWh, €0.09/kWh, and €0.07/kWh.
- the electricity tariffs—the average local electricity tariff of €0.12/kWh [31] was used as the base case scenario, together with €0.09/kWh, €0.15/kWh, and €0.20/kWh.

It needs to be noted that although the prices and tariffs quoted for fuel and electricity, were the ones in force in 2020, these have remained largely unaltered over the last two years, as the Government of Malta decided to financially absorb and cap much of the international increases in energy prices. Therefore, notwithstanding some subtle increases, these increases are well within the ranges investigated in the study.

All simulations were carried out for the 6 hotels to gauge the feasibility of using such systems. Figure 4 shows the parameters and variables considered, and the different simulation combinations created.

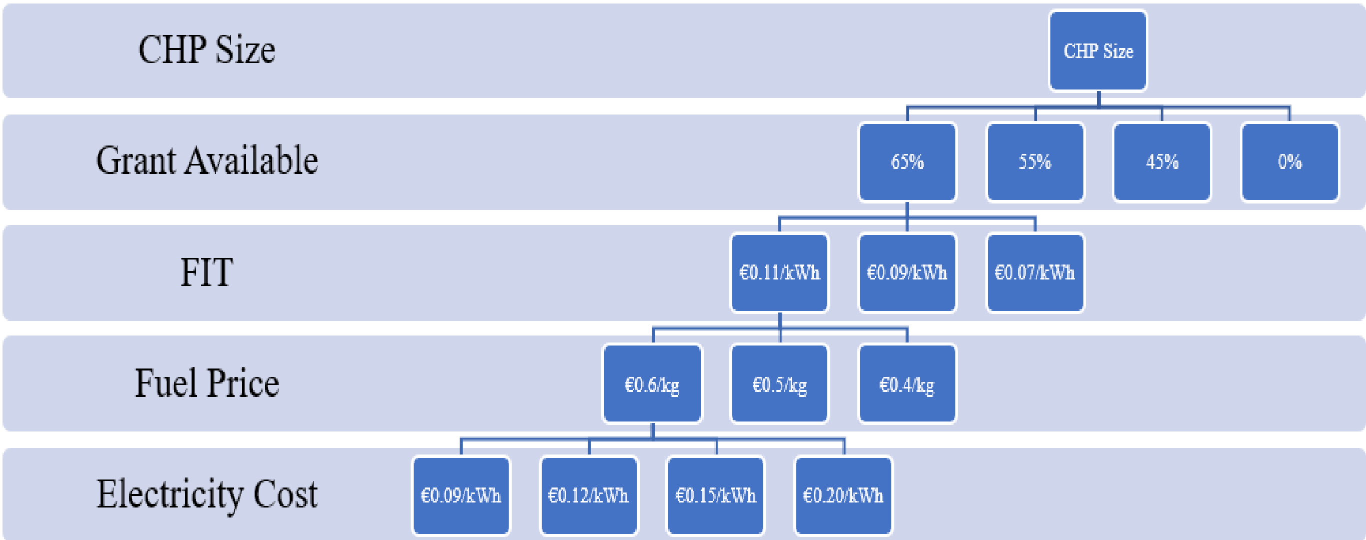

Figure 4. Parameters and variables investigated in each simulation.

3.3. Assumptions and Modelling Considerations

As part of the study, a number of assumptions needed to be considered. Below are some of the assumptions considered as part of the modelling created and the simulations carried out:

- As is the norm for such projects, it was assumed that for all scenarios investigated, the system was connected to the electricity grid.
- A heating load following control strategy was chosen as the mode of operation, based on the premise that the target of the reciprocating engines was to reduce the fuel consumption of the boilers while having the highest working efficiency.
- The lower heating values assumed were 48.1 MJ/kg for propane and 42.7 MJ/kg for diesel.
- The weather data file assumed was that for Malta.
- The seasonal efficiency chosen took into consideration that currently a boiler having mid-range efficiency of 65% is being used in all the hotels.
- The value of the domestic hot water base demands was chosen according to the amount of fuel which was used by the respective hotel.
- For the simulations considering the CCHP system, the thermally activated chiller was assumed to be a single stage absorption chiller having a seasonal coefficient of performance of 0.5, while the comparative cooling system was assumed to have a seasonal efficiency of 3.8 [32]. For the former, although higher values closer to 0.75 are often claimed by manufacturers, [33] has shown that realistic long-term values are actually smaller.
- The electrical power load was modelled by using the average monthly power loads. This data was collected through the BEST program and inputted directly in RETScreen. It was assumed that the hotel operated at system peak electricity load for 20% of the time.
- Assuming that the lowest cost energy is used to produce base loads while the top portion of the energy consumed is met by other separate systems, the electrical and

heating peak loads were assumed to be met using power from the grid, and an additional boiler, respectively.

When modelling the reciprocating engine, four factors were taken into consideration, namely, the power capacity (kW), the minimum capacity (%), the engine's heat rate (kJ/kWh), and the heat recovery efficiency (%). The latter three conditions were kept constant, while the power capacity, being one of the investigated parameters, was varied between oversized, matching, and undersized.

The minimum capacity is the lowest power at which the engine can operate. A value of 25% was chosen, this being the typical minimum capacity for reciprocating engines. This value is of importance since, if the system cannot be turned down according to the heating needs, the electricity would have to be sold to the grid or the CHP would have to be turned off and intermediate systems would need to be used. The heat rate specifies the fuel consumed per unit of power output. The heat rate was set at 9500 kJ/kWh, a typical heat rate for different reciprocating engine sizes [34]. The heat recovery efficiency specifies the amount of available heat which can be recovered by the system being proposed. Not all the heat produced can be recovered as sometimes the recovery temperature is too low, therefore the heat recovery efficiency was set to 75%. The system availability was set to 95% to account for annual maintenance [35].

4. Results

4.1. Energy Results

For each simulation carried out, the energy and financial performance of the proposed system was evaluated. Table 2 shows the energy analysis for the CHP systems of all the representative hotels considered.

From the values shown in Table 2, it can be observed that the results obtained are indeed affected by the size of the engine chosen. In all cases the efficiency of the CHP system was constant at 81.4%, since the operating strategy was kept constant as heat load following. However, it can be noted that for *hotel 1*, *hotel 2*, *hotel 5*, and *hotel 6* the matched size and oversized reciprocating engines deliver the same amount of electricity to the load, and the same amount of fuel is consumed, while for *hotel 3* and *hotel 4*, when the system is oversized, less electricity is supplied to the load and less fuel is consumed. The reason for this can be attributed to the fact that the minimum capacity was set to 25% of the power capacity of the reciprocating engine. If the monthly load is less than the minimum capacity, the model assumed that the system is 'Off' during that period. For the former hotels, this shows that when oversizing the system, the engine still works over the specified minimum capacity. The results obtained for the latter two hotels indicate that these hotels are more sensitive to the amount of operating hours, and in these cases, less heat is recovered.

When the CHP system is undersized, it can be observed for *hotel 1*, that more electricity is being produced and more heat is being recovered, than when the system was at the matched size. This is likely because when a smaller system is being utilised it has a better matching power-to-heat demand ratio, thus operating for a higher number of hours and eventually producing more energy. The excess heat recovered is being used by the hotel and some heat is still required, therefore in some time periods the boiler is still required to reach the peak load. This also applies to *hotel 2*, *hotel 4*, and *hotel 6*. In *hotel 3* and *hotel 5* when the system is undersized, slightly less electricity is being produced and less fuel is being consumed compared to the matched sized system.

Finally, it is interesting to observe how in all scenarios there is no electricity exported, meaning that the power-to-heat demand ratio of the hotels is in all cases significantly higher than that which can be provided by the CHP systems considered in the analysis. For warm climates this could be solved either by adding the cooling load to the total thermal load, as will be discussed for the CCHP case, or by adding thermal storage to the system.

Table 2. Energy analysis of CHP systems.

	CHP Size	**CHP Size (kW)**	**Electricity Delivered to Load (MWh)**	**Electricity Exported to Grid (MWh)**	**Balance Electricity Required (MWh)**	**Heat Recovered (MWh)**	**Balance Heat Re quired (MWh)**	**Fuel**
			(MWh)					
Hotel 1	Matched Size	247	353	0	6859	405	182	931
	Oversized	296	353	0	6859	405	182	931
	Undersized	197	386	0	6825	443	143	1020
Hotel 2	Matched Size	146	195	0	2106	224	79	515
	Oversized	175	195	0	2106	224	79	515
	Undersized	117	212	0	2089	243	59	560
Hotel 3	Matched Size	90	161	0	676	184	75	424
	Oversized	108	143	0	694	164	95	378
	Undersized	72	158	0	679	182	77	418
Hotel 4	Matched Size	40	93	0	638	107	49	246
	Oversized	47	86	0	645	99	57	228
	Undersized	32	128	0	604	146	9	337
Hotel 5	Matched Size	67	305	0	786	350	18	804
	Oversized	81	305	0	786	350	18	804
	Undersized	54	294	0	797	337	31	775
Hotel 6	Matched Size	29	41	0	268	47	20	107
	Oversized	35	41	0	268	47	20	107
	Undersized	24	45	0	264	51	15	118

4.2. Financial Results

In terms of financial results, this study utilized the Simple Payback as the assessing method, as it quickly shows when a CHP system would be most feasible to operate, and therefore best summarizes the financial performance which can be obtained.

In the analysis carried out in this study, a payback period higher than 30 years was considered not to be feasible, since the lifetime of most CHP systems typically does not exceed that range [36]. To this effect, Table 3 illustrates a heat map showing the results obtained in terms of the payback period in years for the different scenarios investigated.

Table 3. Simple payback (years) heat map analysis for all scenarios.

Grant (%)	Propane €/kg	Avg. Electricity Tariff €/kWh	Hotel 1 5-Star			Hotel 2 5-Star			Hotel 3 4-Star			Hotel 4 4-Star			Diesel €/l	Hotel 5 3-Star			Hotel 6 3-Star		
			O	**M**	**U**	**O**	**M**	**U**	**O**	**M**	**U**	**O**	**M**	**U**		**O**	**M**	**U**	**O**	**M**	**U**
65	0.60	0.09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	25.3	8.0	1.212	NP	NP	NP	NP	NP	NP
		0.20	7.9	5.8	3.7	9.3	6.6	4.2	6.4	4.1	3.1	3.8	2.8	1.5		3.0	2.4	1.9	30.5	15.5	8.9
	0.40	0.09	NP	NP	26.6	NP	NP	NP	NP	NP	17.1	30.7	14.1	5.3	0.808	NP	NP	NP	NP	NP	NP
		0.20	7.0	6.7	3.3	8.1	5.9	3.8	5.7	3.7	2.8	3.4	2.5	1.4		2.0	1.6	1.3	13.0	8.6	5.5
55	0.60	0.09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	10.3	1.212	NP	NP	NP	NP	NP	NP
		0.20	10.2	7.4	4.7	11.9	8.5	5.4	8.2	5.2	4.0	4.8	3.6	2.0		3.9	3.1	2.5	NP	19.9	11.5
	0.40	0.09	NP	NP	NP	NP	NP	NP	NP	NP	22.0	NP	18.1	6.9	0.808	NP	NP	NP	NP	NP	NP
		0.20	9.0	6.7	4.3	10.4	7.6	4.9	7.4	4.8	3.7	4.4	3.3	1.8		2.6	2.1	1.7	16.7	11.0	7.0
45	0.60	0.09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	12.5	1.212	NP	NP	NP	NP	NP	NP
		0.20	12.4	9.1	5.8	14.6	10.4	6.6	10.0	6.4	4.9	5.9	4.4	2.4		4.7	3.8	3.0	NP	24.3	14.0
	0.40	0.09	NP	NP	NP	NP	NP	NP	NP	NP	26.9	NP	22.1	8.4	0.808	NP	NP	NP	NP	NP	NP
		0.20	11.0	8.2	5.3	12.7	9.2	5.9	9.0	5.8	4.5	5.4	4.0	2.2		3.2	2.6	2.1	20.5	13.5	8.6
No Grant	0.60	0.09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	22.8	1.212	NP	NP	NP	NP	NP	NP
		0.20	22.6	16.5	10.5	26.5	18.9	12.0	18.2	11.6	8.9	10.7	7.9	4.3		8.6	6.8	5.5	NP	NP	25.5
	0.40	0.09	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	15.3	0.808	NP	NP	NP	NP	NP	NP
		0.20	20.0	14.8	9.6	23.1	16.8	10.8	16.4	10.6	8.1	9.8	7.3	4.0		3.7	4.6	3.8	NP	24.5	15.6

Given the large number of combinations carried out, for space limitations, only the extreme values for each variable are being shown. These are shown under three headings: thermally matched CHP system (heading M), oversized CHP system (heading O), and undersized CHP system (heading U). The feed-in tariff is not being included, given that for the CHP-only analysis, no electricity was exported to the grid. To better show the results obtained, a color coding system was used to show the results. The scenarios marked in red show that the payback period is too high for the system to be considered feasible (>30 years). These results are marked as (NP), meaning that the system is not profitable and that the annual costs incurred are higher than the annual savings generated, and therefore the system would not be feasible. The result boxes marked in green show that the system is feasible (<30 years). Different shades of green are used to indicate for which scenarios the system would be most feasible. The darker the shade of green, the lower the payback period.

Although the study was carried out on only six different hotels, certain trends when laid out in tabular form become quite clear. For this reason, rather than analyzing the numbers for each individual hotel, the general trends which have been observed through the study will be presented. Amongst these general trends, the following observations are perhaps the most important:

- When a higher grant is available the payback period is reduced significantly; increasing the grant available increases the profitability of the system, since the capital expenditure required upfront becomes considerably less.
- The lower the fuel costs to run the CHP system, the lower the payback period.
- The higher the average grid electricity tariff, the lower the payback period; the higher the average electricity tariff, the more significant the replaced electricity produced by the CHP system becomes, and therefore it is more cost-worthy.
- Downsizing a system results in a significantly lower payback period; For the same conditions, downsizing a system makes more sense financially, given that the system will be operational for a longer period of time and hence provide a better return on the investment. If, however, any of the fiscal conditions are not the same, such a result holds no more.
- Relation to Star-Rating; Even when a CHP is correctly sized, hotels with a 5-star rating (therefore with significant ancillary services) and 3-star rating have a longer payback period than hotels with a 4-star rating. For 5-star hotels, very large systems are often required to satisfy the heating load, therefore the initial investment is high and would most likely take a considerable amount of time to recoup the initial investment. Three-star hotels typically install smaller CHP systems but then they would typically have a lower return.

Comparing the results on a star rating basis, it can be observed that when comparing the two 5-star rated hotels, although *hotel 2* has a much smaller CHP system due to a lower heating demand, a higher payback period can be observed than *hotel 1* for all CHP sizes investigated. It can therefore be concluded that even if the initial investment is lower, the project may still not be as feasible due to a lower return.

For the 4-star hotels, a low payback period can even be observed at mid-point electricity tariff of €0.15/kWh, which is around 4.7 years for systems having matched CHP system size, a grant of 65%, and coupled with the highest fuel rate. The table show that the payback period of a CHP system installed in the 4-star rated *hotel 4* remains quite feasible, even if the CHP system is oversized. However, similarly to the 5-star hotels when the grid electricity tariff is at its lowest point, that is €0.09/kWh, the system becomes less feasible, except for the undersized system.

Relating the 3-star hotels, it can be observed that *hotel 6*, which has a CHP system half the size of *hotel 5*, was still less feasible than *hotel 5*. Even when the system was oversized, *hotel 5* was still deemed to be feasible, however when no grant was considered in the analyzis the system had a much higher payback period, especially at the higher fuel rates.

4.3. Combined Cooling, Heat, and Power Results

Based on the fact that the simple payback period results obtained for *hotel 4*, were the most promising, it was decided that *hotel 4* was the hotel chosen to be modelled with a complete CCHP system.

When modelling a CCHP system, some minor changes had to be carried out on the base model to have a more realistic CCHP model. Apart from selecting the combined cooling, heating, and power model and setting up the cooling load and the cooling equipment, as explained in the assumptions listed in Section 3.3, the size of the reciprocating engine had to be increased from 40 kW to 301 kW to include for the additional thermal load required to drive the absorption chiller. If instead of an absorption system, an electrical system was chosen, the heat load required would have remained the same.

Additionally, as indicated in previous sections, the minimum capacity of the reciprocating engine had to be specified. For CHP systems, the minimum capacity throughout the simulations was kept at 25%, however for the CCHP system simulations this had to be reduced to 10%. Since the engine was enlarged in size to cover for the thermally driven cooling load, if the minimum capacity had been kept higher than 10% it would have rendered the system non-operational for the shoulder months. In fact, due to the higher power capacity in these modelled scenarios, electricity was exported to the grid, and therefore the feed-in tariff also played a role in these simulations.

In order to satisfy the additional heating load imposed by the absorption chiller, the size of the boiler also had to be increased from 45 kW_{th} to 345 kW_{th}.

4.3.1. CCHP—Energy Results

Table 4 below shows the energy results when adding an absorption system to the originally modelled CHP system. It can be observed that even when the reciprocating engine is undersized by 20% it still had a higher capacity than that required to satisfy the electricity load (after removing the cooling load).

Table 4. Energy analysis for a CCHP system following the heating load feeding *hotel 4*.

CHP Size	CHP Size (kW)	Electricity Delivered to Load (MWh)	Electricity Exported to Grid (MWh)	Balance Electricity Required (MWh)	Heat Recovered (MWh)	Balance Heat Re quired (MWh)	Fuel
		(MWh)					
Matched Size	301	539	621	28.4	1331	70	3061
Oversized	360	539	621	28.4	1331	70	3061
Undersized	240	539	613	28.4	1321	79.5	3039

4.3.2. CCHP—Financial Results

Table 5 shows the financial results obtained for the *hotel 4* equipped with a CCHP system. In this case, only the simulations for a 65% grant on the capital cost are being considered for the matched size CCHP system, as shown.

Table 5. Financial analysis for a CCHP system following the heating load feeding *hotel 4*.

	Grant (%)	FIT (€/kWh)	Propane €/kg	Avg. Electricity Tariff (€/kWh)	Simple Payback (Years)	Net Present Value (€)
Matched Sized CCHP 301 kW	65	0.11	0.60	0.09	NP	−2,345,549
				0.20	NP	−1,433,118
			0.40	0.09	NP	−1,831,646
				0.20	NP	−919,215
		0.09	0.60	0.09	NP	−2,467,517
				0.20	NP	−1,555,087
			0.40	0.09	NP	−1,953,614
				0.20	NP	−1,041,184
		0.07	0.60	0.09	NP	−2,589,486
				0.20	NP	−1,677,055
			0.40	0.09	NP	−2,075,583
				0.20	NP	−1,163,152

A general observation from the results obtained is that a CCHP system for the hotel investigated, *hotel 4*, at the proposed financial conditions (and heat demand matching) is not feasible. In fact, when considering the simple payback period, it is always not profitable, since none of the scenarios investigated returned a payback period smaller than 25 years. Likewise, the Net Present Value is always negative for all the different sized systems. When analyzing the simulations further, for the matched sized system to be feasible, the electricity tariff must be in the region of €0.30/kWh, whilst the propane cost must be at around €0.40/kg. Alternatively, increasing the feed-in tariff to more than the current €0.11/kWh is also a possible solution to get the system feasible.

5. Conclusions

Based on the premise that typically a detailed feasibility study needs to be done whenever a CHP or CCHP is being considered as a possible energy-efficiency measure for an energy-demanding and complex building such as a hotel, the scope of this study was to diverge from that basic idea by providing a holistic high-level approach towards providing general trends on the performance of CHP and CCHP systems in the hospitality sector in Malta. Instead of focusing on just one hotel, this study therefore analyzed a variety of hotels, ranging from 3-star to 5-star hotels to investigate the performance of an installed CHP system, and how a number of technical and fiscal parameters would affect such a performance.

By using RETScreen, an energy management software program, six hotels were modelled using real-life measured data from existing hotels. The hotels were chosen to cover a wide range of hospitality energy consumption trends. Once the six chosen hotels were modelled, five different parameters were chosen and varied to study their impact on the feasibility of a CHP system installed in these six hotels. Simulations were done to determine which variable had the most influence on the feasibility of installing a CHP system. The parameters considered were the size of the CHP system, the availability of a capital grant, the grid supplied electricity tariff, fuel prices, and the feed-in tariff. A total of 144 simulations were carried out. For the hotel with the most promising results, a detailed CCHP analysis was then added to include for the provision of space cooling. Notwithstanding the fact that the study was conducted on a sample size of only six hotels, interesting trends and results were obtained, which will be augmented and consolidated in future with the inclusion of more hotels in the study.

From an energy point of view, the main results and trends observed mainly revolved around three aspects:

- Undersizing a system does not necessarily mean less energy being provided, but depending on the hotel energy demand variability and the specific control arrangements made, it may be the case that the system will still operate adequately;
- For heat matching CHP driven systems, matched and oversized systems operate similarly, as the system will simply cut-off when the heat load is exceeded. This leads to the importance of having heat storage capability;
- For warm climates, assuming CHP only systems under heat matching control strategies, electrical surplus, and hence exporting to the grid is unlikely, the CHP power-to-heat ratio is not enough to produce electricity significantly and constantly higher than that required by the hotel, and hence have enough to export. This leads to the importance of coupling the cooling load to the total thermal load.

From a financial point of view, the main results and trends observed mainly revolved around the sensitivity of the system performance to the fiscal parameters being analyzed. Specifically, that:

- When a higher grant is available the payback period is reduced significantly;
- The lower the fuel costs, the smaller the payback period;
- The higher the average electricity tariff, the smaller the payback period;
- Given the lower capital expenditure and the steadier operation, at the modelled conditions, undersizing a system results in a significantly lower payback period.

For CCHP systems considering the additional cost of the chiller, the same results obtained for the CHP-only case largely apply, with the FIT playing an important part in terms of the financial soundness of such systems.

Author Contributions: Conceptualization, B.M. and S.P.B.; methodology, B.M. and S.P.B.; software, B.M. and S.P.B.; validation, B.M. and S.P.B.; formal analysis, B.M. and S.P.B.; investigation, B.M. and S.P.B.; resources, B.M. and S.P.B.; data curation, B.M. and S.P.B.; writing—original draft preparation, B.M.; writing—review and editing, S.P.B.; visualization, B.M. and S.P.B.; supervision, S.P.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Given the financial nature of the data, only a limited amount of data is disclosed in this paper.

Acknowledgments: The manuscript is a revised version of an original scientific contribution that was presented at the 17th Sustainable Development of Energy, Water and Environmental Systems (SDEWES) conference held between the 6th and the 10th of November 2022 in Paphos, Cyprus and that was subsequently invited to be submitted for review for inclusion in a special issue of Sustainability dedicated to the said Conference. Compared to the original conference paper, the introduction, the literature review and the conclusion were completely re-written and expanded to better highlight the approach taken in this study, thus better highlighting the novelty addressed within the research article. Additionally, the results were re-organized to improve on the presentation. Specifically, Table 3, the '*Simple payback heat map analysis for all scenarios*' was added to better show the results obtained.

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

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