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Quantification of CO_2 emission reductions from energy efficiency actions and solar photovoltaic generation at the Federal Institute of Education, Science, and Technology of Goiás

M. A. Vidal[2,3], A. F. Faria[1], A. H. M. Stach[1,2,3], D. P. Neto[1,2,3], L. S. Pinto[1,2,3], A. G. Pinho[2,3] and E. G. Domingues[1,2,3]

Master's Program in Technology of Sustainable Process[1]
Electrical Engineering/Control and Automation Engineering Program[2]
NeXT - Nucleus of Experimental and Technological Studies[3]
Federal Institute of Education, Science and Technology of Goiás - Câmpus Goiânia
Rua 75, nº46 - Centro, Goiânia - GO, 74055-110 (Brasil)
Phone: +0055 62 3227-2769, e-mail: **marianevidal1989@gmail.com**, **prof.eldergd@gmail.com**

Abstract. In 2016, the Brazilian Agency of Electric Energy launched a public call for research and development projects to reduce barriers to implementing energy efficiency projects and own electricity generation. One objective of this public call was to encourage pilot projects at the Brazilian public higher education institutions. In this context, the Federal Institute of Education, Science, and Technology of Goiás has approved the research project, entitled "Energy efficiency and mini generation at the Federal Institute of Education, Science, and Technology - IFG." The project consists of implementing energy efficiency actions and installing photovoltaic distributed generation (mini generation) in twelve of the fourteen IFG campuses. The main objective of this work is to quantify the CO_2 emission reductions from the project through the methodologies used by the United Nations Framework Climate Change Convention for projects under the Clean Development Mechanism. The emission reductions over the project lifetime was estimated at approximately 37,400 tCO_2 equivalent, evidencing the environmental benefit to be provided by the referred project.

Keywords. Clean Development Mechanism, Emission Reductions, Energy Efficiency, Photovoltaic Distributed Generation,

1. Introduction

Climate change has been showing an undeniable anthropogenic effect widely discussed by scientists worldwide. So the countries and global organizations have committed to looking for sustainable development alternatives, such as searching for clean and renewable energy sources and stimulating energy-conscious consumption.

During the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, was drafted the international treaty known as the United Nations Framework Convention on Climate Change (UNFCCC). During this event was defined the commitments and obligations for countries called Parties to the Convention to achieve the stabilization of greenhouse gas (GHG) emissions into the atmosphere. A complementary UNFCCC treaty, called the Kyoto Protocol, was signed in Kyoto in December 1997, setting the GHG emission reductions targets, in which the signatory countries have committed to reducing GHG emissions by an average of 5% compared to 1990 levels [1]. Among the flexibility mechanisms implemented, it highlights the Clean Development Mechanism (CDM). A project is in the CDM scope when its implementation proves the reduction of additional emissions compared to its absence. This proven reduction can generate Certified Emission Reductions (CERs) that can be purchased from the primary market (purchased from an original party that makes the reduction) or secondary market (resold from a marketplace) [1,2].

In this context, energy efficiency actions have been implemented together with distributed generation (DG) in several countries, including Brazil, for environmental and economic purposes. The efficient use of energy is an essential vector in meeting demand, contributing to energy security, low tariffs, economic competitiveness, and reducing greenhouse gas emissions. DG is presented as an alternative to the current planning model for expanding the Brazilian energy system and may be an alternative for more efficient energy, economic, financial, and environmental resources.

Within this context, in [3] was used methodologies of the CDM to quantify the CO_2 equivalent (CO_{2e}) emission reductions from projects involving installation of photovoltaic distributed generation (PVDG) of the strategic research and development (R&D) projects approved under the Public Call Nº 013/2011 of the Brazilian Agency of Electric Energy (ANEEL). The work indicated that the projects could generate approximately 25 GWh/year, with two scenarios for reduced emissions: the base year 2011 and the base year 2012, indicating

6,212 tCO_{2e} and 11,009 tCO_{2e} of emission reductions, respectively.

In [4] was analyzed the technical and economic feasibility of implementing an energy efficiency project, contemplating lighting and environmental conditioning systems, and a photovoltaic microgeneration system at the IFG. The results indicated that the campus would become energy self-sufficient, including generating surpluses of electricity. The paper also quantified CO_{2e} emission reductions considering the methodologies used by the UNFCCC for CDM projects that address energy efficiency activities and renewable energy generation connected to the network. The results indicated that the emission reductions were equal to approximately 1,100 tCO_{2e} in the base year 2015.

IFG participated in an ANEEL Public Call entitled “Priority project of energy efficiency and strategic R&D: energy efficiency and mini generation in public higher education institutions” [5]. The main goal of this Public Call is to reduce the obstacles to the implementation of energy efficiency (EE) and own power generation projects. The idea of the strategic project is to promote the development of pilot projects in Brazilian higher education public institutions to obtain subsidies for implementing such actions throughout the public sector.

In this context, the project entitled “Energy efficiency and mini generation at the Federal Institute of Education, Science, and Technology of Goiás - IFG” [6] was approved and executed between April 2018 and May 2019 on the twelve campuses of IFG located in the cities of Goiás state, as illustrated in figure 1.

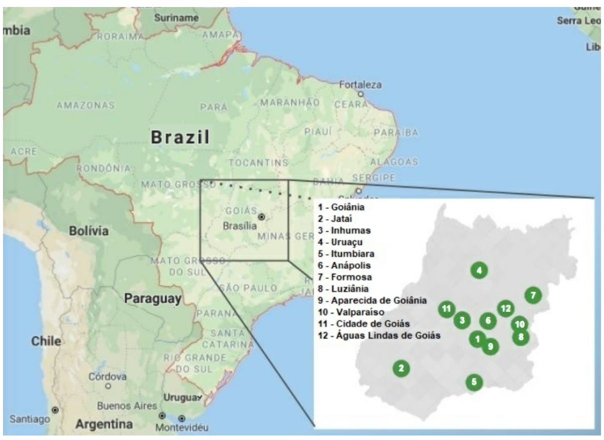


Fig. 1. Location of IFG campuses contemplated with the project.

The energy efficiency action implemented in the project was the replacement of the existing lighting system consisting of fluorescent lamps and sodium vapor lamps for the LED lighting system. In addition, the project included the installation of PVDG in the twelve campuses of IFG, totaling approximately 1.255 MWp of installed capacity.

This paper aims to quantify the CO_{2e} emission reductions to the PV distributed generation projects and the implementation of energy efficiency actions at the IFG campuses under the context of the CDM. Since in [2, 4] the total avoided CO_{2e} emissions were not accounted (recorded) for, over the lifetime of the analyzed projects, one of the contributions of this paper is to estimate this environmental advantage over time. For this, the project's lifetime was considered equal to 25 years, corresponding to the lifetime of the PV systems.

2. Methodology

In the project in question, small-scale methodologies[1] were used to quantify annual CO_{2e} emission reductions due to energy efficiency actions and the implementation of PV distributed generation (PVDG). Figure 2 illustrates the general flowchart of the methodology used to quantify the annual avoided CO_{2e} emissions of the project.

The total CO_{2e} emission reductions due to PVDG installation and energy efficiency action implemented can be calculated by using equations (1), (2), and (3) [7, 8].

$$ER_{T,y} = ER_{pv,y} + ER_{ee,y} \tag{1}$$

$$ER_{pv,y} = BE_{pv,y} - PE_{pv,y} - LE_{pv,y} \tag{2}$$

$$ER_{ee,y} = BE_{ee,y} - PE_{ee,y} - LE_{ee,y} \tag{3}$$

In (1), $ER_{T,y}$ is the total CO_{2e} emission reductions in year y (tCO_{2e}/year); $ER_{pv,y}$ and $ER_{ee,y}$ are the CO_{2e} emission reductions due to PVDG installation and energy efficiency actions implementation in year y (tCO_{2e}/year), respectively. In (2), $BE_{pv,y}$, $PE_{pv,y}$, and $LE_{pv,y}$ are the baseline emissions, project emissions, and leakage emissions in year y (tCO_{2e}/year), due to PVDG installation. In (3), $BE_{ee,y}$, $PE_{ee,y}$, and $LE_{ee,y}$ are the baseline emissions, project emissions, and leakage emissions in year y (tCO_{2e}/year), due to energy efficiency actions implementation.

We use the methodology AMS-I-D: Grid-connected renewable electricity generation (Version 18.0)[8] to quantify the annual CO_{2e} emission reductions due to the installation of PVDG. Baseline emissions for small-scale PVDG include only CO_2 emissions from electricity generation in power plants displaced due to the project activity. The methodology presented in [8] assumes that all project electricity generation above baseline levels would have been generated by existing grid-connected power plants and the addition of new grid-connected power plants. According to AMS-I-D methodology, project and leakage emissions from PV systems are considered to be zero ($PE_{pv,y} = 0$ and $LE_{pv,y} = 0$) [8].

[1] For projects involving renewable energy, the methodology is considered small-scale if the maximum renewable energy production capacity is less than 15MW. In the case of energy efficiency improvement projects, the methodology is considered small-scale if the reduction in consumption is a maximum of 60GWh/year [7], [8].

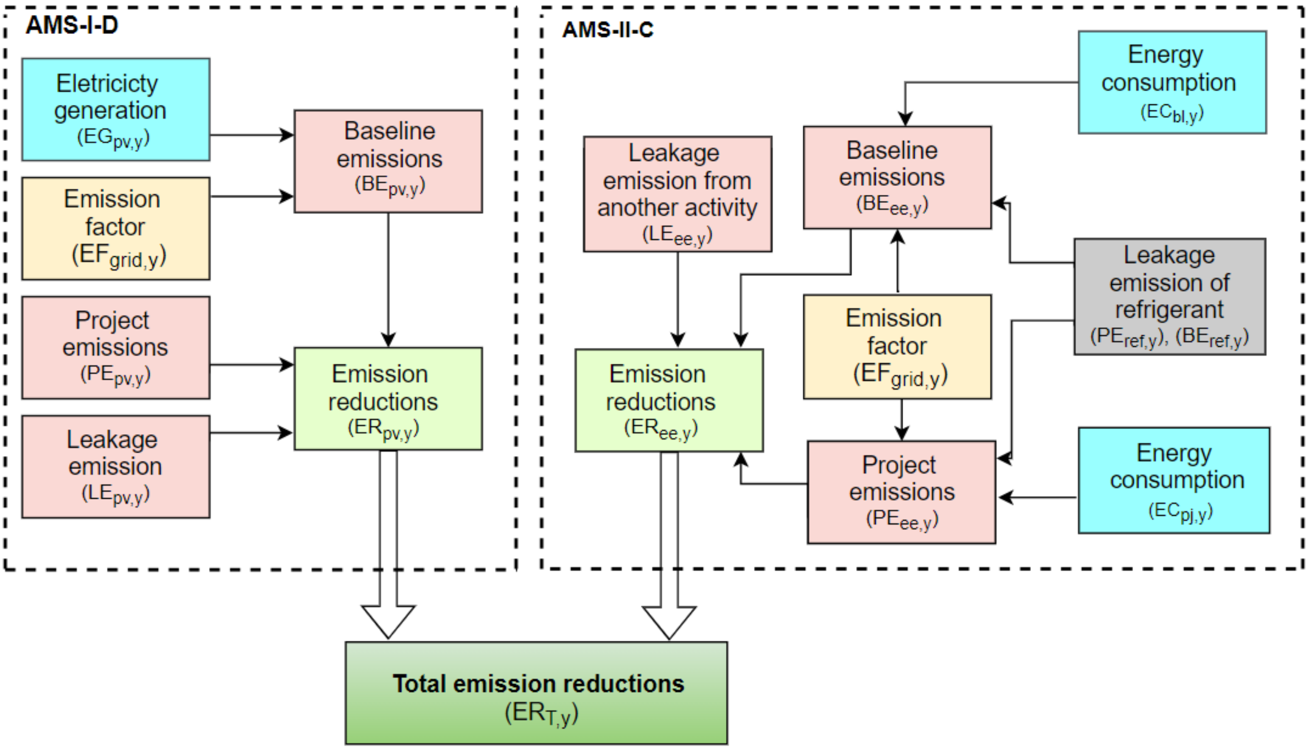


Figure. 2. Flowchart of the methodology used to quantify the reduction of CO_{2e} emission reductions from the project

The baseline emissions in year *y* due to PVDG installation are calculated according to Equation (4).

$$BE_{pv,y} = EG_{pv,y} \times EF_{grid,y} \quad (4)$$

In (4), $EG_{pv,y}$ is the amount of net electricity generation that is produced and fed into the grid as a result of the implementation of the PVDG in year *y* (MWh); and $EF_{grid,y}$ is the CO_2 emission factor of the National Interconnected System (NIS) in year *y* (tCO_2/MWh), calculated using the latest version of the "Tool to calculate the emission factor for an electricity system" (tCO_2/MWh) [9].

The emission factor of the electrical network is a combination of the build margin factor and the operating margin factor. It symbolizes the intensity of CO_{2e} emissions due to the construction and operation of the plants. UNFCCC provides the emission factor through the tool to calculate the emission factor of an electrical system, calculated according to Equation (3) [9].

$$EF_{grid,y} = EF_{mo,y} \times W_{mo} + EF_{mc,y} \times W_{mc} \quad (5)$$

In (5), $EF_{mo,y}$, and $EF_{mc,y}$ are the CO_2 emission factor of the operating margin and construction margin in year y (tCO_2/MWh). W_{mo} and W_{mc} are the operating margin and construction margin emission factor weights, respectively. For new renewable energy projects, W_{mo} = 0.75 and W_{mc} = 0.25.

We use the methodology AMS-II-C: Demand-side energy efficiency activities for specific technologies (version 15.0) [7] to quantify the annual CO_{2e} emission reductions due to the energy efficiency actions. This methodology includes activities that encourage the adoption of equipment, lamps, reactors, refrigerators, motors, fans, air conditioners, and appliances, which are energy efficient. These technologies can replace existing equipment or be installed in new locations.

Equation (3) is used to quantify the emission reductions due to replacing the existing lighting system with the LED lighting systems. According to the AMS-II-C methodology, if the project lamps are LED type, the project activity is considered additional.

To calculate the baseline emissions, it is necessary to obtain the baseline energy consumption. The baseline emissions and baseline energy consumption in the year *y* are obtained according to Equation (6) and Equation (7), respectively [7].

$$BE_{ee,y} = EC_{bl,y} \times EF_{grid,y} + Q_{ref,bl} \times GWP_{ref,bl} \quad (6)$$

$$EC_{bl,y} = \Sigma(ni \times pi \times hi)/(1 - ly) \quad (7)$$

In (6), $EC_{bl,y}$ is the baseline energy consumption in year y (MWh); $PE_{ref,y}$ is the project emissions from physical leakage of refrigerant from project equipment in year y (tCO_{2e}); $Q_{ref,bl}$ is the average annual quantity of refrigerant used in the baseline to replace the refrigerant that has leaked (tonnes/year), only applies to projects that replace equipment containing Ozone Depleting Substances (ODP) refrigerants; and $GWP_{ref,bl}$ is the Global Warming Potential of the baseline refrigerant (tCO_{2e}/t refrigerant). In (7), ni, pi, and hi are the number of pieces of equipment, electrical power demand (kW), and the average annual operating hours of the group of i baseline equipment, respectively; and ly is average annual technical grid losses (transmission and distribution) during year y for the grid serving the locations where the devices are installed, expressed as a fraction. A default value of 0.1 shall be used for average annual technical grid losses if no recent data are available or the data cannot be regarded as accurate and reliable.

Project emissions consist of electricity and/or fossil fuel used in project equipment, determined in accordance with Equation (8) [7].

$$PE_{ee,y} = EC_{pj,y} \times EF_{grid,y} + Q_{ref,pj,y} \times GWP_{ref,pj} \quad (8)$$

In (8), $PE_{ee,y}$ is the project emissions in year y (tCO_{2e}); $EC_{pj,y}$ is the energy consumption in the project activity in year y (MWh); $Q_{ref,pj,y}$ is the average annual quantity of refrigerant used in year y to replace refrigerant that has leaked in year y (tonnes/year); and $GWP_{ref,pj}$ is the Global Warming Potential of the refrigerant that is used in the project equipment (tCO_{2e}/t refrigerant).

The project's energy consumption after the implementation of energy efficiency actions is determined according to Equation (9) [7]. It is the same expression as Equation (7), but with another denomination to better separate consumption before and after the priority project is executed.

$$EC_{pj,y} = \Sigma(ni \times pi \times hi)/(1 - ly) \quad (9)$$

The emission reductions are calculated according to Equation (3). Refrigerant leakage emissions are only added to baseline and project emissions when there are energy efficiency actions involving environmental conditioning or refrigerators. As the project in question does not include changes in air conditioning equipment and refrigerators, this data will not be used in this work. Then, Equations (6) and (8) becomes:

$$BE_{ee,y} = EC_{bl,y} \times EF_{grid,y} \quad (10)$$

$$PE_{ee,y} = EC_{pj,y} \times EF_{grid,y} \quad (11)$$

3. Results

A. *Project description*

The methodology described in Figure (2) was applied to all IFG campuses, which are shown in Figure (1). The energy efficiency action implemented in the project was the replacement of the lighting system consisting of fluorescent lamps and sodium vapor for the LED lighting system. In addition, the project included the installation of photovoltaic systems distributed on campuses, totaling 1.255 MWp of installed power. In total, the installation of 3,850 photovoltaic modules of the polycrystalline type of 315 Wp and an efficiency of 16.68% was predicted. The installation was made on the rooftop of the twelve selected IFG campuses.

B. *Brazilian Emission Factor*

The emission factor of the Brazilian interconnected electrical system has been provided by Brazil's Ministry of Science, Technology, and Innovations since 2006 [10]. From its historical data, it was possible to observe that until 2012, the emission factor historical data series pattern was oscillating with a growing trend. However, from 2012 on, this pattern has changed, oscillating around an average emission factor between 0.45tCO_{2e}/MWh to 0.55tCO_{2e}/MWh with a declining trend.

There is a close relationship between the participation of thermal generation and the increase of emissions of CO_{2e} of the Brazilian interconnected electrical system. However, from 2012 the emission factor did not follow the growth trend observed in previous years, regardless of the thermal generation growth. This situation may be due to the participation of natural gas in thermoelectric generation from 2010. Natural gas has a lower specific emission factor, decreasing the overall emission factor of the system, and keeping it constant, even with the increased thermal generation [11]. Another possibility for the interruption of the growth of the emission factor from 2012 on is the approval Normative Resolution, issued by the Brazilian Electricity Regulatory Agency (ANEEL), which took place in April 2012. This resolution came into force and established the initial rules for developing electricity distributed generation in Brazil. From that moment, Brazilian consumers have been able to produce electricity from renewable sources and offset the surplus with their local distribution company [12].

Due to uncertainties related to the emission factor forecast and its intrinsic ability to affect the annual emission reductions over the project's lifetime, in this study, we consider a constant emission factor equal to 0.4811tCO2e/MWh over the project's lifetime. This value corresponds to an average emission factor obtained from the historical data from 2012 to 2018.

C. *Emission reductions from PVDG*

Table (I) presents the data of installed power (P_i) and estimates of annual energy generated (EG) by each PVDG and the annual energy consumption (EC) of each of the twelve campuses of the IFG. The annual power generation was estimated based on the manufacturer's datasheet data (Canadian CS6X-315P), the local solar radiation index, and the inclination angle of the panels. For this analysis, it was considered a Peak-Sun Hour (PSH) equal to 5.2 hours, based on the lower limit of the solar yield of the State of Goiás [6].

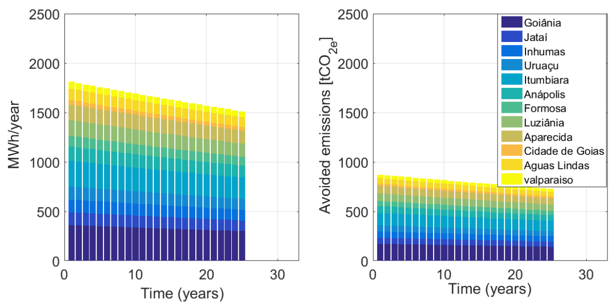
Through the historical data of each IFG campuses' energy bills (in 2017), the annual energy consumption of each campus was accounted for. It can be seen in Table I that the city of Anápolis has become energy-independent, while the others reduce the use of energy from the electricity grid significantly. It also can be noted that the project constituted from PVDG systems can provide about 62,2% of the annual energy needs of the campuses[2].

Table I. - Installed power and energy generated by each PVDG and the annual energy consumption of each campus [5]

Campus	P_i (KWp)	EG (MWh/y)	EC (MWh/y)
Goiânia	251.87	362.70	949.42
Jataí	90.35	130.10	229.09
Inhumas	90.42	130.20	168.91
Uruaçu	89.76	129.25	302.28
Itumbiara	170.37	259.74	298.26
Anápolis	100.10	144.14	139.34
Formosa	75.40	108.57	141.17
Luziânia	110.50	159.12	167.77
Aparecida	110.50	159.12	171.29
Valparaíso	44.85	64.58	97.87
Aguas Lindas	80.52	115.94	*
Cidade de Goiás	30.55	43.99	54.29
TOTAL	**1,255.20**	**1,807.47**	**2,719.69****

*No data available ** Without Aguas Lindas Campus

Figure 3 shows the behavior of electricity generation and CO_{2e} emission reductions from PVDG installed on the rooftops of the IFG campuses during the project's lifetime.



(a) Power generation (b) CO_{2e} emission reductions

Fig. 3. Generation of electricity and CO_{2e} emission reductions of PVDG systems installed at the IFG campuses.

Due to the annual efficiency loss of photovoltaic modules (considered in this study equal to 0.75%a.y.), it is noticed that the PVDG energy production decreases over the lifetime, as can be observed in Figure (3.a).

The project is expected to generate around 1,800 and 41,350 MWh in the first year and over the project's lifetime, respectively. The emission reductions (avoided emissions) were estimated at 870tCO_{2e} in the first year and 19,900 tCO_{2e} over the project lifetime, as shown graphically in Figure (3.b).

D. *Emission reductions from energy efficiency actions*

Table (II) and Table (III) present the existing lighting system and the proposed lighting system for the twelve campuses of IFG. Regarding the yearly operating time (OT) of the lamps, the following were considered: i) 20W compact lamps, 250W and 400W metal steam lamp, 9W LED tube, 70W LED bulb: 4,015 hours; ii) 40W and 32W fluorescent lamps, 18 LED tube: 2,592 hours; and iii) 16W and 20W fluorescent lamps, 11W LED tube: 1,971 hours.

Table II - Existing lighting system in the twelve campuses

Type of lamp	Quantity	Power [W]	OT [h/y]	EC [kWh/y]
Metal steam lamp	122	400	4,015	195,932.00
Metal steam lamp	125	250	4,015	125,468.75
Fluorescent lamp	6,468	40	2,592	670,602.24
Fluorescent lamp	17,228	32	2,592	1,428,969.60
Fluorescent lamp	1,088	20	1,971	42,888.96
Fluorescent lamp	700	16	1,971	22,075.20
Compact lamp	670	20	4,015	53,801,00
TOTAL				**2,539,737.75**

Table III. - Proposed lighting system in the twelve campuses

Type of lamp	Quantity	Power [W]	OT [h/y]	EC [kWh/y]
LED outdoor Spotlight	122	70	4,015	34,288.10
LED outdoor Spotlight	125	70	4,015	35,131.25
LED Tubular Light	6468	18	2,592	301,760.64
LED Tubular Light	17228	18	2,592	803,779.20
LED tube light	1088	11	1,971	23,592.87
LED tube light	700	11	1,971	12,417.30
LED Bulb	670	9	4,015	24,210.45
TOTAL				**1,235,179.81**

With the change of the lighting system, the electricity consumed decreased from 2,539.74 MWh/y to 1,235.18 MWh/y, which corresponds to a reduction of approximately 51,37 %, maintaining the same amount of light lamps. The annual CO_{2e} emission reductions were approximately 700 tCO_{2e} and over the project lifetime about 17,500 tCO_{2e}, disregarding the reactors.

The CO_{2e} emission reductions from the project due to energy efficiency action and PVDG installation at the twelve campuses of the IFG are illustrated in Figure (5).

[2] Considering only campuses with a history of energy consumption

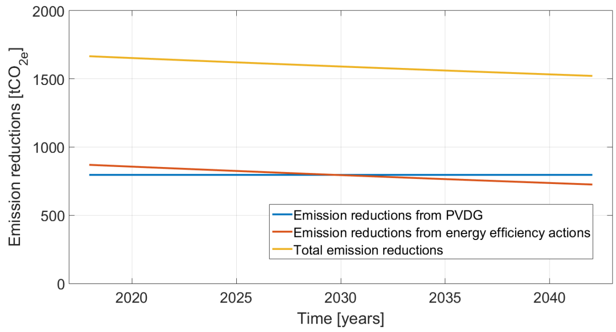


Fig. 5. - Project emission reductions

Over the project lifetime, the annual total CO_{2e} emission reductions ranged from 1,666 tCO_{2e} at the first operation year to 1,522 tCO_{2e} in the 25th operation year (lifetime). During the project lifetime, the total CO_{2e} emission reductions are equal to 39,796 tCO_{2e}, which shows the environmental benefit of the project.

4. Conclusion

The research project, approved by the Brazilian Electricity Regulatory Agency, aimed at the installation of 1.255 MWp of PVDG and implementation of energy efficiency actions (replacement of the existing lighting system by LED lighting system) in twelve campuses of IFG. The results presented in this paper showed the environmental benefit of the project, quantified by the CO_{2e} emission reductions during the project lifetime.

The emission reductions were obtained using the AMS-I-D, AMS-II-C methodologies, and the tool to calculate the emission factor for an electricity system [9]. In this study, it was considered that the emission factor in future years is equal to the average emission factor, obtained from historical data from 2012 to 2018.

The results showed that: i) the installation of PVDG systems can provide about 62,2% of the annual energy needs of the campuses; ii) the change of the lighting system will provide an annual consumption reduction of approximately 51,37%; iii) during the project's lifetime, the total CO_{2e} emission reductions are equal to 39,796 tCO_{2e}, being 19,905 tCO_{2e} due to the replacement of the existing lighting system by LED lighting system and 19,891 tCO_{2e} due to the PVDG systems.

Reduction emissions over the years can be converted into CERs, which can be traded in specialized markets. These sources of revenue can contribute to the economic viability of these types of investment projects. In order to obtain such revenue sources, the Project Design Document must be elaborated and submitted for approval by the responsible agencies.

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