Response to comments by referees #1 and #2 on the manuscript egusphere-2024-2348

We, the authors, thank the editor for handling the paper and the reviewers for their comments and suggestions. We value the careful feedback provided, and we believe this is important for improving the quality of our review paper. We provide a table with detailed responses to each separate comment. Since the last submission of the referees' reply, we have done minor edits, especially regarding English and referencing, and this document includes these edits.

Sincerely,

Renata Moura da Veiga (on behalf of all co-authors)

Reviewer 1	
Comment	**Authors' response**
The question that the authors use to guide their review process is the following: "How compiling published material on fire emission in natural areas of the Cerrado can provide a better understanding of the placement of these emissions in the atmospheric carbon budget?". This question is not mentioned again in the manuscript and it is left unanswered in the Discussion. Additionally, its formulation is not in line with the main goals of the manuscript.	We have now mentioned the question again, and have answered the question more directly, in the discussion section. The following new paragraphs are meant to complement the information that was already in the manuscript: "Our research question is "How compiling published material on fire emissions in areas of the Cerrado that do not explicitly include anthropogenic land uses can provide a better understanding of the placement of these emissions in the global carbon budget?". Analyzing published papers on fire emissions in these areas in the Cerrado provides valuable insights into its role in the carbon balance. This includes understanding the parameters used to estimate emissions, quantifying the amount of carbon, especially CO_2, released into the atmosphere by fires, and identifying important aspects of fire dynamics that are sources of uncertainty or are not considered in fire emission estimates. These are summarized in Table 3. Aiming at compiling literature on fire emissions in the Cerrado has led to several papers that do not explicitly estimate fire emissions

	themselves, but rather discuss fire dynamics and parameters used to estimate emissions. This indicates that there is a gap in the literature regarding fire emissions estimates in the Cerrado. However, studies have indicated that fires in the Cerrado play an important role in the global carbon balance. For example, Van Der Werf et al. (2017) found that savanna fire emissions from the Southern Hemisphere South America region, which includes the Cerrado, averaged 0.14 PgC $year^{-1}$ over 20 years, accounting for more than 6% of global fire emissions per year. Similarly, and from a national perspective, da Silva Junior et al. (2020) have shown Cerrado fires contribute more than 32% of the Brazilian total fire emissions (about 0.13 PgC $year^{-1}$ over the 20 years)."
For instance, the question refers to "natural areas of the Cerrado". If this were to mean areas of intact native vegetation, the authors would need to provide a keyword for this, as the vast majority of papers that are mentioned do not focus on natural areas, and are often estimates for the entire biome or specific land cover types.	Regarding the "natural areas" limitation - this means that we have excluded papers that explicitly include anthropogenic land uses. We have made this clearer in the research question and when explaining the inclusionary criteria: After establishing our research question as "How compiling published material on fire emissions in areas of the Cerrado that do not explicitly include anthropogenic land uses can provide a better understanding of the placement of these emissions in the global carbon budget?" We applied four inclusionary criteria to identify relevant literature: papers had to be (1) published in peer-reviewed journals with an impact factor greater than 1; (2) encompass the Cerrado biome; (3) be published after 2003, for a two-decade period (2003-2022); and (4) be conducted in areas that do not explicitly include anthropogenic land uses, here referred to as "natural areas". We define natural areas as those covered by natural vegetation of the Cerrado, where anthropogenic land uses do not occur (e.g.

	pasture and agriculture). According to this criteria, 48.66% (965,783 km^2) of the Cerrado is covered by natural vegetation (MapBiomas, 2022). Because papers found by this review often do not specify the land use of their study area, we have not included papers that explicitly document fire occurring in anthropized areas, as a proxy for documenting existing literature on natural areas of the Cerrado.”
I also believe that "global carbon budget" would be more appropriate than "atmospheric carbon budget".	We have replaced “atmospheric carbon budget" for "global carbon budget", including in the title.
This is a major concern, as the papers found through the PRISMA method are never listed. The authors refer to many papers throughout the text, but the reader does not know if these papers are those included in the literature review, or just part of a discussion. There is no list, even in Supplementary Material, of the papers, along with their respective topic (fire dynamics parameters, emission estimates, and fire management and policy) and study design (empirical, review, and perspective).	The 69 papers reviewed will be included as a table in the supplementary material. The columns included are: paper title, year of publication, authors, area of study, topic, methodological technique, study design.
Moreover, these classifications are explained in the Results section (e.g. lines 210-214) rather than in Methods. The authors also divide the papers according to study area (Global, Tropical region, South America, Brazil, Cerrado) which is never mentioned in Methods.	We have outlined what the study areas are in the Methods section: “We classified the reviewed papers based on (a) location range, from global to local scales: global, tropical region, South America, Brazil and Cerrado”.
There are many papers, especially in the "fire dynamics parameters" category, that do not evaluate emissions. Although burned area and fire intensity are parameters used to estimate emissions, discussing fire patterns and their climatic and human drivers should not be a main focus of this literature review.	The aim of our review is to provide a comprehensive view of the knowledge and gaps related to fire emissions in the Cerrado, specifically focusing on impacts on the carbon cycle. To clarify, while we emphasize emissions, we view fire dynamics (such as burned area and fire intensity) as essential parameters that

	support our understanding of emissions. They represent important "tools" in our framework, helping us interpret the conditions under which emissions are generated and their variability due to climatic, ecological, and human influences. Additionally, fire emissions data are often limited, and the literature reflects more studies on patterns and drivers, which provides useful background to identify gaps. • The influence of fire parameters in estimating fire emissions is also stated in the following paragraph (specifically in the bold sentence) in the Results section: "Of the 69 papers reviewed, 37 relate to fire dynamics parameters used to estimate emissions, 40 report the amounts of fire emissions, and 7 report fire management and policy - the total does not round up to 69 because 15 papers are related to more than one topic. **These numbers indicate that many papers are not related to reporting emissions but provide information to support the understanding and estimation of fire emissions, demonstrating a potential to expand the study of GHG emissions from fire in the Cerrado**. For example, Santos et al. (2021) use satellite imagery to estimate emissions and parameters, such as burned area and fire intensity, to support the application of prescribed burning in the Cerrado, but actual emissions estimates are not included." • Further, we have added the following sentences in the discussion and in the conclusion section to emphasize this point: "Aiming at compiling literature on fire emissions in the Cerrado has led to several papers that do not explicitly estimate fire emissions themselves, but rather discuss fire dynamics and parameters used to estimate emissions. This indicates that there is a gap

	in the literature regarding fire emissions estimates in the Cerrado." "This review demonstrates that papers fail to report on fire emissions themselves, with fire dynamics and parameters used to estimate emissions in the Cerrado often being the focus of published literature." Additionally, we have done major revisions to the "Fire dynamics parameters to estimate fire emissions" section. It now contains introductory paragraphs to make this point clear, and it is further divided into subsections: Burned area and fuel characteristics; Combustion efficiency, combustion completeness and emission factor; Fire behavior and intensity. The introductory paragraphs are: "Papers under 'fire dynamic parameters' encompass 44% of the studies reviewed, underscoring the importance of variables like burned area, fuel characteristics, combustion completeness, combustion efficiency and emission factor in fire emissions research. These parameters directly influence emission estimates, with their combination playing key roles in determining carbon emissions from fires. By examining these variables within the specific ecological and climatic context of the Cerrado, we gain insights into how fire behavior and emissions in this biome interact. The area burned, typically measured via satellite or ground surveys, is one of the primary parameters for estimating emissions (Libonati et al., 2015; Mangeon et al., 2016; Silva et al. 2021). Coupled with the available biomass for burning and its characteristics — which depend on vegetation type, density, moisture and seasonal growth patterns — these elements set the stage for potential emissions. Fire intensity, driven by conditions such as dry weather, strong winds, and fuel

	accumulation, influences combustion efficiency. High-intensity fires tend to consume more fuel, resulting in higher combustion efficiency and more complete combustion. This reduces emissions of pollutants such as carbon monoxide and particulate matter but increases emissions of carbon dioxide. In contrast, incomplete combustion results in higher emissions of pollutants such as particulate matter and carbon monoxide and produces pyrogenic carbon, which may persist in soils over long periods. Combustion completeness further influences the amount of biomass converted to carbon and released into the atmosphere. Together, these parameters allow for the estimation of emissions based on the combination of burned area, fuel load, and combustion completeness. The prevalence of studies on these fire dynamics parameters reflects both the accessibility of these variables and a gap in linking fire dynamics directly to emission. This focus on fire dynamics provides some of the most current information available, yet it suggests a need for more research to fill the gaps in understanding the chain from fire drivers to emissions. We further discuss the fire dynamics parameters found in the literature review process." • We have also updated aims a and b of the paper to make this clearer: "Thus, this systematic literature review synthesizes published material on fire emissions in areas of the Cerrado that do not explicitly include anthropogenic land uses, with aims to: (a) outline current emissions estimates, specifically CO_2, or fire dynamic factors that help support these estimates, in regions that encompass Cerrado or are limited to it; (b) understand how these estimates fit the carbon budget".

The authors also select burned area as the sole parameter to estimate fire emissions in Figure 5 (Section 3.1), to then explain how Fire Radiative Power (FRP) can also be used in the last paragraph of Section 3.2. This shows a lack of grasp of some of these concepts: for instance, the authors introduce FRP in Section 3.2 as if it was not the same parameter as "fire intensity" in Section 3.1; they also mention that "FRP considers (...) area affected by fire" and that it uses "MODIS active fires are inputs" which is, at best, vey badly worded.	• FRP was moved to the “Fire behavior and intensity” subsection. • Figure 5 was adjusted to include a combustion completeness box beside the burned area box, coming from fire behavior and seasonality. Both burned area and combustion completeness result in fire emissions. This figure is also in the “Fire behavior and intensity” subsection.
The Introduction fails to provide background to the importance of fire emissions in the Cerrado, both in the national and global context. The role of fire emissions in the global carbon cycle/budget should also be highlighted, along with the role of Brazil in the LULC emissions as the highest emitter (see the Global Carbon Budget 2023). Information on how carbon emissions are estimated worldwide should be included (e.g. what data and methods are usually employed), so that the reader can better understand results found in the literature review. Moreover, as a tropical savanna, the Introduction could also leverage on information from other tropical savannas worldwide.	Thank you for your comment. We have already provided extensive background on Cerrado's role in emissions nationally and globally in the Introduction, especially in the following paragraph: “From 1997-2016, savanna fires from Southern Hemisphere South America, which the Cerrado dominates, accounted for 6.36% of the global carbon from fires annually (Van Der Werf et al., 2017). This contribution is substantial, as it highlights the Cerrado’s role as one of the world's major fire-emitting ecosystems. To put this into perspective, savanna fires from the Australia and New Zealand region, which refer to the Australian savanna, account for 4.55% of the global carbon from fire emissions emitted each year for the same period (Van Der Werf et al., 2017). Compared with the Cerrado, a relatively high number of fire studies were performed in Australia. Da Veiga and Nikolakis (2022) counted 64 papers from Australia and 29 from Brazil when documenting the interaction between fire management and carbon programs worldwide.” However, we have added more detail in response to this point, including the number for LULC emission for comparison: “The Cerrado’s fires are potentially responsible

	for more than 30% (about 0.13 PgC $year^{-1}$) of Brazil's total fire emissions (da Silva Junior et al., 2020). As a comparison, the Cerrado accounts for about 14% of Brazil's emission from land use and land cover change (SEEG, 2023). Brazil is the highest emitter in the world in this category (Friedlingstein et al., 2023), contributing with up to 0.4 PgC $year^{-1}$ (Rosan et al., 2021). The Cerrado's role in Brazil's overall emissions profile is, therefore, critical, with fires contributing to a substantial share of the country's fire emissions, which has national implications for climate policies and international commitments (da Silva Junior et al., 2020; Pivello et al., 2021)." "Beyond immediate emissions, fire also influences carbon balance over time. For example, post-fire recovery critically shapes the Cerrado's long-term carbon balance (Burton et al. 2024; Gomes et al., 2020b; Hamilton et al., 2024). If vegetation fully regenerates to its pre-fire state, there is no net effect on atmospheric CO_2 levels over time. However, even in this scenario, fires can influence other greenhouse gases and aerosols. Alternatively, if fire activity decreases and vegetation accumulates, the landscape may shift to a net carbon sink. Conversely, if fires reduce long-term vegetation cover, the Cerrado could become a sustained carbon source, as observed globally (Burton et al., 2024)."
As mentioned previously, the Methods section is missing key information (e.g. that the analysis only considers papers up to 2022, or how the trend line in Figure 2 is estimated and its significance level), and in the Results section is hard to distinguish between description of papers found through the review process and discussion (e.g. lines 163-165, 272-278, 279-282, 330-333, 375-379, 396-398, 402-405, 441-460).	We have added more details in the Methods section to address the reviewer's suggestions: • Research question changed to: "How compiling published material on fire emissions in areas of the Cerrado that do not explicitly include anthropogenic land uses can provide a better understanding of the placement of these emissions in the global carbon budget?" • Inclusionary criteria updated: "We applied four inclusionary criteria to identify relevant

	literature: papers had to be (1) published in peer-reviewed journals with an impact factor greater than 1; (2) encompass the Cerrado biome; (3) be published after 2003, for a two-decade period (2003-2022); and (4) be conducted in areas that do not explicitly include anthropogenic land uses, here referred to as “natural areas”. We define natural areas as those covered by natural vegetation of the Cerrado, where anthropogenic land uses do not occur (e.g. pasture and agriculture). According to this criteria, 48.66% (965,783 km2) of the Cerrado is covered by natural vegetation (MapBiomas, 2022). Because papers found by this review often do not specify the land use of their study area, we have not included papers that explicitly document fire occurring in anthropized areas, as a proxy for documenting existing literature on natural areas of the Cerrado.” • Sentence added to explain the period of analysis: “We then conducted the search for a two-decade period, covering research from 2003 to 2022.” • Criteria for excluding papers updated: “The criteria led to the initial screening of 90 papers. Although we used keywords to conduct our review, the searches still returned papers not in English, or that did not mention fire emissions. 21 papers were excluded due to being duplicates, not in English, not mentioning fire emissions, or explicitly analyzing fire in anthropized lands.” • Classification of papers updated: “We classified the reviewed papers based on (a) location range, from global to local scales: global, tropical region, South America, Brazil and Cerrado” • We have also updated Figure 1 (the PRISMA diagram) to include the updates mentioned. • Trendline removed from Figure 2.

Lastly, the Discussion should include limitations on current methods and estimates, especially those found in the review process.	Substantial edits were also done to the Discussion section. It includes a Table, which was already in the text, with the parameters included in current studies and parameters to be considered for future fire emission estimates in the Cerrado, outlining limitations of current literature. To complement this Table, we have added paragraphs that discuss the limitations found while conducting this literature review. Examples are: “Analyzing published papers on fire emissions in these areas in the Cerrado provides valuable insights into its role in the carbon balance. This includes understanding the parameters used to estimate emissions, quantifying the amount of carbon, especially CO_2, released into the atmosphere by fires, and identifying important aspects of fire dynamics that are sources of uncertainty or are not considered in fire emission estimates. These are summarized in Table 3.” “Aiming at compiling literature on fire emissions in the Cerrado has led to several papers that do not explicitly estimate fire emissions themselves, but rather discuss fire dynamics and parameters used to estimate emissions. This indicates that there is a gap in the literature regarding fire emissions estimates in the Cerrado. However, studies have indicated that fires in the Cerrado play an important role in the global carbon balance. For example, Van Der Werf et al. (2017) found that savanna fire emissions from the Southern Hemisphere South America region, which includes the Cerrado, averaged 0.14 PgC $year^{-1}$ over 20 years, accounting for more than 6% of global fire emissions per year. Similarly, and from a national perspective, da Silva Junior et al. (2020) have shown Cerrado fires contribute more than 32% of the Brazilian total fire emissions (about 0.13 PgC $year^{-1}$ over the 20 years). Our review also indicates that published literature fails to analyze fire emissions from a

	holistic approach in the Cerrado. Including the perspectives of fire culture, ecology and policy within emissions is essential given the importance of fire to the biome. However, studies that discuss these aspects often do not discuss them from the emissions' perspective. Despite the difficulty in quantifying the social and cultural aspects of fire, the lack of inclusion of these in fire emission estimates could also be due to the shift towards recognizing fire as essential to the Cerrado being recent, especially when compared to other fire-prone settings. For example, the WALFA project in northern Australia became entirely active in 2005 (Russell-Smith et al., 2013), where traditional people, scientists and governmental institutions collaborate to reduce fire emissions through fire management activities (Russell-Smith et al., 2013). Meanwhile, the Pilot Integrated Fire Management project in the Cerrado started in 2014 (Schmidt et al., 2018)."
Most importantly, the authors fail to deliver on their main goal as it is not clear the importance of Cerrado's emissions to the global carbon budget. The authors also fail to conclude what is obvious for the reader: that there is barely any literature on fire emissions in the Cerrado, especially if comparing with other biomes worldwide.	Thank you. We have made clearer in the manuscript by answering the research question more directly, and by explicitly stating the lack of published material on fire emissions in the Cerrado. These can be found in the paragraphs added to the Discussion section, and in the sentence added to the Conclusion section: "Aiming at compiling literature on fire emissions in the Cerrado has led to several papers that do not explicitly estimate fire emissions themselves, but rather discuss fire dynamics and parameters used to estimate emissions. **This indicates that there is a gap in the literature regarding fire emissions estimates in the Cerrado.** However, studies have indicated that fires in the Cerrado play an important role in the global carbon balance. For example, Van Der Werf et al. (2017) found that savanna fire emissions from the Southern Hemisphere South America region, which includes the Cerrado, averaged 0.14 PgC

	year^{-1} over 20 years, accounting for more than 6% of global fire emissions per year. Similarly, and from a national perspective, da Silva Junior et al. (2020) have shown Cerrado fires contribute more than 32% of the Brazilian total fire emissions (about 0.13 PgC year^{-1} over the 20 years). Our review also indicates that published literature fails to analyze fire emissions from a holistic approach in the Cerrado. Including the perspectives of fire culture, ecology and policy within emissions is essential given the importance of fire to the biome. However, studies that discuss these aspects often do not discuss them from the emissions' perspective. Despite the difficulty in quantifying the social and cultural aspects of fire, the lack of inclusion of these in fire emission estimates could also be due to the shift towards recognizing fire as essential to the Cerrado being recent, especially when compared to other fire-prone settings. For example, the WALFA project in northern Australia became entirely active in 2005 (Russell-Smith et al., 2013), where traditional people, scientists and governmental institutions collaborate to reduce fire emissions through fire management activities (Russell-Smith et al., 2013). Meanwhile, the Pilot Integrated Fire Management project in the Cerrado started in 2014 (Schmidt et al., 2018)." "This review demonstrates that papers fail to report on fire emissions themselves, with fire dynamics and parameters used to estimate emissions in the Cerrado often being the focus of published literature."
They also do not discuss the mitigation potential for Brazil in LU emissions, and the impact and importance of such policy changes in keeping to the 1.5ºC goal (see Roe et al., 2019 in Nature Climate Change).	The purpose of this paper is not to discuss land use, but rather land management in the context of the potential of fire management in mitigating fire emissions in the Cerrado. With reference to fire management, we have added the impact and importance of fire policies in keeping to the 1.5ºC goal in the Discussion

	section: “Thus, this review indicates a critical need to develop interdisciplinary studies to bridge fire policies and fire emissions in the Cerrado. Understanding fire dynamics, including the opportunities for mitigating emissions from fire activities, is essential for recognizing fire's role in achieving global environmental and climate targets. For instance, Martin (2019) identifies United Nations Sustainable Development Goals that are related to fire and land management, as goals 3 (good health and well-being), 13 (climate action), and 15 (life on land). These impact the 2015 Paris Agreement target to limit warming to 1.5 °C by 2100. The Paris Agreement outlines commitments for climate actions and acknowledges the importance of mitigation and removal actions, where fire management can play an important role. The 1.5 °C target is ambitious, yet achievable if great effort is put into mitigating emissions and removing carbon, with Brazil holding the highest mitigation potential in the land sector (Roe et al., 2019). Together with other countries, improved forest management – which includes fire management – in Brazil could be able to increase carbon removal by 40 $GtCO_2$ by 2050 (Roe et al., 2019). Climate change increasingly affects fires, and adaptation and mitigation activities are essential to limit these effects (Burton et al., 2024). Direct human impacts may offset the effects of climate change in fire worldwide (Burton et al., 2024), especially in fire-prone environments, and this is an opportunity to investigate the potential of fire management to mitigate emissions in the Cerrado, and to understand fire emissions in the biome. Pathways towards improving fire emissions in the Cerrado include connecting observational information with modeling and a better assessment and quantification of the impact of qualitative aspects in fire estimates. Examples of how these can be achieved are by valuing prescribed burning emissions and including

	these in fire modeling, representing fire management in land surface models, using on-site observations to assess models' utility and as input data to modeling, and incorporating non-carbon aspects of fire in fire emission estimates, such as the ecological, social and cultural aspects. These could address uncertainty and improve models' accuracy, thus providing better accounting of fire emissions in the Cerrado and worldwide."
Line 441: I believe the authors are confusing emission factors with carbon emissions.	This sentence refers to the complexity in estimating fire emissions, reflected in the different values and units reported in Table 2. Emission factors are reported in Table 1, while table 2 summarizes fire emissions in the Cerrado found in the literature, which are estimated through different methods and thus result in different values.
Line 327: "low fuel moisture and low flammable biomass" if there is low fuel moisture, there should be high flammability. Please clarify.	Figure 4 was edited and this sentence was excluded from the legend.
Line 380: "GFED relies on the study done by (...) to quantify emissions worldwide" GFED doesn't rely on Van Der Werf et al. (2017). Its fourth version is described in that paper. Moreover, "small burned areas detection derived from MODIS" seems to entail that GFED did not rely on MODIS, which is incorrect. Please clarify how small burned areas were included in the GFED dataset (which also relies on active fire information).	Thank you. These were fixed in the text and replaced by "GFED quantifies fire emissions globally, and estimations are based on MODIS burned area products and on the Carnegie–Ames–Stanford Approach (CASA) model (Van Der Werf et al., 2017). Version 4s of GFED also includes small burned area detection to improve its results, and small burned area detection in GFED4s relies on MODIS burned area product, on active fire from MODIS, and on surface reflectance observations (Van Der Werf et al., 2017)."
Line 558-559: how are fire emissions a sink of CO2?	This was not phrased correctly and 'fire emissions' was replaced by 'fire dynamics'.
Standardize units throughout the manuscript (e.g. Pg year-1 or Pg per year)	The manuscript has been revised to standardize units to Pg $year^{-1}$.

Please write biome in lowercase.	Biome is now in lowercase throughout the manuscript.
Line 502: "we found" should be "Van Der Werf et al. (2017) found"	“We found” replaced by “Van der Werf et al. (2017) found”.
Authors' contribution is missing an author.	All authors were included in the sentence “All authors interpreted and analyzed data.” To make this clearer, the sentence is now replaced by “RMV, CvR, CB, DIK, MC and FM interpreted and analyzed data”.
Either "burnt area" or "burned area". Both are used in the manuscript.	“burnt area” replaced by “burned area” throughout the manuscript.
Figure 3 has 25 papers in the Cerrado, while the text mentions 26 (line 182).	The correct is 26 papers. This has been fixed in the new Figure 3.
Figure 3 and 4 could be merged into one.	Figures 3 and 4 were merged into the new Figure 3.
Figure captions need to be much more detailed.	Figure captions were improved as follows: • Figure 1: Adapted PRISMA flow diagram demonstrating the systematic literature review process divided into three steps: identification of potential papers through searched terms in the Google Scholar database, and exclusion of papers based on the four criteria established for this research; screening of the papers selected and exclusion of papers with the reported reasons; and inclusion of papers in this literature review. • Figure 2: Number of papers published per year from the 69 papers included in this literature review, from 2003 to 2022. • Figure 3: Number of papers per study design and per coverage of study area in both percentage (chart) and actual numbers (data table). • Figure 4 (new figure added in response to Reviewer 2 to include the institutions that lead the papers selected for this review):

	Institutions of the first authors from the papers reviews. The chart on the left indicates that 43 papers involve first authors from international (non-Brazilian) institutions, while 26 come from Brazilian institutions, of which 10 are within the Cerrado region. The chart on the right indicates that, from the international-led papers, 14 involve authors from Brazilian institutions, while 29 do not. • Figure 5: Variables associated with estimating fire emissions in the Cerrado found in the literature. The Cerrados's physiognomies, separated into forests, savannas and grasslands, increase in fine fuel load and decrease in fuel moisture from forests to grasslands. Microclimatic conditions also change across the physiognomies, with increasing wind speed and air temperature, and decreasing relative humidity from forests to grasslands. The Cerrado's seasonality is divided into wet and dry seasons. The wet season is characterized by high precipitation, lightning ignitions and accumulated biomass, whereas the dry season is characterized by low precipitation, anthropogenic ignitions and flammable biomass. Fuel characteristics (square boxes), climatic conditions (circle boxes) and ignition (hexagon boxes) interact (dashed lines) to determine the Cerrado's fire behavior. Two aspects of fire behavior are presented (numbers 1 and 2): 1) fire spread increases from forests to grasslands; 2) fire intensity increases in the dry season. The Cerrado's physiognomies, seasonality and fire behavior together drive the size of burned area, resulting in fire emissions (solid lines). High-intensity fires typically consume more fuel, leading to higher combustion efficiency and more complete combustion. Combustion completeness then affects the proportion of biomass converted into carbon and released into the atmosphere, also

	resulting in fire emissions (solid lines). The image representing the Cerrado's physiognomies was adapted from the Brazilian Agricultural Research Corporation (Embrapa, 2024). • Figure 6: Treemap of the methodological techniques used across study areas in empirical papers. The numbers represent the number of studies of each methodological technique within each study area. The study areas Global, Tropical region, South America and Brazil are regions that include results for the Cerrado. Some papers combine different techniques and are double-counted.
Line 489: dos Santos et al. (2021) found that fire management reduced LDS in 3 PAs of the Cerrado, not in "areas of the Cerrado", this should be clear.	This refers to the Schmidt et al. (2018) reference. The sentence was replaced by "Fire management has reduced LDS area burned by 40-57% in the three PAs encompassed in the Cerrado-Jalapão project during the first three years (2014-2016) of implementation (Schmidt et al., 2018)."
Reviewer 2	
Comment	**Authors' response**
The introduction provides a useful overview of the geographical, seasonal, vegetative, and emission characteristics of the Cerrado. However, it overlooks two crucial aspects: (1) The Cerrado's role in water resource availability in Brazil, as it is responsible for surface water in 8 of the 12 major Brazilian hydrographic regions, and how climate change and extreme fire events could impact the hydrological cycle. (2) The socio-biodiversity of the Cerrado, shaped by its peoples' socio-cultural relationships with nature, is highly relevant when considering the connection between ancestral knowledge and integrated fire management.	We have included two sentences in the introduction to contemplate these suggestions. However, we did not go too deep into these, to also contemplate the reviewer's 1 view of not focusing too much on fire dynamics. The sentences are: (1) "Drought-heatwaves episodes and extreme fire events intensified by climate change also impact hydrological processes, including precipitation and evaporation trends, groundwater recharge and soil infiltration capacity (Klink et al., 2020; Libonati et al., 2022). This is particularly important because the Cerrado region supports aquifers that supply major hydrographic basins in the whole

I believe these points would enhance the introduction.	country (Klink et al., 2020).” (2) “The cultural, socio-economic and ecological aspects of fire are crucial to execute and evaluate IFM activities (Myers, 2006). IFM integrates traditional knowledge and its connection with fire, and Australia is a leader in documenting these (da Veiga and Nikolakis, 2022). Measuring the social and cultural dimensions of fire presents significant challenges, and often is excluded from fire emission estimates in the Cerrado.”
In the introduction, you discuss how fire and climate regulate one another and can form a positive feedback loop. However, there is no mention of the interaction between droughts and heat waves, which amplifies fire risks. Recent research highlights the importance of understanding compound drought, heatwaves, and fires, which I consider essential to this work's context.	We have included the influence of compound events in fire activity in the Cerrado in the Introduction: “Fire participates in many complex interactions in the carbon cycle, from releasing carbon to benefiting ecosystems trajectories (Hamilton et al., 2024). Fire and climate regulate one another and can be in a positive feedback loop – climate and humans can influence fire patterns, and fire can influence climate by releasing carbon (Bowman et al., 2009). In the Cerrado, higher temperatures and reduced precipitation are now more common due to climate change, which also changes its fire regimes, with fire events becoming increasingly common (Gomes et al., 2020b; Hofmann et al., 2021). The IPCC AR6 WGI/WGII (IPCC, 2021, 2022) and the UNEP “Spreading like Wildfire'' report (UNEP, 2022) warn that climate change increases drought conditions, which can aggravate heatwaves, increasing the risk of fire occurrence and the intensity and frequency of extreme events, such as wildfires. This happens because the combination of extreme weather events that occur simultaneously, or compound events, can amplify their effects (dos Santos et al., 2024). For example, the year 2020 was marked by compound drought-heatwave episodes, which favored fire activity and the

	increase in burned area in the Cerrado (Libonati et al., 2022; dos Santos et al., 2024). Drought-heatwaves episodes and extreme fire events intensified by climate change also impact hydrological processes, including precipitation and evaporation trends, groundwater recharge and soil infiltration capacity (Klink et al., 2020; Libonati et al., 2022). This is particularly important because the Cerrado region supports aquifers that supply major hydrographic basins in the whole country (Klink et al., 2020)."
You classify the studies by location range, from global to local scales, indicating that the number of studies is higher for the Cerrado and global levels. I was curious about the spatial distribution of the institutions involved in these studies. Are they predominantly Brazilian or located in the Cerrado region? In other words, who is driving research on fire impacts in the Cerrado?	Thank you for this question, this is an interesting analysis. We have now included a paragraph to answer this in the Results section: • "We also observed that international (non-Brazilian) institutions drive most of the research captured by this literature review. We gathered the institution from the first author of each paper, of which 43 are international (62.3%) and 26 are Brazilian (37.7%). From the Brazilian-led papers, 10 (38.5%) are from institutions located within the Cerrado area. Also, 14 papers (32.6%) from the international-led studies involve authors from Brazilian institutions (Fig. 4), while half of the Brazilian-led studies (13 papers, 50%) include authors from international institutions. These numbers indicate that most studies in fire dynamics and emissions in the Cerrado are not led by institutions within the Cerrado region. In fact, most institutions are not even located within Brazil, with international institutions leading the studies and often not collaborating with Brazilian institutions." • We have also included a Pie of Pie chart (Figure 4) to demonstrate these numbers. Figure legend: "Institutions of the first authors from the papers reviewed. The chart on the left indicates that 43 papers involve first authors from international (non-

	Brazilian) institutions, while 26 come from Brazilian institutions, of which 10 are within the Cerrado region. The chart on the right indicates that, from the international-led papers, 14 involve authors from Brazilian institutions, while 29 do not." We have also added an analysis of the results in the Discussion section: "Additionally, we found that many of the papers covered in this systematic literature review is driven by non-Brazilian institutions and/or do not include authors associated with Brazilian institutions. Of all the papers included, only 10 involve first authors from institutions located within the Cerrado region. This indicates an opportunity to enhance collaboration between Brazilian and non-Brazilian institutions, and even a potential to increase partnership between different regions within Brazil."
The sharp drop in publications in 2022 is striking. Could this reflect a shift in focus toward another biome, such as the Pantanal? A simple analysis of publication trends in other biomes could provide insight. Also, might the pandemic have affected research outputs? While I understand this is not the article's focus, the significant drop warrants more than a brief mention.	We have expanded the discussion about the 2022 drop. Although we do think it could be related to the COVID-19 pandemic, we think this requires a deeper analysis that is out of the scope of this paper. A brief search revealed papers on fire dynamics and emissions in Pantanal and in the Amazon published in 2022. We then included the following paragraph in the Results section (Systematic Literature review process subsection): "There is an increasing tendency in the number of papers published throughout the time series, but the year 2022 did not follow the growth trend shown in Fig. 2. This sharp drop in publications could indicate a gap in publications this year or a limitation of our research method that could not capture publications in 2022. It could also indicate a shifted focus away from the Cerrado studies due to political or financial constraints to encourage scientific studies in the region, or

	due to a shifted focus towards other regions of Brazil. For example, papers about fire dynamics and emissions in the Pantanal and in the Amazon rainforest were published in 2022 (see Barbosa et al., 2022; Dutra et al., 2022; Menezes et al., 2022; Silva et al, 2022; Walker et al., 2022). Papers published in 2022 related to fire dynamics and emissions in the Pantanal and in the Amazon show fire as a consequence of the compound impact of land use and climate in these regions (Barbosa et al., 2022; Silva et al., 2022; Walker et al., 2022)."
Your findings show that 2020 was the most critical year in terms of burned area. Is there any information on what caused this increase? Could it be related to drought and exacerbated heat, or perhaps changes in government policy or legislation? This point deserves further discussion in the text.	2020 was a critical year in terms of burned area, but not the most critical one. We have included a paragraph in the results section, in the new subsection "Burned area and fuel characteristics", to explain the 2020 fires: "The year 2020 was a significant year in terms of burned area in the Cerrado due to a combination of factors (Pivello et al., 2021). 2020 was a drought year in the biome, intensified by prolonged dry season and heatwave (Hofmann et al., 2021; Libonati et al., 2022; dos Santos et al., 2024). This compound drought-heatwave episode aggravated fire activity in the Cerrado (Libonati et al., 2022; dos Santos et al., 2024). Although no estimates were found correlating the compound event of 2020 with fire emissions, it is expected that the drought-heatwave episode led to increased fire emissions due to the increased fire activity and burned area that occurred in that year. Also, 2020 was critical in terms of environmental policies and legislation in Brazil, which also reflected in the Cerrado (Schmidt and Eloy, 2020). The increase in deforestation, encouraged by political discourses, and the decline in environmental legislation enforcement created a favorable setting for fire occurrence in the Cerrado. The combination of climatic conditions and the intensification of an anti-environmental discourse by the Federal government favored

	the occurrence and spread of fires in the Cerrado in 2020, which was also observed in 2021, when INPE estimated 143,342 km^2 of burned area in the Cerrado."
You identify that only 8% of papers focused on fire management, and state that "this review captured no studies quantifying the amount of fire emissions mitigated by fire management in the Cerrado." This seems to contradict the statement that "three prominent topics identified were fire dynamics, emission estimates, and fire management". I believe adjusting the scientific question or the criteria for topic selection is necessary.	Thank you for your comment. Although 8% of papers are classified under 'fire management and policy', none of them discuss fire emissions itself within fire management and fire policy. For this reason, we discuss this topic in the sense of the influence of fire management and policy in estimating fire emissions in the Cerrado. We have made this clearer in the manuscript by editing the first paragraph of the 'The influence of fire management and policy in estimating fire emissions in the Cerrado', which now reads: "In synthesizing the literature on fire emission in the Cerrado, we identified 8% of papers focused on fire management and policy, all under the 'review' and 'perspective' categories. This indicates that fire management and policy are important in understanding fire dynamics in the Cerrado. Still, papers that address these do not usually bring new information based on observation or experiments but tend to synthesize or opine on existing literature. **For example, this review captured no studies quantifying the amount of fire emissions mitigated by fire management in the Cerrado, probably due to the difficulty in quantifying the social and cultural aspects of fire, which are intrinsic to fire management and policy.** Estimating the influence of humans on fire emissions is a complex task, which is also reflected in the lack of equations and algorithms to reproduce fire management strategies in land surface models. That makes sense, given all factors that need to be considered beyond quantifying the amount of GHG emitted to the atmosphere."

Additionally, while there may be no studies on integrated fire management reducing emissions in Brazil, may research outside Brazil, such as in Australia have shown this potential? Expanding this discussion would add valuable global context.	In the 'The influence of fire management and policy in estimating fire emissions in the Cerrado' section, we have expanded the discussion on the potential of fire management, especially EDS burns, in reducing emissions in other savanna countries. For this, we have included the following paragraph: "Dos Santos et al. (2021) have shown that LDS burns have higher combustion factor, heat released, and fire intensity when compared to EDS burns. Fire management has reduced LDS area burned by 40-57% in the three PAs encompassed in the *Cerrado-Jalapão* project during the first three years (2014-2016) of implementation (Schmidt et al., 2018). In the Canastra National Park in Brazil, areas under fire management also presented less annual area burned (Batista et al., 2018). These reaffirm the potential of management activities to reduce emissions, as shown in other savanna countries. In northern Australia, more specifically in the WALFA (West Arnhem Land Fire Abatement) area, a region recognized as a reference for integrating fire studies with traditional knowledge, EDS burns emit 48% of what is emitted in the LDS (Russell-Smith et al., 2009). The WALFA project applies EDS burns to reduce LDS burns, and during its first 7 years of implementation, GHG emissions have reduced more than 37% when compared to the pre-project 10-year emissions baseline (Russell-Smith et al., 2013). Similarly, Khatun, Corbera, and Ball (2017) suggest that, in the Tanzanian miombo, EDS burns could avoid carbon emissions and enhance carbon uptake by approximately 10 tC ha^{-1} in a 20-year period. Studies in Mozambique and Botswana explore the potential of EDS burns to reduce emissions in southern African savannas (Russell-Smith et al., 2021)."
The discussion on combustion efficiency values seems underdeveloped. Is 0.94	The MCE values are considered high and are consistent with the MCE found for other

considered high or low? Is it normal or anomalous?	savannahs in the world. We have made this clear in the following sentences added to the manuscript, in the subsection “Combustion efficiency, combustion completeness and emission factor” within the “Fire dynamics parameters to estimate fire emissions” section: “Values above 0.9 tend to characterize fires in a flaming stage, and these are predominant in the Cerrado due to the dry fine fuel that are likely to rapidly burn (Hodgson et al., 2018).” “These values are considered high and are consistent with other savannas in the world – MCE in the African and in the Australian savannas have been reported as 0.938±0.019 and 0.86–0.99, respectively (Hodgson et al., 2018).”
More CO_2 or CO affects the atmospheric carbon budget in different ways, and it would be useful to discuss air pollution and atmospheric chemistry versus greenhouse gas effects, as well as comparisons with other biomes in Brazil or other savannas globally.	We have expanded the impacts of CO and CO_2 on the atmosphere in the Introduction: “During biomass burning, a large amount of carbon gases is released into the atmosphere. These emissions are mainly in the form of carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) – CO_2 and CO combined account for 95% of the carbon emitted during biomass burning (Ward and Hardy, 1991). CO_2 and CO are both involved in atmospheric chemistry and the greenhouse effect in different ways. CO is recognized as a major indirect greenhouse gas, meaning that it does not absorb enough terrestrial infrared radiation to be considered a direct greenhouse gas, but it influences the concentration of other direct greenhouse gases, such as CH_4 and tropospheric ozone, through atmospheric chemistry (Ehhalt et al., 2001). Savanna burning dominates the emission of CO through incomplete combustion due to limited oxygen (Ehhalt et al., 2001). Similarly, CO_2 is released during complete combustion of biomass burning (Prentice et al., 2001). CO_2 is a major greenhouse gas, and it is crucial in

	absorbing and trapping infrared radiation in the atmosphere, causing the greenhouse effect. However, the increased concentration of CO_2 in the atmosphere has intensified the greenhouse effect and warmed the Earth in alarming amounts. Thus, understanding the emission of CO and CO_2 during the combustion process is important to recognize the impact of these gases in fire emissions, especially in fire-prone settings like the Cerrado. Due to their importance, the studies captured by this review often report emissions in terms of carbon released by fire, including all the carbon components emitted during biomass burning, or in terms of CO_2 alone, due to its impact on the greenhouse effect." Additionally, we have provided more details in the complete x incomplete combustion in the new subsection "Combustion efficiency, combustion completeness and emission factor" within the "Fire dynamics parameters to estimate fire emissions" section. These are also reflected in changes in Figure 5. "The area burned, typically measured via satellite or ground surveys, is one of the primary parameters for estimating emissions (Libonati et al., 2015; Mangeon et al., 2016; Silva et al. 2021). Coupled with the available biomass for burning and its characteristics — which depend on vegetation type, density, moisture and seasonal growth patterns — these elements set the stage for potential emissions. Fire intensity, driven by conditions such as dry weather, strong winds, and fuel accumulation, influences combustion efficiency. High-intensity fires tend to consume more fuel, resulting in higher combustion efficiency and more complete combustion. This reduces emissions of pollutants such as carbon monoxide and particulate matter but increases emissions of carbon dioxide. In contrast, incomplete combustion results in higher emissions of pollutants such as particulate matter and carbon monoxide and

	produces pyrogenic carbon, which may persist in soils over long periods. Combustion completeness further influences the amount of biomass converted to carbon and released into the atmosphere. Together, these parameters allow for the estimation of emissions based on the combination of burned area, fuel load, and combustion completeness.”
I believe it is essential to list all 69 articles reviewed. This could be done as a table or supplementary material, with details such as publication year, method, and category. It is unclear whether the 69 articles are all in the reference list or if those cited throughout the text are part of this selection.	The 69 papers reviewed will be included as a table in the supplementary material. The columns included are: paper title, year of publication, authors, area of study, topic, methodological technique, study design.
The question posed—"How compiling published material on fire emissions in natural areas of the Cerrado can provide a better understanding of the placement of these emissions in the atmospheric carbon budget?"—is not adequately addressed or answered throughout the text. My impression is that the answer is "no," due to the lack of studies with a holistic approach. If that is indeed the case, a more in-depth discussion of this point is needed.	We have improved the research question and we have done major edits to the Discussion section and we have expanded it to include a more complete discussion of the answers to the research questions, especially the lack of holistic approach towards estimating fire emissions in the Cerrado. We have included the following: “Our research question is “How compiling published material on fire emissions in areas of the Cerrado that do not explicitly include anthropogenic land uses can provide a better understanding of the placement of these emissions in the global carbon budget?”. Analyzing published papers on fire emissions in these areas in the Cerrado provides valuable insights into its role in the carbon balance. This includes understanding the parameters used to estimate emissions, quantifying the amount of carbon, especially CO_2, released into the atmosphere by fires, and identifying important aspects of fire dynamics that are sources of uncertainty or are not considered in fire emission estimates. These are summarized in Table 3.”

	"Aiming at compiling literature on fire emissions in the Cerrado has led to several papers that do not explicitly estimate fire emissions themselves, but rather discuss fire dynamics and parameters used to estimate emissions. This indicates that there is a gap in the literature regarding fire emissions estimates in the Cerrado. However, studies have indicated that fires in the Cerrado play an important role in the global carbon balance. For example, Van Der Werf et al. (2017) found that savanna fire emissions from the Southern Hemisphere South America region, which includes the Cerrado, averaged 0.14 PgC $year^{-1}$ over 20 years, accounting for more than 6% of global fire emissions per year. Similarly, and from a national perspective, da Silva Junior et al. (2020) have shown Cerrado fires contribute more than 32% of the Brazilian total fire emissions (about 0.13 PgC $year^{-1}$ over the 20 years). Our review also indicates that published literature fails to analyze fire emissions from a holistic approach in the Cerrado. Including the perspectives of fire culture, ecology and policy within emissions is essential given the importance of fire to the biome. However, studies that discuss these aspects often do not discuss them from the emissions' perspective. Despite the difficulty in quantifying the social and cultural aspects of fire, the lack of inclusion of these in fire emission estimates could also be due to the shift towards recognizing fire as essential to the Cerrado being recent, especially when compared to other fire-prone settings. For example, the WALFA project in northern Australia became entirely active in 2005 (Russell-Smith et al., 2013), where traditional people, scientists and governmental institutions collaborate to reduce fire emissions through fire management activities (Russell-Smith et al., 2013). Meanwhile, the Pilot Integrated Fire Management project in the Cerrado started in 2014 (Schmidt et al., 2018).

	Thus, this review indicates a critical need to develop interdisciplinary studies to bridge fire policies and fire emissions in the Cerrado. Understanding fire dynamics, including the opportunities for mitigating emissions from fire activities, is essential for recognizing fire's role in achieving global environmental and climate targets. For instance, Martin (2019) identifies United Nations Sustainable Development Goals that are related to fire and land management, as goals 3 (good health and well-being), 13 (climate action), and 15 (life on land). These impact the 2015 Paris Agreement target to limit warming to 1.5 °C by 2100. The Paris Agreement outlines commitments for climate actions and acknowledges the importance of mitigation and removal actions, where fire management can play an important role. The 1.5 °C target is ambitious, yet achievable if great effort is put into mitigating emissions and removing carbon, with Brazil holding the highest mitigation potential in the land sector (Roe et al., 2019). Together with other countries, improved forest management – which includes fire management – in Brazil could be able to increase carbon removal by 40 $GtCO_2$ by 2050 (Roe et al., 2019). Climate change increasingly affects fires, and adaptation and mitigation activities are essential to limit these effects (Burton et al., 2024). Direct human impacts may offset the effects of climate change in fire worldwide (Burton et al., 2024), especially in fire-prone environments, and this is an opportunity to investigate the potential of fire management to mitigate emissions in the Cerrado, and to understand fire emissions in the biome. Pathways towards improving fire emissions in the Cerrado include connecting observational information with modeling and a better assessment and quantification of the impact of qualitative aspects in fire estimates. Examples of how these can be achieved are by valuing prescribed burning emissions and including these in fire modeling, representing fire management in land surface models, using

	on-site observations to assess models' utility and as input data to modeling, and incorporating non-carbon aspects of fire in fire emission estimates, such as the ecological, social and cultural aspects. These could address uncertainty and improve models' accuracy, thus providing better accounting of fire emissions in the Cerrado and worldwide."
On line 511, the term "estimate emissions" should likely be "estimate fire emissions."	"estimate emissions" changed to "estimate fire emissions".