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COMPARATIVE STUDY OF ENERGY COSTS IN IRRIGATION ACCORDING TO THE NEW BRAZILIAN ELECTRICITY TARIFF MODEL

ABSTRACT: The tariff flags on Brazil came into force in January 2015, applied to all electrical distribution agents of the national interconnected system (SIN) and all final consumers are being charged for this new model. Given this, the cost of electricity in irrigation suffered representative additions involving searches of alternatives, such as the use of diesel engines. This study aimed to analyze the costs and the total annual costs of pumping with diesel and electric operation in 3 regions of Brazil, considering the application of the tariff flags. We concluded that the Southeast region (SE) features an hourly cost of electricity above the Central-West (CO) and the Northeast (NE) regions at any adopted tariff, regardless of the time of pumping and the use of diesel engines in irrigation is feasible in terms of distances from the electrical grid that can range from 2.8 to 72.4 km, the first being the most favorable condition in the Southeast with the operation of 4 months per year with fertirrigation, in conventional tariff and red flag is the less favorable in the Northeast with 10 months/year operation with/without fertirrigation, in bohemia blue and green flag tariff.

KEY WORDS: tariff flags, costs, diesel, irrigation.

INTRODUCTION

Electricity is an essential input to the society, essential to the socioeconomic development of nations. In Brazil, the main source of generation is hydroelectric (running water of rivers) which accounts for 65% of installed capacity in operation in the country, followed by thermal plants, with 28% (ANEEL, 2013).

Hydroelectric plants depend on rainfall and water level in tanks, when there is little water stored, the power plants are turned on in order to save water from these tanks, and thus the cost of generation increases because these plants use fuels such as natural gas, coal, fuel oil and diesel.

With the Resolution Nº 700 of January, 26, 2016 (ANEEL, 2016) that approved the Sub module 6.8 of the Tariff Regulation Procedures has changed the way that the taxation of electricity in Brazil was measured. According to PRORET (2015), to signal to consumers the conditions of electricity generation in the NSI (National Interconnected System), tariff flags were created. Charging an additional amount in power tariff does this signaling. This gives the consumer the opportunity to adapt their consumption, helping to prevent further increase. The tariff flags system works as a "traffic light" indicating the difference in cost of power generation for consumers. Thus, the green flag, which has favorable conditions for power generation, the tariff does not suffer any increase. In the yellow and red flag, representing the generation in less favorable conditions, the tariff will suffer increases in the kWh consumed.

In this scenario, an irrigation system may not be economically feasible due to factors such as the cost of energy, as energy is a significant percentage of the total costs of water pumping (about 40%), requiring further study of the economic variables involved in the project (PERRONI et al., 2011; RODRÍGUEZ-DÍAZ et al., 2011).

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Thus, the irrigator possibly seeks alternatives that minimize the effects of increases in the electricity for irrigation. One of these alternatives would be the use of diesel engines that according to FRIZZONE (2005) has more mobility than the electric, has operating possibility at any time of the day, and are useful in remote parts of the electrical system of the local dealership where the cost of the line power causes the electrical system to may have a higher initial cost than the diesel system.

However, a detailed study of energy costs for irrigation is necessary to state that in the electric charging current condition, the use of alternatives, such as the diesel engine, is more viable. Therefore, the aim of this study was to analyze the costs and total annual costs of pumping with the operation of diesel and electric motors in three regions of Brazil, considering the application of tariff flags.

SUBJECT DESCRIPTION

The methodology for the comparison calculation of energy costs for irrigation using diesel and electric motors was divided into three steps: calculation of energy costs for irrigation using diesel engines, calculation of energy costs for irrigation using electric motors and the comparison of these costs. At the end, we performed simulations for three regions of Brazil (Northeast, Central-West and Southeast) using a calculation spreadsheet developed to obtain the total annual and hourly costs for the studied conditions involving tariff flags, two subgroups of the “A” group using electrical motors in addition to the extension of the electrical gridwhich enables the use of the diesel engine.

Calculation of energy costs for irrigation using diesel engines

According to ZOCOLER et al. (2011), the total cost of energy when using diesel engines can be calculated from the sum of the fixed cost and variable cost:

$$CT_d = C_f + C_v \tag{1}$$

where,

CT_d – total cost of using diesel, R$;

C_f – fixed cost, R$, and

C_v – variable cost, R$.

In this situation the fixed cost can be calculated by the sum of the cost of maintenance and the product between capital recovery fund of the diesel engine and the cost of the diesel engine:

$$C_f = C_m + (CRF_e C_{de}) \tag{2}$$

where,

C_m – cost of maintenance, R$;

CRF_e – capital recovery fund (depreciation + interest) of the diesel engine, R$, and

C_{de} – cost of the diesel engine, R$.

According to ZOCOLER et al. (2011), in practice, it is customary to calculate the costs of annual maintenance as an average percentage fraction of the purchase of the equipment value, in this methodology we considered this cost being equal to 6% per year of the diesel engine cost:

$$C_m = 0{,}06\ C_{de} \tag{3}$$

According to ZOCOLER et al. (2013), the Capital Recovery Fund (depreciation + interest) of the diesel engine is calculated by the following equation:

$$CRF_e = \frac{i(1+1)^{ul}}{(i+1)^{ul} - 1} \tag{4}$$

where,

i – interest rate, decimal, and

ul – useful life, years.

As for the variable cost, this can be calculated by multiplying the power output of the diesel engine, the specific consumption, the dollar price and the diesel price:

$$C_v = P_e \, b \, US\$ \, d \tag{5}$$

where,

P_e – net power of the diesel engine, cv;

b – specific consumption, L $cv^{-1}h^{-1}$;

US$ - dollar price, R$, and

d – diesel price, US$.

In some cases, the irrigator can recover the amount paid by the ICMS (price component of diesel), so it is possible to use the following equation to calculate the variable cost:

$$C_v = (P_e \, b \, US\$ \, d)\,(1 - ICMS) \tag{6}$$

where,

ICMS – tax on goods and services circulation, decimal.

Calculation of energy costs for irrigation using electric motors

According to ZOCOLER et al. (2011), the total cost of energy when using electric motors can also be calculated from the sum of the fixed cost and the variable cost:

$$TC_{ee} = C_f + C_v \tag{7}$$

where,

TC_{ee} – total cost using electricity, R$;

C_f – fixed cost, R$, and

C_v – variable cost, R$.

In this situation the fixed cost can be calculated by the sum of the maintenance cost, the product of the electric motor of the capital recovery fund and the cost of the electric motor, and the product between capital recovery fund of the electric motor and the electrical grid cost:

$$C_f = C_m + (CRF_{em}\, C_{em}) + (CRF_{eg}\, C_{eg}) \tag{8}$$

where,

C_m – maintenance cost, R$;

CRF_{em} – capital recovery fund (depreciation + interest) of the electric motor, R$;

CRF_{eg} – capital recovery fund (depreciation + interest) of the electrical grid, R$;

C_{em} – electric motor cost, R$, and

C_{eg} – electrical grid cost, R$.

The capital recovery fund of the electric motor should be calculated separately from the electrical grid because these have different useful life. The grid has a useful life of 20 to 30 years, while the electric motor varies from 10 to 15 years.

As per ZOCOLER et al. (2011), repairs and maintenance correspond to the annual cost required to maintain the capital asset in working condition, in this methodology we considered this cost being equal to 2% per year of the cost of the electric motor:

$$C_m = 0.02\ C_{em} \tag{9}$$

According to ZOCOLER et al. (2013), the Capital Recovery Fund (depreciation + interest) of the electric motor and the electrical grid are calculated by the same formula:

$$CRF_{em}\ and\ CRF_{eg} = \frac{i\ (1+1)^{ul}}{(i+1)^{ul} - 1} \tag{10}$$

where,

i – interest rate, decimal, and

ul – useful life, years.

The cost of the electrical grid may be determined using an adaptation of the equation of SOUZA (2001):

$$C_{eg} = [(3.9291\ E_{xt}) + 2935.8]\ Fac \tag{11}$$

where,

C_{eg} – electrical grid cost, US$, and

E_{xt} – extension of the electrical grid, m.

Fac – correction factor to update the price adapted from RIBEIRO (2014):

$$Fac = (0.3\ US\$\#) + (0.35\ IGPM\ FGV) + (0.35 IPCA\ IBGE) \tag{12}$$

where,

US$# – Average selling price of commercial dollar in the considered period, US$;

IGPM FGV– General index of market prices accumulated in the period considered, %, and

IPCA IBGE– Price index accumulated to the consumer in the period considered, %.

As for the variable cost in this situation, it can be calculated by the sum of the total sales of electricity and the ICMS on these sales:

$$C_v = S_t\ (1 + ICMS) \tag{13}$$

where,

S_t – total sales, R$, and

ICMS - tax on goods and services circulation, decimal.

In some cases, the irrigator can recover the amount paid by the ICMS, so equation 13 can be simplified to:

$$C_v = S_t \tag{14}$$

In accordance with PROCEL (2011), the total billing is calculated by the sum of the demand billing, consumption billing, flag billing and the setting:

$$B_t = B_d + B_c + B_f + S \tag{15}$$

where,

B_d – demand billing, R$;

B_c – consumption billing, R$;
B_f – flag billing, R$, and

S – setting, R$.

The demand and consumption billing depend on the tariff framework in which the irrigator belongs. According to FUGIMOTO (2010), there are three possible types of tariffs for irrigators: the conventional tariff, the green tariff and the blue tariff, however, it is necessary that the consumer meets the requirements to fit into each of these categories.

According to the ANEEL (2012), there are different types of timetable for the application of different consumption tariffs and demands (Table 1).

TABLE 1. Types of hourly for different application tariffs of consumption and demand.

Type of Timetable	**Time of day(h)**
Peak	17:00 to 20:00
Off- peak	20:01 to 16:49
Off- peak[1]	23:00 to 05:00

[1]Irrigators may have discount in the consumption tariff at this time.

There is also a discount to irrigators, called night discount, which varies according to the region of the country, as shown in Table 2 (ANEEL, 2012).

TABLE 2. Discount percentage in the consumption tariff in function of the irrigating region.

Region	**Discount**
Northeast and other municipalities of the operating area of the Northeast Development Superintendence - SUDENE, as art. 2º of Annex I of Decree n° 6219, 2007	90%
North, Central-West and other cities in the state of Minas Gerais	80%
Other Regions	70%

[1]According to Art. 74 Normative Resolution n° 479/2012

Conventional tariff

According to PROCEL (2011), the framework in the conventional tariff requires a specific agreement with the concessionaire in which agreed a single value of the desired demand by the consumer (contracted demand) regardless of the time of the day (peak or off-peak) or period of the year (dry or wet).

Thus, the demand billing is calculated by the following equation:

$$B_d = D_m\, T_{cd} \tag{16}$$

where,

D_m – measured demand, kWh, and

T_{cd} – conventional tariff demand, R$ kWh^{-1}.

If the consumer does not use electricity in a given period, the demand billing will result in 10% of the highest monthly amount paid in the last 12 months:

$$B_d = D_m\, T_{cd}\, 0.1 \tag{17}$$

In cases where the contracted demand exceeds, the demand billing shall be calculated as follows:

$$B_d = (D_m\ T_{cd}) + (D_c\text{-}D_m)\ T_e \quad (18)$$

where,

D_c – contracted demand, kWh, and

T_e – exceeded tariff, R\$ kWh^{-1}.

The consumption billing is calculated as follows:

$$B_c = C_m\ T_{cc} \quad (19)$$

where,

C_m – measured consumption, kWh, and

T_{cc} – Conventional consumption tariff, R\$kWh^{-1}.

Green tariff

This tariff mode requires a specific agreement with the concessionaire in which agreed the desired demand for the consumer (contracted demand) regardless of the time of the day (peak or off-peak). It allows them to hire two different values of demand, one for the dry period and one for the wet period, however, the demand value of the wet period can not be less than the demand value of the dry period (PROCEL, 2011).

The demand billing can be calculated by the following equation:

$$B_d = D_c\ T_{gd} \quad (20)$$

where,

T_{gd} – green demand tariff, R\$kWh^{-1}.

If the consumer does not use electricity in a given period, the demand billing will result in 10% of the highest monthly amount paid in the last 12 months:

$$B_d = D_m\ T_{gd}\ 0.1 \quad (21)$$

In cases where the contracted demand exceeds, the demand billing shall be calculated as follows:

$$B_d = (D_m\ T_{gd}) + (D_c\text{-}D_{ma})\ T_e \quad (22)$$

The consumption billing is calculated by the following equation:

$$B_c = (C_p\ T_{gcp}) + (C_{op}\ T_{gcop}) \quad (23)$$

where,

Cp – consumption at peak hours, kWh;

Tcvp – green consumption tariff at peak hours, R\$ kWh^{-1};

Cop – consumption at off-peak hours, kWh;

Tgcop – green consumption tariff at off-peak hours, R\$ kWh^{-1}, and

In this case, it is important to note the time of the year and then apply the tariffs for that time.

Blue tariff

According to PROCEL (2011), this tariff mode requires a specific agreement with the concessionaire in which agreed both the value of the required demand by consumers at peak hours (contracted demand at peak) and the desired value at the off-peak hour (contracted demand of off-peak). It allows them to hire two different values of demand, one for the dry period and one for the wet period, however, the demand value of the wet period can not be less than the demand value of the dry period.

The demand installment is calculated by summing the product of the demand tariff at the peak by the contracted demand in the peak to the product of the demand tariff at off-peak by the demand contracted at off-peak:

$$B_d = (D_{cp}\ T_{bdp}) + (D_{cop}\ T_{bdop}) \qquad (24)$$

that,

D_{cp} – contracted demand at peak, kWh;

T_{bdp} – blue demand tariff at peak hours, R$ $^{-1}$kWh;

D_{cop} – contracted demand at off-peak, kWh, and

T_{bdop} – blue demand tariff at off-peak hour, R$kWh^{-1};

The demand tariffs are not differentiated by time of the year.

In cases where the contracted demand exceeds the demand billing shall be calculated as follows:

$$B_d = (D_{cp}T_{bdp}) + (D_{cop}T_{bdop}) + (T_{ep}\ (D_{mp} - D_{cp})) + (T_{eop}\ (D_{mop} - D_{cop})) \qquad (25)$$

where,

T_{up} – exceeded tariff at peak, R$kWh^{-1};

D_{mp} – measured demand at peak, kWh;

T_{eop} – exceeded tariff at off-peak, R$kWh^{-1}, and

D_{mfp} – measured demand at off-peak, kWh.

Exceeded tariffs are differentiated by time, being more expensive at peak hours.

The consumption amount may be calculated by the following equation:

$$A_c = (C_p\ T_{bcp}) + (C_{op}\ T_{bcop}) \qquad (26)$$

where,

C_p – consumption at peak hour, kWh;

T_{bcp} – blue consumption tariff at peak hour, R$kWh^{-1};

C_{op} – consumption at off-peak hour, kWh, and

T_{bcop} – blue consumption tariff at off-peak hour, R$kWh^{-1}.

The consumption tariff at peak and off-peak is differentiated by time of the year, being more expensive in the dry season (May to November).

In this methodology the flag billing was considered an additional cost. Thus, the calculation of flag billing can be calculated as follows:

$$F_b = (C_p + C_{op})\ 0.015 \qquad (27)$$

where,

C_p – consumption at peak hours, kWh, and

C_{op} – consumption at off-peak hours, kWh.

When the flag signal the red color, the generation conditions will be the most expensive. The tariff will suffer an increase of R$ 0.030 for each kWh consumed in Level 1 or R$ 0.045 to each kWh consumed in Level 2 (PRORET, 2015).

Thus, the calculation of flag billing in this situation can be calculated by the equation:

$$F_b = (C_p + C_{op})\ 0.030 \text{ or } 0.045 \quad (28)$$

where,

C_p – consumption at peak hours, kWh, and

C_{op} – consumption at off-peak hours, kWh.

In addition to active energy, there is another type of energy, called reactive power. This is a different energy: although we can not classify it as useless, it does not work and produce losses due to heating in the conductors (PROCEL, 2011).

If the irrigator does not have a capacitor bank, he will pay for this energy, which is called adjustment.

It can be calculated by the equation:

$$A = (B_d + FB_c)\left(\left(\frac{0.92}{\cos\varphi}\right) - 1\right) \quad (29)$$

where,

$\cos\varphi$ – power factor.

Energy cost comparison for irrigation using diesel and electricity engine

This comparison can be made equaling the total cost of using diesel engines to the total cost of using electric motors.

$$C_{td} = C_{tee} \quad (30)$$

In this case, the use of some iterative calculation tools of spreadsheet is necessary, like "reach goal or solver" to identify the length limit of the electrical grid that would allow the use of electricity.

Determination of the constants used in the simulations

The input data provided to the calculations can be seen in Table 3. The values of the engines are in accordance with the market value for March 2015, including the electric motor value, the starting key value. The diesel engine specific consumption was set according to the characteristics provided by the manufacturer.

TABLE 3. Engines specifications and data used for the calculation.

Specifications	Electric Motor	Diesel Engine
Motor Cost (R$)	42,000.00	52,000.00
Power of the useful motor (hp)	100	100
Motor useful life (years)	15	10
Useful life of the electrical grid (years)	20	-
Specific consumption[1]	0.78 kWh cv^{-1}	168 g cv^{-1} h^{-1}
Diesel Price (US$ L^{-1}) [2]	-	0.87 [3]
Annual interest rate	4%	4%
ICMS	-	-
Cosine of ϕ (power factor)	0.92	-

Source: Authors. [1]Electric motor with an efficiency of 94%. [2]Commercial value of the dollar quoted in R$ 3.59. [3]Average value of the national distribution: SE (0.81), CW (0.87) and NE (0.82).

All tariffs were calculated based on the ANEEL Resolution n° 1.858 of February 27, 2015, using the tariffs concerning the month of May 2016, the companies: CEMIG (SE), CELG (CW) and CEAL (NE). The Resolution has allowed numerous distributors in addition to the aforementioned, electricity distribution in Brazil to readjust their tariffs according to their distribution properties and local conditions following the procedures indicated by the Resolution n° 700 of January 26, 2016. It is important to noted that the Resolution n° 1.858 is only for the adjustment of tariffs in early 2015.

In Table 4, we can see that most of the tariff consumption distribution showed an increase, while the demand price showed different values according to the region.

TABLE 4. Tariff percentage increase between the periods of March/2014 to May/2016[1].

Region	Model	Consumption		Demand	
		Off-peak	Peak	Off-peak	Peak
NE	Green	78%	22%	9%	9%
	Blue	71%	67%	-66%	-64%
SE	Green	72%	28%	29%	29%
	Blue	71%	60%	-36%	-32%
CW	Green	53%	16%	5%	5%
	Blue	53%	38%	5%	5%

Source: Authors. [1]Positive numbers indicate a tariff increase, null there was no change, while negative decrease in value.

A type of system according to the operating time in each region was established considering the dry period. We adopted four operating schemes of irrigation systems: schemes 1 and 2 without fertirrigation at off-peak and peak hour, respectively. And the schemes 3 and 4 with fertirrigation at off-peak and peak hour, respectively. We observed that in the Northeast the schemes 1-3 and 2-4 become close, this is because the schemes 3 and 4 were made using only two days of fertirrigation (Table 5).

For the simulations, we used 4 months of operation in the Southeast, 6 months in the Central-West and 10 months in the Northeast, and the schemes 1 and 2 with empty months (there is no consumption bill), while in schemes 3 and 4 in each month we run a fertirrigation (featuring consumption bill).

TABLE 5. Operation time (h) of the engines by region by operating condition, without the use of fertirrigation at off-peak and at peak (scheme 1 and 2) and with the use of fertirrigation at off-peak and at peak (scheme 3 and 4).

Region	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Southeast	2520	2880	2688	3072
Central-West	3780	4320	3906	4464
Northeast	6300	7200	6342	7248

Simulation results

Although the Northeast has some arrangements for cheaper tariffs and higher discounts than other regions of the country, this does not imply lower annual cost of energy, since the number of hours of irrigation is greater in this region resulting in total annual cost of electricity, generally, higher than in other regions (Table 6).

Considering the situation of the SIN since the beginning of 2015 that used red tariff flag in every month and that in future conditions the yellow tariff flag tends to prevail, we can say that the total annual cost would be around R$ 120,000.00 and R$ 110,000.00 for the bohemia green and blue tariff, respectively, for the Northeast on the condition of 6300 hours of service.

TABLE 6. Total annual cost of electricity for an irrigation engine of 100 HP (x R$ 1000.00), depending on the tariff, current flag and operating hours in the Northeast, Southeast and Central-west, using the period-time tariff of March/2015.

Region[1]	Flag	Time used	Green tariff	Bohemia green tariff	Blue tariff	Bohemia blue tariff	Conventional tariff
M10 - NE	Green	21 h/day	129.62	92.85	119.37	84.05	151.81
		24 h/day	190.12	153.35	146.58	111.26	168.81
	Yellow	21 h/day	143.51	106.74	133.26	97.94	165.70
		24 h/day	206.00	169.23	162.45	127.14	184.68
	Red	21 h/day	157.41	120.64	147.15	111.83	179.59
		24 h/day	221.87	185.10	178.33	143.02	200.56
M10 + F2– NE	Green	21 h/day	131.86	9484	120.56	85.00	157.18
		24 h/day	192.86	155.85	148.94	113.38	174.29
	Yellow	21 h/day	145.84	108.83	134.54	98.99	171.16
		24 h/day	208.85	171.83	164.92	129.37	190.27
	Red	21 h/day	159.82	122.81	148.53	112.97	185.15
		24 h/day	224.83	187.81	180.90	145.36	206.26
M4 - SE	Green	21 h/day	67.44	53.10	66.01	51.71	77.19
		24 h/day	92.43	78.08	81.24	66.94	85.70
	Yellow	21 h/day	73.00	58.66	71.57	57.27	82.75
		24 h/day	98.78	84.43	87.59	73.29	92.05
	Red	21 h/day	78.56	64.21	77.12	62.83	88.31
		24 h/day	105.13	90.78	93.94	76.51	98.40
M4 + F8 - SE	Green	21 h/day	76.03	60.73	72.72	57.47	97.36
		24 h/day	103.09	87.79	95.30	80.05	106.42
	Yellow	21 h/day	81.96	66.66	78.64	63.39	103.28
		24 h/day	109.86	94.56	102.07	86.82	113.20
	Red	21 h/day	87.88	72.58	84.57	69.32	109.21
		24 h/day	116.64	101.34	108.85	85.77	119.97
M6 - CW	Green	21 h/day	98.74	73.89	98.74	73.89	111.78
		24 h/day	135.11	110.27	123.97	99.13	124.64
	Yellow	21 h/day	107.07	82.23	107.07	82.23	120.11
		24 h/day	144.64	119.79	133.50	108.65	134.17
	Red	21 h/day	115.41	90.56	115.41	90.56	128.45
		24 h/day	154.16	129.32	143.02	109.28	143.69
M6 + F6 - CW	Green	21 h/day	105.63	79.96	105.63	79.96	126.90
		24 h/day	143.51	117.84	138.74	113.06	140.19
	Yellow	21 h/day	114.25	88.57	114.25	88.57	135.51
		24 h/day	153.36	127.68	148.58	122.91	150.04
	Red	21 h/day	122.86	97.19	122.86	97.19	144.12
		24 h/day	163.20	137.52	158.42	116.57	159.88

1-The letter "M" followed by a number indicates the number of months in operation, the letter "F" followed by a number indicates the number of fertigation comprising 21 h / day (off-peak) and 24 h / day (off-peak + peak hours), "NE, SE, CW" represent: Northeast, Southeast and Central-West, respectively.

Regarding the Southeast, considering only scheme 1 in the bohemian green mode, we observed that there is an increase of 17% and 39% for yellow and red flags, respectively, in relation to the green flag. These increases represent R$ 9,260.00 and R$ 20,380.00 for the mentioned flags.

The total cost of electricity in conventional tariff showed data that corroborate with MONTEIRO et al. (2007), which commented that the conventional tariff showed the highest annual cost in all regions and in pumping weather conditions, in conditions of few months of irrigation, the use of the diesel engine can be a feasible implementation, once the hourly cost becomes equivalent, a situation also observed in this study.

The hourly cost of the diesel engine in all regions and operating conditions was approximately R$ 43.29 ± 1.80, because of the cost of pumping using diesel engines is highly dependent on the working system time and fuel price, representing 91 to 96% of the quoted value.

For the electric motor, there were different hourly costs according to the tariff mode, active flag and time of use. The bohemian blue tariff for all regions and conditions is the most economic tariff option (Table 7).

TABLE 7. Timetable variable electric energy cost with an irrigation engine of 100 HP (R$ h^{-1}), depending on the tariff, current flag and operating hours in the Northeast, Southeast and Central-West, using the period-time tariff of March/2015.

Region[1]	Flag	Time used	Green tariff	Bohemia green tariff	Blue tariff	Bohemia blue tariff	Conventional tariff
M10 - NE	Green	21 h/day	19.48	13.64	17.85	12.25	23.00
		24 h/day	25.45	20.34	19.40	14.50	22.49
	Yellow	21 h/day	21.69	15.85	20.06	14.45	25.21
		24 h/day	27.65	22.55	21.61	16.70	24.69
	Red	21 h/day	23.89	18.05	22.26	16.66	27.41
		24 h/day	29.86	24.75	23.81	18.91	26.90
M10 + F2 - NE	Green	21 h/day	19.70	13.87	17.92	12.32	23.70
		24 h/day	25.66	20.55	19.60	14.69	23.10
	Yellow	21 h/day	21.91	16.07	20.13	14.52	25.90
		24 h/day	27.86	22.76	21.80	16.90	25.30
	Red	21 h/day	24.11	18.28	22.33	16.73	28.11
		24 h/day	30.07	24.96	24.01	19.10	27.51
M4 - SE	Green	21 h/day	24.03	18.34	23.46	17.79	27.90
		24 h/day	29.70	24.72	25.81	20.85	27.36
	Yellow	21 h/day	26.23	20.54	25.66	19.99	30.10
		24 h/day	31.90	26.92	28.02	23.05	29.57
	Red	21 h/day	28.44	22.75	27.87	22.20	32.31
		24 h/day	34.11	29.13	30.22	24.17	31.77
M4 + F8 - SE	Green	21 h/day	25.72	20.03	24.49	18.81	33.65
		24 h/day	31.31	26.33	28.78	23.81	32.40
	Yellow	21 h/day	27.93	22.23	26.69	21.02	35.86
		24 h/day	33.52	28.54	30.98	26.02	34.60
	Red	21 h/day	30.13	24.44	28.90	23.22	38.06
		24 h/day	35.72	30.74	33.19	25.67	36.81
M6 - CW	Green	21 h/day	24.30	17.72	24.30	17.72	27.75
		24 h/day	29.68	23.93	27.10	21.35	27.26
	Yellow	21 h/day	26.50	19.93	26.50	19.93	29.95
		24 h/day	31.89	26.13	29.31	23.56	29.46
	Red	21 h/day	28.71	22.13	28.71	22.13	32.16
		24 h/day	34.09	28.34	31.51	23.70	31.67
M6 + F6 - CW	Green	21 h/day	25.28	18.71	25.28	18.71	30.72
		24 h/day	30.60	24.85	29.54	23.78	29.86
	Yellow	21 h/day	27.48	20.91	27.48	20.91	32.93
		24 h/day	32.81	27.06	31.74	25.99	32.07
	Red	21 h/day	29.69	23.12	29.69	23.12	35.13
		24 h/day	35.01	29.26	33.95	24.57	34.27

1-The letter "M" followed by a number indicates the number of months in operation, the letter "F" followed by a number indicates the number of fertigation comprising 21 h / day (off-peak) and 24 h / day (off-peak + peak hours), "NE, SE, CW" represent: Northeast, Southeast and Central-West, respectively.

In all cases the cost of the diesel engine is higher than electric. ZOCOLER et al. (2013) obtained similar results.

The Northeast region had the best conditions for electric motor use with 29.6 to 72.4 km of long grid, this occurs because the operating time is high so there is a high electricity cost; the Southeast had from 2.8 to 22.6 km, for this region the smaller lengths occur because the operating time is in few months, in the case of the Central-West the maximums were from 12.2 to 36.9 km (Table 8).

TABLE 8. Maximum length of the electrical grid (km), necessary to match the total annual cost of electric pumping to diesel, depending on the tariff, current flag and operating hours in the Northeast, Southeast and Central-West regions, using the period-time tariff of March 2015.

Region[1]	Flag	Time used	Green tariff	Bohemia green tariff	Blue tariff	Bohemia blue tariff	Conventional tariff
M10 - NE	Green	21 h/day	51.4	65.6	55.4	68.9	42.9
		24 h/day	42.2	56.3	58.9	72.4	50.3
	Yellow	21 h/day	46.1	60.2	50.1	63.6	37.6
		24 h/day	36.1	50.2	52.8	66.3	44.2
	Red	21 h/day	40.8	54.9	44.7	58.3	32.3
		24 h/day	30.0	44.1	46.7	60.2	38.1
M10 + F2 - NE	Green	21 h/day	51.2	65.5	55.6	69.2	41.5
		24 h/day	41.8	56.1	58.7	72.4	49.0
	Yellow	21 h/day	45.9	60.1	50.2	63.9	36.1
		24 h/day	35.7	49.9	52.6	66.2	42.8
	Red	21 h/day	40.5	54.7	44.8	58.5	30.8
		24 h/day	29.6	43.8	46.4	60.1	36.7
M4 - SE	Green	21 h/day	16.2	21.7	16.8	22.3	12.5
		24 h/day	12.1	17.6	16.4	21.9	14.7
	Yellow	21 h/day	14.1	19.6	14.6	20.1	10.4
		24 h/day	9.7	15.2	14.0	19.5	12.3
	Red	21 h/day	12.0	17.5	12.5	18.0	8.2
		24 h/day	7.3	12.8	11.6	18.2	9.8
M4 + F8 - SE	Green	21 h/day	15.5	21.4	16.8	22.6	7.3
		24 h/day	11.0	16.8	14.0	19.8	9.7
	Yellow	21 h/day	13.2	19.1	14.5	20.4	5.0
		24 h/day	8.4	14.2	11.4	17.2	7.1
	Red	21 h/day	10.9	16.8	12.2	18.1	2.8
		24 h/day	5.8	11.6	8.8	17.6	4.5
M6 - CW	Green	21 h/day	27.6	37.1	27.6	37.1	22.6
		24 h/day	22.5	32.0	26.7	36.3	26.5
	Yellow	21 h/day	24.4	33.9	24.4	33.9	19.4
		24 h/day	18.8	28.3	23.1	32.6	22.8
	Red	21 h/day	21.2	30.7	21.2	30.7	16.2
		24 h/day	15.1	24.7	19.4	32.4	19.2
M6 + F6 - CW	Green	21 h/day	27.0	36.9	27.0	36.9	18.8
		24 h/day	21.6	31.4	23.4	33.3	22.9
	Yellow	21 h/day	23.7	33.6	23.7	33.6	15.5
		24 h/day	17.8	27.7	19.6	29.5	19.1
	Red	21 h/day	20.4	30.2	20.4	30.2	12.2
		24 h/day	14.0	23.9	15.9	31.9	15.3

1-The letter "M" followed by a number indicates the number of months in operation, the letter "F" followed by a number indicates the number of fertigation comprising 21 h / day (off-peak) and 24 h / day (off-peak + peak hours), "NE, SE, CW" represent: Northeast, Southeast and Central-West, respectively.

In a parallel simulation where the three regions work with the same time in "yellow flag", we observed that the Northeast has the cheapest energy. The total annual cost of electrical grid (x R$ 1,000.00) for the off-peak hour, only 21 h day^{-1} without using fertirrigation (-F) and with fertirrigation (+ F), for this specific case there were six months of energy use and six of fertirrigation, when the case only for the green and blue modes with night discount (bohemian) and conventional mode, which do not have discounts (Figure 1).

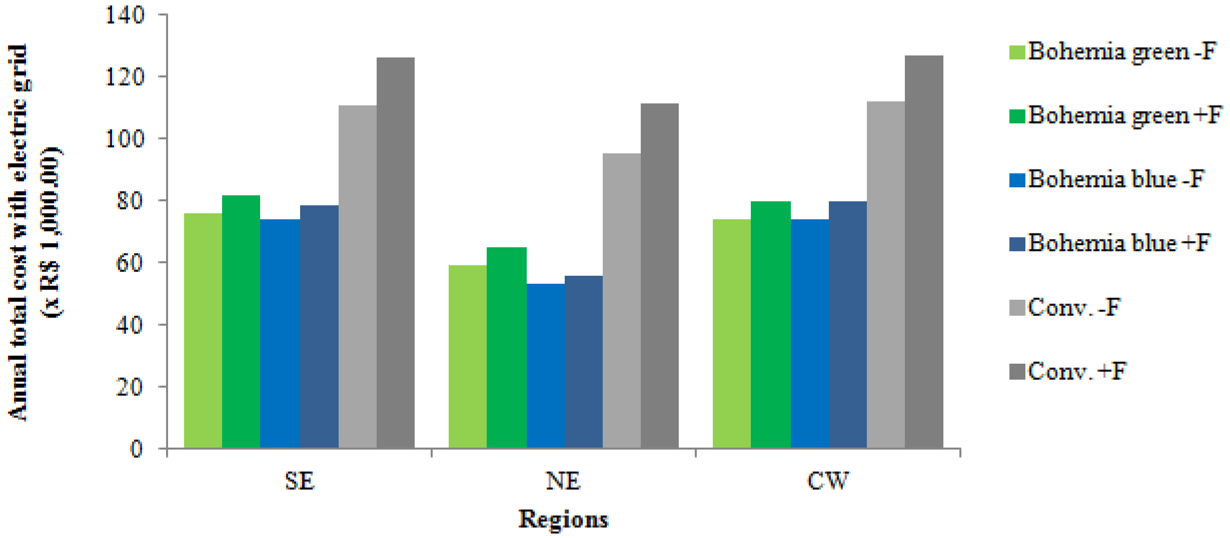

FIGURE 1. Total annual energy cost for a 100 HP engine (x $ 1,000 .00), for the three regions of the country at off-peak hour with both regions working 3780h without fertirrigation (-F) and 3906h with fertirrigation (+ F), with yellow flag tariff.

The hourly cost in this situation has a similar behavior to the total annual cost as can be seen in Figure 2.

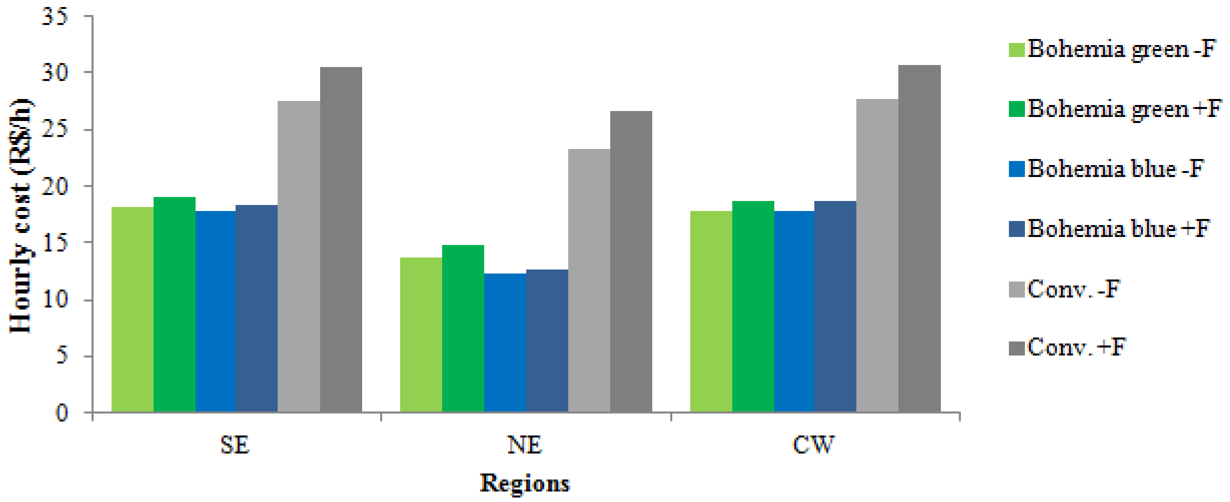

FIGURE 2. Hourly cost of electricity for a 100 HP engine ($ h^{-1}), for the three regions of the country at off-peak hour with both regions working 3780h without fertirrigation (-F) and 3906h with fertirrigation (+ F), with yellow flag tariff.

The maximum extent of the electrical grid that enables the use of the diesel engine showed inversely proportional to the values of the costs; annual total and hourly. Even each region having its own tariffs for each modality, the similarity to the grid extensions for bohemia green and blue tariffs for both regions is due to the fact that the demand values (R$ kW) are very close, so these had little influence on the results because both are close to each other, in the case of the Northeast beyond the 90% night discount it still has cheaper consumption tariffs, because of this it has the largest grid dimensions. The size of the grid in bohemia green tariff ranged from 44.9 km (-F, SE) to 52.5 km (+ F, NE), while the blue tariff showed similar behavior with dimensions from 45.6 km (-F, SE) to 55.8 km (+F, NE), the dimensions for the conventional tariffs showed values between 28 km (+ F, SE) and 38.5 km (-F, NE), because this modality has demand tariff almost three times higher than the other modalities (Figure 3).

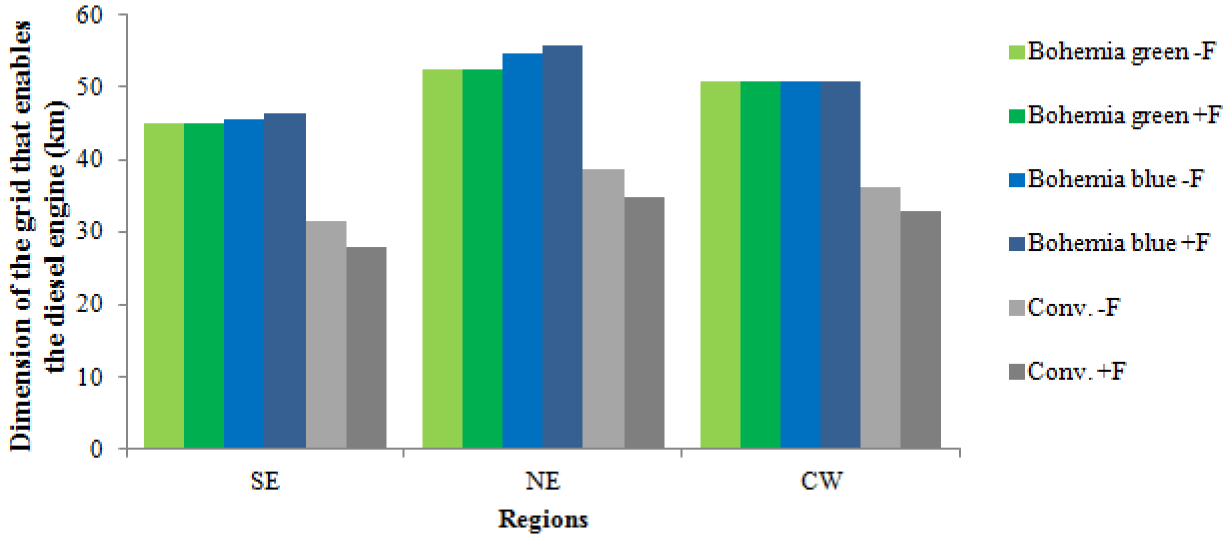

FIGURE 3. Dimension of the electrical grid that enables the use of diesel engine (km), to the three regions of the country at off-peak hour with both regions working 3780 h without fertirrigation (-F) and 3906 h with fertirrigation (+ F), with yellow flag tariff.

CONCLUSIONS

The described methodology allows the calculation of energy costs for irrigation, using diesel and electric engines, taking into account the new charging system by flags in the country, thus enabling comparisons between these costs and inferences about the economic viability of different energy sources in irrigation systems.

In the simulations we concluded:

a) The bohemia blue tariff proved to be the best choice for the irrigator in any region of the country and in any active flag;

b) In the Southeast, in some situations, the combined use of diesel and electric engine can be an alternative to reduce energy costs;

c) The Northeast region has the lowest hourly cost in the country;

d) Irrigators that will use electricity less than four months a year, should study the possibility of the combined use of diesel engine, in order to reduce costs;

e) The use of conventional tariff should be avoided, since it has higher cost.

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