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Sentinel-5P TROPOMI satellite application for NO_2 and CO studies aiming at environmental valuation

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A R T I C L E I N F O

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A B S T R A C T

The European Space Agency (ESA) provides opportunities for researchers on a global scale to identify gaseous pollutants using the most modern techniques of analysis by satellite images from the Sentinel-5P satellite, in the TROPOspheric Monitoring Instrument (TROPOMI), for the formation of current scenarios, applied to valuation environment aimed at possible improvements attributed to air quality and human health. The general objective of this manuscript is to analyze the amounts of NO2 and CO gases with Sentinel-5P TROPOMI satellite images, collected during the year 2019, and apply the environmental valuation focused on air quality pollution, in the northern region of the state of Rio Grande do Sul, in the host city, Passo Fundo (southern Brazil) from 2020 to early 2021. The air quality valuation study applied the Contingent Valuation Method (CVM). The results showed that NO_2 had the highest concentration with a value of 7.88e +15 Column mol/cm^2. CO presented a value of 9.43e +33 Column mol/cm^2. The creation of scenarios aimed at valuation for the application of improvements in atmospheric air quality the understanding of the Willingness to Pay (WTP) of the interviewees. 514 residents of the City of Passo Fundo were queried as to their WTP for clean air quality in the city. The resulting WTP values, when applied to all households in the city as a whole, yielded an average WTP value of R$1,517,478.24 and the median WTP is R$599,390.00. It is suggested that pubic policies be written to enable these, or similar, amounts to be collected annually in order to mitigate harmful pollutants, such as NO_2 and CO, currently found in the air of the City of Passo Fundo.

1. Introduction

Scientific investigations related to the levels of atmospheric compounds, such as: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), methane (CH_4), ozone (O_3) and aerosols (ultra-fine particles), were conducted utilizing equipment subsidized by the European Space Agency (ESA), through the use of images from the Sentinel-5P satellite, within the ultraviolet (UV), visible (VIS), Near InfraRed (NIR) and short-wave infrared (SWIR) detection spectrometer. Using the TROPOspheric Monitoring Instrument (TROPOMI) system (Prunet et al., 2020; Kang et al., 2021; Saw et al., 2021; Xia et al., 2021) is the most innovative way of detecting existing pollutant levels in the world (Prunet et al., 2020; Kang et al., 2021a).

Air quality monitoring is currently carried out in some of the most important cities in the world utilizing modern techniques such as high-resolution mapping (Liu, 2021), advanced microscopy (Oliveira et al., 2021), and geoinformation technologies (Mendez-Espinosa et al., 2020). Technical uses combining satellite observations utilizing the

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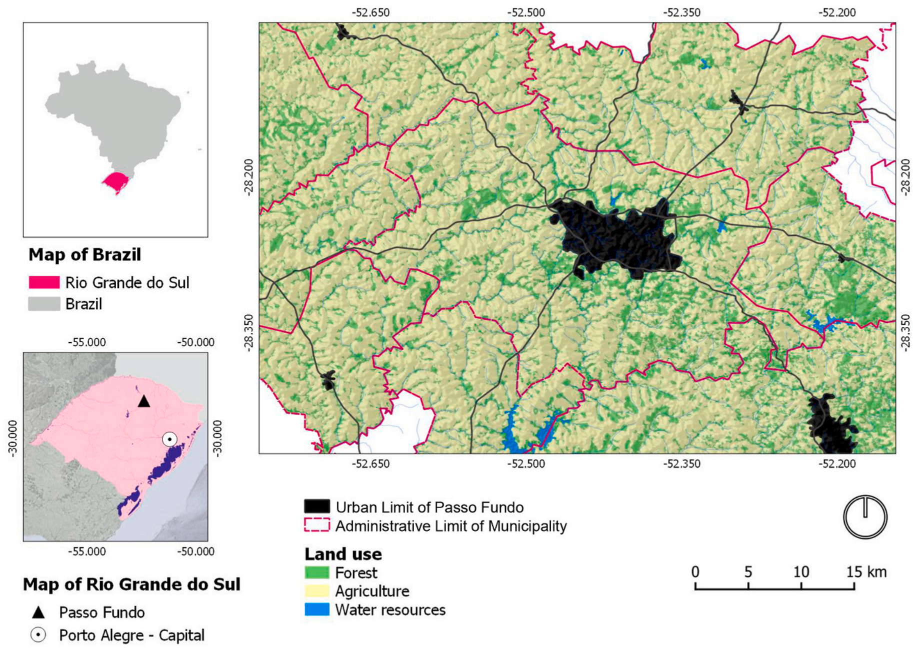

Fig. 1. Location of the City of Passo Fundo in the State of Rio Grande do Sul, Brazil. Adapted from IBGE's geographic database (IBGE, 2021).

TROPOspheric Monitoring Instrument are relevant to estimate anthropogenic emissions and for designing future air pollution abatement strategies based on regulatory action. NO_2, SO_2, CO and CH_2O are all gasses that have historically been and continue to be released into the atmosphere in large amounts in industrial and urban areas (Neckel et al., 2021). The main source of these gaseous releases is the use of fossil fuels (Prunet et al., 2020; Kang et al., 2021a; Saw et al., 2021; Xia et al., 2021). Globally, the consequences of the release of NO_2, SO_2, CO and CH_2O are increasing (Xia et al., 2021). Levels, in which the levels of missions of these gases were 2.7 times higher in 2006, aggravated by the increase of 2.3% in 2019 and 2.6% in (2020) of the number of vehicles, associated with the industrial production that registered an accumulated growth of 15% of the fleet between 2015 and 2018 (Prunet et al., 2020; Kang et al., 2021a; Oliveira et al., 2021; Raparthi et al., 2021; Tang et al., 2021). It should be remembered that NO_2 and CO are gases that are harmful to human health, as they are extremely carcinogenic (Cetin, 2016; Oliveira et al., 2021; Maharjan et al., 2022). CH_4 primarily originates from volcanic activities, in addition to the degradation of organic residues in anoxic environments (Amodeo et al., 2021).

As known human carcinogens, NO_2 and CO were labeled as components that can directly compromise human health, causing high incidents of cancer the world over (Çetin and Sevik, 2016; Ozel et al., 2019; Oliveira et al., 2021). As the population residing in cities the world over continues to increase, the level of pollutants emitted will likewise continue to increase. This will have harmful effects on human health which will worsen with time (Cetin et al., 2017, 2018; Ozel et al., 2019). One possible solution can be found in the creation of ecological corridors, intertwined with the urban landscape (Çetin and Sevik, 2016).

Global databases recorded at least 18 million cases of cancer in calendar year 2018, of which 2.1 million cases consisted of lung cancer. Human exposure to these gasses occurs through inhalation and contact with the lungs. Lung cancer is also cited as the most common cancer registered by the National Cancer Institute, headquartered in Brazil (INCA, 2021).

Justification for this study comes from 2020 estimates recorded in the scientific reports of INCA (2021). When considering an adjusted rate of cancer incidence per 100,000 inhabitants in the state of Rio Grande do Sul, the data revealed that the new cases of tracheal, bronchial and lung cancer for men were 2300 and 1440 new cases in women, totaling 3740 (100%). In the City of Passo Fundo, located in the northern region of the same state, the majority of the state's cases were registered. New cancers of the trachea, bronchus and lung totaled 870 cases in men and 590 in women, totaling 1460 (39.03%) cases overall (INCA, 2021).

This elevated risk of cancer in Passo Fundo, led to it's selection as the object of this study. The state's highest concentration of cancer of the respiratory tract could likely be attributed to poor air quality, thus, the need to analyze the proportions of NO_2 and CO in the localized atmosphere (Oliveira et al., 2021; Maharjan et al., 2022). The Sentinel-5P satellite has been shown to serve as the most modern investigation technique in the world when examining quantitative proportions of NO_2 and CO (Prunet et al., 2020; Kang et al., 2021a; Saw et al., 2021; Xia et al., 2021).

NO_2 is credited with causing 71,000 premature deaths per year in the European Union and 11,000 deaths in the UK (Lyons et al., 2020), due mostly to cancer. Long-term exposure to NO_2 has also been associated with increased rates of morbidity and increased rates of mortality due to exacerbation of chronic respiratory and cardiovascular diseases (Lyons et al., 2020). Exposure to NO_2 is has also been shown to be tied to the development of chronic obstructive pulmonary disease (COPD), with adverse health effects (Lamichhane et al., 2018).

In general, urban populations the world over have little information on the levels of air contaminants in the city or region, where they live or work (Camargo et al., 2021). This lack of knowledge regarding daily exposures of the population to contaminants which may be harmful to human health is highlighted in environmental valuation studies regarding air quality. Such studies allow an individual, through an opinion poll, to assign a certain Willingness to Pay (WTP) in a hypothetical manner aimed at preserving air quality (Li and Hu, 2018; Yin et al., 2018; Moon et al., 2021).

For several scientific studies, the average of the total value attributed by respondents in environmental valuation studies enhance the creation of public policy, with the function of collecting monetary resources in municipal taxes, destined for the preservation and maintenance of the environmental good, through urban projects (Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021). This study deals with the environmental valuation of air quality previously proposed by some studies (Yin et al., 2018).

Consequently, data revealed by the Sentinel-5P TROPOMI satellite images is of utmost importance to clarify the concentrations of NO_2 and CO present at certain levels in the atmospheric column (Prunet et al., 2020; Kang et al., 2021a; Saw et al., 2021; Xia et al., 2021). This is required to serve as a basis for the application of environmental valuation using the Contingent Valuation Method (CVM) (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Basu and Srinivasan, 2021).

The general objective of this manuscript is to analyze the amounts of NO_2 and CO gases present in the atmosphere through the analysis of Sentinel-5P TROPOMI satellite images in the City of Passo Fundo (Rio Grande do Sul State, Brazil), collected during the year 2019. This analysis is then applied to an environmental valuation focused on local air quality and pollution in the same city from 2020 to early 2021. This manuscript stands out for its innovation regarding the use of images from the Sentinel-5P TROPOMI satellite, launched into Earth orbit on October 13, 2017 (6:27 a.m. BRT). Through the use of this technology, we are now able to improve the technique of analysis of these pollutants by satellites to a greater degree. This technique can be used as a basis for other researchers to conduct studies of environmental valuation of air quality in cities on a global scale.

2. Materials and methods

2.1. Study area

The Brazilian Institute of Geography and Statistics (IBGE) lists a total 2020 population of the state of Rio Grande do Sul (RS) as 11,422,973 persons. This makes RS the sixth most populous state in Brazil (IBGE, 2021). The northern region of RS State is highly industrialized and contains many vehicles. The City of Passo Fundo (Fig. 1), the focal point of this study is the largest city located within the northern region of RS State, with a 2020 population of 204,722 persons (IBGE, 2021). The main industries that operate in the area include: metalworking, clothing, food and biodiesel production. These industries may be negatively affecting air quality. The occurrence of fires in agriculture in the Passo Fundo region is noteworthy. The area surrounding the city is highly agricultural, and such fires may be contributing to the accumulation of atmospheric pollutants.

The City of Passo Fundo has climatic influences of sub-tropical climate (Cfa) with average annual temperatures above 22 °C, according to the Köppen classification and the temperate oceanic climate (Cfb) with average temperature below 22 °C (INMET, 2016; Maroni et al., 2021). Passo Fundo is located in a region composed of Mixed Ombrophilous Forest, containing the arboreal species *Araucaria angustifólia* (Maroni et al., 2021). Consequently, in studies carried out by Rojas et al. (2019) and Mazutti et al. (2020) in practical studies in the Passo Fundo region, in relation to a macro-neighborhood scale in the State of Rio Grande do Sul, warn of the high amounts of contamination by NO_2 and CO. However, this study, using images from the Sentinel-5P TROPOMI satellite, enables the understanding of the spatial dimension of the presence of contamination by NO_2 and CO, enabling data for the application of environmental valuation, through the WTP of the interviewees.

2.2. Air pollution data collection procedures

The Tropospheric monitoring sensor (TROPOMI), which is aboard the Copernicus Sentinel-5P Precursor (S–5P) satellite (Prunet et al., 2020; Kang et al., 2021a; Saw et al., 2021; Xia et al., 2021), has been operational since its launch in 2017. Daily information regarding atmospheric air quality has been recorded throughout this time. This study used information on the quantity of atmospheric gases of NO_2 and CO present in the atmosphere of the City of Passo Fundo.

The Sentinel-5 Precursor (S5P) mission is part of the European Union's Copernicus Earth program. The S5P floats low relative to land, at a height of 824 km. The Sentinel-5P TROPOMI contains four spectrometers with spectral bands in the ultraviolet (UV), visible (UVIS), near infrared (NIR) and shortwave infrared (SWIR) wavelengths, with CO and NO_2 recovery algorithms applied. Thus, registered researchers who are allowed access to the computerized system are capable of attributing detailed information on the concentration of atmospheric pollutants in certain regions of the globe. (Borsdorff et al., 2019; Magro et al., 2021). The application of TROPOMI consists of three steps, measured by a highly reliable Level-1b spectrum: 1) use of the DOAS method (Differential Optical Absorption Spectroscopy), which indicates the absolute density of NO_2 and CO in Level-1b, by radiance and irradiance spectra, applied to TROPOMI metric measurements; 2) disaggregate both NO_2 and CO into stratospheric (N strats) and a tropospheric zones (N trops), according to the ESA's computerized data assimilation information system basis; and 3) trigger the horizontal tropospheric column (N trops) and the tropospheric vertical factor column (N tropv). Later, apply the calculation with the average kernel color on the vertical distribution of NO_2 and CO in the TM5-model (Borsdorff et al., 2019; ESA, 2020; Prunet et al., 2020; Magro et al., 2021). The U. S. National Aeronautics and Space Administration (NASA) and ESA act as space agencies focused on innovation, by providing researchers with images collected by the Sentinel-5P TROPOMI satellite (the last satellite launched, capable of analyzing atmospheric contaminants).

This study used the bands from the Sentinel-5P TROPOMI satellite images for the analysis of NO_2 and CO, in which the NO_2 values represent the tropospheric column and the CO values represent the total atmospheric column (level 2) (ESA, 2020; Prunet et al., 2020; Kang et al., 2021a). Daily NO_2 and CO data were retrieved from the ESA, Sentinel-5P platform, which through the use of TROPOMI provided off-line measurements of NO_2 and CO with a spatial resolution of 7 km $\times$ 3.5 km and a spectral resolution in the range of 0.25–0.55 nm (ESA, 2020). The analysis of NO_2 and CO concentration was only possible in images in which the quality exceeded 50%, thus, monitoring was only possible in the months of January, May, August and November 2019. The images utilized were all taken at 12:00 p.m. (noon), the period of the most intense solar reflectance, where temperatures are higher in the City of Passo Fundo and Region (Maroni et al., 2021). The missing sample dates throughout the periods analyzed in 2019 consisted of images that did not present appropriate sequences for the analysis. This may be due to a layer of deep clouds or low concentrations of the pollutants sampled (Mendez-Espinosa et al., 2020). Sampling did not continue into 2020 due to the COVID-19 epidemic, which according to Mendez-Espinosa et al. (2020), caused an inaccuracy in the sample data in previous periods, as it considerably reduced the flow of vehicles and industrial activities in Latin America, as in many other parts of the world.

2.3. Procedures applied to environmental valuation of air quality

Environmental valuation consists of attributing monetary values to environmental goods (Brandli et al., 2014; Neckel et al., 2020; Moon et al., 2021). For environmental valuation, the Contingent Valuation Method (CVM) was applied in this study, allowing the sampled population to assign monetary values to a given environmental good, in this case, it is the valuation of air quality, through the survey respondents' WTP (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021). This environmental valuation study was conducted according to Brandli et al. (2014) and Neckel et al. (2020) for the development of open and closed questions, containing the following variables: age, gender, income, education, presence of children in the family, concern with air quality, knowledge of air quality, and the WTP for quality, clean air. Together with the questionnaire, a portfolio with seven scenarios built by 22 university professors (PhDs) with an emphasis in the area of urban planning in Brazil, was laid out according to Brandli et al. (2014) and Neckel et al. (2020). The opinions of these 22 interviewees aimed at building scenarios were based on the contamination results of the levels of NO_2 and CO provided by the Sentinel-5P TROPOMI satellite images.

Table 1
Concentrations of atmospheric contaminants of NO_2 and CO related to temperature, unit, wind speed and direction in the S5-P data collection region (January 2019). Source: Data collected from S5-P (ESA, 2020) and EMBRAPA (2021).

January 2019						
Day	NO_2	CO	Median Temperature	Relative Humidity	Average Wind Speed	Wind Direction
	Column mol/cm^2	Column mol/cm^2	°C	%	m/s	-
1	9.35e +15	1.39e +34	25.6	68	10.6	NE
2	9.88e +15	1.54e +34	26.6	69	10.8	NW
3	1.10e +16	1.45e +34	24.5	89	16.4	NW
4	9.95e +15	1.44e +34	20.8	86	6.8	SE
5	7.36e +15	-	23.7	80	8.6	NW
6	6.01e +15	1.60e +34	22.7	82	10.0	NW
7	5.81e +15	-	22.3	89	21.0	NW
8	1.73e +16	1.14e +34	22.3	79	15.1	NE
9	7.79e +15	1.40e +34	22.8	84	19.4	NW
10	-5.27e +15	-	22.5	92	18.2	NW
11	-2.70e +15	-	21.0	84	8.0	SE
12	7.10e +15	1.52e +34	22.2	82	10.5	SE
13	5.03e +13	-	22.7	84	10.6	NW
14	9.22e +15	-	22.8	87	11.3	SE
15	5.40e +15	-	23.4	81	16.4	NE
16	3.37e +15	-	23.8	88	19.1	SW
17	5.92e +15	1.36e +34	23.3	81	11.0	SW
18	8.27e +15	1.43e +34	22.1	87	12.4	NW
19	4.88e +15	1.22e +34	19.5	87	10.0	SE
20	3.84e +15	1.33e +34	19.5	89	10.0	SE
21	6.02e +15	1.33e +34	22.2	75	8.2	SW
22	4.68e +15	1.21e +33	24.4	66	6.0	SW
23	5.67e +15	1.12e +34	23.4	83	15.3	NW
24	5.90e +15	1.46e +34	23.3	76	13.2	NE
25	1.37e +16	1.42e +34	23.5	75	10.3	NE
26	7.69e +15	1.39e +34	24.5	68	8.9	NE
27	8.99e +15	1.42e +34	24.0	73	9.9	NE
28	1.00e +16	1.45e +34	24.6	70	10.4	NW
29	1.01e +16	1.55e +34	25.5	72	10.8	NW
30	1.50e +16	1.57e +34	26.7	69	8.1	SW

Table 2
Concentrations of atmospheric contaminants of NO_2 and CO related to temperature, unit, wind speed and direction in the S5-P data collection region (May 2019). Source: Data collected from S5-P (ESA, 2020) and EMBRAPA (2021).

May 2019						
Day	NO_2	CO	Median Temperature	Relative Humidity	Average Wind Speed	Wind Direction
	Column mol/cm^2	Column mol/cm^2	°C	%	m/s	-
1	5.61e +15	1.25e +33	16.8	85	2.4	SE
2	1.20e +15	1.18e +34	17.2	89	3.8	NE
3	1.00e +15	1.42e +34	20.4	85	6.1	NW
4	8.62e +15	-	22.6	78	2.3	VAR
5	5.48e +15	-	21.0	88	2.4	VAR
6	1.48e +16	1.31e +34	18.6	95	1.7	SW
7	5.46e +15	-	16.9	91	2.7	SE
8	1.95e +16	-	19.3	86	3.3	NE
9	8.83e +15	-	18.2	88	4.6	NE
10	7.35e +16	-	16.9	93	4.4	NE
11	-	-	17.3	96	3.0	SE
12	1.11e +16	1.23e +33	14.6	95	3.3	SE
13	8.77e +15	1.20e +34	15.1	94	4.4	VAR
14	5.56e +15	1.12e +34	12.5	92	3.7	SE
15	2.54e +15	1.07e +34	14.7	81	4.9	SE
16	6.75e +15	1.19e +33	15.1	71	3.9	NE
17	3.09e +15	1.27e +34	14.2	71	6.1	NE
18	7.99e +15	1.16e +33	16.9	77	5.6	NE
19	5.53e +15	1.25e +34	17.7	79	1.9	VAR
20	7.65e +15	-	17.6	78	3.2	NE
21	-	1.38e +34	16.2	94	2.5	E
22	2.08e +16	-	16.5	97	1.6	VAR
23	6.35e +15	-	15.0	92	1.6	VAR
24	3.34e +16	1.17e +34	13.0	93	3.5	VAR
25	2.10e +15	1.22e +34	11.4	88	2.3	SE
26	7.40e +15	-	13.9	80	3.8	NE
27	7.31e +15	1.20e +34	16.8	91	3.8	NE
28	9.11e +15	1.25e +33	17.6	92	2.1	NW
29	2.47e +15	1.29e +34	16.8	83	1.9	E
30	1.38e +16	-	16.8	97	1.1	C

Table 3
Concentrations of atmospheric contaminants of NO_2 and CO related to temperature, unit, wind speed and direction in the S5-P data collection region (August 2019). Source: Data collected from S5-P (ESA, 2020) and EMBRAPA (2021).

August 2019						
Day	**NO_2**	**CO**	**Median Temperature**	**Relative Humidity**	**Average Wind Speed**	**Wind Direction**
	Column mol/cm^2	Column mol/cm^2	°C	%	m/s	-
1	4.02e +15	1.36e +34	17.8	63	5.7	VAR
2	6.34e +14	1.15e +34	8.1	84	1.6	VAR
3	3.41e +15	1.35e +33	5.1	70	0.0	C
4	2.78e +15	1.57e +34	7.0	62	1.7	SE
5	2.59e +15	1.45e +34	10.1	62	5.0	VAR
6	1.17e +16	-	15.1	73	5.0	NE
7	-	1.79e +33	18.2	71	3.9	NE
8	1.59e +16	1.65e +33	19.2	68	5.0	VAR
9	1.94e +16	1.26e +34	19.2	72	2.2	VAR
10	7.87e +15	8.37e +32	11.3	83	2.2	W
11	1.11e +16	1.94e +33	13.6	71	3.1	VAR
12	1.99e +16	1.35e +34	16.7	86	2.0	VAR
13	6.38e +15	1.19e +32	8.6	75	3.5	SW
14	3.68e +15	1.23e +34	6.8	61	3.9	SE
15	9.81e +15	1.80e +33	12.5	56	4.4	NE
16	7.59e +15	1.71e +34	17.7	64	3.3	NE
17	6.56e +15	-	18.4	58	4.9	VAR
18	8.32e +15	1.34e +34	13.1	83	2.2	VAR
19	3.91e +15	1.29e +34	8.6	65	4.9	SE
20	3.56e +15	1.08e +34	10.5	77	2.9	SE
21	6.20e +15	1.16e +34	10.2	74	2.7	VAR
22	7.43e +15	-	13.2	75	3.6	NE
23	1.66e +15	1.36e +34	9.0	86	2.4	VAR
24	5.08e +15	1.15e +33	11.8	77	2.4	VAR
25	3.98e +15	1.96e +34	13.7	63	5.5	NE
26	8.64e +15	1.29e +34	15.1	66	2.7	NE
27	5.16e +15	1.75e +34	17.7	72	3.0	VAR
28	1.03e +16	1.72e +34	18.1	72	4.4	NE
29	5.69e +15	1.65e +33	20.3	55	2.7	NE
30	8.22e +15	-	21.5	54	4.3	VAR

Table 4
Concentrations of atmospheric contaminants of NO_2 and CO related to temperature, unit, wind speed and direction in the S5-P data collection region (November 2019). Source: Data collected from S5-P (ESA, 2020) and EMBRAPA (2021).

November 2019						
Day	**NO_2**	**CO**	**Median Temperature**	**Relative Humidity**	**Average Wind Speed**	**Wind Direction**
	Column mol/cm^2	Column mol/cm^2	°C	%	m/s	-
1	7.02e +15	1.75e +32	22.9	66	4.5	NE
2	-	-	23.0	74	3.4	VAR
3	-	-	20.7	84	2.2	VAR
4	5.46e +15	-	20.9	89	4.0	VAR
5	-	1.62e +34	19.2	85	3.4	SE
6	4.96e +15	-	21.3	64	2.7	NE
7	1.25e +16	1.63e +34	18.0	93	2.7	NE
8	7.50e +15	1.53e +33	21.1	77	3.9	NE
9	-	-	21.4	71	3.3	VAR
10	-	-	20.1	73	4.0	S
11	-	1.45e +34	21.4	66	6.1	SE
12	4.39e +15	-	21.9	63	4.4	VAR
13	8.27e +15	1.55e +33	19.6	78	4.4	NE
14	2.28e +15	-	20.0	85	1.3	SW
15	-	-	20.2	65	2.4	SE
16	-	-	18.4	55	2.3	VAR
17	-	1.38e +34	21.4	45	3.3	SE
18	4.79e +15	1.39e +34	23.1	45	2.7	VAR
19	8.21e +15	1.78e +34	23.9	51	3.0	VAR
20	-	1.64e +34	25.3	49	3.2	NE
21	1.17e +16	1.61e +34	25.5	52	2.8	N
22	5.87e +15	-	24.0	63	3.8	VAR
23	-	-	18.2	73	5.8	SE
24	-	1.50e +33	19.1	53	3.9	VAR
25	7.26e +15	-	21.6	47	2.7	NE
26		-	19.2	87	4.1	NE
27	3.46e +15	1.49e +34	18.7	90	2.8	SE
28	4.83e +15	1.35e +33	18.6	44	5.2	SE
29	6.06e +15	-	22.6	51	3.9	VAR
30	-	-	23.8	57	1.4	VAR

Table 5
Descriptive statistics of the results of quantitative NO_2 and CO.

January 2019		
Attributes	NO_2 column mol/cm^2	CO column mol/cm^2
Valid	28	22
Missing	2	8
Mean	7.88e +15	1.35e +34
Std. Deviation	3.63e +15	3.02e +33
Variance	1.32e +31	9.10e +66
Minimum	5.03e +13	1.22e +33
Maximum	1.74e +16	1.60e +34
May 2019		
Attributes	NO_2 column mol/cm^2	CO column mol/cm^2
Valid	28	19
Missing	2	11
Mean	1.09e +16	9.43e +33
Std. Deviation	1.40e +16	5.10e +33
Variance	1.97e +32	2.61e +67
Minimum	1.00e +15	1.17e +33
Maximum	7.35e +16	1.43e +34
August 2019		
Attributes	NO_2 column mol/cm^2	CO column mol/cm^2
Valid	29	26
Missing	1	4
Mean	7.30e +15	9.75e +33
Std. Deviation	4.80e +15	6.53e +33
Variance	2.30e +31	4.27e +67
Minimum	6.34e +14	1.19e +32
Maximum	1.99e +16	1.96e +34
November 2019		
Attributes	NO_2 column mol/cm^2	CO column mol/cm^2
Valid	16	13
Missing	14	17
Mean	6.55e +14	1.05e +34
Std. Deviation	2.75e +14	7.23e +33
Variance	7.56e +30	5.23e +67
Minimum	2.28e +15	1.76e +32
Maximum	1.26e +16	1.78e +34

The WTP opinion survey applied to the resident population of the City of Passo Fundo included a total of 514 questionnaires, displayed a margin of error of 4.32%, and a confidence level of 95%. Next, the data of the variables assigned by the respondents were compared in relation to WTP (Brandli et al., 2014; Neckel et al., 2020). The most significant variables were identified through the Linear Regression Model (LRM) (Barreto et al., 2021), empirically, related to the WTP of the respondents, to perform the performance of statistical tests of each of the 514 respondents, thus allowing a high reliability of the data analyzed using the LRM, aimed at evaluating the preference of respondents in relation to improvements in air quality, using the CVM (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021).

3. Results and discussion

3.1. *Atmospheric pollution from Sentinel-5P TROPOMI satellite images*

January 4th yielded the highest readings recorded that month for NO_2, with a value of 9.95e +15 Column mol/cm^2. This was recorded on a day with an average temperature of 20.8 °C (TM) and 86% relative humidity (Average RH). The wind speed was 6.8 m/s toward the southeast (SE). On January 30, an increase in CO of 1.60e +34 Column mol/cm^2 was identified on a day with an average temperature of 22.7 °C, 82% RH, average wind speed of 10.0 m/s toward the northwest (NW) (ESA, 2020; EMBRAPA, 2021) (Table 1).

On May 28, that month's highest atmospheric concentration of NO_2 was recorded with value of 9.11e +15 Column mol/cm^2. The average temperature that day was 17.6 °C, 92% RH, and winds of 2.1 m/s were recorded in the NW direction. The highest concentration of CO recorded for May occurred on May 3, with a reading of 1.42e +34 Column mol/cm^2. The average temperature that day was 20.4 °C, 85% RH, and a wind speed at 6.1 m/s in the NW direction (Table 2).

August's highest monthly concentration of NO^2 occurred on August 15, with a reading of 9.81e +15 Column mol/cm^2. The average temperature that day was 12.5 °C, 56% RH, and a wind speed of 4.4 m/s toward the northeast (NE). August's highest concentration of CO

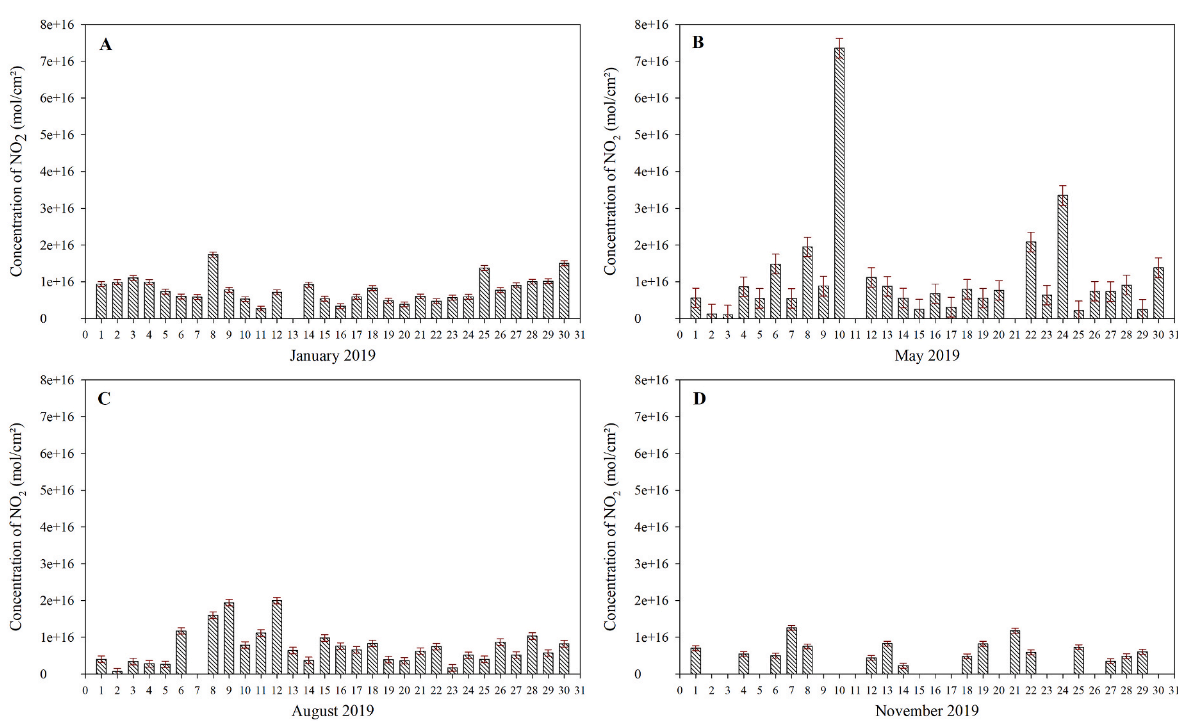

Fig. 2. NO_2 concentrations identified by Sentinel-5P TROPOMI images for the months of January (A), May (B), August (C) and November (D) 2019.

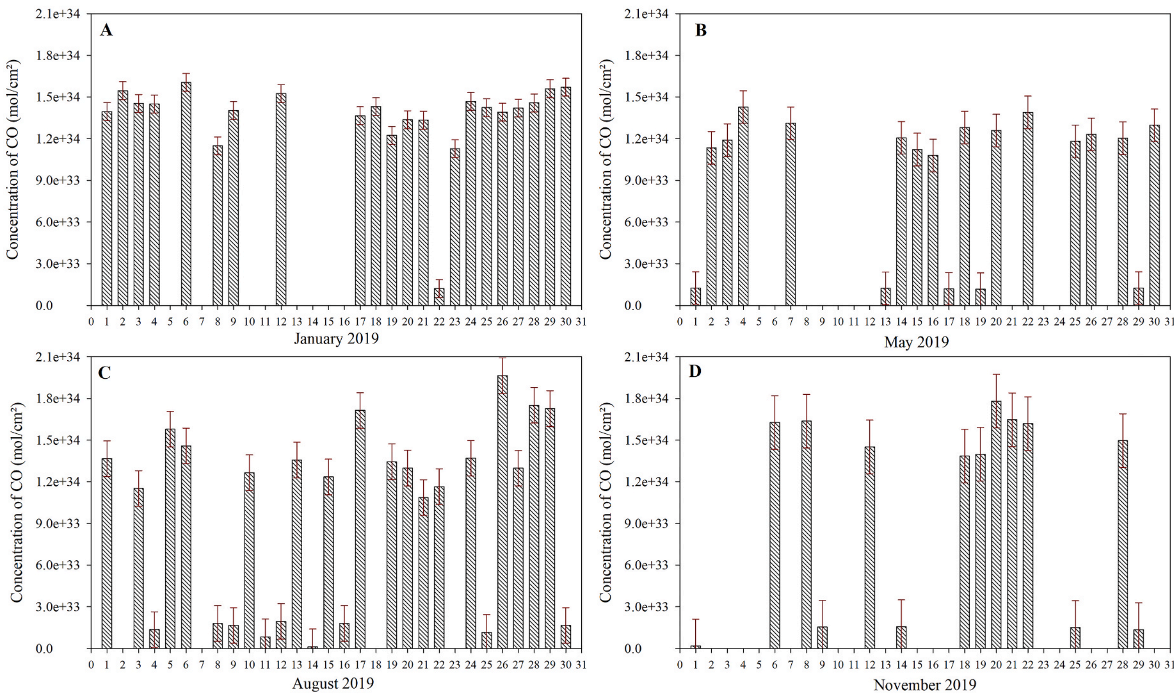

Fig. 3. CO concentrations identified by Sentinel-5P TROPOMI images for the months of January (A), May (B), August (C) and November (D) 2019.

occurred on August 10 at 8.37e +32 Column mol/cm^2. The average temperature that day was 11.3 °C, 83% RH, and wind speed of 2.2 m/s toward the west (W) (Table 3).

November's highest monthly concentration of NO_2 occurred on the 13th of that month, with a value of 8.27e +15 Column mol/cm^2. The average temperature that day was 19.6 °C, 78% RH, and a wind speed of 4.4 m/s in the NE direction (Table 4). It is interesting that the lowest overall values for atmospheric NO_2 concentrations for the analyzed period tend to occur when the predominant winds are to the southeast (SE) and southwest (SW) (Table 4). The highest monthly CO value was recorded on November 19, with a value of 1.78e +34 Column mol/cm^2. The average temperature that day was 23.9 °C, 51% RH, with variable wind direction and an average wind speed of 3.0 m/s (Table 4). Interestingly, it was observed that the lowest overall CO concentrations are associated with winds of variable direction (VAR). 2019 monthly average atmospheric concentrations of NO_2 (Column mol/cm^2) were as follows: January, 7.88e +15, May, 1.09e +16, August, 7.30e +15 and November, 6.54e +15 (Table 5). Monthly average atmospheric concentrations of CO (Column mol/cm^2) were as follows: January, 1.35e +34, May, 9.43e +33, August, 9.75e +33 and November, 1.05e +34 (Table 5).

The 2019 NO_2 results presented during the month of November showed a minimum value of 2.28e +14 and a maximum value of 1.26e +15, with a high standard deviation of 2.75e +14; demonstrating that the variation was significant (Maroni et al., 2021).

The time series data for NO_2 (Fig. 2 A, B, C and D) and CO (Fig. 3 A, B, C and D), showed daily variations in gas emissions during the months of January, May, August and November 2019. This is due to the displacement of air masses, which consequently also displace the atmospheric contaminants according to the intensity of the winds (Mendez-Espinosa et al., 2020). In relation to NO_2, greater variations in the daily results can be observed (Fig. 2 A, B, C and D). This is related to Hashim et al. (2021) the heterogeneous variations in the concentrations of pollutants, such as: NO_2, O_3, PM2.5 and PM10 that vary in relation to the flow of vehicles, which are responsible for the constant emissions of these gases into the atmosphere. The CO values reported display a similar trend (Fig. 3 A, B, C and D). Silva et al. (2021) highlight that CO emissions can often be constant, especially due to industrial operations which generally emit similar daily levels of gases to the atmosphere.

The observations in the Sentinel-5P TROPOMI satellite images allowed a satisfactory visual analysis of NO_2 (Figs. 4–7) and CO (Figs. 8–11), tropospheric levels that demonstrate a regional transport of pollutants affecting the City of Passo Fundo during the study period in 2019. The month of May yielded the highest overall period of maximum NO_2 recorded during 2019 (Fig. 5) in relation to the months of January (Fig. 4), August (Fig. 6) and November (Fig. 7). In addition to local air pollution as a consequence of mobile and stationary sources, the City of Passo Fundo received polluted air masses from two main areas that month, episodically. The first episode was related to the uncontrolled burning of biomass in the Amazon basin (northwest of the city), moving into the city through predominant winds (Pivello et al., 2021). Concentrated NO_2 and CO pollution is associated with the largest city in the State of Rio Grande do Sul, Porto Alegre. Porto Alegre has a well established industrial footprint in addition to a high number of vehicles, each of which constantly emit gaseous pollutants into the atmosphere (Schneider et al., 2020).

Conversely, the observations shown in Figs. 8–11, examining total CO, show only emissions from the east associated with maritime industrial activity. This, according to Oliveira et al. (2021) and Silva et al. (2021), comes from the ability of the atmosphere to transport gaseous contaminants to other regions, which contributes to the harmful risks posed to human health.

3.2. *Environmental valuation of air quality in Passo Fundo*

3.2.1. *Respondents profile*

The results of air pollution were made available to the 22 professors interviewed, trained to assign actions to improve air quality for the City of Passo Fundo and the region. Through these suggestions, improvement scenarios were built (Fig. 12). As 90% of those interviewed attributed the need for an Action Plan for the Prevention and Control of Air Pollution (Figs. 12 A), 82.5% attributed the need to create a Working Group for the construction and implementation of actions to improve air quality (Fig. 12 B). 80% suggest a sensible planting of tree species in areas with intense air movement (Figs. 12 C), 74% proposed a series of air pollution monitoring points (Fig. 12 D). 68% lent support for the

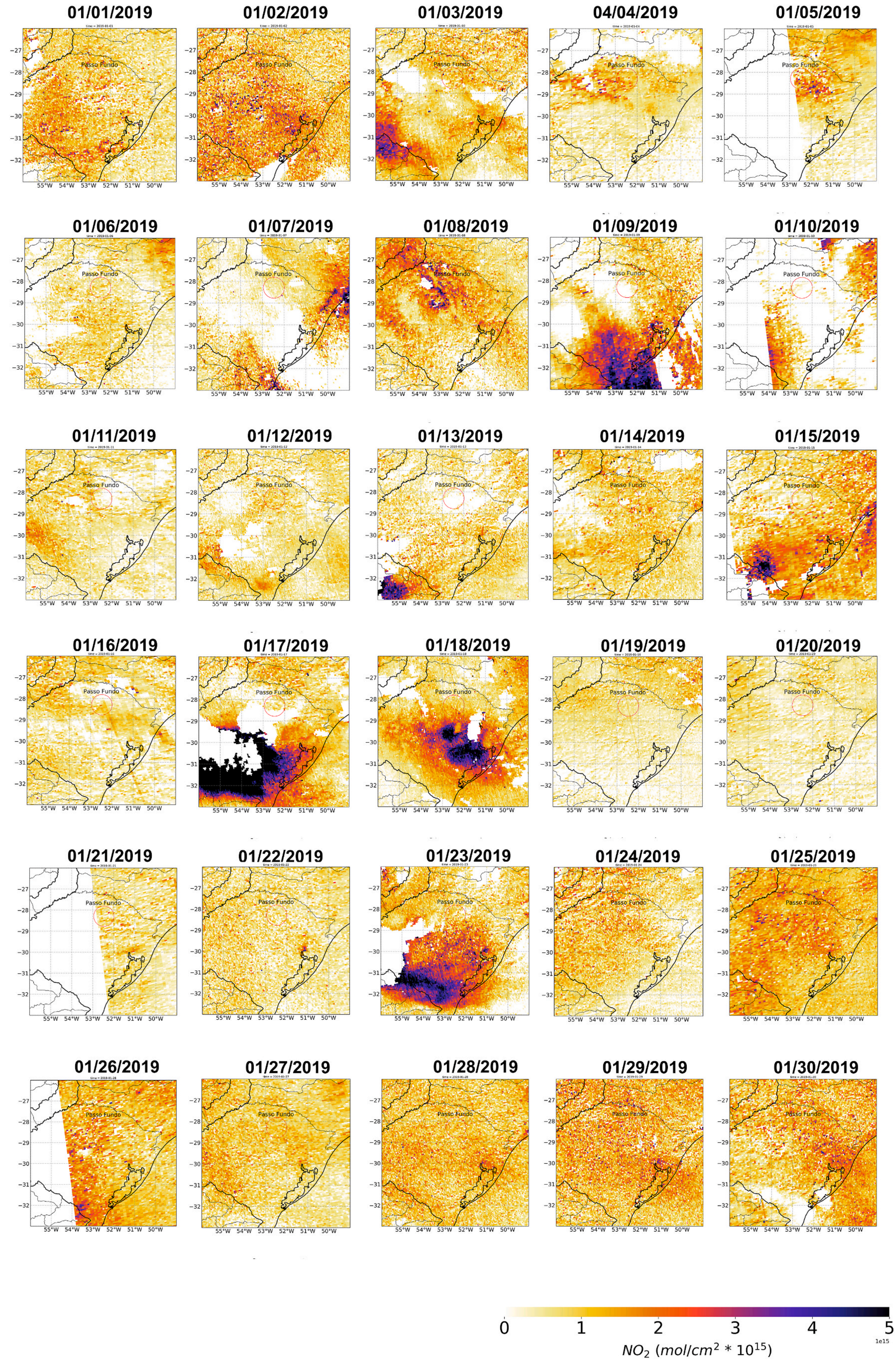

Fig. 4. Space-time variation of NO_2 changes (mol/m^2) sampled in January 2019, derived from the Sentinel-5P TROPOMI sensor.

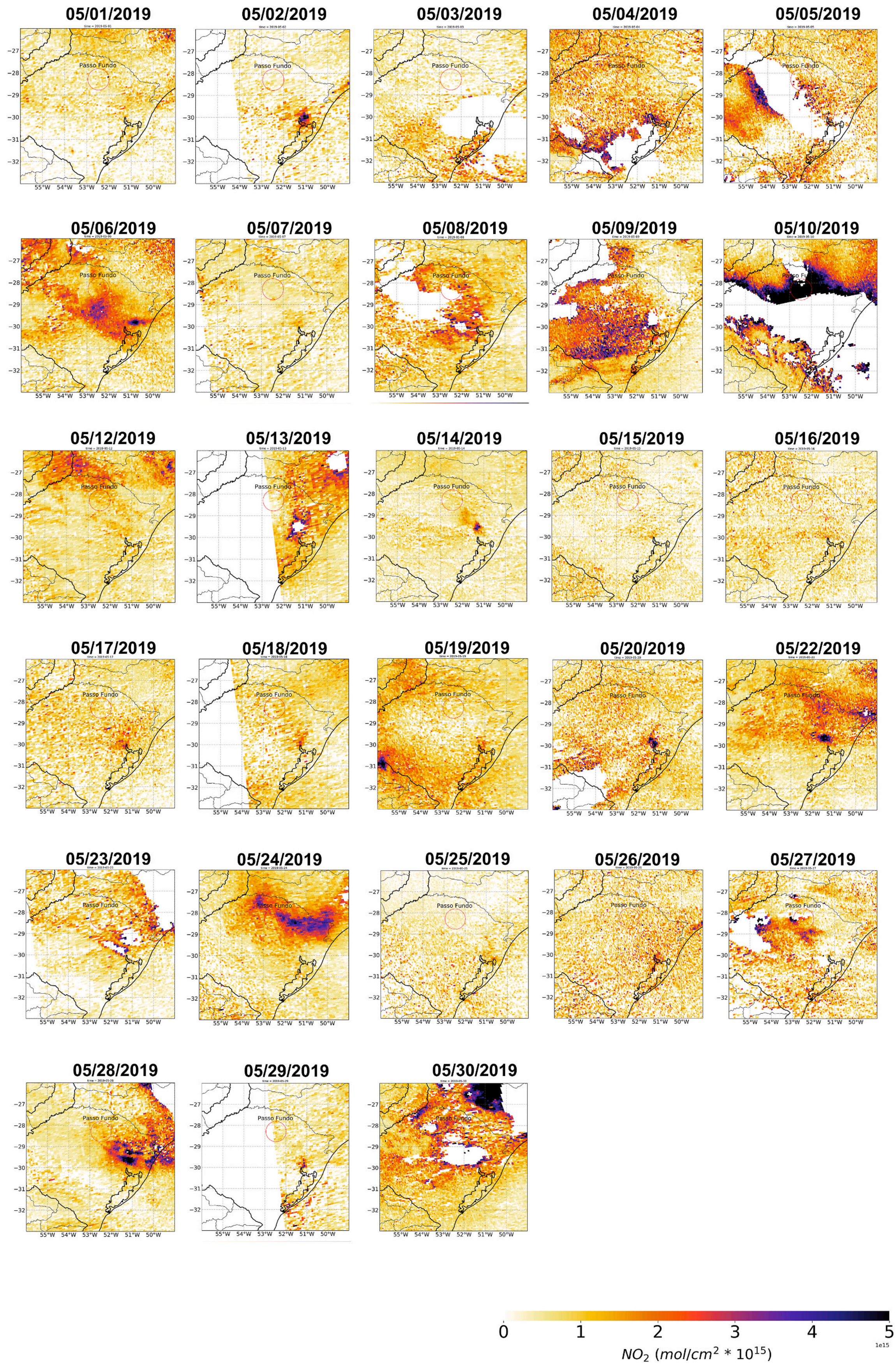

Fig. 5. Space-time variation of NO_2 changes (mol/m^2) sampled in May 2019, derived from the Sentinel-5P TROPOMI sensor.

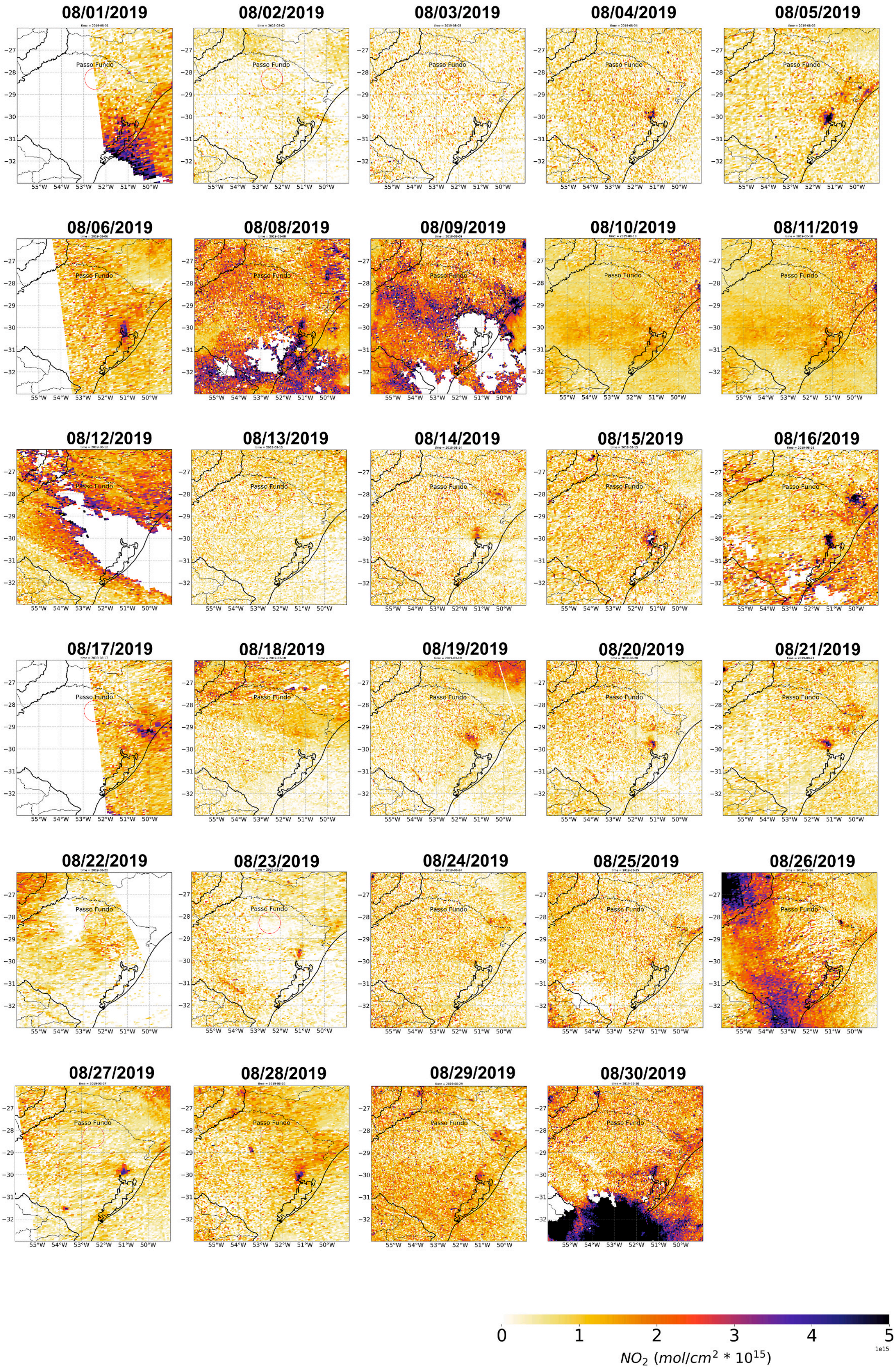

Fig. 6. Space-time variation of NO_2 changes (mol/m^2) sampled in August 2019, derived from the Sentinel-5P TROPOMI sensor.

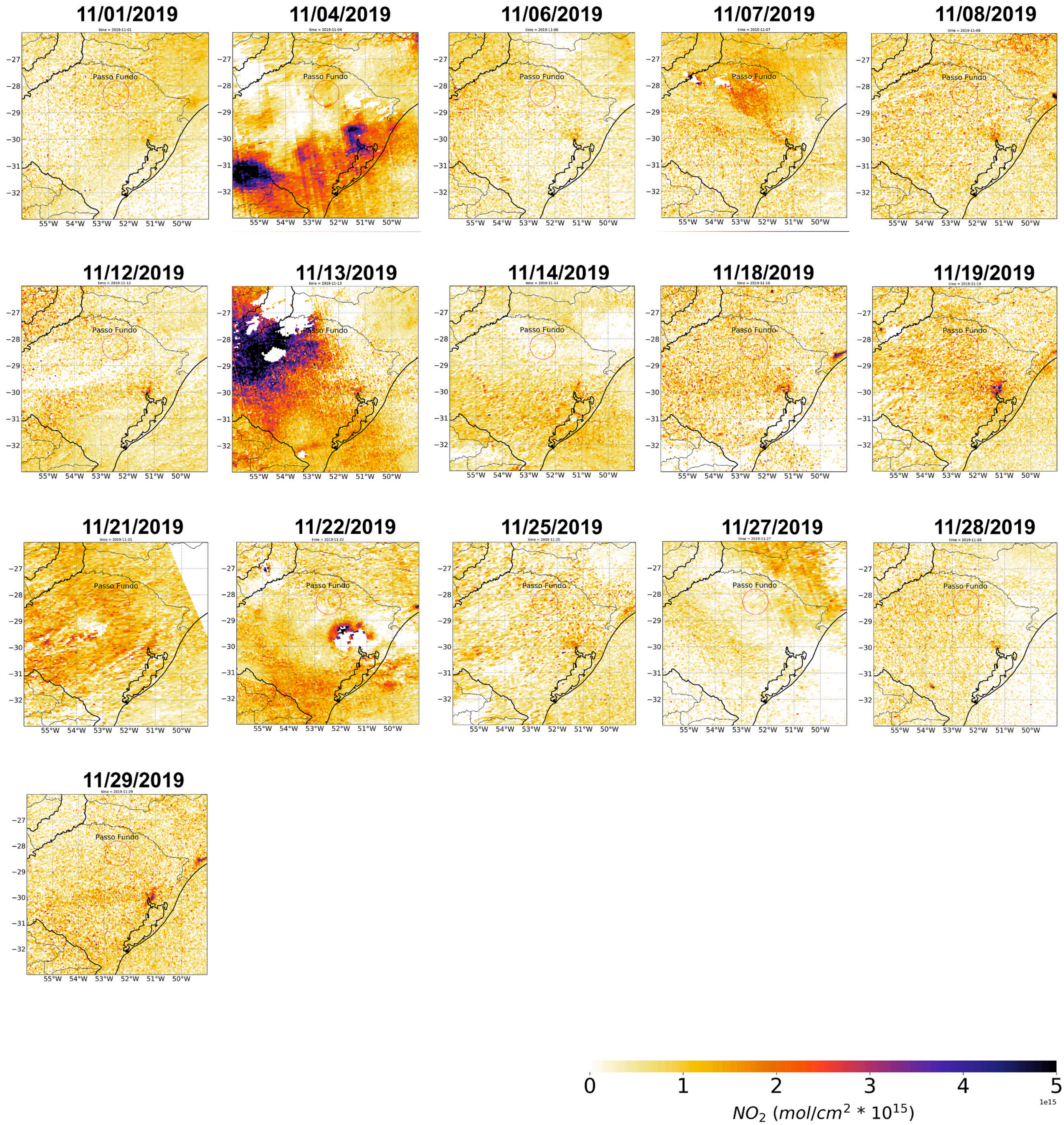

Fig. 7. Space-time variation of NO_2 changes (mol/m^2) sampled in November 2019, derived from the Sentinel-5P TROPOMI sensor.

construction of charging points for electric vehicles in order to change the current pollution scenario recorded in the Sentinel-5P TROPOMI satellite images (Fig. 12 E). 48.8% point to the need for inspection in industries, for filter checks to ensure the Brazilian Technical Standard - NBR 16,101 is complied with, which is determined specifically on air filters for suspended particles, and the standard makes determinations of the tolerated efficiency of coarse filters (Fig. 12 F). Finally, 32% suggest the carrying out of intense vehicular inspections, in compliance with Brazilian resolution, No. 490, of November 16, 2018, with requirements of the Air Pollution Control Program by Motor Vehicles - PROCONVE, in order to control and establish the control of emissions of polluting gases in motor vehicles (Fig. 12 G). For Brandli et al. (2014) and Neckel et al. (2020), the construction of scenarios, through technical perceptions, is of fundamental importance in valuation studies, as they make it possible to inform the population, in this case, about the compromise of air quality, by the gaseous elements of NO_2 and CO. It should be remembered that the monetary feasibility of the scenarios assigned for the environmental valuation is hypothetical, it consists only of a representative way for the population to attribute the WTP value (Brandli et al., 2014; Neckel et al., 2020).

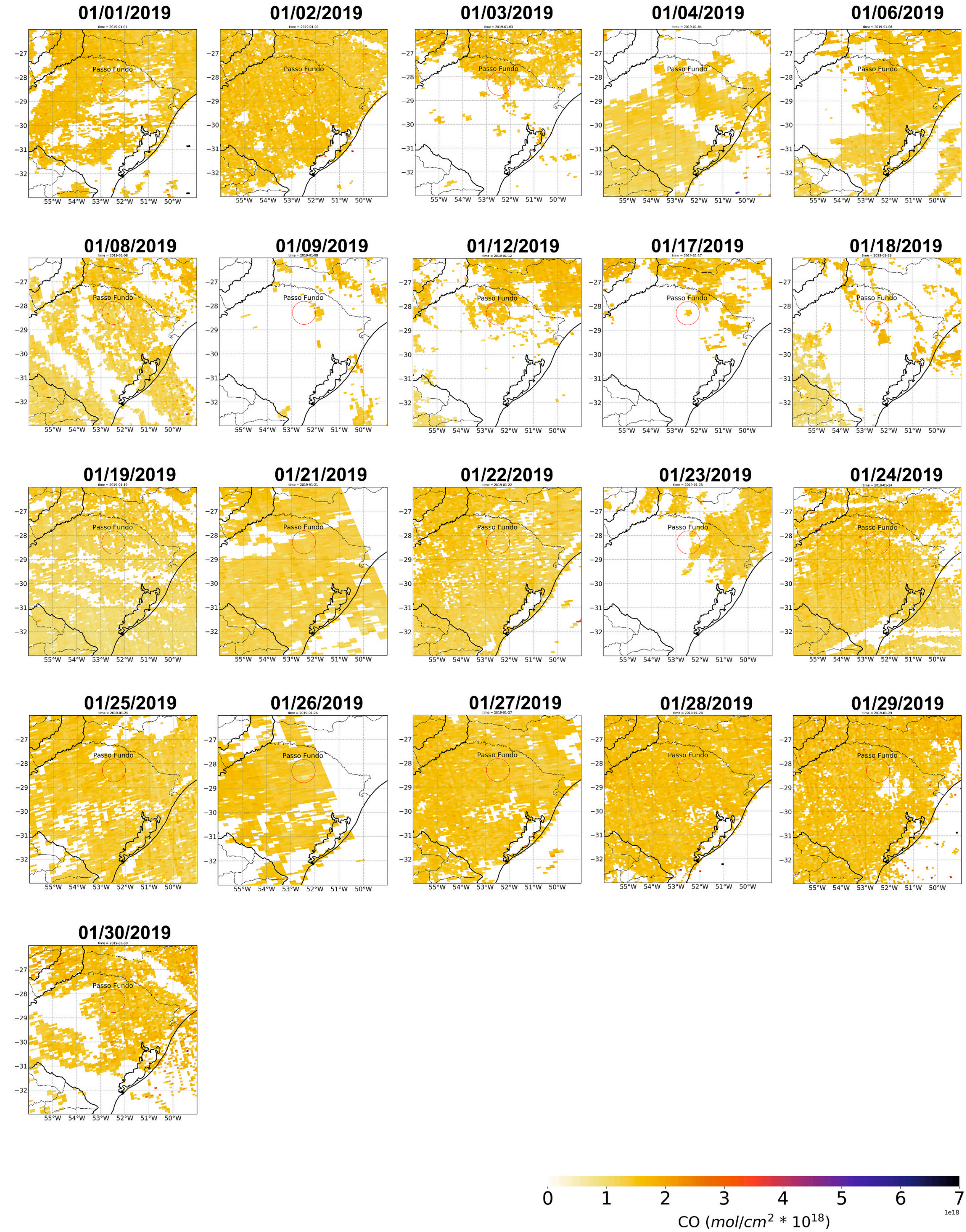

Fig. 8. Space-time variation of CO changes (mol/m^2) sampled in January 2019, derived from the Sentinel-5P TROPOMI sensor.

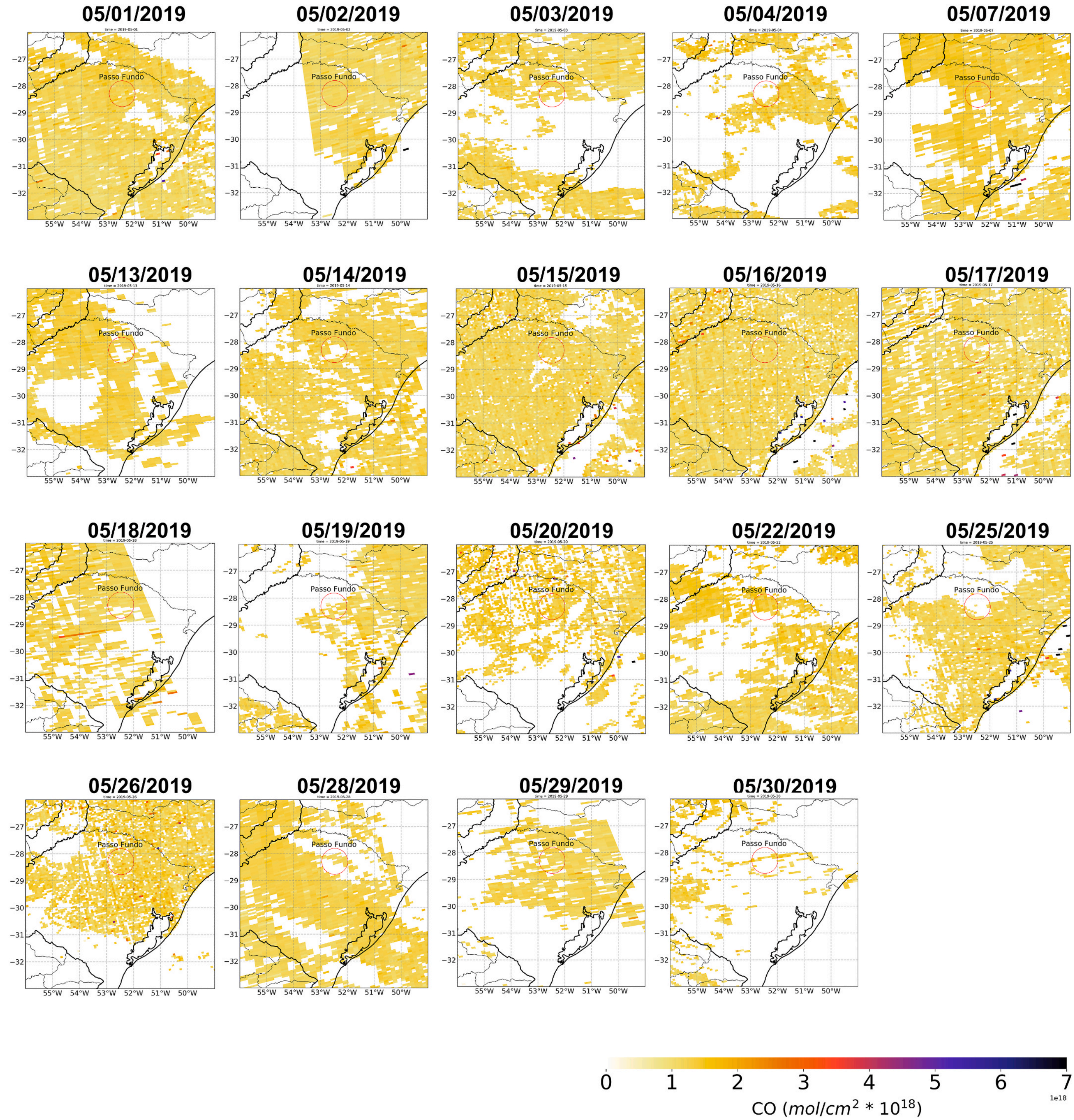

Fig. 9. Space-time variation of CO changes (mol/m^2) sampled in May 2019, derived from the Sentinel-5P TROPOMI sensor.

The opinion survey applied to the resident population of the City of Passo Fundo, on a total of 514 questionnaires, which corresponds to approximately 0.25% of the population, considered a margin of error of 4.32%, with a confidence level of 95% and standard deviation of 0.5. After applying the 514 questionnaires (100%) to the population residing in the City of Passo Fundo, it is clear that they attributed the considerable importance to air quality, which enhance the attribution of a higher WTP (Table 6). When comparing with other environmental valuation studies (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021), the importance value that the respondent attributes to the environmental good, tends to be repeated in the value of WTP, as it is the value of individual importance attributed by each respondent. In this relationship, 26.65% of interviewed individuals aged over 35 would pay more for air quality than other respondents. Regarding the interviewees' income, the 43.58% of individuals with the lowest income from 1 to 2 minimum wages (in Brazil the minimum wage is defined as a monthly wage as opposed to an hourly wage, R$1045 per month in 2021) would like to pay more to improve the air quality of Passo Fundo. Of the 33.66% of respondents who have completed high school but have not gone on for more schooling, they are the ones who would pay the most for the implementation of improvement scenarios (Fig. 12 A, B, C, D, E, F and G)

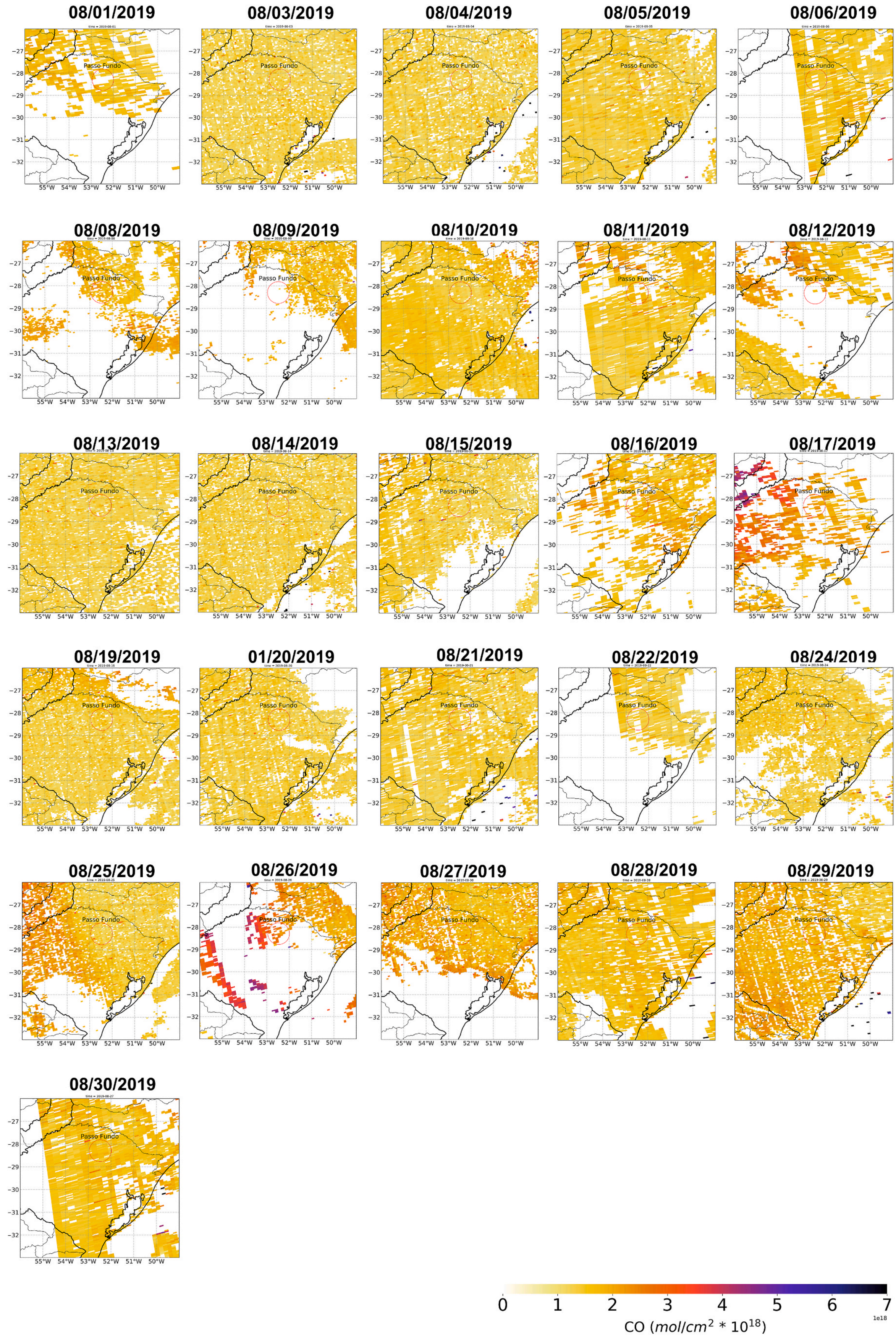

Fig. 10. Space-time variation of CO changes (mol/m^2) sampled in August 2019, derived from the Sentinel-5P TROPOMI sensor.

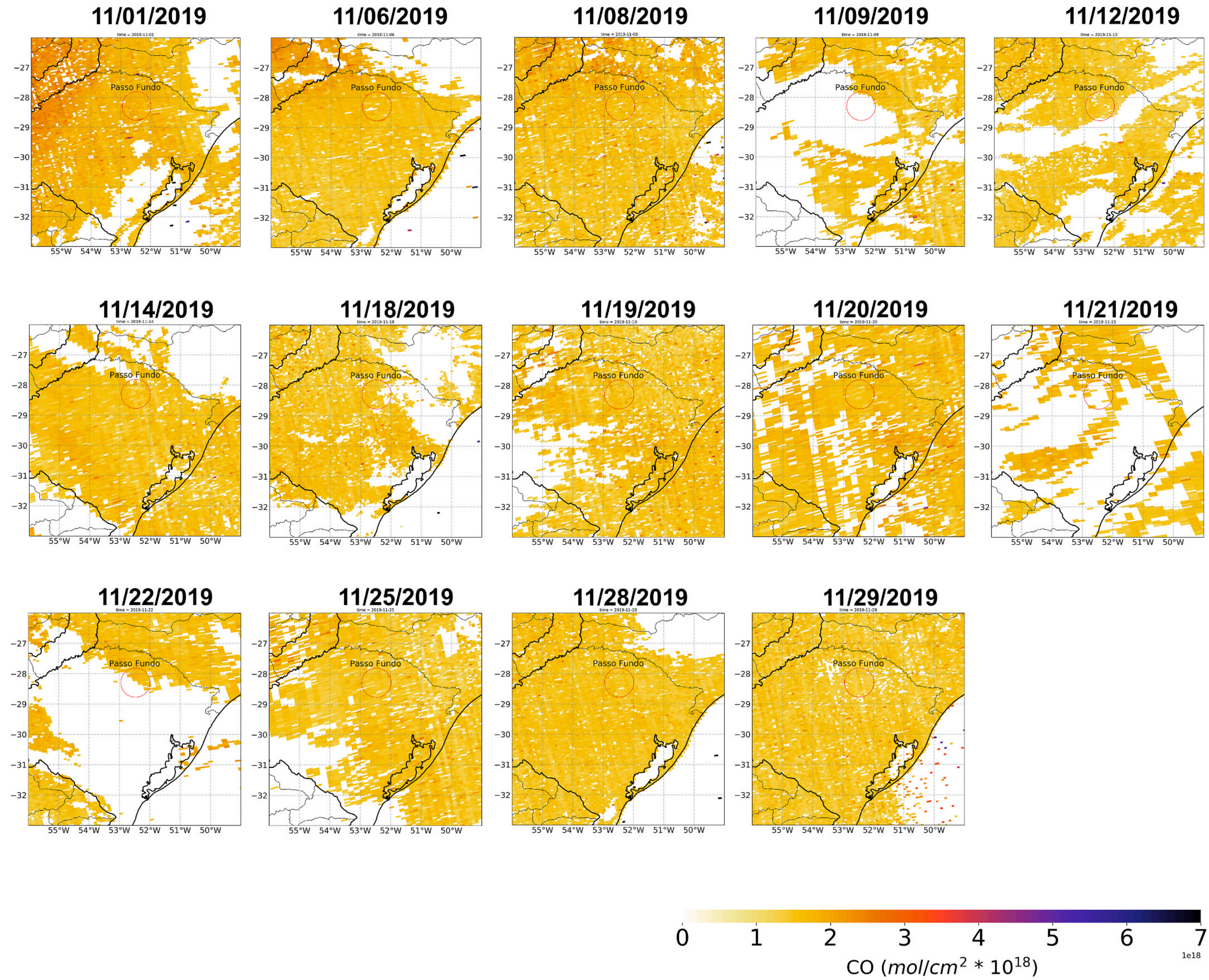

Fig. 11. Space-time variation of CO changes (mol/m^2) sampled in November 2019, derived from the Sentinel-5P TROPOMI sensor.

aimed at air quality (Table 6), these data, which were contrary to the results of Brandli et al. (2014) and Neckel et al. (2020), where individuals with the highest degree of schooling were the ones who attributed the highest values to environmental goods. These diversity of opinions are extremely understandable in valuation studies, the application of the CVM, when related to values of importance of the environmental good, vary based on the individuals who complete the questionnaire (Barreto et al., 2021; Perni et al., 2021).

3.2.2. Demographic profile of respondents in relation to WTP control

The WTP of respondents for higher air quality corresponded to 53.50% in the female audience and 46.50% in the male audience. This correlates with Brandli et al. (2014) and Neckel et al. (2020) who also found females more willing to pay in environmental valuation surveys. Another determining item for a greater attribution of values is the presence of children in the family. In this case, 68.87% of respondents have children, as opposed to 31.13% respondents who do not. However, 84.24% do not know about air quality and 15.76% have knowledge about air quality. For this, environmental valuation studies need to work with results (Figs. 4–11) with scenarios (Fig. 12) (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021), which prove the actual levels of contamination by NO_2 and CO during the sampled period. This technical information makes it possible to base the population on attributing WTP to the environmental good (Brandli et al., 2014; Neckel et al., 2020; Barreto et al., 2021; Perni et al., 2021). Thus, of the 514 respondents (100%), 73.93% would be willing to pay to obtain improvements in Passo Fundo's air quality, as opposed to 26.07% of the respondents who would not pay any amount. In this context, the importance value is attributed by the interviewees on a scale from 1 (least importance) to 10 (highest importance), symbolizing the importance that the respondents themselves attribute to air quality (Neckel et al., 2020). Importance levels 0 to 6 have no assigned WTP value, while 7 to 10 have an average WTP median value of R\$25.40, including several outliers that exceed R\$50.00 (Fig. 13). Neckel et al. (2020) contextualize the population's need to highlight the importance of the environmental good in relation to WTP, which increasingly justifies the values attributed during the opinion poll. In this case, air quality concentrated high values of importance in WTP among the 514 respondents.

When relating the age of respondents with the value of WTP, a high influence was identified between the results, which showed higher values in the two age groups, 28–35 years and 35 years or more, which increase the value of WTP (Fig. 14 (A)). As for income, it was possible to see (Fig. 14 (B)) a characteristic linear increase as the salary ranges of

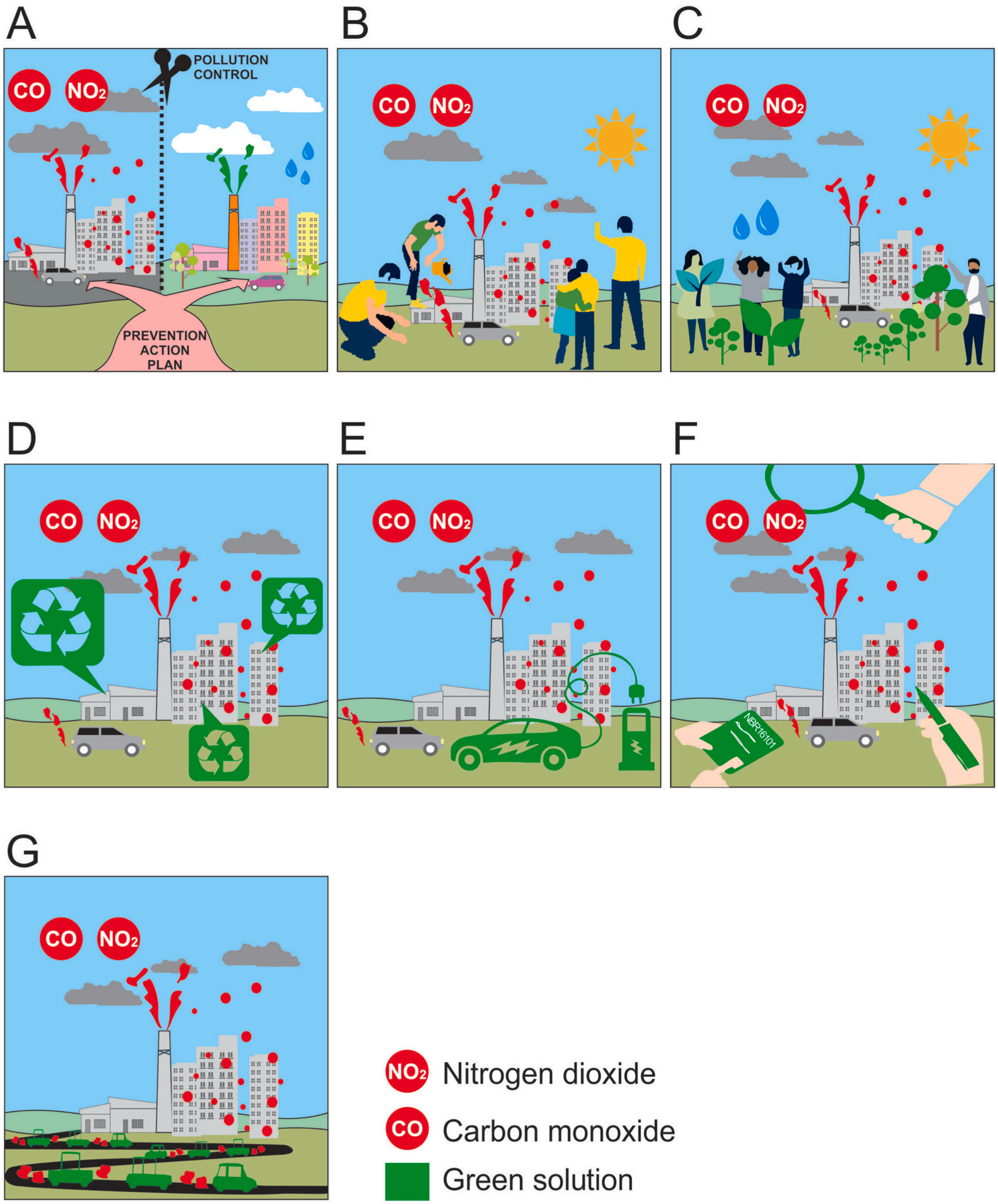

Fig. 12. Scenarios for achieving improvements in air quality: (A) Air Pollution Prevention and Control Action Plan, (B) work management group for the construction and implementation of air quality improvement actions, (C) sensitive planting of tree species in high flow areas, (D) definition of air quality monitoring points, (E) construction of electric vehicle charging points, (F) inspection in industries for filter checks, if it serves NBR 16101, (G) Carrying out intense vehicular inspections. Source: Perceptions attributed by the 22 professors interviewed.

respondents increase, with average values of R$8.72 for up to a single Brazilian monthly minimum wage and R$27.65 for more than four Brazilian monthly minimum wages. It is worth remembering that the Brazilian minimum wage in the year 2021 totals R$1045. In this relationship, the variable education of respondents showed a high statistical significance in relation to the results of the sample. According to Maroni et al. (2021), the statistical significance makes it possible to obtain greater reliability of the research results. The higher the level of education of the interviewees, the greater their WTP due to the benefits allocated to the air quality of the City of Passo Fundo. Thus, average WTP values of R$8.61 were reported for individuals whose highest education was complete primary education, R$22.43 for those who completed secondary education, and R$37.00 for those with an undergraduate college degree. For those who have graduate degrees the average WTP value of R$58.62 was obtained among the interviewees (Fig. 15). This follows a trend commonly expressed in environmental valuation studies, as the higher the level of education of respondents, the greater the WTP attributed to the preservation and restoration of the

Table 6
Variables resulting from the WTP survey.

Variables	WTP Total	WTP – Willingness to Pay (R$)						
		Mean	Standard Deviation	Minimum	1st Quartile	Median	3rd Quartile	Maximum
Importance of air quality								
(0 - 4)= 0	0	0	0	0	0	0	0	0
(5)= 0.19	0	0	0	0	0	0	0	0
(6)= 0.19	0	0	0	0	0	0	0	0
(7)= 1.56	235	29.375	21.278	5	10	25	50	60
(8)= 4.47	551	23.957	31.193	0	3.500	10	30	100
(9)= 9.53	808	16.490	23.601	0	0	6	20	100
(10)= 84.05	11419	26.433	41.143	0	0	10	40	300
100								
Age – 16-21	939	7.394	15.296	0.00	0	2	7.500	80
21-28	1261	10.965	16.282	0.00	0	5	11	60
28-35	3114	23.067	27.840	0.00	5	12	30	205
35+	7699	56.197	56.006	0.00	20	50	70	300
< 1 Minimum Salary	218	8.720	12.679	0	0	1	10	40
1-2 Minimum Salaries	4896	21.857	39.105	0	0	10	30	300
3-4 Minimum Salaries	5928	30.715	39.620	0	2	20	50	300
4+ Minimum Salaries	1963	27.648	41.954	0	0	10	45	205
Illiterate	8	2.667	3.771	0	0	0	4	8
Incomplete Primary Education	432	12.706	25.123	0	0	4	10	120
Complete Primary Education	508	8.610	13.673	0	0	5	10	60
Incomplete Secondary Education	2343	25.467	50.785	0	0	10	30	300
Complete Secondary Education	3880	22.428	29.018	0	0	10	30	200
Incomplete Undergraduate Degree	2400	32.432	36.793	0	3.500	20	50	200
Complete Undergraduate Degree	2035	37.000	43.124	0	10	20	50	200
Graduate Degree	1407	58.625	67.606	0	10	45	80	300
Male	4813	20.138	32.433	0	0	8	30	200
Female	8200	29.818	43.776	0	2.500	11	50	300
Has Children	9407	26.573	37.720	0	2	10	40	300
Has no children	3606	22.538	42.199	0	0	5	32.500	300
No knowledge about the air quality	12188	28.148	40.221	0	3	11	40	300
Knowledge about the air quality	825	10.185	28.952	0	0	0	5	200
Willing to pay	12993	34.192	42.152	1	10	20	50	300
Not willing to pay	20	0.149	1.721	0	0	0	0	20

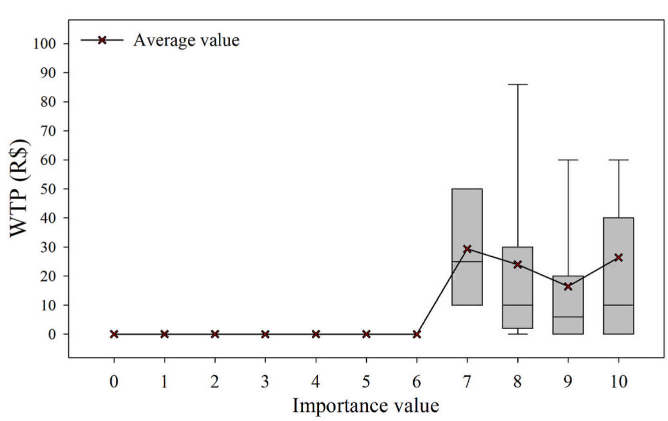

Fig. 13. WTP attributed by respondents in relation to the Importance Value (1–10) related to air quality.

environmental asset (Brandli et al., 2014; Xie and Zhao, 2018; Neckel et al., 2020; Wang et al., 2020; Moon et al., 2021).

An imbalance in valuation of the environmental asset was also evident when examining the gender of the respondents. Although there was a relative quantitative balance (45.53% men and 54.47% women) between them, it was noticed that women were more willing to pay for improvements in the air quality of the City of Passo Fundo, showing average attributed values of R$29.33. The average WTP value attributed to male respondents was R$20.13. Consequently, the preference between the WTP attributed in the environmental valuation studies conforms to a common pattern in such studies (Neckel et al., 2020). However, a factor that directly influences environmental valuation studies, according to Brandli et al. (2014) and Neckel et al. (2020), consists of the presence of children in the interviewee's family group. For, the results of these 514 questionnaires showed that in homes where there was the presence of children in the respondent's family, the WTP was higher. We observed average WTP values of R$26.57 in homes with children and R$22.53 in homes without children.

3.2.3. *Regression equation representation*

The applicability of the Regression Equation, for Barreto et al. (2021) and Nab et al. (2021), is extremely important to delimit the most significant variables attributed to the demographic information of the population of the analyzed sample. Through the results of this study, from the answers acquired by the 514 questionnaires, MS Excel was utilized for the generation of the empirical model, with the application of the linear regression equation, having the DBH as the dependent variable. As the methodology established by Brandli et al. (2014), Xie and Zhao (2018), Neckel et al. (2020), Wang et al. (2020), Barreto et al. (2021), Moon et al. (2021) and Nab et al. (2021) applied in this study, came to Equation (1), applied to the valuation of the air quality of the City of Passo Fundo, with population and control variables related to the DBH value (Table 7):

$$Y = c_0 + \sum_{i=1}^{n} c_i{}^{*}x_i \qquad (1)$$

Where:

- Y = dependent variable (–WTP - Willingness to Pay)
- c_0 = constant term;
- c_i = regression coefficients;
- x_i = independent variables (income, education, gender, etc.).

Resulting from Equation (1), the values adjusted in relation to the

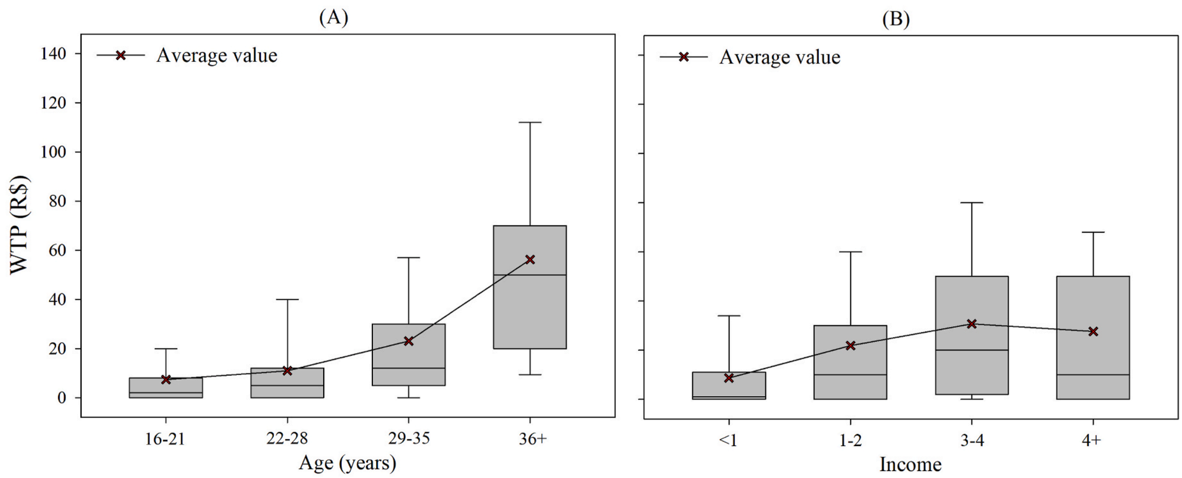

Fig. 14. List of WTP attributed by respondents in relation to Age (A); WTP ratio in monthly income of respondents.

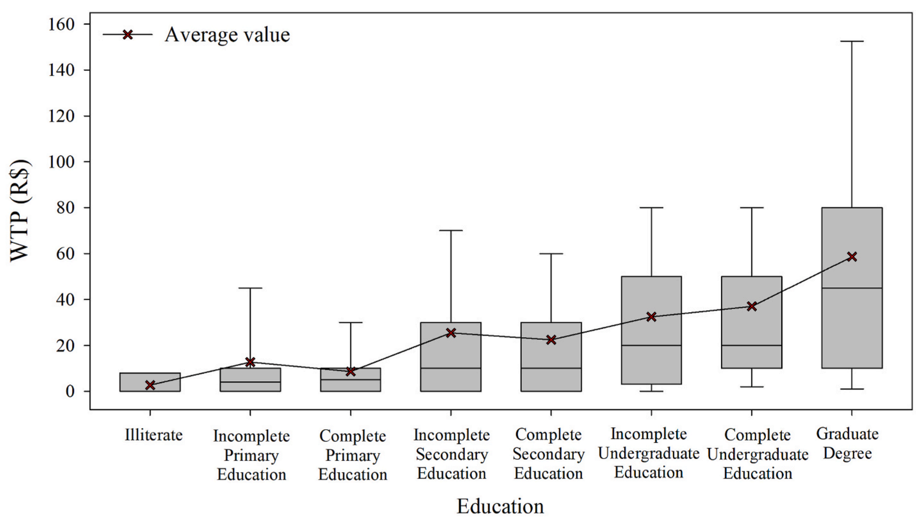

Fig. 15. Relationship between WTP and the level of education of respondents.

average DBH showed values of −9.8 + 9.7 for the Age of respondents (A), +3.02 for the level of education (E), −34.8 the knowledge of respondents about air quality (C) and −9.6 in relation to respondents would be willing to pay for the implementation of improvements in air quality in the City of Passo Fundo (P) (Table 8). It is worth remembering that the P-value for the variables with greater statistical objectivity, such as: intercept, act, know the air quality and would pay for the air quality, remained at a value < 0.05, thus demonstrating a greater reliability of the regression applied in this study (Barreto et al., 2021; Nab et al., 2021). The Adjusted R Square of the regression model was 0.34, with a significance level (P value) of <10%, not showing statistical values greater than 0.1, which increases the degree of reliability of the adopted regression model in this study (Table 9).

The Adjusted R Square of 0.34 (Table 9), related to other environmental valuation studies attributed to air quality, with the application of the CVM, enhances the segment of the linear regression statistical adjustment pattern related to other studies that valued quality atmospheric air, with the CVM, considering approaches to the respondent's households (Li and Hu, 2018; Wang et al., 2020; Basu and Srinivasan, 2021). In this relation, the studies by Li and Hu (2018) presented an Adjusted R Square of 0.08 when they carried out the valuation of the air quality of Jinchuan mining area in China. Wang et al. (2020) applied the environmental valuation of air quality in the cities of Guiyang (Adjusted R Square = 0.12) and Guiyang (Adjusted R Square = 0.20) in Xingtai in China, this linear regression fit values were very close in both cities, which enhanced a better balance of the regression equation. Basu and Srinivasan (2021) when carrying out their air quality valuation studies in the district of Allahabad, located in India, the Adjusted R Square of the linear regression equation was 0.34. These studies (Li and Hu, 2018; Wang et al., 2020; Basu and Srinivasan, 2021), confirm the proximity sequence between the linear regression pattern adopted in this study.

When applying the WTP values provided by the 514 respondents of this study to the entire population of the City of Passo Fundo, based on approximated educational attainment levels and age ranges, the total value of air quality valuation of 1,3013,000 reais was reached, which could be collected annually. The studies by Brandli et al. (2014) and Neckel et al. (2020), recommend the collection of monetary values generated with WTP through the creation of public collection policies, allocated to the Urban Property and Land Tax (IPTU) in Brazil. This study showed that 73.93% of respondents would be willing to pay for air quality improvements in the City of Passo Fundo, and 26.07% would not be willing to pay any monetary amount for air quality improvements. The fact that some individuals do not want to pay for air quality does not invalidate the study, when the vast majority of respondent's attribute value to WTP (Brandli et al., 2014; Neckel et al., 2020). In this sense, the average WTP value, attributed by the person responsible for the residential unit was R$25.32 and the median WTP value was 10 reais per household. Due to some WTP outlyers, the median WTP is R$10, divided

Table 7
Initial regression equation applied to sampled variables.

WTPmean = -36.43 + 2.54*IMP + 9.7*A – 1.2*I + 3.2*E + 1.26*G + 4.8*C-0.78*AT-34.8*CG-19.6*PG

Variable	Definition	Value
IMP	Importance	(0) to (10)
A	Age	(0) 16-21; (1) 21-28; (2) 28-35; (3) 35+
I	Income	(0) up to 1 min. salary; (1) 1-2 min. salaries; (2) 3-4 min. salaries; (3) 4+ min. salaries
E	Education	(0) Illiterate.; (1) Incomplete Primary Education; (2) Complete Primary Education; (3) Incomplete Secondary Education; (4) Complete Secondary Education; (5) Incomplete Undergraduate Degree; (6) Complete Undergraduate Degree; (7) Graduate Degree
G	Gender	(0) Male; (1) Female
C	Children	(0) Yes; (1) No
AT	Attendance	(0) Yes; (1) No
CG	Know the air quality of the City of Passo Fundo	(0) Yes; (1) No
PG	Would you be willing to pay to improve air quality in the City of Passo Fundo	(0) Yes; (1) No

Table 8
Adjusted air quality valuation regression equation.

WTPmean = -9.8 + 9.7 A +3.02 E – 34.8 C -19.6 P

Variable	Definition	Value
A	Age	(0) 16-21; (1) 21-28; (2) 28-35; (3) 35+
E	Education	Incomplete Secondary Education; (4) Complete Secondary Education; (5) Incomplete Undergraduate Degree; (6) Complete Undergraduate Degree; (7) Graduate Degree
C	Know the air quality of the City of Passo Fundo	(0) Yes; (1) No
P	Would you be willing to pay to improve air quality in the City of Passo Fundo	(1) Yes; (1) No

by 59,939 households (IBGE, 2021). Through the respective WTP values, it is estimated aggregate values of R$1,517,478.24 for the average WPD and R$599,390.00 for the median WTP.

When considering these values acquired at WTP, in this valuation study in favor of air quality improvements in the City of Passo Fundo, they can subsidize the financing of actions and projects aimed at implementing scenarios A, B, C, D, E, F and G (Fig. 12), making it possible to contribute to a better quality of health in the population, since the images from the Sentinel-5P TROPOMI satellite show the presence of NO_2 and CO in relation to the period analyzed. According to Omrani et al. (2020), Benchrif et al. (2021), Wang et al. (2021) and Zorzi et al. (2021) studies involving quality become of fundamental importance in order to stimulate the creation of public policies with concrete actions aimed at mitigating air pollutants, with the application of constant monitoring of NO_2 and CO on a global scale.

4. Conclusions

The analysis of images from the Sentinel-5 TROPOMI satellite, which is the most advanced technique for the detection of atmospheric pollutants on a global level, proved to be efficient in this study, as it helped in the detection of the concentration levels of NO_2 and CO in the atmosphere of the City of Passo Fundo at the following levels: NO_2 (value of 7.88e +15 Column mol/cm^2) and CO (value of 9.43e +33 Column mol/cm^2). It is suggested that these improvement actions could be applied globally in other studies that aim to mitigate the qualitative emissions of air pollutants, harmful to human health in other large cities or localities.

514 residents of the City of Passo Fundo were queried as to their WTP for clean air quality in the city. The resulting WTP values, when applied to the city as a whole, showed an average WTP value of R$1,517,478.24 and for the median WTP of R$599,390.00 when applied to all city households. It is suggested that these values be incorporated into public policies in the City of Passo Fundo, guaranteeing annual collection through the IPTU, in order to improve the quality of the air. It is assumed that the increase in cancerous diseases linked to the respiratory and pulmonary system of the population in the region of the City of Passo Fundo, may be directly linked to air pollution. It is recommended that the methodology utilized in this study be applied in other cities on a global scale, in order to justify annual taxation amounts (WTP) in order to mitigate air pollution, thus improving the quality of health of the world population.

CRediT authorship contribution statement

Brian William Bodah: Conceptualization, Funding acquisition. **Alcindo Neckel:** Conceptualization, Funding acquisition. **Laércio Stolfo Maculan:** Writing – review editing. **Celene B. Milanes:** Writing – review editing. **Cleiton Korcelski:** final manuscript writing. **Omar Ramírez:** final manuscript writing. **Juan F. Mendez-Espinosa:** final manuscript writing. **Eliane Thaines Bodah:** final manuscript writing.

Table 9
Air quality significance analysis, adjusted in the regression equation.

Var	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	9.856	22.496	0.438	**0.661**	-34.341	54.054
Importance	9.709	1.415	6.861	**<0.05**	6.929	12.490
Age	3.023	1.154	2.621	**<0.05**	0.757	5.290
Know the air quality of the City of Passo Fundo	-34.798	4.842	-7.186	**<0.05**	-44.311	-25.284
Would you be willing to pay to improve air quality in the City of Passo Fundo	-19.612	3.632	-5.400	**<0.05**	-26.748	-12.477
Adjusted Regression Equation						
Factor	**Df**		**SS**	**MS**	**F**	**Significance F**
Regression	9		277634.108	30848.234	30.322	<0.05
Residual	504		512743.201	1017.348	-	-
Total	513		790377.309	-	-	-
Regression Statistics						
Multiple R						0.593
R Square						0.351
Adjusted R Square						0.400
Standard Error						31.896
Observations						514

Marcos L.S. Oliveira: Writing – review editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131960.

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