Response to comments by referee #2 on the manuscript egusphere-2024-2348

We, the authors, thank the editor for handling the paper and the reviewer 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. According to the editor's instructions, the revised manuscript should not be prepared at this stage. Therefore, we have not included the specific line(s) or page(s) where changes were made, nor the updated figures and tables. Instead, we have provided the edited or added paragraphs and sentences to demonstrate how we have addressed the reviewer's comments.

Sincerely,

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

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. I believe these points would enhance the introduction.	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 important hydrographic basins in the whole 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 (Silva 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; Silva 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 important 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: Division of the 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.

	We have also added an analysis of the results in the Discussion section: • "Additionally, we found that the majority 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. From 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 timeseries, 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 in 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). In Pantanal, the main focus was the 2020 extreme fire event, when burned areas were 200% greater than the average for 2003-2020 (Barbosa 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; Silva et al., 2024). This compound drought-heatwave episode aggravated fire activity in the Cerrado (Libonati et al., 2022; Silva 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 to 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 km2 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 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 area (West Arnhem Land Fire Abatement), 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 to 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, meaning that 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. Combustion completeness further influences the amount of biomass converted to carbon and released into the atmosphere. 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. 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 a number of papers that do not explicitly estimate fire emissions itself, 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 it from an 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 from 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, including fire 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 this can be achieved is 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".