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Economic viability of implementing a diesel generator group in a grain storage facility located in the City of Cascavel, State of Paraná, Brazil

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The objective of the present study is to verify the viability of implementing a diesel-generating group, which would work at peak times, in a grain-processing facility located in the town of Cascavel, in western region of Paraná, Brazil. The demand and consumption of electrical energy for the unit were determined for four operational scenarios. For each of these scenarios, the annual cost of using a diesel-fueled generator was compared to the cost of using electrical energy under three pricing systems. The criteria used for making investment decisions were the Internal Rate of Return and the Payback Discount method. It was determined the minimum annual use necessary for the implementation of a diesel generator to become viable. In the most critical scenario of the operation, the implementation of a generator becomes viable in the fourth year of use. The main results allowed concluding that implementing a diesel generator group at peak times is only not viable when using a conventional rate system and when demand and consumption are low.

Key words: Storage, peak time, electrical energy production.

INTRODUCTION

Brazilian agriculture has gained international attention due to its competitive potential and its agriculture and livestock expansion possibilities. In the last survey on grain production, CONAB (CompanhiaNacional de Abastecimento / National Food Supply Company) verified that the 2012/2013 crop reached 187.09 million tons, 12.6% more than the 2011/2012 crop (CONAB, 2013). The harvest flow system involves the process of storing agricultural products, an extremely important step for maintaining grain quality, since it is useless to produce well if this production could be compromised by an inadequate storage process (Alencar et al., 2009; Kolling et al., 2012).

A storage unit consists of a system that has been

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appropriately designed and structured to receive, clean, dry, store, and expedite grains. To accomplish this, the unit must be comprised of efficient structures, processing equipment, and transportation equipment (Konopatzki et al., 2006). These units are large complexes that consume high quantities of energy, mainly because of the number of electric motors they use (Teixeira et al., 2007; Costa et al., 2010). When it is used a lot of energy in the production process, optimum use of energy becomes very vital for agricultural productions (Mousavi-Avval et al., 2010; Ommani, 2011). Consequently, electrical energy consumption becomes a significant monthly utility expense for these facilities.

In Brazil, the rates charged for supplying electricity are linked to the characteristics of each consuming unit and categorized under three modalities, which vary according to the consumer's power demands and voltage supplied. The first modality, referred to as Conventional Rate (Flat Rate), consists of a single price for power demands (US$/kWh) and for the consumption of energy (US$/kWh). The other two modalities are variable and based on seasonal time (in Brazil, they are called "green" or "blue" rates, described below). These differ from the conventional rate because they are based on Time of Use (TOU), that is, they are higher at peak times (the peak time corresponds to the three consecutive weekday hours, normally between 6 and 9 PM, in which the supplier's rate increases significantly, because there is an increase in consumption during these times at a national level, overloading the energy generation, transmission, and distribution systems). The "green" rate consists of a single price for power and two prices for energy consumption (one for peak times and one for off-peak times). The "blue" rate, however, consists of two prices for power and two prices for energy consumption (peak and off-peak times for both cases).

At harvest time, one storage unit may function without interruptions, even during peak times, increasing electrical energy expenses by four hundred percent during this period. To minimize costs with electricity during peak hours, one option is to make use of alternative energy sources, such as, for example, diesel generator groups (Petrilli et al., 2013). Mbodji et al. (2013) showed the importance of decentralized application of multi-sources electrical systems. Such a management allows optimizing the system in function of the costs.

A diesel generator group is understood as the combination of a diesel-fueled motor and an alternating current generator, with supervision and control components that allow it to function autonomously. Its purpose is to supply electrical energy generated by diesel oil. According to Masseroni and Oliveira (2012), the use of this type of equipment at peak hours can represent a 30% savings on the monthly energy bill. However, the decision to implement a generator group should only be made once a detailed study of its economic viability has been executed.

This project studied the economical implementation of a diesel generator group at peak hours in a grain processing/storage unit situated in the town of Cascavel, in the western region of Paraná - Brazil.

MATERIALS AND METHODS

The present study was executed in a grain processing/storage unit situated in the town of Cascavel, in the western region of Paraná - Brazil. The static storage capacity for this particular unit is 30 thousand tons, equally distributed among 8 metallic silos. During the harvest period, it processes corn and soy crops. The electric motors involved in grain processing in this unit are listed in Table 1.

To estimate the local demand for electricity, four operational scenarios were considered, established according to the characteristics of the product the unit receives.

Scenario 1 - clean and dry product with this configuration, the product does not go through any processing stages; it is simply transported to storage. In this scenario, energy consumption occurs from using the equipment 1, 10, 11, 12, and 13 (listed in Table 1) and the demand for electricity is 38.7 kVA. Allthese equipment are used simultaneously;

Scenario 2 - clean and damp product: With this configuration, the product must go through a drying process before it can be stored. As such, energy consumption occurs from using the equipment listed under scenario 1 plus items 5 to 9 (from Table 1). In this process, the demand for electricity is 101.4 kVA. All these equipment are used simultaneously.

Scenario 3 - dirty and dry product: With this configuration, the product must be cleaned prior to storage. As such, energy consumption occurs from using equipment 1 to 4 and 10 to 13 (from Table 1). In this process, the demand for electricity is 48.2 kVA. All these equipment are used simultaneously.

Scenario 4 - dirty and damp product: This is the most critical operational configuration because all processing stages must be completed before storage. As such, all of the equipment listed in Table 1 is used and the demand for energy equals 110.9 kVA. All these equipment are used simultaneously.

One generator group was attributed to each scenario described. This attribution was performed using *Cummins Power* generators and a safety margin of 20% over the scenario's demand. The generators selected for each case are listed in Table 2.The generator group will be used to supplement the demand for electrical energy only at peak times (6 to 9 PM), when the supplier increases the rates charged.

For each scenario, the viability of implementing the generator group at peak times was verified, comparing the annual costs of using the diesel generator with the annual costs of using electrical energy. The costs of using diesel-generated energy were calculated according to the information listed in Table 3.

Three rate systems were used to calculate the costs incurred from using electrical energy: 1-Conventional rate application; 2-"Blue" TOU rate application; and 3-"Green" TOU rate application. The rates used in this study (Table 4) refer to the consumption group supplied between 30 and 44 kV, and have been calculated according to the CompanhiaParanaense de Energia (COPEL, 2013).

The costs incurred with the diesel generator group, as well as the costs incurred with electrical energy, were calculated for one year according to total peak periods (60 h per month or 720 h per year). Under these conditions, the equipment's operational life is 14 years.

To complete an economic analysis, the Internal Rate of Return (IRR) and the Payback Discount (PBD) method were used (Casarotto and Kopittke, 2010). The Minimum Acceptable Rate of

Table 1. Electric motors used in grain processing.

Item	Equipment identification	Place of installation	Power (cv)	Efficiency (%)	Power factor	Demand (kVA)
1	Hopper lifter	Reception	25	91.0	0.83	14.06
2	MPL fan	Cleaning Machine	7.5	88.0	0.82	4.42
3	MPL sieve motor	Cleaning Machine	7.5	88.0	0.82	4.42
4	MPL residue motor	Cleaning Machine	1	79.5	0.82	0.65
5	Dryer lifter	Grain Dryer	20	90.2	0.83	11.35
6	Dryer fan	Grain Dryer	30	91.0	0.84	16.68
7	Dryer fan	Grain Dryer	30	91.0	0.84	16.68
8	Dryer fan	Grain Dryer	30	91.0	0.84	16.68
9	Dryer motor	Grain Dryer	2	82.5	0.78	1.32
10	Screw conveyor	Storage	7.5	88.0	0.82	4.42
11	Conveyor belt	Storage	7.5	88.0	0.82	4.42
12	Conveyor belt	Storage	20	90.2	0.83	11.35
13	Lifter	Storage	7.5	88.0	0.82	4.42

Table 2. Characteristics of the generators attributed.

Scenario	Generator model	Nominal power (Use at peak - kVA)	Consumption (liters/hour)			
			Complete	¾	1/2	1/4
1	C40D6	48	11	9	7	5
2	C110D6	128	29	22	16	9
3	C50D6	56	14	12	9	6
4	C110D6	128	29	22	16	9

Table 3. Diesel-generated energy costs.

	Cost
48 kVA generator purchase	US$ 19,772.73
56 kVA generator purchase	US$ 20,636.36
128 kVA generator purchase	US$ 26,727.27
Equipment maintenance	2% of the cost of the equipment[1]
Installation	3% of the cost of the equipment[1]
Lubricating oil	US$ 5.454/liter[2]
Cost of fuel	US$ 0.964/liter

[1]Information from the Manufacturer.[2]Lubricating oil consumption calculated at 10 L for 100 hours of use.

Table 4. Fees charged to the 3 rate modalities during peak times.

Rate	Peak time cost	
	Demand (US$/kW)	Energy (US$/kWh)
"Blue" TOU	12.2955	0.1609
"Green" TOU	3.7500	0.4567
Conventional	12.6091	0.1074

Return (MARR) considered for this study was 8% per year. Additionally, through a series of graphs, it was possible to determine the minimum annual use, in hours, necessary for the implementation of a diesel generator group to become viable economically.

Table 5. Cash flow scenario 1.

Year	"Blue" TOU			"Green" TOU			Conventional		
	CF(US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV (US$)
0	-20,365.91	-20,365.91	-20,365.91	-20,365.91	-20,365.91	-20,365.91	-20,365.91	-20,365.91	-20,365.91
1	3,421.23	3,167.81	-17,198.10	7,838.98	7,258.31	-13,107.60	2,033.86	1,883.20	-18,482.71
2	3,421.23	2,933.15	-14,264.95	7,838.98	6,720.66	-6,386.94	2,033.86	1,743.70	-16,739.01
3	3,421.23	2,715.88	-11,549.07	7,838.98	6,222.83	-164.11	2,033.86	1,614.54	-15,124.47
4	3,421.23	2,514.71	-9,034.36	7,838.98	5,761.88	5,597.77	2,033.86	1,494.94	-13,629.52
5	3,421.23	2,328.43	-6,705.93	7,838.98	5,335.07	10,932.85	2,033.86	1,384.21	-12,245.32
6	3,421.23	2,155.95	-4,549.98	7,838.98	4,939.88	15,872.73	2,033.86	1,281.67	-10,963.64
7	3,421.23	1,996.25	-2,553.72	7,838.98	4,573.97	20,446.70	2,033.86	1,186.73	-9,776.91
8	3,421.23	1,848.38	-705.34	7,838.98	4,235.15	24,681.85	2,033.86	1,098.83	-8,678.08
9	3,421.23	1,711.47	1,006.13	7,838.98	3,921.44	28,603.29	2,033.86	1,017.43	-7,660.64
10	3,421.23	1,584.69	2,590.82	7,838.98	3,630.96	32,234.25	2,033.86	942.07	-6,718.58
11	3,421.23	1,467.31	4,058.13	7,838.98	3,362.00	35,596.25	2,033.86	872.29	-5,846.29
12	3,421.23	1,358.62	5,416.74	7,838.98	3,112.96	38,709.22	2,033.86	807.67	-5,038.62
13	3,421.23	1,257.98	6,674.72	7,838.98	2,882.37	41,591.59	2,033.86	747.84	-4,290.77
14	3,421.23	1,164.80	7,839.52	7,838.98	2,668.87	44,260.46	2,033.86	692.45	-3,598.33

CF = Cash flow; PV = present value; CPV = cumulative present value.

RESULTS AND DISCUSSION

Payback Discount (PBD) method

For the first scenario, in which there is a lower demand for electricity (38.7 kVA), the cash flow obtained is presented in Table 5. In the cash flow, the 1st column, at year 0, indicates the cost of purchasing and installing the diesel generator. The remaining values, from years 1 to 14, indicate the avoidable electrical energy costs paid to a supplier, minus the costs of operating and maintaining the diesel generator. When comparing generator group usage with electrical energy usage under the "blue" TOU rate system, the rate of return on invested capital is 9 years. When considering the "green" TOU rate system, the rate of return is 4 years. When the conventional rate is used, the rate charged at peak times is the lowest among the three modalities, and the implementation of a generator group is not viable economically.

In the second scenario, where the demand for electrical energy is 101.4 kVA, the use of a generator group of larger capacity and higher cost was considered in the calculations. Table 6 presents the cash flow for this configuration.

In Table 6, it is possible to observe that for the "blue" TOU rate system, the equipment's implementation becomes viable at year 4. When the "green" TOU rate is used, the rate of return on invested capital is as early as 2 years. This result is very interesting to an investor, since the rate of return is considerably low. However, when compared to the conventional rate, the implementation of this equipment is only viable in year 7.

For the third scenario, where the demand for electrical energy is 48 kVA, the cash flow obtained (Table 7) is very similar to the one generated in the first scenario, since the energy demand and generator costs are similar.

As in the first scenario, the "blue" TOU system, the rate of return on capital invested is 9 years. However, when using the "green" TOU, the rate of return is only 3 years. In contrast, when using the conventional rate, the equipment's implementation is not viable economically.

Table 8 presents the cash flow obtained for the fourth scenario, where the demand for electrical energy is 110.9 kVA. When it is used the "blue" TOU rate system or the conventional system, the generator's implementation becomes economically viable at year 4. When it is used the "green" TOU, the rate of return is 2 years.

Results obtained using the Internal Rate of Return method (IRR)

The IRR is based on the same cash flow values previously presented. The results for each rate system in the four scenarios are listed in Table 9.

For scenario 1, the investment should only occur as a replacement for the "blue" or "green" TOUs, because the IRR is higher than the Minimum Acceptable Rate of Return- MARR (8% per year). Similarly, when conventional rates are used, it is best not to implement the generator. Under scenario 2, the investment can be made under any circumstance, since the IRR is superior to the MARR. In fact, the IRR value for the "green" TOU rate is well above the MARR, indicating that this configuration is the most interesting when considering the implementation of a diesel-fueled generator. Under the

Table 6. Cash Flow Scenario 2.

Year	"Blue" TOU			"Green" TOU			Conventional		
	CF (US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV (US$)
0	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09
1	9,230.96	8,547.19	-18,981.91	20,827.54	19,284.76	-8,244.33	5,589.10	5,175.09	-22,354.00
2	9,230.96	7,914.06	-11,067.85	20,827.54	17,856.26	9,611.93	5,589.10	4,791.75	-17,562.24
3	9,230.96	7,327.83	-3,740.01	20,827.54	16,533.57	26,145.50	5,589.10	4,436.81	-13,125.43
4	9,230.96	6,785.03	3,045.02	20,827.54	15,308.87	41,454.37	5,589.10	4,108.16	-9,017.28
5	9,230.96	6,282.44	9,327.46	20,827.54	14,174.88	55,629.25	5,589.10	3,803.85	-5,213.43
6	9,230.96	5,817.07	15,144.53	20,827.54	13,124.88	68,754.13	5,589.10	3,522.08	-1,691.34
7	9,230.96	5,386.18	20,530.70	20,827.54	12,152.67	80,906.80	5,589.10	3,261.19	1,569.84
8	9,230.96	4,987.20	25,517.90	20,827.54	11,252.47	92,159.27	5,589.10	3,019.62	4,589.46
9	9,230.96	4,617.78	30,135.68	20,827.54	10,418.96	102,578.23	5,589.10	2,795.94	7,385.40
10	9,230.96	4,275.72	34,411.40	20,827.54	9,647.18	112,225.41	5,589.10	2,588.84	9,974.24
11	9,230.96	3,959.00	38,370.40	20,827.54	8,932.58	121,157.99	5,589.10	2,397.07	12,371.31
12	9,230.96	3,665.74	42,036.15	20,827.54	8,270.90	129,428.89	5,589.10	2,219.51	14,590.82
13	9,230.96	3,394.20	45,430.35	20,827.54	7,658.24	137,087.13	5,589.10	2,055.10	16,645.92
14	9,230.96	3,142.78	48,573.13	20,827.54	7,090.97	144,178.10	5,589.10	1,902.87	18,548.79

Table 7. Cash Flow Scenario 3.

Year	"Blue" TOU			"Green" TOU			Conventional		
	CF (US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV (US$)	CF (US$)	PV (US$)	CPV(US$)
0	-21,255.45	-21,255.45	-21,255.45	-21,255.45	-21,255.45	-21,255.45	-21,255.45	-21,255.45	-21,255.45
1	3,678.74	3,406.24	-17,849.22	9,200.92	8,519.37	-12,736.09	1,944.52	1,800.48	-19,454.97
2	3,678.74	3,153.92	-14,695.29	9,200.92	7,888.30	-4,847.78	1,944.52	1,667.11	-17,787.86
3	3,678.74	2,920.30	-11,774.99	9,200.92	7,303.99	2,456.21	1,944.52	1,543.62	-16,244.24
4	3,678.74	2,703.98	-9,071.01	9,200.92	6,762.95	9,219.15	1,944.52	1,429.28	-14,814.96
5	3,678.74	2,503.69	-6,567.33	9,200.92	6,261.99	15,481.15	1,944.52	1,323.41	-13,491.56
6	3,678.74	2,318.23	-4,249.10	9,200.92	5,798.14	21,279.28	1,944.52	1,225.38	-12,266.18
7	3,678.74	2,146.51	-2,102.59	9,200.92	5,368.65	26,647.93	1,944.52	1,134.61	-11,131.57
8	3,678.74	1,987.51	-115.08	9,200.92	4,970.97	31,618.90	1,944.52	1,050.56	-10,081.01
9	3,678.74	1,840.28	1,725.20	9,200.92	4,602.75	36,221.65	1,944.52	972.74	-9,108.26
10	3,678.74	1,703.97	3,429.17	9,200.92	4,261.81	40,483.46	1,944.52	900.69	-8,207.58
11	3,678.74	1,577.75	5,006.92	9,200.92	3,946.12	44,429.57	1,944.52	833.97	-7,373.61
12	3,678.74	1,460.88	6,467.79	9,200.92	3,653.81	48,083.39	1,944.52	772.20	-6,601.41
13	3,678.74	1,352.66	7,820.46	9,200.92	3,383.16	51,466.54	1,944.52	715.00	-5,886.42
14	3,678.74	1,252.47	9,072.92	9,200.92	3,132.55	54,599.10	1,944.52	662.03	-5,224.38

third scenario, the values are a close match to those in the first scenario. As such, the investment should only be made in replacement to the "blue" or "green" TOU rate systems. For the fourth scenario, all of the values are favorable to the implementation project.

Graphs comparing the costs of using electrical energy or using a generator group

The graph in Figure 1 presents a comparison between yearly electrical energy usage and generator group costs for scenario 1. On Figure 1, it is possible to see that for annual usage above 250 h, the implementation of a diesel generator group is economically viable in comparison to the cost of electrical energy charged at the "green" TOU rate system. For the "blue" TOU rate system, the investment is only viable at 540 usage hours. Moreover, when compared to the conventional rate, the implementation of a generator group is not viable economically.

Figure 2 presents a cost comparison for scenario 2.

Table 8. Cash flow scenario 4.

Year	"Blue" TOU			"Green" TOU			Conventional		
	CF(US$)	PV(US$)	CPV(US$)	CF(US$)	PV(US$)	CPV(US$)	CF(US$)	PV(US$)	CPV(US$)
0	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09	-27,529.09
1	8,761.32	8,112.33	-19,416.76	25,883.86	23,966.53	-3,562.56	9,194.14	8,513.09	-19,016.00
2	8,761.32	7,511.42	-11,905.34	25,883.86	22,191.23	18,628.68	9,194.14	7,882.49	-11,133.51
3	8,761.32	6,955.02	-4,950.33	25,883.86	20,547.44	39,176.12	9,194.14	7,298.60	-3,834.91
4	8,761.32	6,439.83	1,489.50	25,883.86	19,025.41	58,201.52	9,194.14	6,757.96	2,923.05
5	8,761.32	5,962.81	7,452.31	25,883.86	17,616.12	75,817.64	9,194.14	6,257.37	9,180.43
6	8,761.32	5,521.12	12,973.43	25,883.86	16,311.22	92,128.86	9,194.14	5,793.87	14,974.29
7	8,761.32	5,112.14	18,085.57	25,883.86	15,102.98	107,231.84	9,194.14	5,364.69	20,338.98
8	8,761.32	4,733.47	22,819.04	25,883.86	13,984.24	121,216.08	9,194.14	4,967.31	25,306.29
9	8,761.32	4,382.84	27,201.88	25,883.86	12,948.37	134,164.46	9,194.14	4,599.36	29,905.65
10	8,761.32	4,058.19	31,260.06	25,883.86	11,989.23	146,153.69	9,194.14	4,258.66	34,164.31
11	8,761.32	3,757.58	35,017.64	25,883.86	11,101.14	157,254.83	9,194.14	3,943.21	38,107.52
12	8,761.32	3,479.24	38,496.88	25,883.86	10,278.84	167,533.67	9,194.14	3,651.12	41,758.63
13	8,761.32	3,221.52	41,718.40	25,883.86	9,517.44	177,051.11	9,194.14	3,380.66	45,139.30
14	8,761.32	2,982.89	44,701.29	25,883.86	8,812.44	185,863.55	9,194.14	3,130.25	48,269.54

Table 9. Internal rate of return for each rate system and scenario studied.

Scenario	"Blue" TOU	"Green" TOU	Conventional
	IRR (%)	IRR (%)	IRR (%)
1	14	38	5
2	33	76	18
3	15	43	3
4	31	94	33

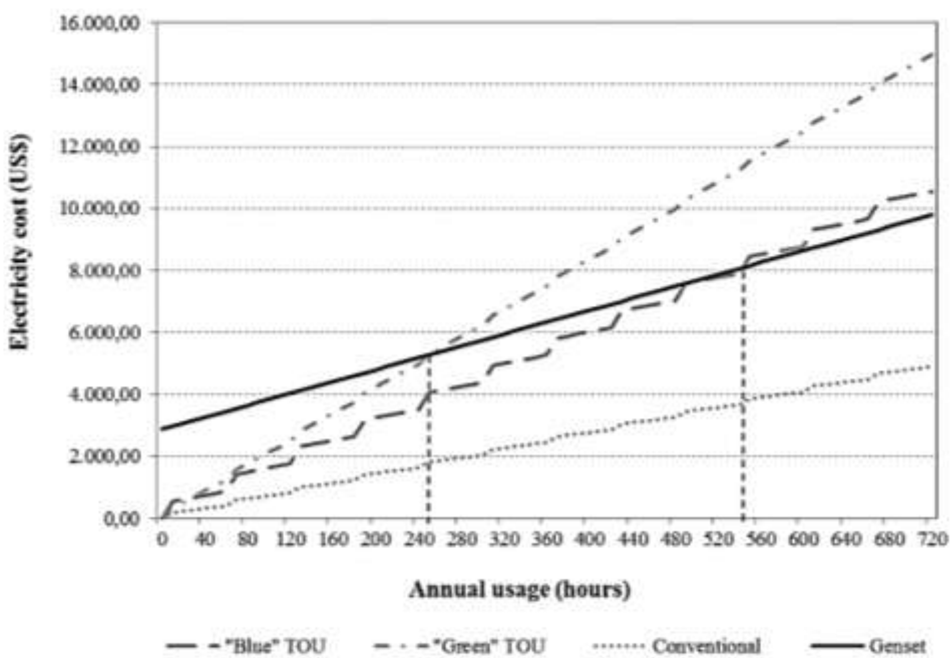

Figure 1. Costs incurred with electrical energy and generator group for scenario 1.

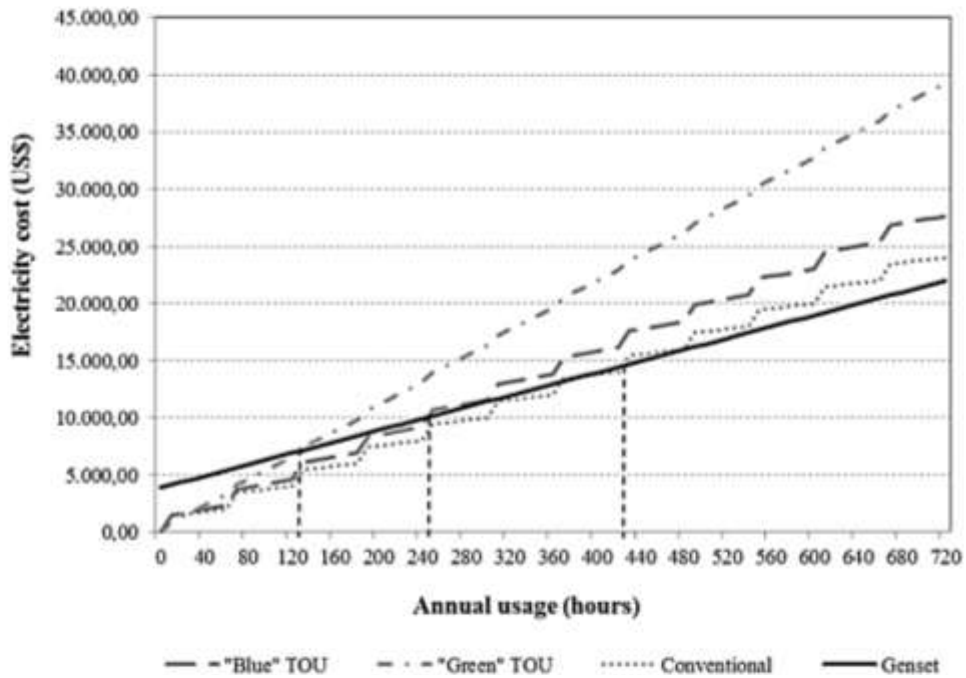

Figure 2. Costs incurred with electrical energy and generator group for scenario 2.

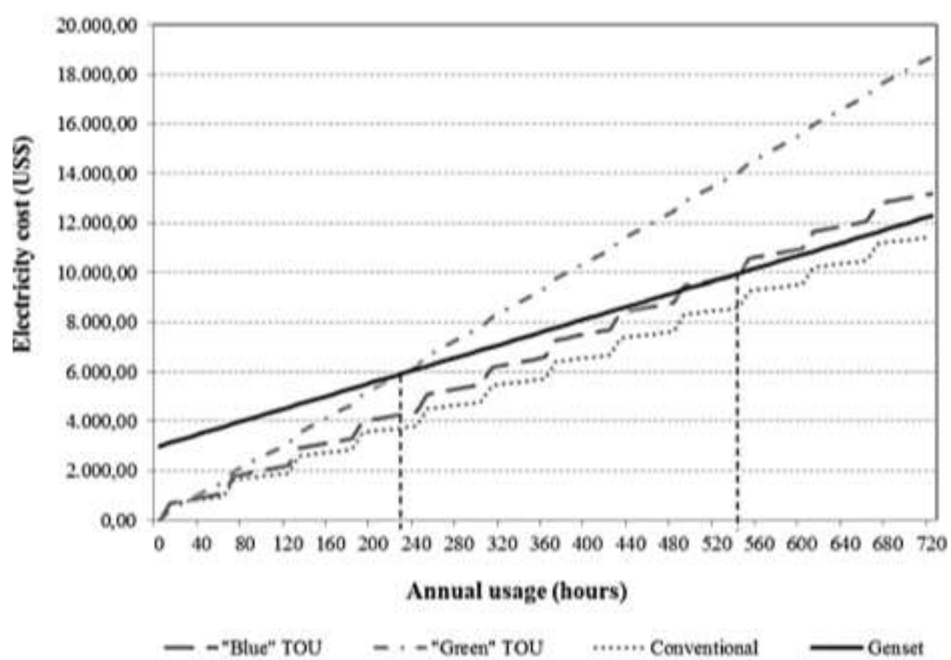

Figure 3. Costs incurred with electrical energy and generator group for scenario 3.

Figure 2 shows that 130 annual usage hours are needed for the implementation of the generator, to become viable under the "green" TOU rate system. Under the "blue" TOU rate system, 250 usage hours are needed, and for the conventional system, 430 h.

Figure 3 represents a cost comparison for scenario 3. The graph in Figure 3 shows that for the "green" TOU rate, the generator's implementation is viable after 230 usage hours. Under the "blue" TOU rate system, at least 540 usage hours are needed, and in comparison to the

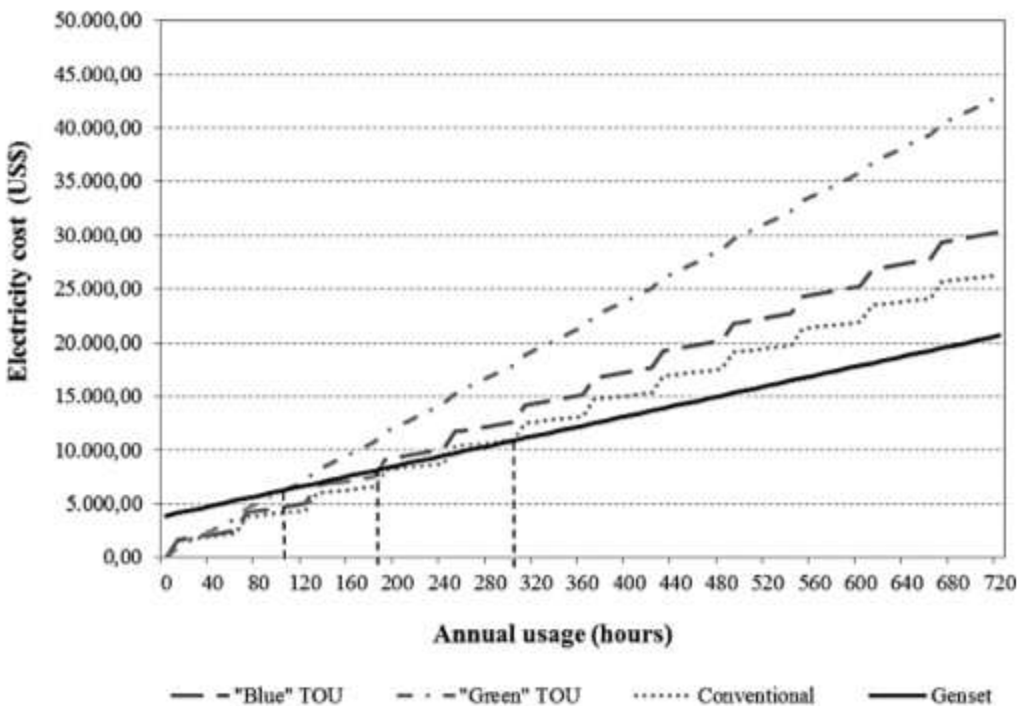

Figure 4. Costs incurred with electrical energy and generator group for scenario 4.

conventional system, the generator's implementation is not viable economically.

Figure 4 represents a cost comparison for scenario 4. Figure 4 shows that under the "green" TOU rate system, investment becomes viable after 100 hours of use. Comparatively, under the "blue" TOU system, it becomes viable to implement the generator after 180 annual usage hours, and under the conventional system this number rises to 300 h.

Conclusions

According to the data obtained from the assessments performed in this article, it is possible to conclude that:

1. The use of a diesel generator group can reduce costs during the times of day in which the electrical energy rate is highest (peak times);
2. Substituting the "green" TOU rate for a generator group is an interesting option, since the Payback Discount is very low;
3. For the "blue" TOU rate system, the implementation of a generator group presented positive economic results. However, it is important to also consider the balance between costs and number of usage hours of the generator;
4. Implementing a diesel generator group at peak times is only not viable when using a conventional rate system and when demand is low.

Conflict of interest

The authors have not declared any conflict of interest.

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