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TECHNICAL PAPER

DECREASE IN OFF-PEAK ELECTRICAL ENERGY DEMAND BY AGROINDUSTRIES DUE TO PHOTOVOLTAIC SOLAR GENERATION

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KEYWORDS

load curve, demand curve, cost reduction, load factor, photovoltaic system externality.

ABSTRACT

The largest energy losses and voltage variations from electricity suppliers occur at times of peak demand. Daytime peaks are mainly influenced by large industrial and commercial consumers. The installation of photovoltaic systems without energy storage to supply part of the demand can contribute to stabilize the voltage and reduce losses. These and other benefits constitute the so-called externality of the decrease in off-peak demand due to photovoltaic generation. The objective of this study was to investigate the role of this externality in agroindustry, as a consumer of electrical energy, in order to better understand its effects on the consumer and the utility. The implementation of photovoltaic systems was simulated with the objective to reduce the off-peak contracted demand by agroindustries. Both the energy balance and the economic viability of the photovoltaic system implantation were analyzed. It was concluded that the photovoltaic system contributed to the reduction in energy costs, improved the load factor by about 47%, and reduced the off-peak contracted demand by about 20.2% and 54.2% for the small and medium-sized agroindustries considered, respectively.

INTRODUCTION

Every consumer can be characterized by its electric utility through its load curve, which is a graph that identifies the distribution profile of the electrical energy used over a period (Jong et al., 2013).

In Brazil, time-of-use rates discriminate between two periods of the day, called peak and off-peak hours. The peak period is comprised of three consecutive hours of high electricity demand, typically from 6:00 to 9:00 p.m. on weekdays, and the off-peak period covers the remaining 21 hours of the day or 24 hours a day for Saturdays, Sundays and national holidays. Due to the capacity limitations of the distribution networks, each new consumer that is inserted generally represents a greater cost to the utility during the peak hours. Thus, the electricity tariff is the highest at peak times.

To improve the load curve, battery banks are used in some countries to store solar photovoltaic (PV) generation during off-peak hours for reinjection into the grid during peak hours. When injecting electricity into the grid during peak or off-peak hours, the load curve has a diminished peak and off-peak, which reduces the demand in the distribution system. Therefore, the technical losses in the distribution network are also reduced (Reihani & Ghorbani, 2016).

For legal reasons, Brazilian consumers cannot use battery banks to store energy from PV systems connected to the grid to benefit from the compensation system provided by ANEEL resolutions 487 and 682 on the distributed generation of electric energy. Thus, the electricity generated is injected directly into the network, without storage, and as a result, energy cannot be injected into the network during peak hours.

On the other hand, Urbanetz et al. (2012) evaluated two PV systems connected to the power grid: the first was installed with 12 kWp and the second was simulated with 4.2 MWp. The study concluded that the insertion of

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grid-connected PV systems in urban areas improves voltage profiles and reduces technical losses. In addition, the results showed that the use of PV systems connected to the grid can contribute to reduce electricity losses in Brazil.

Given the assumptions presented, investing in PV systems can be a viable way to reduce off-peak consumer demand. This reduction leads to lower costs of electric power supply to the consumer and lower costs of technical losses to the utility, in addition to increasing the overall reliability of the supply system. These benefits, among others, constitute the so-called externality of the decrease in off-peak demand due to PV solar generation.

The objective of this study was to evaluate the role of the externality of the decrease in off-peak demand due to PV solar generation in agroindustries in order to acquire a deeper understanding of this issue in Brazil.

MATERIAL AND METHODS

Characterization of the study area

Real data on small- and medium-sized agroindustries in Brazil were used in developing this research.

The small-sized agroindustry was represented by Farm I. This farm is located in the microregion of Pará de Minas in the state of Minas Gerais, at latitude 19° 51’ 37” S, with 28 employees, 800 sows for swine farming, and no plans to expand production.

The medium-sized agroindustry was represented by Farm II. This farm is located in the rural area of the municipality of Juiz de Fora in the state of Minas Gerais, at latitude 21° 45’ 51” S, with 128 employees, 2508 sows for swine farming activity, and also no plans to expand production.

Obtaining the demand curve

The representative daily demand curve for the two selected agroindustries were determined from the electrical data acquisition system of the electricity distribution utility, Companhia Energética de Minas Gerais (CEMIG). The available data for the small- and medium-sized agroindustries covered the periods from September 5, 2013 to October 3, 2014 and from August 5, to September 19, 2014, respectively. These average hourly demand data are shown in Table 1.

TABLE 1. Hourly average demand for small- and medium-sized agroindustries.

Hour	Average demand (kW)	
	Small-sized	Medium-sized
00:00	38.3	40.5
01:00	50.5	41.0
02:00	51.3	39.5
03:00	51.0	38.3
04:00	49.3	41.3
05:00	50.5	39.8
06:00	50.8	43.0
07:00	67.0	51.3
08:00	74.7	52.5
09:00	81.8	57.3
10:00	81.3	64.8
11:00	69.2	104.0
12:00	74.0	109.8
13:00	83.6	101.0
14:00	78.1	104.0
15:00	76.8	99.3
16:00	70.7	77.3
17:00	48.2	45.3
18:00	31.3	43.3
19:00	32.7	43.5
20:00	32.0	43.8
21:00	34.6	46.5
22:00	34.1	44.5
23:00	34.3	45.0

Sizing the photovoltaic system

The implantation of PV systems into the networks of the small- and medium-sized agroindustries was simulated in order to reduce the demand of each industry and thus reduce the contracted demand during off-peak hours. These simulations were performed using the MS Excel 2013 software.

The following criteria were considered:

1. The demand for each agroindustry begins to increase at 6 a.m. and reduces to the lowest value at 6 p.m.;
2. The PV system for the small-sized agroindustry is designed such that the demand between 7 a.m. and 6 p.m. is less than 67.0 kW, and
3. The PV system for the medium-sized agroindustry is designed such that the demand between 7 a.m. and 6 p.m. is less than 51.3 kW.

The values 67.0 kW and 51.3 kW represent the demands at 7:00 a.m., which corresponds to the beginning of PV electricity generation. As part of the design criteria, it was assumed that solar PV generation between 6 a.m. and 7 a.m. is insignificant and therefore does not contribute significantly to reducing the demand.

The hourly solar radiation data used in the design of the PV systems were obtained from the National Institute of Meteorology (INMET); these data covered the period from January 1, 2011 to December 31, 2018. The minimum values of solar radiation for each agroindustry location were extracted from the original data, as shown in Table 2.

TABLE 2. Minimum hourly solar radiation during the period from Jan 1, 2011 to December 31, 2018 for the small- and medium-sized agroindustries.

Hour	Hourly global solar radiation ($kWh \cdot m^{-2}$)	
	Small-sized Agroindustry Latitude 19° 51’ 37” S	Medium-sized Agroindustry Latitude 21° 45’ 51” S
00:00	0	0
01:00	0	0
02:00	0	0
03:00	0	0
04:00	0	0
05:00	0	0
06:00	0	0
07:00	0.0042	0.0057
08:00	0.1043	0.0734
09:00	0.2713	0.1923
10:00	0.4477	0.2662
11:00	0.5578	0.3871
12:00	0.5703	0.3726
13:00	0.5023	0.4534
14:00	0.4880	0.3774
15:00	0.3806	0.3035
16:00	0.2343	0.2194
17:00	0.1034	0.0824
18:00	0.0061	0.0019
19:00	0	0
20:00	0	0
21:00	0	0
22:00	0	0
23:00	0	0

To size the PV system for each farm, it was necessary to determine the number of PV modules needed. This number was determined by using an iterative procedure that was developed for this study. This procedure, which was also implemented with the MS Excel 2013 software, involves determining the best system to meet the demand of each agribusiness, as follows:

1. Simulate a PV system using an arbitrarily selected number of modules;
2. Calculate the electric power generated by the PV modules every hour using [eq. (1)] and the hourly radiation data provided in Table 2. Equation 1 is a modification of the equation proposed by Lacchini & Santos (2013):

$$P_{ger} = R_d\, A\, \eta\, t \quad (1)$$

Where:

P_{ger} - power generated per hour (kWh/h);

R_d - mean hourly irradiation ($kWh \cdot m^{-2}$);

A - area of the set of modules (m^2);

η - total system efficiency (%),

t - considered period (1 h);

3. Calculate the difference between the demand data presented in Table 1 and the electric power generated at every hour;
4. If the difference between the hourly demand and the hourly electric power generation exceeds the demand criterion (67.0 kW or 51.3 kW for the small- or medium-sized agroindustries, respectively), simulate another system using a different number of modules;
5. Repeat steps 2, 3, and 4 until the above-mentioned demand criterion is met;
6. Verify that the final number of PV modules simulated is the minimum number necessary to meet the demand criterion for each agroindustry. This verification is performed by repeating steps 2, 3, and 4, but with one less PV module, and
7. If the verification is successful, the procedure ends.

After determining the minimum number of PV modules needed to reduce the off-peak demand for each agroindustry, the final PV systems were dimensioned.

Economic analysis of the feasibility of implementing the photovoltaic system

Photovoltaic system

For this analysis, a price survey of PV systems connected to the grid in the Brazilian company, Portal Solar, was performed. The quoted items were PV panels, inverters for connection to the grid, support for the panels, cables for electrical connections, bidirectional meter, and installation. To prepare the quotation, panels of 260 Wp each were chosen because they had the lowest US$/W ratio. Table 3 presents the investment cost of the simulated PV system for implantation in the small- and medium-sized agroindustries.

TABLE 3. Basic characteristics of the photovoltaic system and cost composition in 2017.

System Features	Small-sized agroindustry	Medium-sized agroindustry
Technology	polycrystalline silicon	polycrystalline silicon
Installed capacity (kWp)	91.0	200.2
Number of 260-Wp modules	350	770
Efficiency (%)	16.0	16.0
Area per module (m^2)	1.62	1.62
Cost of components	US$	US$
PV modules	89,772.73	197,500.00
Frequency inverter	72,463.94	159,420.30
Bidirectional meter and cables	14,013.94	30,830.30
Installation of all modules	12,878.79	31,969.70
Electrical project	3,030.30	4,545.45
System investment cost	192,159.70	422,750.61

Exchange rate: US$ 1.00 = BR$ 3.30

Table 4 shows the average daily global solar radiation on the shed area of the selected agroindustries. The values were obtained from data provided by the Reference Center for Solar and Wind Energy Sergio de Salvo Brito (CRESESB) and were used to calculate the electric power generated by the PV systems.

TABLE 4. Average daily global solar radiation on the inclined plane at the latitude of the selected agroindustries.

State	Agroindustry	Latitude	Solar Radiation ($kWh.m^{-2}.day^{-1}$)
Minas Gerais	Small-sized	19° 51\` 37\`\` S	4.80
	Medium-sized	21° 45\` 51\`\` S	4.34

Source: (CRESESB, 2017).

The annual electric energy generated by the PV modules for one year was calculated according to [eq. (2)] (Lacchini & Santos, 2013):

$$E_{ger} = 365\, R_d\, A\, \eta \quad (2)$$

Where:

E_{ger} - electric power generated annually ($kWh.year^{-1}$);

R_d - mean daily solar radiation ($kWh \cdot m^{-2}.day^{-1}$);

A - area of the set of modules (m^2);

η - total system efficiency (%).

Table 5 presents other operational parameters assumed for the economic feasibility analysis of the implantation of PV systems. These parameters were obtained from a literature review of climatic and economic conditions for solar PV generation in Brazil.

TABLE 5.Operating and economic parameters assumed in each solar photovoltaic system scenario.

Calculation parameters		References
DC−AC conversion efficiency (%)	85	Lacchini & Santos (2013)
System life (years)	30	
Annual discount rates (%)	8 and 12	ANEEL (2013)
Operating costs in 30 years (%)**	0.5	Mitscher & Rüther (2012)
Annual increase in energy tariff from zero to 15 years (%)	3	Mitscher & Rüther (2012)
Annual increase in energy tariff from 16 to 30 years (%)	2	Mitscher & Rüther (2012)
Annual loss of system efficiency (%)	0.65	Mitscher & Rüther (2012)

** of the initial investment in the photovoltaic system.

Economic analysis considering the externality of the decrease in demand during off-peak hours

The economic analysis considered the net metering policy regulated by Normative Resolution 482 of the National Electric Energy Agency (ANEEL), as amended by Normative Resolution 687, whereby energy credits are generated and can be used for up to 60 months. This analysis also considered the fact that there is no taxation on electric power generated and injected into the distribution network in the state of Minas Gerais.

- Financial income

The revenues resulting from the implementation of PV systems are due to financial savings generated by the non-use of electricity from the electricity distribution company according to the net metering policy and the reduction in contracted demand during the off-peak hours.

The electrical energy tariffs of the agribusinesses were obtained, in addition to federal and state taxes.

Both agroindustries are included in the tariff group A4 of CEMIG in the green time-of-use (TOU) tariffs. Table 6 shows the electrical energy tariffs that were used in this study, as well as the contracted demand with CEMIG for the small- and medium-sized agroindustry.

It was assumed that the use of the PV system would result in a reduction in the daily demand during the off-peak hours, and as a result, a lower demand would be contracted, which in turn would generate savings. These savings were treated as financial income. This premise constitutes the effect of the externality of the decrease in off-peak demand due to the generation of electricity by the solar PV system.

TABLE 6. Contracted demand and electrical energy tariffs in the green time-of-use, TOU, tariff modality applied to the small- and medium-sized agroindustry.

TOU tariff A4 group[1,2]		Small-sized agroindustry	Medium-sized agroindustry
Contracted demand (kW)		108	115
Demand (U$S/kW)		3.567	3.567
Excess demand (U$S/kW)		7.136	7.136
Consumption (U$S/kWh)	Dry season Wet season	0.481	0.481
	Off-peak and dry season Off-peak and wet season	0.128	0.128

Notes: (1) Rates include taxes; (2) Green TOU A4 Group.
Exchange rate: US$ 1.00 = BR$ 3.30
Source: (CEMIG, 2017).

A new contracted off-peak demand was assumed for each agroindustry that was 20% higher than the maximum power demanded in the daily demand curve after the implantation of the PV system. Thus, the value of 80 kW was assumed for the small-sized agroindustry and 62 kW for the medium-sized agroindustry. The increase of 20% represents the safety margin that was assumed.

The effect of cloudiness on PV solar generation was considered such that each agroindustry pays a fine for exceeding the contracted demand, but the total annual value is lower than the economy with a reduction in the contracted off-peak demand after implementing the PV system.

- Investments

Table 3 shows the details of the investments required for the implementation of the PV systems.

- Operational costs

Operating costs were based on the costs of maintenance and operation of the PV system. The operational cost of the PV system during its lifetime was estimated at 0.5% of the initial investment (Mitscher & Rüther, 2012).

- Economic indicators

Once the costs and benefits of the systems were established, the project cash flows and economic feasibilities were analyzed using the following indicators: net present value (NPV), internal rate of return (IRR), and discounted payback time.

RESULTS AND DISCUSSION

Demand curve of small and medium-sized agroindustries

Figures 1 and 2 show the time demand curves representing the selected small and medium-sized agroindustries, respectively.

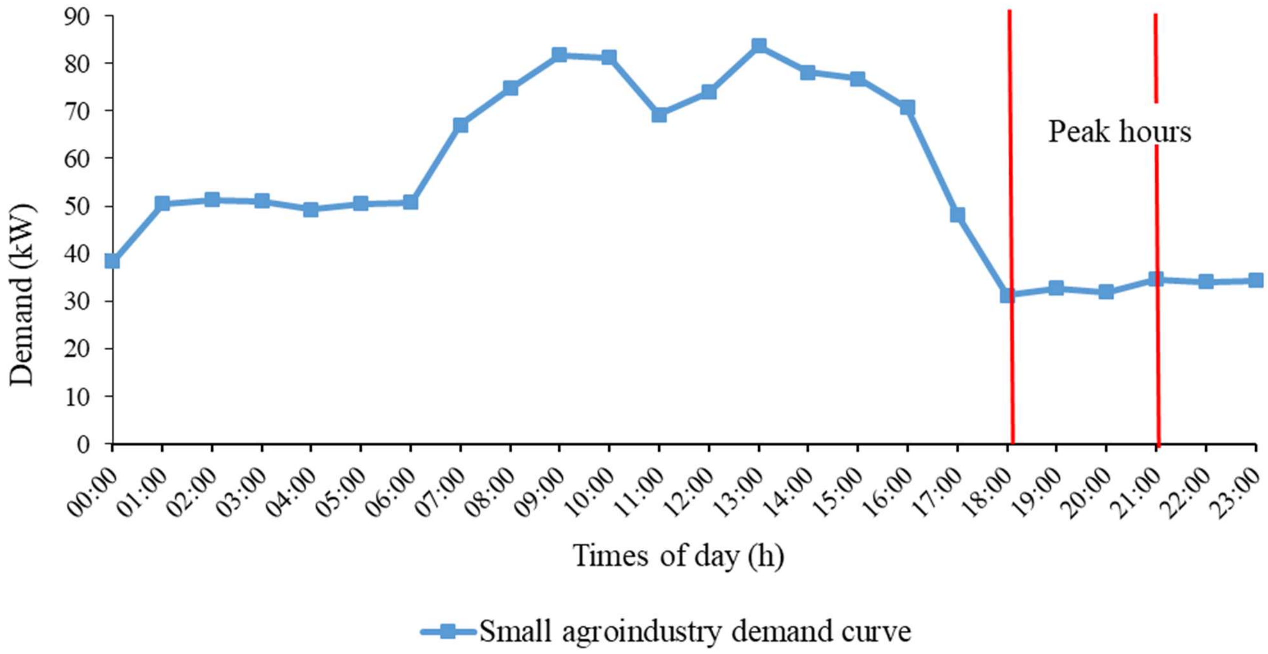

FIGURE 1. Load curve of the small-sized agroindustry.

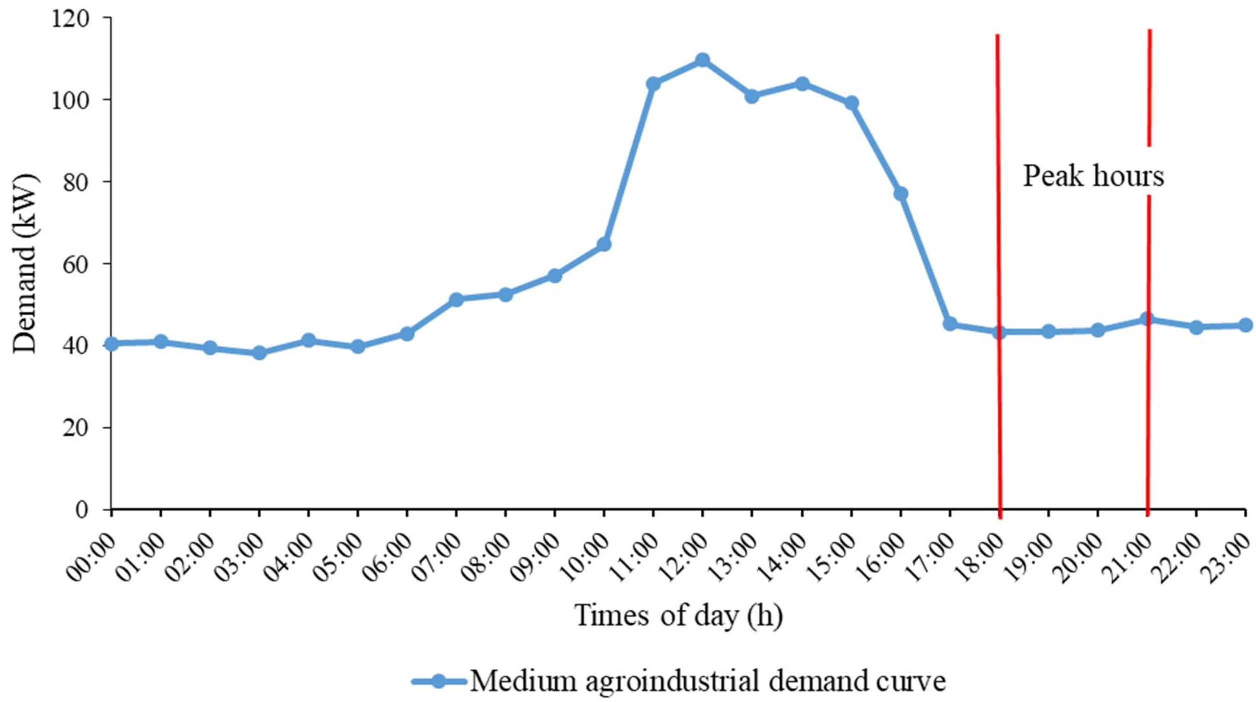

FIGURE 2. Load curve of the medium-sized agroindustry.

Each point on the demand curve represents the maximum electrical power required from the utility by the agroindustry at a given time. Thus, each point on the curve represents the maximum power that each agroindustry reaches at the corresponding time of day, as long as its daily production does not increase, and the production process does not change.

In this study, it was assumed that the selected agroindustries do not plan to increase production in the short and long terms. Thus, it can be assumed that the demand curves shown in Figures 1 and 2 are applicable throughout the useful lives of the PV systems in these agroindustries.

It should be noted that the modification in the demand of the small-sized agroindustry starts around 6:00 a.m. and ends around 6:00 p.m. with a peak at 1:00 p.m. (Figure 1), while that of the medium-sized agroindustry is between 6:00 a.m. and 5:00 p.m. with a peak at 12 noon (Figure 2). Both curves present demand patterns that are typical of industrial load curves in Brazil, according to research by Xavier (2015) on the typical demand curves for various consumer categories.

As shown in Figures 1 and 2, the peak demand for each agroindustry occurs five to six hours ahead of the peak hours, which contributes to the reduction in energy expenditure.

In addition, the load curves indicate that the highest demands coincide with the periods of high incident solar radiation, which is ideal for using PV systems to generate electric power. This coincidence provides the externality benefits of decreasing the demand during off-peak hours due to solar PV generation.

The load curves presented in Figures 1 and 2 are different from each other because they present demand values and their distributions at different times. However, they present an important similarity: both curves indicate peak demands between 9 a.m. and 5 p.m., which follows the general pattern of demand curves for industries in Brazil (Xavier, 2015). Therefore, the results of this study may serve as illustrative examples for using PV systems to reduce the demand in other industries in Brazil.

Photovoltaic system for off-peak demand reduction

Figure 3 presents the results of the simulation of a PV system of 91.0 kWp capacity implanted in the selected small-sized agroindustry in order to reduce its maximum daily demand during the off-peak hours. Likewise, Figure 4 shows the results for the selected medium-sized agroindustry using a PV system of 200.2 kWp capacity.

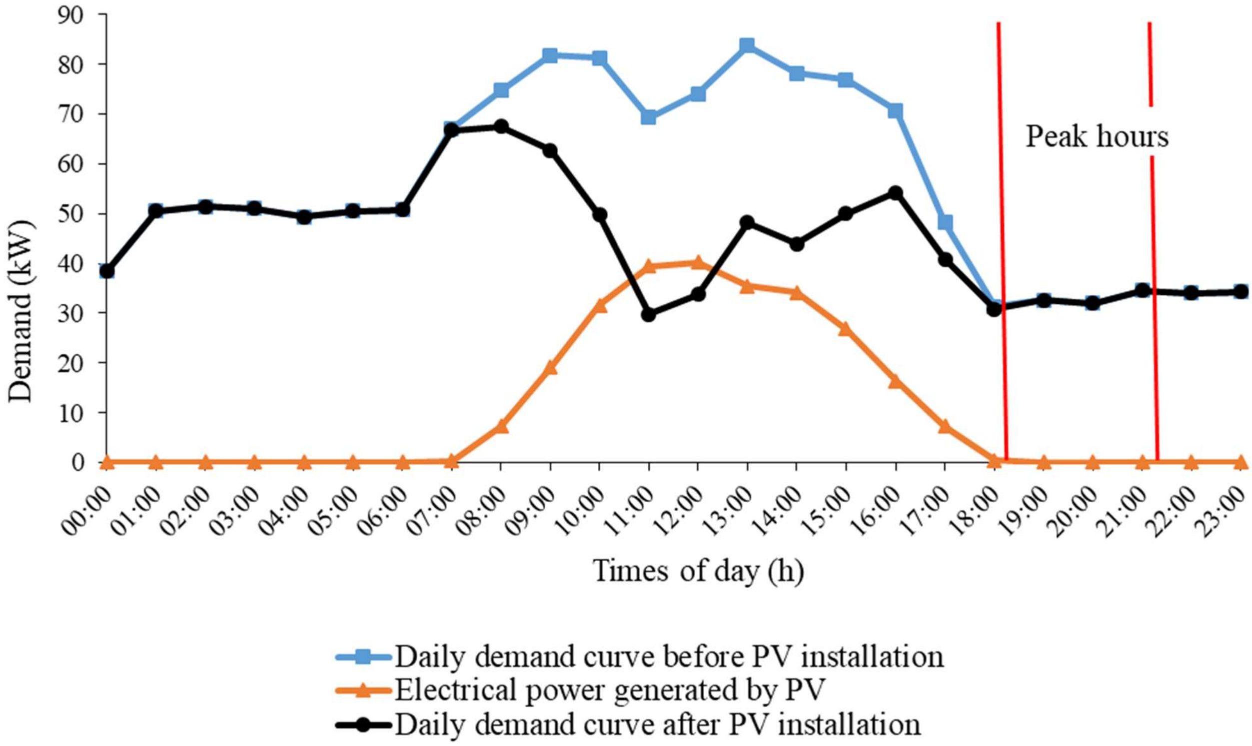

FIGURE 3. Demand curve of the small-sized agroindustry evaluated before and after the implantation of the photovoltaic (PV) system.

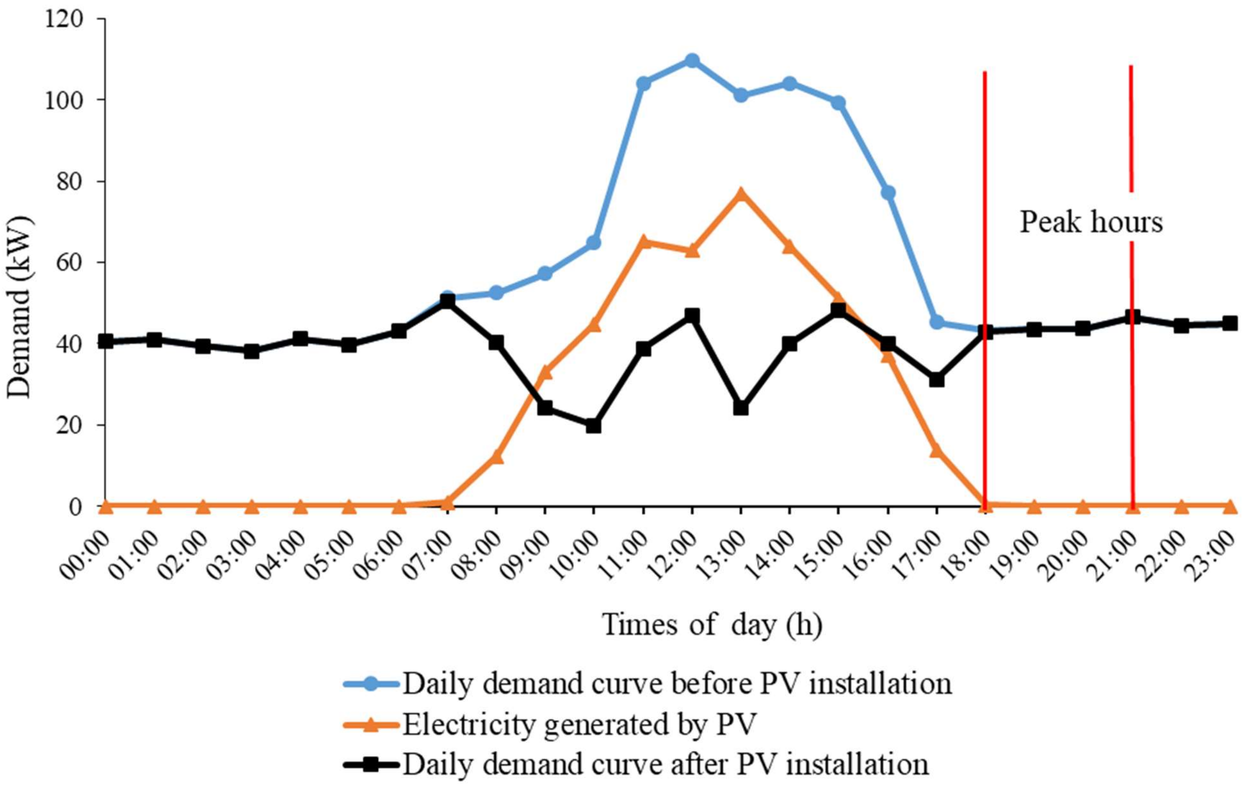

FIGURE 4. Demand curve of the medium-sized agroindustry evaluated before and after the implantation of the photovoltaic (PV) system.

In each of Figures 3 and 4, there are three curves. The first is the representative demand curve of the agroindustry before the implantation of the PV system, the second is the demand curve of the agroindustry after simulating the implantation of the PV system, and the third depicts the generation of electric energy by the PV system.

These curves reflect some data treatment: the demand curves show the highest demand values, while the solar PV generation curves correspond to the lowest levels of solar radiation observed. Thus, the benefits of the evaluated externality will be even greater when at a given moment the generation of electric energy by the PV system is greater than that considered, since the radiation considered for simulation was the minimum observed in the period.

Figures 3 and 4 indicate that the use of the PV system reduces the demand during the off-peak hours, which include the hours with the highest solar radiation. Thus, the higher the solar radiation, the larger is the demand reduction.

For the small-sized agroindustry (Figure 3), the maximum demand from the grid (83.6 kW) occurs at 1 p.m. When the PV system will be installed, the maximum demand (66.7 kW) occurs at 7 a.m.; i.e., the demand to the utility reduces by 20.2%. For the medium-sized agroindustry (Figure 4), the maximum demand without PV generation is 109.8 kW at 12 noon. With PV generation installed, the maximum demand will be 50.3 kW at 7 a.m.; i.e., the demand to the utility reduces by 54.2%. These demand reductions also relieve the electric power system.

The percentage of reduction depends on the load curve. The greater the difference between the highest demand during the period from 11 a.m. to 3 p.m. and the highest demand recorded in the period of zero (or near-zero) solar radiation, the greater is the percentage of reduction in peak demand due to solar PV generation.

In addition to reducing the demand, the PV system also produced better load factors for the demand curves. Before the implantation of the PV system, the load factors of the small- and medium-sized agroindustries were 0.670 and 0.538, respectively, and after implantation, these values were 0.672 and 0.790, i.e., improvements of 0.25% and 46.98%, respectively.

The typical demand curve for the industrial sector, which includes the agroindustries evaluated in this study, is identical to that of the commercial sector. At midday, the air conditioning load of commercial consumers increases, which raises the demand curve to its highest value between midday and 3 p.m. (Rüther et al., 2008). This behavior shows that the use of PV systems can also contribute to the reduction in the off-peak demand for consumers that exhibit load curves identical to that of the commercial sector.

Rüther et al. (2008) evaluated the use of PV systems to reduce peak demand in the city of Florianópolis. Their results indicated that grid-connected PV systems contribute significantly to the reduction in peak summer demand in regions where the load curve is identical to that of the commercial sector.

The typical demand curve of Brazilian residential consumers has a peak between 5 p.m. and 10 p.m. Currently the use of PV systems alone is not effective in reducing the peak demand since the solar irradiation in this time frame is minimal or zero.

From a consumer perspective, the use of PV systems to reduce peak demand has the inherent benefit of reducing the cost of electricity. In addition, consumers with a typical industrial or commercial curve may reduce their contracted demand, which further reducing the amount paid for electricity.

Richardson & Harvey (2015) evaluated strategies for increasing the correlation between solar PV generation and peak demand in the province of Ontario, Canada. Their results indicated that the PV system is ideal when peak demand coincides with peak generation, which is beneficial to both the consumer and the electricity distribution system.

However, it is important to note that, in the case of PV solar modules, the amount of incident solar radiation on the PV modules may be reduced (Kolling et al., 2004; Michels et al., 2009). Thus, reduction in contracted demand is a risk for the consumer. For instance, if power generation by the PV system during a given period is curtailed by cloudiness to the point where the consumer demand exceeds the contracted amount, then the consumer will be required to pay a fine to the utility, if there were no batteries.

Another way to reduce the likelihood of incurring a fine, without using any form of electrical energy storage, is to size the PV system according to the smallest hourly radiation levels recorded over a period of several years. This approach accounts for prediction uncertainty by identifying cloudiness conditions that may occur over a longer observation period. The longer the historical time series of radiation data used for the design, the lower is the probability of occurrence of cloudiness, that may reduce the level of radiation below the value used in the design of the PV system.

Another way to reduce the possibility of incurring fines is to include backup battery banks in the PV system. However, this option would raise the cost of the PV system by an average of 50%, and the batteries would have to be changed every 10 years, which would increase the maintenance cost of the system (PORTAL SOLAR, 2017). Another issue with the use of batteries in PV systems is that current Brazilian legislation still does not allow grid-connected PV systems with battery banks.

Hoppmann et al. (2014) evaluated the economic viability of energy storage in batteries for residential grid-connected PV systems in Germany. Their results indicated that profitability in the current German scenario is only possible with government incentives. They concluded that the future direction is to increase profitability of integrated systems through battery storage of PV energy and to make this stored energy available to the network at appropriate time. However, they pointed out that this prospect could pose a substantial challenge for electric utilities and probably will require better technical infrastructures.

In a recent study, Guney & Tepe (2017) predicted that the world's energy demand will double by 2050 and could triple in one hundred years. Moreover, they projected that improvements in generation methods would not be enough to meet energy needs, hence energy storage would be imperative. They also cautioned that battery storage will be indispensable and feasible.

Drude et al. (2014) simulated the use of electric vehicles to transfer electrical energy in an intelligent network environment in the city of Florianopolis, Brazil. Their results indicated that such vehicles can reduce network operating costs for utilities and help stabilize these networks. However, they noted that many electric vehicles connected at the same time could also destabilize the network.

It is believed that with these perspectives around the world and in Brazil, the Brazilian legislation will permit the use of batteries in systems connected to the network soon. This authorization will provide benefits to consumers, including the use of batteries to reduce peak demand and the protection from high energy tariffs at peak times.

Regardless of the use of batteries, PV systems alone are already capable of reducing the demand by consumers for which there is a correlation between the peak PV generation and the peak demand. Therefore, the use of PV systems in agroindustries contributes to reduce the cost of electrical energy, which in turn reduces the cost of production.

From the perspective of the utility, the use of PV systems to reduce the peak demand offers several benefits, including the improvement of voltage profiles, reduction of losses, postponement of investments needed to increase network capacities, and reduction of demand on electric power systems (Urbanetz et al., 2012).

The impact of cloudiness on PV systems would be minimal in the case of consumers supplied by a utility that covers several regions, since cloudiness over one region would most likely be compensated by higher solar irradiation (hence higher PV generation) in other regions.

Feasibility of the implantation of photovoltaic systems for the reduction of the off-peak demand

Tables 7 and 8 present the results of the economic feasibility analysis of the implantation of the PV system to reduce the peak demand in the two selected agroindustries. Respectively, these tables show the effects of disregarding or not the economic gains of the externality in off-peak demand reduction due to PV generation.

TABLE 7. Economic feasibility analysis of the implantation of the photovoltaic system in agroindustries when disregarding the economic gain of the externality off-peak demand reduction.

Agroindustry	Annual discount rate	NPV (US$)	IRR (%)	Discounted payback (year)
Small-sized	8%	47,020.91	10.22	19
	12%	−27,567.93	10.22	*atel*[1]
Medium-sized	8%	52,943.46	9.16	23
	12%	−95,404.53	9.16	*atel*[1]

Exchange rate: US$ 1.00 = BR$ 3.30
Note: (1) *atel*, above the expectedf life.

TABLE 8. Economic feasibility analysis of the implantation of photovoltaic system in agroindustries when considering the economic gain of the externality off-peak demand reduction.

Agroindustry evaluated	Annual discount rate	NPV (US$)	IRR (%)	Discounted payback (year)
Small-sized	8%	60,512.23	10.85	17
	12%	−17,914.59	10.85	*atel*[1]
Medium-sized	8%	78,480.62	9.71	21
	12%	−77,132.15	9.71	*atel*[1]

Exchange rate: US$ 1.00 = BR$ 3.30
Note: (1) *atel*, above the expectedf life.

The results presented in Tables 7 and 8 show that, for an annual discount rate of 12%, the implantation of PV systems in agroindustries is infeasible, since the NPVs are negative and the IRRs are less than the discount rate. However, at the discount rate of 8%, the implantation was economically feasible in both agroindustries.

Despite the economic feasibility, the initial cost of implementing the PV system is still high, which hinders access to this electricity generation technology. In this regard, the current policy, as regulated by Normative Resolution No. 482 of ANEEL, is deficient since there is no financial incentive at the national level.

A comparison of Tables 7 and 8 indicates that higher economic gains are obtainable by considering the externality in the reduction of contracted off-peak demand by the agroindustries. As shown, the NPV obtained by considering the externality was at least 22% higher than that obtained without the externality. The larger the decrease in off-peak demand, the higher is the economic return.

The economic infeasibility of the implantation of the PV systems at the discount rate of 12% is attributed to the low electrical energy tariff (0.128 US$/kWh) paid by the agroindustries. This tariff is effective throughout the time of solar PV generation.

To achieve feasibility, the minimum tariff during off-peak hours should be 0.142 US$/kWh for the small-sized agroindustry and 0.158 US$/kWh for the average-sized agroindustry, i.e., 10.9% and 23.5% higher than the current rate, respectively. The difference between these tariffs is a function of the electric power generation. The small-sized agroindustry is in a region with a higher annual average solar radiation. Therefore, at the same energy tariff, this agroindustry will always generate more electricity and achieve higher economic gains than the average-sized agroindustry.

The annual average electricity savings obtained in the small-sized agroindustry was US$ 24,700.11, of which 4.9% was due to the reduction in contracted off-peak demand, and the remaining 95.1% was due to the reduction in electricity consumption from the utility.

The corresponding results for the average-sized agroindustry were US$ 49,017.22 in savings, of which 4.6% was from reduction in contracted off-peak demand and the remaining 95.4% was from reduction in electric power consumption.

Based on the results and perspectives developed in this study, the externality of the decrease in the off-peak demand due to PV solar generation is an important economic factor. This factor and other benefits of PV systems for the consumer and the National Interconnected System should be considered in developing a better financial incentive policy for PV generation and in strengthening the local productive arrangements.

CONCLUSIONS

Photovoltaic systems in agroindustries promote reduction in contracted off-peak demand, thereby reducing the consumption and cost of electric energy, which in turn contributes to decrease production costs in this sector of the economy.

The use of grid-connected PV systems in agroindustries can contribute up to 47% load factor improvement.

The initial investments in PV solar generation systems are high, which hinders access in the short term. Although the externality of the decrease in off-peak demand due to PV generation does not reduce the initial investments, it increases the economic returns on these investments.

Improved policies are needed in order to encourage photovoltaic solar generation in Brazil. These policies should favor the implementation of photovoltaic systems nationwide.

Valuation of the technical and economic benefits of the decrease in the off-peak demand due to PV systems within distributed generation networks is a promising way to encourage consumers to invest in this energy source and even promote better investments in the energy sector.

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