Zero Carbon Program: A Legacy for a Sustainable Environment and for Higher Education Institutions

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Abstract

Climate change is one of the biggest global concerns for scientists. Efforts to limit global temperature are still incipient. In Brazil, Higher Education Institutions (HEIs) can play a central role in achieving these efforts. In this sense, the objective is to show the Legacy of the Zero Carbon Program of the Federal University of Viçosa (UFV) for society, science and environment, in 10 years of operation, with a main focus on the ecosystem service related to carbon off-set. A description of the history, emergence and organizational structure of Zero Carbon Program (CZP) was made, based on research carried out over 10 years of activity in the Atlantic Forest in southeastern Brazil. Five main methodological axes have been described to determine the current legacy of the program: (A) GHG Inventory during the Farmer's Week (FW) at the UFV; (B) GHG neutralization during FW; (C) Development of GHG quantification and neutralization systems; (D) Collection of bibliographic data developed by the CZP; and (E) Survey of sensitized public. The results of the CZP showed that: 4,162 people became aware of the topic of climate change at and 26,186 people at other events; and those 63 scientific studies related were published. A total of 490.64 tCO_2eq. GHG emissions were raised during the FW-UFV. Approximately 4,660 trees were planted in a degraded area in southeastern Brazil as a way to neutralize GHG from the event. The CZP presents opportunities for gains from ecosystem services related to responsive carbon management provided to different social actors.

Introduction

The Global Risk Report, published by the World Economic Forum in 2020, concluded that climate change will be at the center of global concerns for the next decade,[1] due to the collapse that global climate change can bring to economy, environment and society.[2–4] In this sense, the Paris Agreement (PA), signed between the world nations in 2015, has as main goal the reduction of greenhouse gas (GHG) emissions to limit the temperature increase in 1.5 ºC above the industrial levels in the next decades.[5,6] Under the PA, countries must submit Nationally Determined Contributions (NDCs) in which they will communicate actions to limit their GHG emissions.[7,8]

The implementation of NDCs is still uncertain in several countries due to insufficient efforts to date to adequately achieve the limitation of temperature rise established in the Paris Agreement.[9] In Brazil, these uncertainties are even greater due to the difficulty in predicting the behavior of GHG emissions from agriculture and also due to the recent governance crisis.[9,10] Even so, Brazilian society is prone to environmental conservation and the appropriate land use.[11] One of the effective ways suggested to reach NDCs in developing countries is to use HEIs as sustainable institutional capacity-building centers, supported by strengthened long-term financing partnerships.[12] In this sense, Brazilian Higher Education Institutions (HEIs) play an important role and are committed with the *Environmental Sustainability*.

There are two main thoughts regarding the participation of HEIs related to environmental sustainability; the involvement of students in environmental education practices and the implementation of environmental management projects on university campuses as sustainable management showcases for society.[13,14] To reinforce the importance of deeper implementation of environmental management practices in the context of HEIs, it is necessary to understand that there is an interface between these organizations and the economic, social and policy development of the local stakeholders.[15]

Success of environmental management projects implemented in universities include the capacity building of future young leaders to face present and future environmental and climate challenges.[16,17] These arguments are closely related to the "13.3" objective of Sustainable Development of the United Nations, which is to strengthen education and raise awareness and institutional capacity on mitigation, adaptation and reduction of climate change impacts.[8]

The Zero Carbon Program (*Programa Carbono Zero*, in Portuguese) was created in 2010 by the Department of Forest Engineering in partnership with the Dean of Extension and Culture of the Federal University of Viçosa (UFV).[18] The main objective of the program was to quantify and offset GHG emissions from the Farmer's Week (FW),[18,19] a rural extension event for Brazilian farmers that has been held annually at the UFV since 1929, being the largest event of its kind in Brazil.[20–22] In addition to quantifying and offsetting GHG emissions at FW, the Zero Carbon Program (hereafter called ZCP) aims to raise awareness about climate change and the importance of carbon management for farmers, students, teachers, UFV managers, children, teachers, policy makers, and companies concerned with climate change.[18] This program promotes an understanding of the dynamics, benefits and social values of environmental sustainability by the management of carbon in rural institutions and properties. In addition, the ZCP integrates knowledge about carbon-related ecosystem services with sustainable land management.

The organizational structure of the ZCP is centered in the "General Coordination", which encompass strategic functions, such as raise financial resources for the project, formalize partnerships with several important stakeholders and manage ZCP's demands and research (Figure 1A).[18] There are also three graduate students (2 master's and 1 doctoral student) responsible for managing research and

development studies in the following: (1) Survey and quantification of GHG emissions; (2) Implementation of mixed plantations of tree forest species with a focus on GHG neutralization; and (3) Management of mixed plantation areas for offsetting carbon emissions.[18] Undergraduate students (volunteer and holders of a scientific initiation scholarship) are responsible for data collection and implementation and monitoring of carbon offsetting plantations. All involved are in constant communication, holding weekly meetings for discussion of project activities and planning future actions.

The annual activities of the ZCP follow a schedule that include activities performed during the whole year (plantation monitoring and environmental sensation) or in specific months: tree plantation measurement and survival assessment (February to March); survey of GHG emissions during FW and environmental awareness of farmers (July); processing and compilation of GHG emission and offsetting data (August to October); and finally, site preparation and establishment of a plantation to offset FW's carbon emissions (November and December) (Figure 1B).[18]

In this study, we aim to show the legacy of Zero Carbon Program, a 10-years old project from the UFV, to the society, science, and environment. In a more specific approach, we intend to demonstrate the outcomes and lessons learned over the first decade of the project, mainly focusing on carbon-related ecosystem services. These results are expected to stimulate the development of similar initiatives in other HIEs worldwide and to reinforce the importance of these institutions in providing training and knowledge related to the mitigating of global climate change.

Results

GHG inventory during Farmer's Week

During all editions of FW, 490.64 tCO_{2e} of GHG were emitted. The average annual emissions (μG) was 49.1 ± 11.3 tCO_{2e} $year^{-1}$. The increasing order of GHG emissions among the evaluated scopes was: Scope 3 (EAC: 341.8 tCO_{2e}; μG: 34.2 ± 9.8 tCO_{2e}))> Scope 1 (EAC: 105.8 tCO_{2e}; μG: 10.6 ± 2.9 tCO_{2e}))> Scope 2 (EAC: 43.1 tCO_{2e}; μG: 10.6 ± 2.3 tCO_{2e}) (Table 1).

Table 1

Greenhouse Gas (GHG) emissions (tCO_2e) of the Farmer's Week. editions. The emission sources were divided by scopes considered (1. 2 or 3) between 2010 and 2019. Average GHG emissions (µG em CO_2e) considered throughout the editions of the event with their respective Standard Deviation (SD em CO_2e). Accumulated GHG emissions (AcE em CO_2e) to represent the accumulated emission totals by scope.

Scope/ GHG emitting source	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	µG	SD	AcE
Scope 1	GHG Emission (tCO_2e)												
(A.1) Mobile combustion	5.91	9.28	7.74	6.44	8.32	3.65	2.48	3.79	2.01	2.62	5.22	2.52	105.79
Diesel	4.93	5.42	6.55	5.87	6.49	3.41		3.79	2.01	2.62			
Gas	0.98	3.86	1.19	0.57	1.83	0.23		0	0				
alcohol								0	0.01	0			
Biodiesel										0			
(A.2) Stationary combustion	2.63	0.74	0.12	6.6	7.98	3.85	5.81	2.64	8.95	4.52	4.38	2.81	
Biomass	1.58	0.11	0.11	2.03	2.05	3.7	5.81	2.64	0	1.43			
LPG	1.05	0.63	0	4.57	5.93	0.15	0	0	8.95	3.1			
(A.3) Livestock	0	0	0.05	0.94	0.59	1.56	1.28	1.1	2.26	1.95	0.97	0.77	
Horses					0.06		0.12	0.03	0.01	0.02			
Cattle					0.14		1.06	0.56	1.55				
Lhama					0.01		0.05						
Goats					0.04		0.04	0.03	0.07	0.03			
Goat/ovine					0.07		0.01	0.02	0.02	0.02			
Rabbits								0.09	0.1	0.07			
Milk cattle					0.28					0.62			
Beef cattle										1.18			
Sheep								0.02	0.08				
Carneiro								0.01	0.08				
Cabra								0.26	0.11				
Bode								0.08	0.07				
Cow									0.18				
Mare									0				
Horse									0				
Mule									0	0.01			

Subtitle: *LPG: Liquefied Petroleum Gas.

(A) Total scope 1	8.54	10.01	7.91	13.98	16.89	9.06	9.57	7.53	13.21	9.09	10.58	2.91	
Scope 2													43.07
(B.1) Effluent	0.47	0.47	0	0.5	4.6	0.96	2.69	1.96	2.82	2.23	1.67	1.37	
Campus						0.76	2.68	1.95	2.8				
Chemical toilets						0.2	0.01	0.01	0.02				
(B.2) Electric power	0.78	2.45	1.36	1.62	1.83	2.82	2.37	2.19	1.36	1.18	1.8	0.61	
University restaurant	0.06	0.1	0.16	0.11									
Printing	0.02	0.04	0.03	0.03			0.05	0	0.06	0.03			
Water treatment station	0.01	0.02	0.01	0.1	0.06	0.26	0.04	0.03	0.21	0.13			
General *Campus*			1.15	1.38	1.77	2.56	2.28	2.15	1.1	1.03			
Course locations	0.12	0.21											
Multiuso Space	0.15	2.00											
Accommodation	0.13												
Amusement park	0.13												
Stands e trents	0.11												
Hotel	0.05	0.09											
(B) Total scope 2	1.25	2.92	1.36	2.11	6.43	4.74	7.75	6.1	6.99	3.41	4.31	2.29	
Scope 3													341.78
(C.1) Mobile combustion	13.68	9.13	21.04	25.33	5.44	9.43	4.05	4.9	11.51	4.36	10.89	6.93	
(C.2) Hotel electric power	0.3	0.5	0.03	0.03							0.21	0.2	
(C.3) LPG	0.97	1.67	4.38	1.57	4.17	2.01	3.26	5.38	5.14	4.55	3.31	1.55	
(C.4) Livestock (waste management)				0.5							0.5	0	
(C.5) Solid waste	17.24	14.19	12.19	12.54	28.39	45.6	19.46	25.04	12.07	10.3	19.7	10.32	
(C.6) Planting					0.12	0.15	0.16	0.03	0.5	0.5	0.24	0.18	
(C)Total scope 3	32.19	25.49	37.63	39.96	38.11	57.2	26.93	35.36	29.21	19.71	34.18	9.79	
Grand Total	41.98	38.42	46.9	56.05	61.43	71	44.25	48.99	49.41	32.21	49.06	11.34	490.64
Subtitle: *LPG: Liquefied Petroleum Gas.													

The sources with the highest GHG emissions during the evaluated period were “Solid waste” (μG: 19.7 ± 10.3 tCO_{2e}) and “Mobile combustion” (μG: 10.9 ± 6.9 tCO_{2e}), both included in Scope 3. Electricity consumption in hotels (0.21 ± 0.20 tCO_{2e}) and activities related to

the planting of neutralization, carried out at the end of the year for each edition (**μ**G: 0.24 ± 0.18 tCO_{2e}), had the lowest average GHG emissions (Table 1).

The 85th (2014) and 86th (2015) edition of FW had the highest GHG emissions levels in the historical series considered. They were 61.4 and 71.0 tCO_{2e} in 2014 and 2015, respectively. The lowest GHG emissions occurred in 2011 (82nd edition, 38.4 tCO_{2e}) and 2019 (90th edition, 32.21 tCO_{2e}) (Table 1).

GHG neutralization of Farmer's Week (FW) emissions

The entire database of GHG neutralization of this study contains the SP, μDGL, μH and μC data for all forest species in each neutralization plantation (**Table S1**). Plantations with "4" and "7" records had the highest CO_2 stocks verified. Estimates of annual CO_2 storage per individual stood out for the planting of record "4" (20.0 $kgCO_2$ ind^{-1} $year^{-1}$). The lowest CO_2 stock estimates were found for plantations records "1" and "3". The greatest variability between the estimates of individual CO_2 was found for plantations records "1" and "4" (both greater than 80 kg of CO_2 ind^{-1} $year^{-1}$) (Figure 2).

Approximately 30% of tree species used in the CZP neutralization plantations have some degree of threat, according to official lists of Brazilian flora species. Among the tree species used, some deserve to be highlighted: *Cariniana legalis*, *Cederela fissilis*, *Dalbergia nigra* and *Zeyheria tuberculosa* since they reincluded in the three official lists considered as the basis for determining the degree of threat in this study. Among the tree species classified with some degree of thereat, almost 50% of them have a high risk of extinction in the wild nowadays (Table 2).

Table 2
List of species with some degree of extinction threat used in the Greenhouse Gas (GHG) neutralization plantations of the Carbon Zero Program - UFV. “Endangered species”: CR (critically endangered species in nature); EN (species in very high danger of extinction in nature); VU (species that face a high risk of extinction in nature). “Species with low risk of extinction but dependent on conservation”: NT (nearly endangered species) e LC: Species with low risk of extinction

Scientific name	Martinelli e Moraes (2013)	IUCN (2014)	Brasil (2014)
Albizia niopoides	LC		
Amburana cearensis	NT	EN	
Anadenanthera colubrina var. cebil		LC	
Apuleia leiocarpa	VU		VU
Bixa orellana			
Cariniana legalis	EN	VU	EN
Cedrela fissilis	VU	EN	VU
Centrolobium tomentosum	LC		
Chloroleucon tortum	NT	CR	
Clethra scabra	LC		
Colubrina glandulosa	LC		
Dalbergia nigra	VU	VU	VU
Euterpe edulis	VU		VU
Genipa americana	LC		
Handroanthus impetiginosus	NT		
Hymenaea courbaril	LC		
Inga laurina	LC		
Joannesia princeps	LC	VU	
Machaerium nyctitans	LC		
Melanoxylon brauna	VU		VU
Piptadenia gonoacantha	LC		
Plathymenia reticulata	LC		
Plinia edulis	VU		VU
Zeyheria tuberculosa	VU	VU	VU

Development of GHG quantification and neutralization systems

The ZCP has developed its own tools for diagnosing GHG emissions/removals from people, rural properties and events to make environmental awareness more effective. Altogether five tools have been developed since 2010, four of them were developed with the main objective of calculating the carbon balance of residents of urban areas and rural properties (**Table S2**). In addition to these tools developed by the Program in 2010 and 2011, an online calculator (Carbon Neutral (Maxam) http://www.maxambiental.com.br/carbononeutro_ferramenta/) was used to raise public awareness at FW. This calculator, developed by the Carbon Zero Program at the time, only performed the calculation of the carbon balance in rural properties. Therefore, there was a need to use another tool that could do the calculations related to the residents of the urban area. Since 2012, the CZP has developed systems capable of quantifying GHG emissions for urban residents. Only one tool was developed in 2019 aimed in calculating the carbon balance and economic viability in rural properties with a focus on charcoal production (**Table S2**).

Bibliographic data

The surveys showed that 64 manuscripts were published over the 10 years of existence of the CZP. Approximately 33% of these manuscripts were directly related to the Program. In 2017, the highest number of manuscript (22%) for the verified historical series were published. The most published modality was “scientific articles”, representing 48% of the Program's publications, and the least was “book chapter” (1.5%) (Figure 3). All the studies raised in this analysis are listed in **Table S3**.

Public sensitized

The total public sensitized by the CZP during the FW were 4,162 people since its implementation. “Children in the environmental circuit” (39.5%) was the greatest number of sensitized people, followed by “Rural producers” (30.7%) and “Urban residents” (29.8%). The years with the highest public sensitized (59%) were 2017, 2018 and 2019, with 2017 being the year with the highest sensitized rate (24.8%) of the entire historical series surveyed (Figure 4).

In all years of the CZP at the FW, the involvement of students was essential for the realization of environmental awareness.

The Carbon Zero Program acted in the environmental awareness of 28 events outside FW. During these actions, an audience of 26,186 people was sensitized (**Table S4, Table S5**). The vast majority (90%) were participants in the events. The municipal laws that were implemented in the city of Viçosa with a focus on GHG survey and compensation were developed as a result of the awareness work carried out by the CZP. The work of the CZP gained notoriety on the part of politicians who understood that the implementation of the legislation would bring socio-environmental gains for the entire municipality.

Discussion

A 10-year legacy of the CZP and its contributions

The practical evolution of the CZP was motivated through a main ecosystem service, the Carbon. The implementation and conduction of the Program is linked to the UFV, an important Brazilian HEI. The motivation for this study was to show this legacy over the 10 years of its existence. The CZP can serve as a model for the development of other actions with the same focus on other institutions in the world. The engagement of HEIs and students can collaborate decisively in tackling climate change, since HEIs play a central role in defining strategies and training leaders with knowledge of this theme.[12,16,17]

Studies related to the role of HEI in the management of GHG emissions have undergone significant advances in recent years.[23–28]However, in Brazil there are still few studies related to the theme.[29–31] No study has demonstrated the practical application of the management of GHG emissions carried out by a Program consolidated in Brazilian HEIs. Although the CZP is mainly linked to FW carried out at the UFV, its consolidated structure promotes the ability to implement carbon management in any HEI in the world.

Other important studies were carried out reinforcing the importance of the leadership of the HEI in facing climate change. In Mexico and the United States, for example, HEIs are encouraged to have GHG reduction and neutralization targets, but in Brazil, little has been said about the contribution of HEIs to NDCs.[32,33] In addition to the central role of HEIs, previously mentioned, it is necessary to reinforce that this sector can represent an expressive global contribution to the reduction of GHG emissions.[34] In this context, program management mechanisms related to efforts reduce GHG emission need to be more effective considering the role of people in this process.[35,36]

The leadership and commitment of representatives and others involved in the CZP can be compared to the case study developed at the University of Greifswald in Germany.[37] Thus, as in Greifswald, the results over the legacy of the CZP seem to have been driven by the commitment and stance assumed by those involved in the Program, not requiring the formal signing of agreements related to the reduction and compensation of GHG. The co-benefits provided to both the academic community and the society, which receives the actions developed within the framework of the CZP, generated a mutual synergy capable of sustaining the debate on “Climate change”, which is very recurrent among the social actors involved. These co-benefits can be treated as legacies, and the main ones are highlighted below:

The students' technical and scientific knowledge was being improved during the evolution of the CZP. As presented, the GHG survey methodologies in the FW were modified according to the learning evolution of those involved. This aspect is important to be highlighted, since it is understood that the technical discussions were substantial and allowed the survey of emissions data to be adapted to the reality of each edition of the event. Thus, there was an improvement in the technical-scientific analysis of GHG management by the students involved. This experience can be a key to the experimental learning and success of environmental management programs.[33] The GHG quantification and balance tools have undergone a great evolution during this period and currently allowed the development of a more consistent platform that allows the updating of important indicators in a simpler way.[19]

Planting native seedlings have promoted an essential legacy for generating a database with the performance of approximately 80 tree species planted in a degraded area in southeastern Brazil. Some important studies have been published recently focusing on the performance of several species of interest for forest restoration.[38–40] The relevance of these studies lies in the need to develop a solid database on the performance of native species of the Atlantic Forest, mainly for younger ages.[41] Recently, the importance of consistent data on forest restoration in Brazil has increased, due to the international commitments made by Brazil, the reformulation of Brazilian forestry legislation,[42–44] and also the biggest environmental tragedy of Mariana, MG, occurred in 2015.[45,46]

The pillar of the CZP is related to the ecosystem service of Carbon; however, the focus related to forest restoration is quite prevalent.[18] Thus, there is a substantial technical and intellectual contribution to the development of this theme among those involved in the program, allowing the interface between these themes and the expansion of knowledge related to environmental management.[47] However, it is important to highlight that the neutralization of GHG by trees has been questioned by specialized literature.[48,49] However, the CZP in addition to uses methodologies that promote carbon storage in the forest in a sustainable way over time,[50] also explores the multiple benefits of carbon neutralization achieved by planting forest species. In addition, the neutralization plantations function as a study laboratory that allows the development of scientific research, and educational activities in disciplines related to efficient management of land use, forestry, recovery of degraded areas, seed production and dendrology.

The carbon neutralization plantations are located in an area easily accessible to urban residents, who can enjoy ecosystem services such as landscape comfort. The approval of Law number 2,875/2020 and Decree number 5,622/2021 in Viçosa, MG, demonstrated the commitment and dialogue between Science and Politics in the municipality.[51,52] Although the importance of legislation related to climate change is widespread,[53] the direct influence of the dialogue between science and politics at the municipal level in this topic had not yet been verified in the literature.

Perspectives of the CZP - Federal University of Viçosa

The evolution of the CZP has been important to consolidate the technical and scientific background of the actors involved and reveal a pilot program in the management of GHG emissions. UFV is expected to expand the financial resources allocated to this program to offset the GHG emissions of the entire campus and promote the implementation of the program in other HEIs. This effort shows the environmental commitment of the HEIs and helps to improve international environmental indicators that have been evaluated at UFV.[54]

Other forms of GHG neutralization should be implemented in the coming years, aiming to link other forest restoration techniques to the mitigation of global climate change.[55–57] It is expected a greater reach of environmental awareness and a greater number of studies promoted by the CZP, due to the greater visibility and the allocation of resources. The plantations of the CZP fulfill their function of storing carbon in the plant biomass of forests; however, in the next 10 years, a careful evaluation of the indicators considered for the planned carbon neutralization must be carried out.[38] Currently, it is possible to conclude that the planned neutralization is being achieved because the minimum average is 6.0 kg of CO_2 individual^{-1} year^{-1}.

In this study, it was prioritized the presentation of the institutional structure of the CZP to provide a review of the program, including its social context and legacy reaching up to the present day, as a way to encourage other institutions to establish carbon emission management programs.

Conclusions

The CZP presents opportunities for gains from ecosystem services related to responsive carbon management provided to different social actors. Ten years of the CZP revealed important lessons and learnings related to the administration of a carbon management program in large events at a HEI. The neutralization of GHG by planting seedlings can enhance the social, educational and research gains of HEIs. The 10-year results of the CZP showed that: 4,162 people were sensitized on the theme of climate change at FW and 26,186 people at other events; and 63 scientific studies related to this program have been published. A total of 588.42 tCO_{2eq}. GHG emissions were raised during the FW. Approximately 4,660 trees were planted in a degraded area in southeastern Brazil as a way to neutralize emissions from an event. Several GHG emissions management tools have been developed to help raise the environmental awareness of the CZP. The software “CZ 1.0” was the most modern tool for the analyses performed.

Methods

Study area and context

The study area belongs to the municipality of Viçosa (20º45'44” S; 42º51'67” O), in Minas Gerais, southeastern Brazil. Viçosa has about 300 km² and a population of 79,000 inhabitants (IBGE, 2020). The local climate is Cwa (Köppen classification) with averages of temperature, humidity and annual precipitation of 21.9ºC, 79% and 1.274 mm, respectively.[58]

The region has pedogeomorphological gradients with abundant dystrophic oxisols in aluminum on top of the hills, colluvial ramps with superficial oxisols and the exchange rate horizon, at the bottom of the forests there is a predominance of epieutrophic cambisols rich in nutrients.[59] The local vegetation is classified as semi-deciduous Atlantic Forest and the altitude of the region is around 700 meters.[60] The municipality has approximately 19% of natural forest cover.[61] As part of the Atlantic Forest, Viçosa's vegetation is considered a global biodiversity hotspost.[62] In addition, although Viçosa was not directly affected by the impacts of the Minas Gerais dams breaches, the hydrographic region, to which the municipality belongs, is part of the Rio Doce River Basin, which was affected by the disruption of the Fundão mining dam in 2015.[63]

The local economy is based on the service sector, which is largely driven by students and civil servants at the UFV.[64] UFV was created in 1926 with an educational purpose aimed at training qualified professionals in the area of Agrarian Sciences.[60] UFV holds an annual extension event, FW, which takes place on the university *campus* in the city of Viçosa, Minas Gerais.[22] The CZP has worked to quantify and offset GHG emissions from each edition of the event since 2010. In the same event and over the years, the CZP works to raise people's awareness of environmental issues related to climate change. It also encourages the team involved in the ZCP to develop studies based on the results achieved in the management of Carbono Zero and other studies related to the theme. Therefore, this study will cover the survey of the technical-scientific and extension legacy of the CZP at UFV in 10 years of operation.

Data collection related to the CZP

The period covered by the surveys in this study corresponds to the first decade of existence of the ZCP from 2010 to 2019.

GHG inventory during Farmer’s Week (FW)

The collection and processing of data related to the GHG emission were carried out according to the scientific bibliography and also through information collected during FW.[65–68] The organizational limit considered for the quantification of the GHG inventory was the UFV campus. The GHG emissions that UFV had operational control were considered as emissions of institutional responsibility during the events.

The operational limits and data collections at the event were defined following the recommendation of relevant literature [69,70]. The scopes established for the sources of GHG emissions were defined: Scope 1: direct GHG connections and come from sources that belong to or are controlled by the organization; Scope 2: indirect GHG deviations arising from electricity consumption and thermal; Scope 3: other indirect GHG orders, more specifically, those that occur as a result of the organization's activities, but occur from sources that not owned or controlled by the company. Data collected varied throughout the editions of the FW due to the peculiarities in each edition and also due to the evolution of the methodological understanding of the teams in the CZP (Table 3).

Table 3
Greenhouse Gas (GHG) emitting source considered by the Carbon Zero Program for quantification and collection of the Greenhouse Gases (GHG) emissions data generated at the Farmer's Week. Viçosa. Minas Gerais.

Scope	GHG emitting source /Form of data collection considered	Year of realization										Percentage (%) of use of the methodology considered in the event editions
		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
1	**(A) Mobile combustion**											
	(A.1) Amount of fuel consumed	x	x	x	x							40
	(A.2) Type of vehicle					x	x	x	x	x	x	60
	(A.3) Type of fuel	x	x	x	x	x	x	x	x	x	x	100
	(A.4) Distance travelled by vehicles					x	x	x	x	x	x	60
	(A.5) Average vehicle consumption					x	x	x	x	x	x	60
	(B) Stationary combustion - Biomass											
	(B.1) Average biomass consumption	x	x	x	x	x	x	x	x		x	90
	(B.2) Average wood density					x	x	x	x		x	50
	(C) Stationary combustion - LPG											
	(C.1) Volume of gas consumed	x	x	x	x	x	x			x	x	80
	(D) Livestock											
	(D.1) Enteric fermentation			x	x	x	x	x	x	x	x	80
	(D.2) Waste management							x	x	x	x	40
2	**(E) electric power**											
	(E.1) Equipment									x	x	20
	(E.2) Energy reading	x	x	x	x	x	x	x	x	x	x	100
	(E.3) Reading on circuit breakers							x	x			20
	(E.4) Estimate by number of participants	x	x	x	x	x	x				x	70
	(E.5) Average water consumption per person	x	x	x	x	x	x				x	70
	(E.6) Reading in hydrometers							x	x	x	x	40
	(F) Effluent generation											0
	(F.1) Estimated amount of effluent	x	x		x							30
	(F.2) Biological Oxygen Demand	x	x		x	x	x	x	x	x		80
	(F.3) Volume of treated water					x	x					20

	(F.4) Estimate by number of participants										x	10
	(F.5) Reading in hydrometers							x	x	x		30
3	**(G) Mobile combustion**											
	(G.1) Amount of fuel consumed	x	x	x	x							40
	(G.2) Type of vehicle					x	x	x	x	x		50
	(G.3) Type of fuel				x	x	x	x	x	x		60
	(G.4) Distance travelled by vehicles					x	x	x	x	x		50
	(G.5) Average vehicle consumption					x	x	x	x	x		50
	(H) Stationary combustion - LPG											
	(H.1) Number of cylinders consumed (13 kg)	x	x	x	x	x	x	x	x	x	x	100
	(I) Solid waste											
	(I.1) Type of waste generated	x	x	x	x	x	x	x	x	x	x	100
	(I.2) Amount of waste generated	x	x	x	x	x	x	x	x	x	x	100
	(G) Emissions generated for the planting of seedlings for neutralization											
	(G.1) Mobile combustion					x	x	x		x	x	50
	(G.1.1) Amount of fuel consumed					x	x	x		x	x	50
	(G.1.2) Type of vehicle					x	x	x		x	x	50
	(G.1.3) Type of fuel					x	x	x		x	x	50
	(G.1.4) Distance traveled					x	x	x		x	x	50
	(G.1.5) Average vehicle consumption					x	x	x		x	x	50
	(G.2) Nitrogen fertilization					x	x	x		x	x	50

Biogenic carbon emissions were considered null because the CO_2 released into the atmosphere, by burning of biomass or the use of ethanol as a vehicle fuel, comes from carbon stored during plant growth.[66,68]

The main gases such as methane (CH_4) and nitrous oxide (N_2O) were converted to a common unit: CO_{2eq}. (carbon dioxide equivalent). This conversion was accomplished by multiplying the measured quantity of each gas by its respective GWP (Global Warming Potential) according to the equation:[66] $E_{CO2eq} = (E_i) \times (GWP_i)$, where: E_{CO2eq} = total carbon dioxide equivalent emissions (tons); E_i = emission of greenhouse gas i (tons); GWP_i = GWP of greenhouse gas i; i = carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O). The GWP of CO_2 = 1; CH_4 = 25 and N_2O = 298 over a 100-year time horizon.[66]

The emission factors (CO_2 eq) that were considered for each emitting source were adjusted according to the relevant scientific bibliography, according to the reality of each emitting source.[30,31,70] Therefore, the total emission of each emission source considered in this study, was carried out considering the multiplication between the specific emission factor of each activity by the quantity measured and/or estimated in data collections throughout the event in each edition of the FW.

ZCP considers as GHG offsetting the planting of seedlings of forest species in areas belonging to UFV. The GHG offsetting plantations were established at the UFV Open Event Space (20°45'34.92'S and 42°52'32.23"W), and the used offsetting coefficient was 6.0 $kgCO_2^{-1}$ $individual^{-1}.year^{-1}$, considering a 30-year horizon for effective offsetting.[38] Annually, 20% more individuals are planted as a safety margin to compensate losses due to the mortality of planted seedlings.

GHG emissions offsetting from Farmer's Week

The plantations to neutralize GHG emitted during the FW were implanted annually in an area with a predominance of invasive exotic grasses (Table 4, Figure 5). A detailed description of the silvicultural treatments used and the land use history can be found in Morais Junior et al.[38,40] All plantations were established in the rainy season (December) to increase survival success and initial growth.

Table 4
List of general information on carbon neutralization plantations of the Carbon Zero Program in 2019

Planting year	Age of planting in the evaluation of this study	Number of seedlings planted	Number of species planted*	Area occupied by planting (m²)	Planting registration code
2010	102 months	397	32	1.592	1
2011	90 months	208	21	964	2
2012	77 months	506	20	2.080	3
2013	66 months	500	25	2.000	4
2014	54 months	666	31	2.664	5
2015	42 months	451	30	1.804	6
2016	30 months	612	24	2.448	7
2017	18 months	540	15	2.160	8
2018	15 months	372	10	1.488	9
2019	6 months	360	7	1.440	10
Total amounts		4.660	80 species	18.640	-

*There are forest species that repeat over the years.

For climatological characterization of the study area, monthly data were used from the automatic Meteorological Station of the National Institute of Meteorology (INMET) in Viçosa, in the period 2010-2019: accumulated precipitation, average atmospheric pressure, average temperature, and average wind speed (**Table S6**).[71] Climatological data are important in view of the presentation of survival, growth and carbon dioxide removal data for forest species.

Survival, diameter at ground level (DGL) and plant height (H) were measured for the different ages of each plantation. The list of information for each planted area was presented in Table 4. The DGL was measured with a precision digital caliper and H with a graduated stick. The scientific names of the species were consulted following recommendations from specialized bibliography (*e.g.* Flora do Brasil,[72]).

The percentage of survival (SP) was determined by the equation: SPj = (Nfj / N0j) × 100, where: Nfj = number of surviving individuals of the j-th species; N0j = initial number of individuals planted in the j-th species. The average annual growth with the respective DGL and H deviations of the species were calculated and had the following nomenclatures (μDGL) and (μH), respectively. The equations used were: μDGL = [(DGLj) / Nj)) / (I)], where: I = planting age; Nj = number of individuals of the j-th species; DGLj = average DGL of the j-th species, in cm; μDH = [(DHj) / Nj)) / (I)], where: I = planting age; Nj = number of individuals of the j-th species; Hj = mean of H of the j-th species, in cm.

The estimated average carbon stock of the stem and branches (C) of tree individuals was calculated using the equation.[40] Cij = [0.000353 × ($DGL^{1.202424}$) × ($H^{0.781883}$)], (Adjustment R^2 = 82.12%; where: Cij = carbon stock of the i-th individual of the j-th species (kg); DGL = diameter of the height of the ground (mm) and H = total height of the individual (cm). The carbon stock averages (μC) were calculated by species using the equation: μC j = [((∑ Cj) / Nj))], where: I = planting age; Nj = number of individuals of the j-th species; μCj = average carbon stock of individuals of the jth species, in kg. The conversion of data from carbon (C) to carbon dioxide (CO_2) was done using the factor 3.67, referring to the conversion between the molecular weights of CO_2 and C.[66] This conversion was adopted to facilitate the

discussion of data regarding the carbon dioxide removal factors. Estimates of the annual increase in carbon stock ($AICO_2$) per individual were performed using the following equation: $AICO_2\ j = [((\sum Cj) / Nj) / (l))]$ (variables previously defined).

The planting of code “10”, planted in 2019, did not have its carbon neutralization data presented due to the survey of the data having been carried out only 6 months after planting. The adjustment intervals of the equation that estimates the carbon stock of Morais Junior et al.[40] is not applicable in seedlings with the diameter range verified for this planting. The conservation status of forest species used in neutralization plantations was consulted in specialized literature,[73,74] to assess the degree of threat of these species.

The letters used to determine the degree of threat of forest species were: “endangered species”: CR (species critically endangered in the wild). - EN (species in very high danger of extinction in the wild); VU (species that face a high risk of extinction in the wild). “Species with low risk of extinction but are dependent on conservation”: NT (species almost with extinction risk) and LC: (species with low risk of extinction).

Development of GHG quantification and neutralization systems

By consulting specific bibliographic studies related to the elaboration and improvement of GHG quantification and neutralization tools and systems within the scope of the ZCP it was possible to determine the evolution of the carbon balance systems developed by the Program.[18,65,75]

Survey of bibliographic data

A systematic literature review was carried out to survey studies that were published by the research group related to the CZP. The searches were carried out in the Scopus and Web of Science databases since 2010 (year of creation of the CZP), with the last visualization in November 2020. The research was carried out considering some important keywords such as “Carbono Zero Program”; "Carbono Zero"; “Carbono Zero Program-UFV”. For the survey a list with names of members of the CZP was also used. Each name was used as a keyword in the search for scientific research on the aforementioned platforms. As the CZP was created by the UFV, this survey was also carried out on the platform entitled “Locus UFV”, which is a digital collection of studies published by students and teachers of the institution.[76] After this initial survey, it was checked if the published study was related to UFV's CZP.

The studies were classified according to the relationship with the CZP in: (A) Direct: when the study was developed directly as an opportunity created by the development of the CZP along the UFV inventory and neutralization proposal. (B) Indirect: when the study was not directly related to the opportunity generated by this program, but in a certain way the discussions and scientific knowledge was fostered by the CZP.

Survey of sensitized public

The sensitized public was raised on two main axes of the extension carried out by the CZP at UFV.

a) Public sensitized directly during the Farmer's Week (FW)

CZP registrations made it possible to survey the public that was sensitized by the CZP during the FW. The classifications of audiences were defined as: “Farmers” for the public residing in rural areas; “Residents of the urban area” for residents of the urban areas and “Children in the environmental circuit” for the definition of children.

b) Public sensitized by the ZCP in other extension events (PSOE)

The ZCP was responsible for spreading the theme about climate change and ecosystem services related to the quantification and neutralization of carbon in other events inside and outside of the UFV. Date, place and the public involved was considered for each event. People involved were classified as “Event organizers”; "Speakers"; "Participants".

The influence of ZCP in the municipal law of Viçosa was used as basis of Law number 2,875/2020 and Decree number 5,622/2021.[51,52]

Declarations

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Author contributions statement

V.T.M.M.J conceived and conducted the experiment, wrote the manuscript. L.A.G.J guided and supervised the study. E.B.B.M.A.; L.B.S.; T.P.A; T.A.R; M.L.B; D.B; S.J.S.S.R; B.L.S.S; I.B.C; F.M.B.R; V.F.S; I.S.F; K.O; T.B.S; M.P.X.R; P.H.V; W.D.D.C; N.L.P and R.D.S participated in the collection and tabulation of data and information. C.M.M.E.T; D.B; G.S.L; H.N.P; S.V.M and R.A.C participated in the technical and scientific reviews of the manuscript.

Must include all authors, identified by initials, for example: A.A. conceived the experiment(s), A.A. and B.A. conducted the experiment(s), C.A. and D.A. analysed the results. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

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Figures

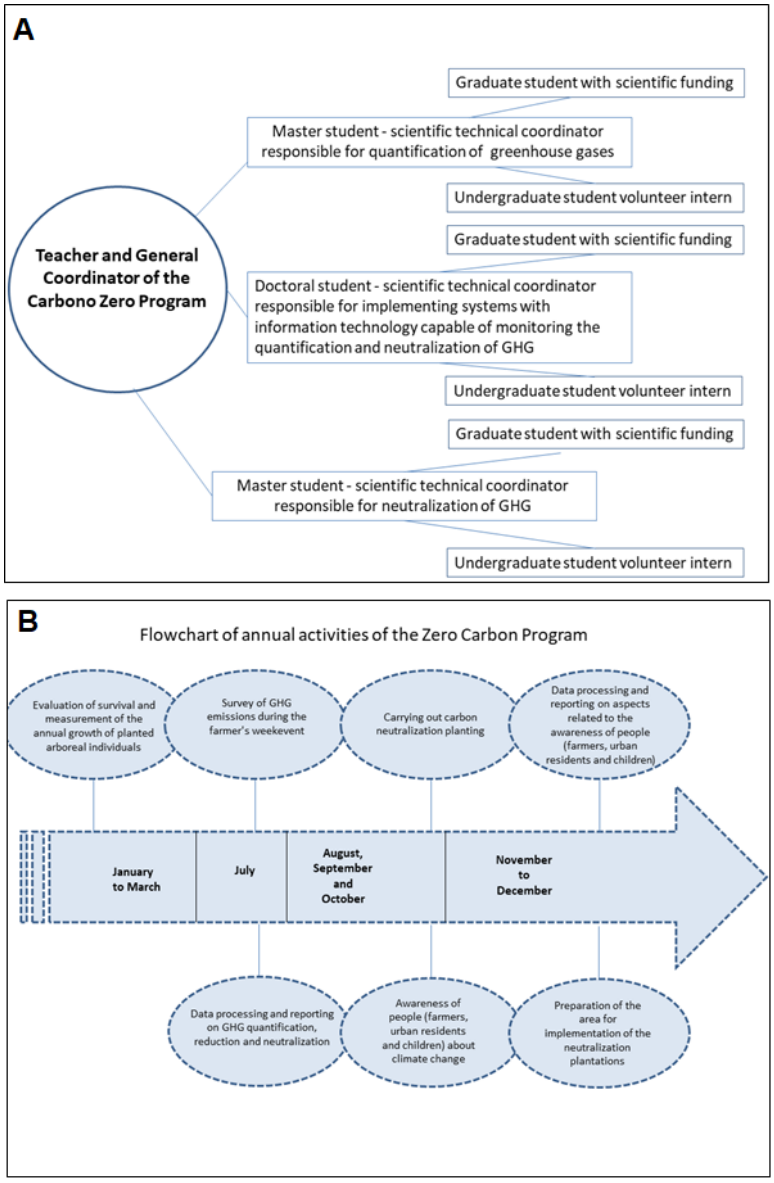

Figure 1

A) Organizational structure of the Carbon Zero Program of the Federal University of Viçosa, Brazil. B) Yearly Zero Carbon Program schedule timeline.

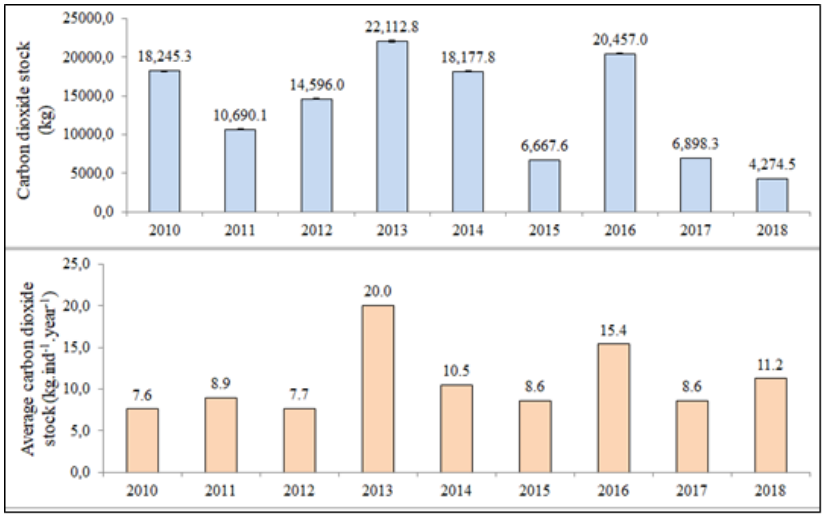

Figure 2

Estimates of carbon dioxide (CO2) stock with the respective standard deviations in kg and average annual storage of carbon dioxide in kg for the neutralization plants of the Carbon Zero Program-UFV.

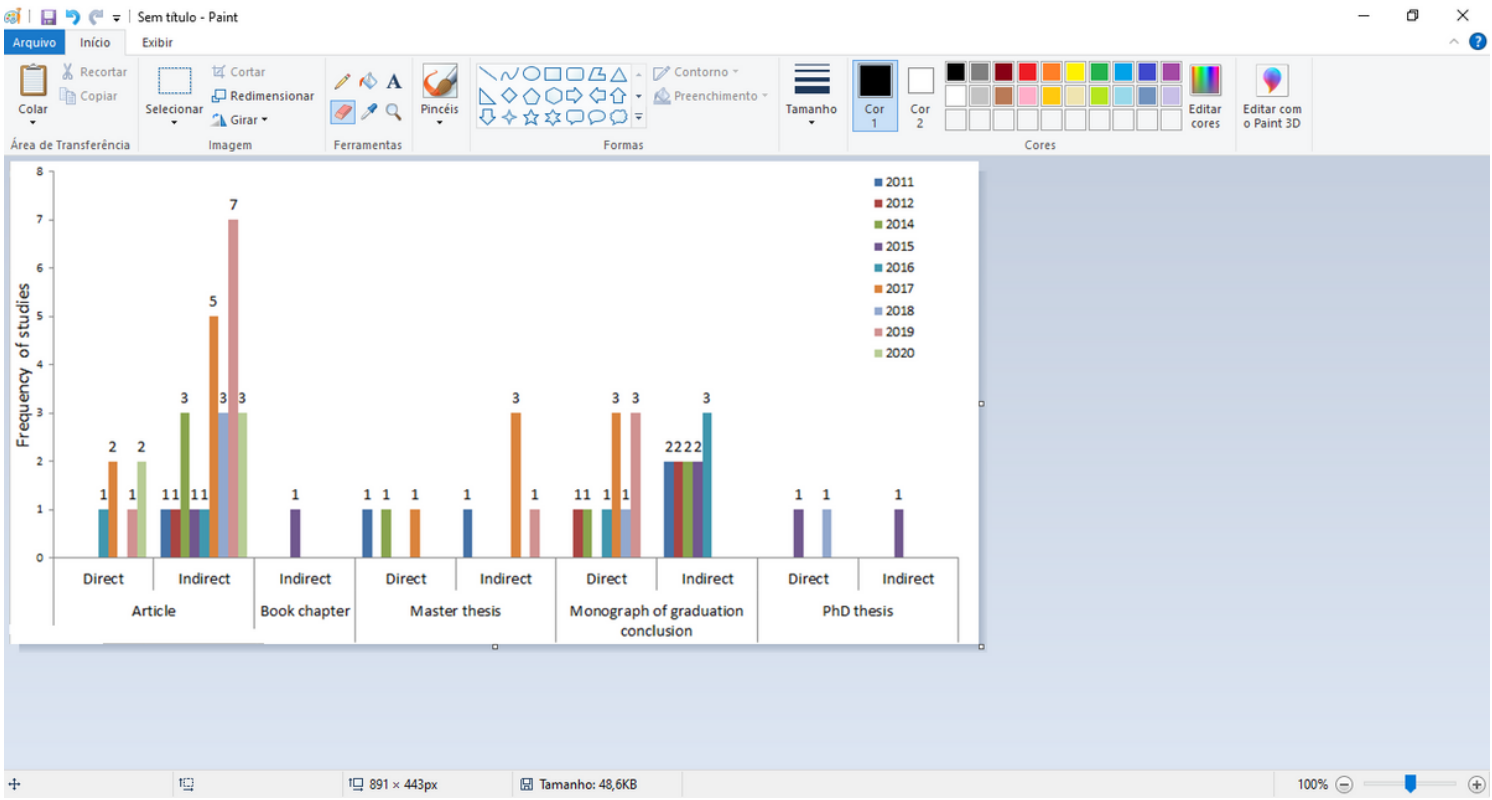

Figure 3

Quantity of studies developed and published annualy by the Carbon Zero Program (Federal University of Viçosa). Direct relationship: when the study was developed directly as an oportunity generated bt the development of the CZP along the proposal of inventory and neutralization of GHG by UFV. Indirect: when the study is not directly related to the opportunity generated by the development of the Carbon Zero Program by UFV, but that in a certain way the disccussion and scientific knowledge was fomented by the program.

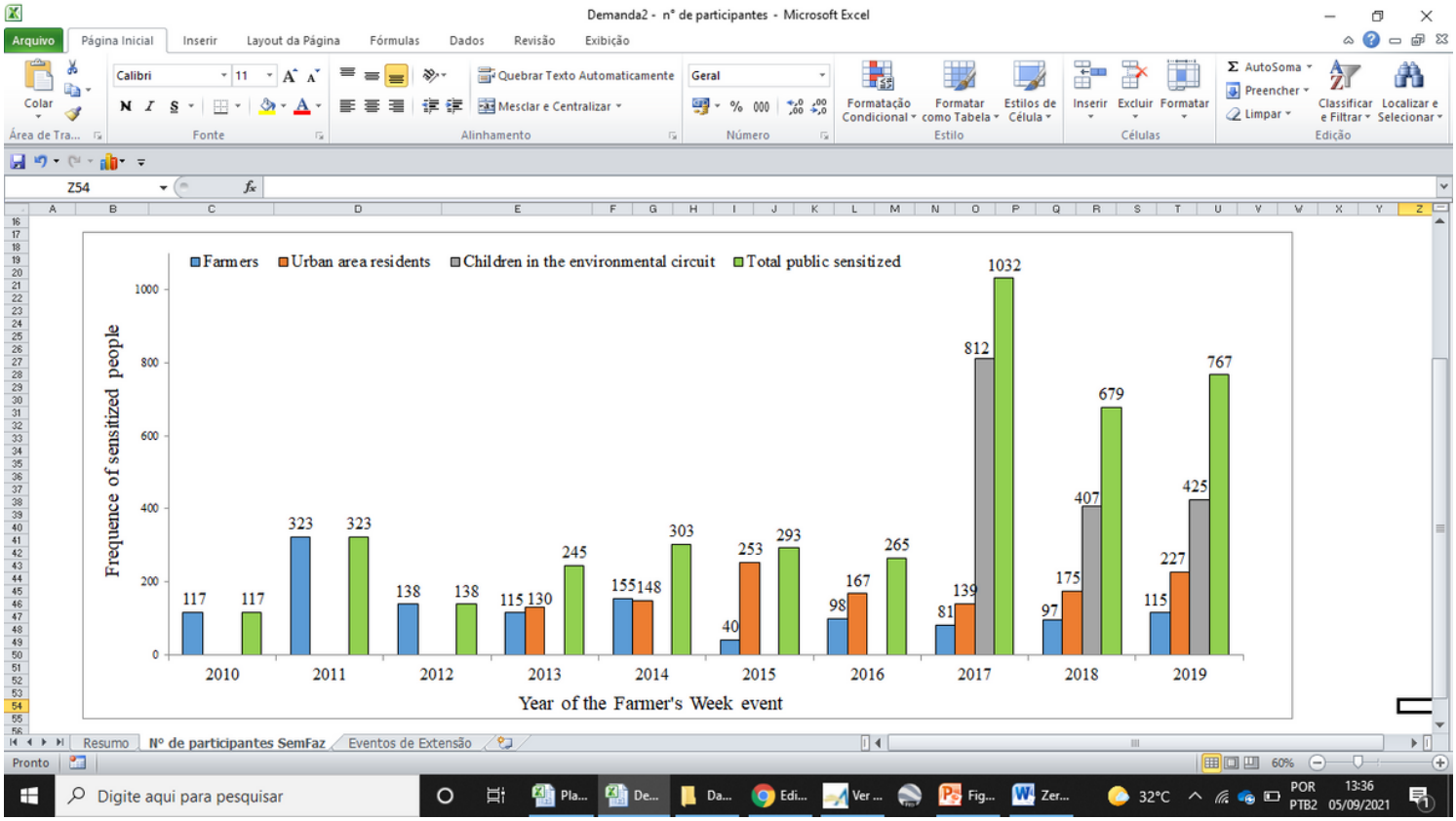

Figure 4

Historical survey of different people (Farmers, Urban area residents, children in the environmental circuit) sensitized during Farmer's Week by the Zero Carbon Program. Data for "urban area residents" and "children in the environmental circuit" are absent between 2010-2012 and 2010-2016, respectively. Environmental awareness aimed at these audiences was subsequently developed as the zero-carbon program gained experience in the subject.

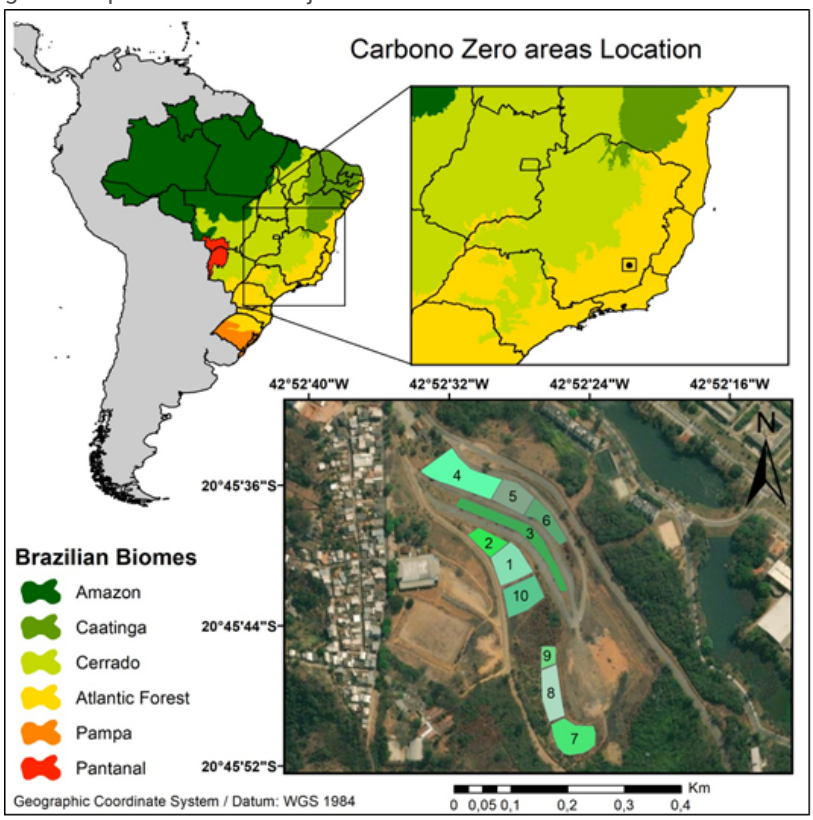

Figure 5

Location of neutralization plantations of the Carbon Zero Program of the Federal University of Viçosa (UFV), in Viçosa, Minas Gerais. The codes under the Neutralization Planting areas (PN) show the space occupied by each plantation. Legend: (1) PN carried out in 2010; (2) PN carried out in 2011; (3) PN carried out in 2012; (4) PN carried out in 2013; (5) PN carried out in 2014; (6) PN carried out in 2015; (7) PN carried out in 2016; (8) PN carried out in 2017; (9) PN carried out in 2018; (10) PN carried out in 2019.

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