CONSEQUENCES OF THE 2024 FIRES IN THE AMAZON: A RAPID VALUATION OF DAMAGES

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About this report

This report presents a rapid valuation of economic damages caused by fires in the Amazon in the 2024 calendar year, with the ultimate objective of raising awareness of the need invest in further research and improved fire management policies and strategies across the region.

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Executive Summary

This report presents a rapid valuation of damage caused by fires[1] in the Amazon[2] during 2024, which saw an unprecedented surge in fires throughout the region, underscoring how climate change is increasingly shaping the patterns, frequency, and severity of such events. The aim of this report is to highlight the significant economic impacts of fires to raise awareness of the need to improve fire management through more efficient policies and the allocation of greater financial resources. This work does not aim to determine the causes of the fires. It focuses solely on assessing the damage for 2024.

The analysis considers the economic impacts of fires across four categories:

- **Production losses**, that is, losses in agricultural crops and livestock due to fire damage
- **Additional greenhouse gas (GHG) emissions**, that is, the release of carbon dioxide and equivalent emissions (CO_2e) from fires
- **Decreases in the provision of forest ecosystem services**, that is, decreases in the forest's ability to provide ecosystem services (in the form of recreation, hunting, fishing, non-wood forest products, and watershed protection services) due to fires
- **The mortality burden**, that is, increases in the mortality risk attributable to fire-related fine particulate matter ($PM_{2.5}$) pollution.

Methodology and data

The analysis relies on a combination of publicly available satellite images and evidence from academic and grey literature, including:

- **Burned area statistics.** Data was obtained from (a) the Moderate Resolution Imaging Spectroradiometer (MODIS) burned area product (MCD64A1v061), which is available at a resolution of 500 meter (m) x 500 m, and (b) the Amazon Regional Observatory, which provides data at a 30 m x 30 m resolution.
- **Land cover data.** High-resolution (30 m x 30 m) land-cover data was obtained from MapBiomas Amazonia to identify forest areas and areas dedicated to agriculture and pasture.
- **Carbon emissions data.** Data for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from the burning of biomass was obtained from the Global Fire Assimilation System (GFAS).
- **Air quality data.** Modelled historical $PM_{2.5}$ data was obtained from the Copernicus Atmospheric Monitoring Service (CAMS) global reanalysis (EC4) dataset, assimilated aerosol diagnostics was obtained from the second Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) dataset, and fire-related $PM_{2.5}$ estimates were obtained from a global dataset developed by the Finnish Meteorological Institute.
- **Mortality data.** Annual death counts and rates were extracted from the Global Burden of Disease study's results provided by the Institute for Health Metrics and Evaluation (IHME), combined with annual population estimates using the Gridded Population of the World, Version 4 dataset provided by NASA's Socioeconomic Data and Applications Center.

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[1] "Fire" in this report refers to landscape fire, as defined in Johnston *et al*. (2024). This term encompasses "all manifestations of fire on Earth, planned and unplanned, beneficial and harmful".

[2] This study uses the Amazon Regional Observatory's definition of "the Amazon" (see Appendix A and Albert *et al*. 2021).

- **Economic data.** Gross value of production and area data for agriculture and livestock were obtained from the Food and Agriculture Organization of the United Nations (FAO).
- **Carbon unit values.** These were obtained from voluntary carbon markets (Forest Trends' Ecosystem Marketplace 2025).
- **Ecosystem services values.** Estimates for the value of recreation, non-wood forest products, and watershed protection services were sourced from The World Bank's The Changing Wealth of Nations report (2024a). This report includes a review of global literature and a meta-analysis that derived value estimates for each of the Amazon countries.
- **Value of a statistical life (VSL).** The VSL was based on the transfer value from evidence in the United States, adjusted by each Amazon country's relative income in relation to the United States, and VSL-income elasticities.

Main findings

The estimated total damage for 2024 is about US$43,103 million, which is equivalent to 1.3 percent of the Amazon countries' collective GDP. Of this:

- **US$23,224 million—53.9 percent of the total value—can be attributed to deaths linked to fire smoke.** This corresponds to about 14,622 premature deaths from short-term exposure to fire smoke containing $PM_{2.5}$, based on a population-weighted average of $PM_{2.5}$ concentration. This is almost three times the region's 2019–2023 mean.
- **US$11,740 million, or 27.2 percent of the total, can be attributed to productive losses**.
- **US$7,867 million, or 18.3 percent of total, can be attributed to greenhouse gases (GHG) emissions** due to fires.
- **US$273 million, or 0.6 percent of total, can be attributed to the loss of other ecosystem services** such as recreation, hunting, fishing, non-wood forest products, and watershed protection services.

These results are in line with similar findings in other regions and countries (such as Canada, Indonesia, or California), where the damage from fires can range from 0.5 percent to 3.4 percent of GDP.

After performing a sensitivity analysis that considers the alternative values that six key parameters could take,[3] the results show that damage estimates may vary between US$ 17,761 million and US$ 76,887 million (equivalent to a range between 0.6 and 2.4 percent of the region's GDP) when considering joint uncertainty.

The damages are predominantly concentrated in Brazil, Bolivia, and Venezuela, which account for about 74.7, 7.1, and 6.9 percent of all damages, respectively. These three countries have the highest share of damages relative to the proportion of their land covered by Amazon forest. The smallest share of Amazon fire losses— less than 0.22 percent of the total—occurs in Suriname and French Guiana (Table ES1).

Table ES1. Estimated annual damages, by category, per country/territory (2024 US$ million)

Category	Bolivia	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela, RB	Amazon

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[3] Specifically, the burned area, the productive value of pastureland dedicated to livestock, the fire related $PM_{2.5}$, the price of carbon, the relative risk of premature death due to fire smoke, and the value of the risk to life.

Ecosystem services	61	138	8	1	0	2	5	0	58	*273*
Health: short term mortality	803	19,203	1,095	477	11	42	1,014	23	555	*23,224*
Agriculture and livestock	288	7,568	762	7	0	454	488	45	2,128	*11,740*
Carbon emissions	1,893	5,291	147	6	7	66	219	23	215	*7,867*
TOTAL (2024 US$ million)	***3,044***	***32,200***	***2,012***	***492***	***18***	***563***	***1,727***	***91***	***2,956***	***43,103***
Country GDP (2024 US$ million)	*48,404*	*2,171,337*	*418,542*	*121,728*	*4,985*	*24,659*	*289,070*	*4,458*	*119,808*	*3,202,991*
Damages as % of GDP	*6.3%*	*1.5%*	*0.5%*	*0.4%*	*0.4%*	*2.3%*	*0.6%*	*2.0%*	*2.5%*	*1.3%*
Shares with respect to the Amazon										
Share of damages	*7.06%*	*74.70%*	*4.67%*	*1.14%*	*0.04%*	*1.31%*	*4.01%*	*0.21%*	*6.86%*	*100.00%*
Share of forest area	*5.61%*	*58.68%*	*7.51%*	*1.56%*	*1.44%*	*3.32%*	*12.45%*	*2.42%*	*7.00%*	*100.00%*
Share of total area	*7.00%*	*60.15%*	*7.18%*	*1.47%*	*1.18%*	*3.01%*	*11.25%*	*2.08%*	*6.69%*	*100.00%*
Share of burned area	*27.46%*	*51.81%*	*3.01%*	*0.06%*	*0.02%*	*3.12%*	*2.61%*	*0.38%*	*11.54%*	*100.00%*

Damages are for the Amazon region of each country or territory, except for health, which includes the whole country or territory. GDP is per country since there is no information on the GDP generated in the Amazon portion of each one of them. GDP for French Guiana is for 2022 as per https://www.insee.fr/en/statistiques/serie/010751772
Source: Original table for this publication.

Limitations

This assessment is subject to limitations due to differences between (and within) countries and economies within the region. These differences were managed by using national averages for fire activity.

Different information sources also collect data at varying spatial resolutions and levels of detail, affecting the accuracy of the available data.

Some types of damage were excluded from the assessment due to lack of relevant data or resource limits. Specifically, the following types of damage were excluded:

- **Direct mortality**, that is, deaths from direct exposure to flames or radiant heat.
- **Morbidity**, that is, injuries and illnesses resulting directly from direct exposure to fires or fire-related $PM_{2.5}$. (Noting that mortality from exposure to fire-related $PM_{2.5}$ is considered.)
- **Psychological impacts**, that is, the mental health impacts of fires.
- **Sociocultural effects on Indigenous Peoples**, which might include altered livelihoods and traditions.
- **Loss or damages to homes and essential infrastructure**.
- **Indirect impacts** such as short-term business interruptions or disruptions in the provision of infrastructure.
- **The cost of emergency response and recovery**, whether from public or private sources.

Conclusions and ways forward

Fires are a significant force, pushing the Amazon rainforest towards a critical ecological tipping point beyond which it could be irreversibly transformed into a drier, more sparsely vegetated, degraded savanna ecosystem. This tipping point risks a catastrophic loss of biodiversity and could significantly impact the global climate by reducing the forest's ability to absorb carbon dioxide, with potential consequences for global and regional precipitation patterns.

The 2024 fires have had a devastating impact on economies and natural environments of countries and territories within the Amazon forest. Prioritizing prevention and strengthening preparedness to respond could help mitigate the risks of future fires and protect human lives while safeguarding the Amazon's valuable natural resources.

Although most of the countries in the Amazon region have allocated fire management funds, these frequently fall short, given the increasing risks posed by fires. Rather than focusing solely on emergency response, research shows that evenly distributing investments between all aspects of fire management—including monitoring, strategic fuel reduction, and engaging local communities on preparedness—would be more effective. To make the most of limited budgets, it is therefore important to prioritize actions and policies that deliver the highest benefits (that is, brings the greatest decreases in damages) for the same cost.

This report finds that it would be beneficial for countries and territories in the region to develop an inventory of all the fire policies and programs already in place to perform a cost-benefit analysis of each of them. Such a cost-benefit analysis would help ensure that funds are allocated to those policies that yield the greatest benefits relative to their costs. A comprehensive cost-benefit analysis would also help guide the development and implementation of effective fire-management policies, further ensuring that resources are used efficiently to protect communities, ecosystems, and economies from the devastating impacts of fires.

The findings of this report raise awareness of the destructive effects of fires and underscore the necessity for more effective policies, both within countries or territories and across the region. The Amazon is not merely a collection of countries and territories; it is a single, interconnected biome with ecological systems, water resources, and biodiversity that transcend borders. Regional cooperation, collaborative strategies, and knowledge-sharing are indispensable tools for reducing the shared threat of fire. Such cooperation could be enhanced through regional organizations like the Amazon Cooperation Treaty Organization and the Amazon Network for Integrated Fire Management. Ultimately, regional collaboration would leverage collective knowledge and resources to safeguard biodiversity and protect the Amazon's integrity, maintaining its vital role in global climate regulation and ensuring the well-being of its people.

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Abbreviations and Acronyms

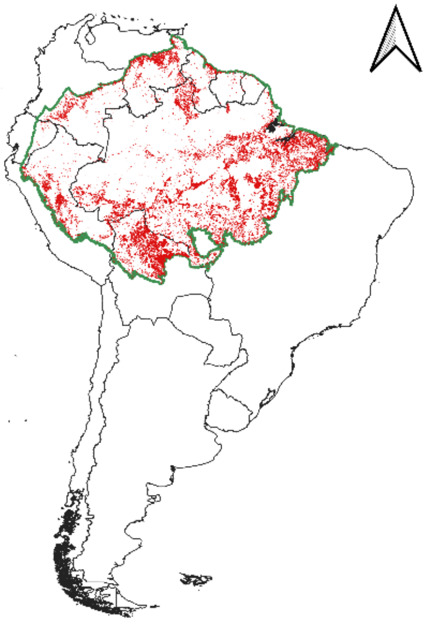
ºC	Degrees Celsius
CAMS	Copernicus Atmospheric Monitoring Service
CH_4	Methane
CO_2	Carbon dioxide
EC4	Global Reanalysis (by CAMS)
GFAS	Global Fire Assimilation System
GHG	Greenhouse gas
IHME	Institute for Health Metrics and Evaluation
IUCN	International Union for Conservation of Nature
MERRA-2	Modern-Era Retrospective Analysis for Research and Applications
MODIS	Moderate Resolution Imaging Spectroradiometer (MODIS)
N_2O	Nitrous oxide
$PM_{2.5}$	Fine particulate matter with a diameter measuring 2.5 micrometers or less (also referred to in this report as air pollution)
RR	Risk ratio
STL	Seasonal trend decomposition using loess
VSL	Value of a statistical life

1. Introduction

The year 2024 was one of the most active years for fires[4] in recent history across the Americas, highlighting the growing influence of climate change on fire behavior, frequency, and intensity. In the second half of the year, several regions in South America—including in the Amazon[5]—were significantly affected by persistent fires (Map 1). These fires had devastating consequences, including a significant deterioration in air quality (Copernicus 2024).

The Amazon experienced above-average fire activity in 2024. Moderate Resolution Imaging Spectroradiometer (MODIS) data indicates that the region experienced the fourth highest number of hot spots[6] since 2001 (the first year that this data was recorded) and the highest since 2011 (Figure 1). Similarly, Visible Infrared Imaging Radiometer Suite (VIIRS) data indicates that the Amazon experienced the highest number of hot spots since 2012, when the data was first recorded (Figure 2).[7] A temporal analysis of other wildfire-related indicators also reveals a clear upward trend in wildfire activity since at least 2011 (Appendix B). If this trend continues, there will be an increased likelihood of more intense and frequent wildfires in the future due to ongoing climate change.

Map 1. Boundary of Amazon used in analysis (green line) and MODIS hot spots between January 1 and December 31, 2024 (red areas)



Source: Original map based on Amazon Regional Observatory boundaries (biogeographic limit) and MODIS hot spots for 2024.

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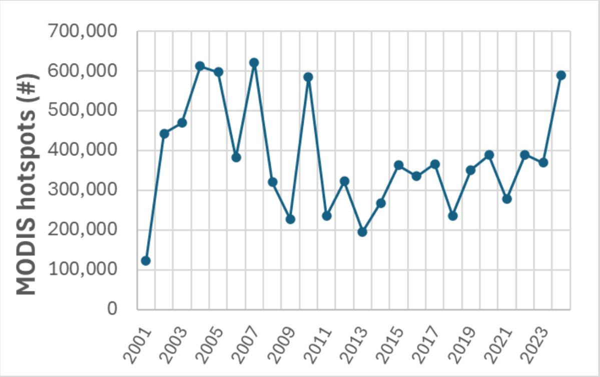
[4] "Fire" in this report refers to landscape fire, as defined in Johnston *et al*. (2024). This term encompasses "all manifestations of fire on Earth, planned and unplanned, beneficial and harmful".

[5] This study uses the Amazon Regional Observatory's definition of "the Amazon" (i.e., biogeographic). See Appendix A for different boundary limits of the Amazon, and Albert *et al*. (2021) for a more detailed discussion.

[6] A hot spot is a heat point detected by satellites due to an increase in surface temperature. Not all hot spots indicate a fire. The presence of hot spots requires further verification on the ground before being classified as a fire. Unlike hot spots, a fire spot is a confirmed active fire. The MODIS grid has a resolution of 500 m x 500 m.

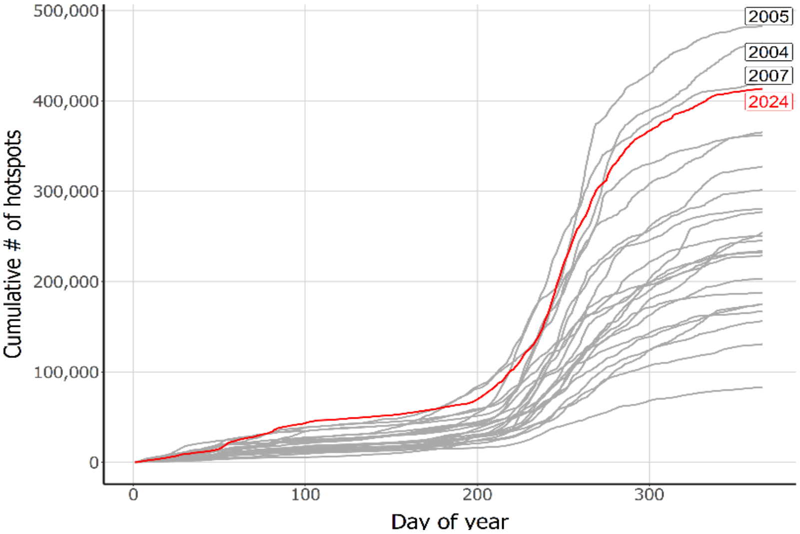
[7] Visible infrared imaging is used to detect, characterize, and map fires from space.

Figure 1. MODIS active fire hot spots, 2001–2024



Source: Original figure based on MODIS data.

Figure 2. Cumulative number of MODIS hot spots by day of year in 2024 (red) and in 2001–2023 (gray)



Source: Original figure report based on MODIS hot spots.

Fire is not inherently destructive; it often contributes positively to both natural ecosystems and those managed by humans. Indigenous Peoples in the Amazon have long practiced controlled burns in order to enrich the soil, safeguard territories, clear land, and fulfill cultural and spiritual needs (Bilbao *et al.* 2025). Nevertheless, when wildfire occurs in forests, farmlands, or areas close to communities, it can lead to a diverse array of direct and indirect harmful impacts. These include, but are not limited to, direct human health impacts or injuries from exposure to flames or worsened air quality levels; the destruction of property (such as homes, buildings, or other critical infrastructure); the loss of economic productivity from, for example, forestry, agriculture, or livestock production; a temporary increase in greenhouse gas

(GHG) emissions; and changes in ecosystem services (Johnston *et al*. 2024). These consequences can be environmental, economic, and social.

Environmental impacts

Fires can affect the natural environment by impacting:

- **Biodiversity.** Wildfires in the Amazon degrade habitats and disrupt ecological interactions, leading to local extinction and the long-term loss of biodiversity. Repeated fires reduce the structure and complexity of the forest, affecting canopy-dependent species such as pollinators, seed dispersers, and endemic fauna. Fire events also displace wildlife, increasing road-crossing attempts and related mortality.
- **Ecosystem services.** Fire-induced degradation reduces evapotranspiration and alters rainfall dynamics while reinforcing a drying-burning feedback loop. Other affected ecosystem services include hydrological regulation, soil fertility, pollination, and the availability of non-timber forest products and cultural value.
- **Carbon emissions.** Fires cause carbon stocks stored in forest biomass, different types of vegetation, and soil to be released into the atmosphere, exacerbating climate change.

Economic impacts

Fires can negatively affect:

- **Production.** Wildfires can cause losses of agricultural, timber, and other products from forest-related industries. In the near term, they also interrupt business operations and systems such as power, water, public safety, and schools. Such losses and interruptions have cumulative economic impacts.
- **Properties.** Fires can cause costly damage to homes, infrastructure, and other assets.
- **Fiscal resources.** Governments face increased costs for activities to suppress fires, provide aid relief and evacuation services, stabilize roads and landscapes, and prevent future wildfires. Wildfires can also reduce public income from taxes due to reduced exports and because people and businesses have less capacity to comply with tax obligations.

Social impacts

Fires affect people by impacting:

- **Health.** Fires contribute to poor air quality, which can negatively affect the health of local populations, resulting in present and future losses of income.
- **Community displacement/migration.** Large-scale fires can disrupt lives and livelihoods, leading to the displacement of communities and, in some cases, permanent migration.

Purpose and structure of this report

The damage caused by fires depends on the intensity, extent, and location of the fires in question. This report draws on such information to develop a valuation of four categories of damage caused by fires in the Amazon in 2024—that is, production losses, additional GHG emissions, decreases in forest ecosystem services, and increases in the mortality risk due to fire smoke-related air pollution. The purpose of the valuation is to develop the case for more efficient and cost-effective policies to reduce fire-related damage. The assessed categories were selected based on the availability of data, the resources available for the valuation, and the time available for this work. (See “Data and Methodology” for detail on how the valuation was done.)

This report is organized as follows:

- The **Introduction** (this section) establishes the geographic and temporal boundaries of this valuation and discusses the various types of impacts that fires can have on the environment, economies, and societies.
- **Section 2** provides a brief overview of international evidence on multi-impact monetary damage estimates.
- **Section 3** outlines the methodology and data sources used in this report, including a detailed description of each data source
- **Section 4** presents the results, explores how findings vary under different parameter assumptions through a probabilistic sensitivity analysis, and discusses the scope and limitations of the estimations.
- **Section 5** concludes the report by summarizing key insights.
- **Section 6** proposes ways forward based on the findings.

2. Global Evidence on Damages from Fires

Very few international studies provide comprehensive estimates covering multiple types of impacts for the same fire event. Most analyses focus on a single type of impact. For the purposes of this literature review, studies that assess fire damage across multiple types of impacts were selected to help identify the main economic impacts of fires, establish which categories of damage are the most relevant, and their related costs. The selected studies focus on four countries and one state—Canada, Indonesia, California, the United States, and the state of Acre (Brazil)—across different time frames within the past five years (Table 1).[8]

The economic share of fire-related losses ranges from 0.5 percent of GDP (in Acre state, Brazil), to more than 3 percent of GDP (in both Canada and Indonesia), underscoring the significance of fires even for economies at differing levels of development (Campanharo et al 2019, Hope et al 2024, Kiely et al 2021). The cost range of damage would be wider if calculated as damage per area burned (US$/ha burned).

The composition of fire-related costs depends on the local context and the severity of the fires.[9] For example, studies in Canada and Indonesia emphasize health and environmental damages, with health impacts accounting for up to 75 percent of total assessed costs in Canada (Hope et al. 2024) and CO_2e emissions representing 40 percent of damages in Indonesia (Kiely et al. 2021). In California, 59 percent of fire-related damage was attributed to indirect economic disruptions across 80 industry sectors, while direct health and capital losses constituted 22 percent and 19 percent, respectively (Wang et al 2020). Acre state's breakdown (Campanharo et al. 2019) is dominated by CO_2e emissions (64.3 percent), followed by crops production re-establishment efforts (14.1 percent) and fences repair and reconstruction costs (10.5 percent). In the United States, reviews of fire-related costs focused on property loss, suppression activities, degraded ecosystem services, and long-term impacts like depreciated property values and landscape rehabilitation (Thomas et al 2017; Barrett 2018).

Fire damage can be complex, with related costs often transcending the immediate burden of fire suppression and property losses to encompass long-term ecosystem degradation, effects on human health, and broader economic repercussions. As Table 1 highlights, fire costs can be multifaceted, reflecting not only the immediate toll on infrastructure and livelihoods, but also the lingering effects on environmental services, public health, and economics. This complexity highlights the need for comprehensive assessment frameworks that capture both the direct and indirect impacts of fire when evaluating their true cost for society.

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[8] The literature review was limited to the past five years to reduce the likelihood of introducing dated evidence. However, even within this window, forest and fire data that was several years older was found.

[9] This report uses the concept of "losses" and "damages" interchangeably, even though this is not necessarily strictly correct because losses are technically irreversible while damages are repairable (The Loss & Damage Collaboration n.d.). The term "cost" is also used as equivalent to losses or damages.

Table 1. Sample of studies that estimate several types of damage at the same time

Country/ state studied	Period	Data source	Categories of damages assessed and shares of total damages	Cost of damage as share of GDP
Canada	2013–2018	Hope *et al*. (2024)	• Health (mortality and morbidity): 75% • Timber: 8% • Property, assets, and infrastructure: 7% • Suppression: 9% • Evacuation: 1%	**3.4%***
Indonesia	2004–2015	Kiely *et al*. (2021)	• Health impacts (smoke exposure, disability adjusted life years): 26% • CO_2e emissions: 40% • Productive losses to crops, plantations: 34%	**3.3%**
Acre state, Brazil	2008–2012	Campanharo *et al*. (2019)	• Respiratory illnesses: 3.6% • CO_2e emissions: 64.3% • Production: 7.5% • Fence: 10.5% • Reestablishment: 14.1%	**0.5%****
California, United States	2018	Wang *et al*. (2020)	• Health costs: 22% • Capital losses: 19% • Indirect losses due to economic disruptions in 80 industry sectors: 59%	**1.5%**
United States, review specific fire cases	Several years between 2002 and 2016	Barrett (2018)	*Short term* • Aid relief and evacuation services: 2% • Home and property loss: 21% • Immediate road and landscape stabilization: 3% • Federal fire-suppression activities: 8% • State/local fire-suppression activities: 1%. *Long term* • Depreciated property values: 8% • Degraded ecosystem services: 34% • Energy and infrastructure repairs: 4% • Human casualties: 1% • Long-term landscape rehabilitation: 16% • Tax, business, and natural resource loss: 2% • Other: 0.1%	**N/A**
United States, review of estimates at several places	Several years depending on the study in the review	Thomas *et al*. (2017)	*Direct* • Health (deaths, morbidity, psychological impacts) • Damage to houses and other infrastructure • Environment (vegetation losses, erosion, watershed, soil quality, carbon emissions) • Timber and agricultural losses. *Indirect* • Short-term business interruption • Short-term infrastructure provision disruptions • Migration	**N/A**

** Calculation based on US$57.2 billion in damages reported and GDP of US$1.744 trillion for 2019. **The peak for 2010 is 7.03%.*
Source: Original table for this publication.

3. Data and Methodology

As already mentioned, this report presents a valuation of the following four categories of damage due to fire:

- Productive losses to agricultural crops and livestock
- Additional GHG emissions
- Decreases in other forest ecosystem services
- Increases in short-term mortality risk due to fire smoke-related exposure to fine particulate matter ($PM_{2.5}$), but not due to direct exposure to heat and fire.

The valuation focuses on damage caused by fires in the Amazon region in 2024. Estimated damages are presented in constant 2024 US dollars.[10] Figure 3 summarizes this methodological framework.

The valuation approach used here is not based on replacement or restoration costs. Such methods are often applied when environmental impacts cannot be directly estimated. However, this approach assumes that replacement costs do not exceed the economic value of damaged assets—an assumption that may not always hold true. Indeed, the cost of replacing damaged assets can sometimes surpass their economic value (Dixon and Pagiola 1998).

A probabilistic sensitivity analysis is used to account for uncertainty relating to the values of key inputs used in this damage valuation. This approach sees randomly selected input parameters—sampled from a range of probable values—being used to determine a range of possible estimated damages. This approach saw the analysis follow these steps:

1. **Key input variables were identified.** The parameters that could have the greatest influence on damage estimates were identified.

2. **Value ranges for each key variable were defined.** A minimum, central, and maximum value for variable inputs was selected based on the available evidence.

3. **A probability distribution was selected.** A triangular distribution was assumed for all input variables, except for the health risk coefficient (i.e., β) for which we assumed a log-normal distribution.

4. **A Monte Carlo simulation was run.** Ten thousand iterations of a Monte Carlo simulation were run to capture the uncertainty across all input variables. Rather than produce a single cost estimate, this method generates a distribution of possible damage outcomes, each associated with a probability. For example, to account for the uncertainty of the carbon price—which could range from $5 to $10 per ton of CO_2e, with a central estimate of $7.50—input values were randomly selected from the triangular distribution when running the simulation to compute the corresponding damage. This process was repeated for all variables and iterations, resulting in a probabilistic range of damage estimates.

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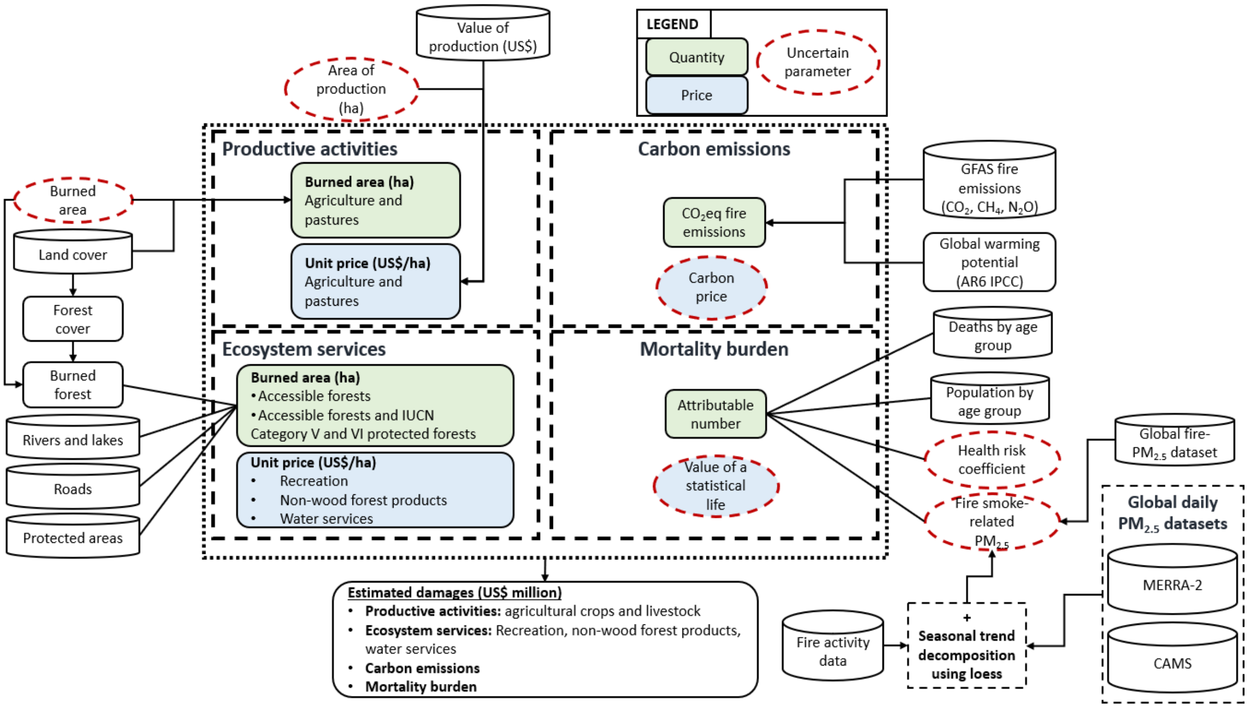
[10] Where necessary, unit costs for a specific year were adjusted to 2024 US dollars using the compounded annual inflation in the United States.

Figure 3. Methodological framework



Parameters with red-dash borders are those for which uncertainty was considered.
Source: Original figure developed for this report.

The central, minimum, and maximum values used for each parameter are discussed in the following section. Results are presented as midpoint estimates, accompanied by 95 percent confidence intervals to reflect the uncertainty inherent in the analysis.

Data sources

The data used for this valuation includes the size of burned areas, land types where economic activities usually take place, fire-related GHG emissions data, “accessible forest” data, data on forests where sustainable activities are allowed, and estimates of fire smoke-related $PM_{2.5}$ concentrations (used to calculate the attributable mortality). The value of fire-related damage is derived from existing databases, reports, and studies for each of the Amazonian countries and territories and expressed in constant 2024 US dollars.

Table 2 provides a summary of the variables used for this valuation, their related units, and the sources of such data, grouped by the category of damage. The way this data is used for the valuation is discussed later in this section.

Table 2. Data sources, variables, and units, categorized by category of damage

Category	Component	Subcomponent	Variable(s)	Units	Source
Productive activities	Burned productive land		Burned area	ha per year	MODIS burned area product (MCD64A1v061) (Giglio *et al.*, 2021) https://doi.org/10.5067/MODIS/MCD64A1.061
			Land cover	–	MapBiomas Amazonia land cover maps (collection 6) https://amazonia.mapbiomas.org/en/
	Unit prices for productive activities		Area of production	ha per year	MapBiomas Amazonia land cover maps (collection 6) https://amazonia.mapbiomas.org/en/ FAO: Area harvested https://www.fao.org/faostat/en/#data/QCL
			Value of production	US\$ per year	FAO: Value of agricultural production https://www.fao.org/faostat/en/#data/QV
Carbon emissions	Net CO_2e biomass burning emissions	Biomass burning emissions	CO_2, CH_4, and N_2O biomass burning emissions	grams per m^2	CAMS global biomass burning emissions based on fire radiative power (GFAS) https://ads.atmosphere.copernicus.eu/datasets/cams-global-fire-emissions-gfas
		Global warming potential (GWP)	CO_2, CH_4, and N_2O GWP	Ton CO_2e per ton	Intergovernmental Panel on Climate Change's (IPCC's) Sixth Assessment Report global warming potential values: https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-7/#7.6 (Section 7.6.1.1)
	Social cost of carbon		Social cost of carbon	US\$ per ton CO_2e	A central value of US\$10/tonCO_2e, with a range of US\$5–US\$15/tonCO_2e, based on various references cited in text
Ecosystem services	Accessible forest burned (and IUCN Protected Areas Category V and Category VI)	Burned area	Burned area	ha per year	MODIS burned area product (MCD64A1v061) (Giglio *et al*. 2021) https://doi.org/10.5067/MODIS/MCD64A1.061
		Accessible forest (and IUCN Protected Areas Category V and Category VI)	Forest cover	–	MapBiomas Amazonia land cover maps (collection 6): https://amazonia.mapbiomas.org/en/
			Rivers and lakes	–	World river and lake centerlines from natural earth: https://www.naturalearthdata.com/downloads/10m-physical-vectors/10m-rivers-lake-centerlines/
			Roads	–	Global Roads Inventory Project (GRIP) dataset (Meijer *et al*. 2018) https://www.globio.info/download-grip-dataset
			Protected areas	–	World Database on Protected Areas (WDPA) https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
	Unit prices from The Changing Wealth of Nations 2024		Value of services: • Recreation, hunting, and fishing • Non-wood forest products • Water services	US\$ per ha	World Bank 2024c
Health (fire smoke-related $PM_{2.5}$ mortality)	Attributable number of deaths (from fire smoke-related $PM_{2.5}$ exposure)	Fire-related $PM_{2.5}$	CAMS daily $PM_{2.5}$ (2019–2023)	$\mu g/m^3$	CAMS global reanalysis (EAC4) (Inness *et al*. 2019)
			Aerosol diagnostics from the second Modern-Era Retrospective analysis for Research and Applications*	kg/m^3	MERRA-2 dataset https://disc.gsfc.nasa.gov/datasets/M2T1NXAER_5.12.4/summary
			Global fire $PM_{2.5}$ dataset	$\mu g/m^3$	Daily surface concentration of fire related $PM_{2.5}$ for 2003-2024, modelled by SILAM CTM when using the MODIS satellite data for the fire radiative power

Category	Component	Subcomponent	Variable(s)	Units	Source
					(Hänninen *et al*. 2025)
			$PM_{2.5}$ biomass burning emissions	grams per m^2	CAMS global biomass burning emissions based on fire radiative power (GFAS)— https://ads.atmosphere.copernicus.eu/datasets/cams-global-fire-emissions-gfas
		Deaths (all ages)		Number per year	Global Burden of Disease Study 2019 (IHME, 2025) https://vizhub.healthdata.org/gbd-results
		Population (all ages)		Number per year	Gridded Population of the World, Version 4: Population Count, Revision 11 https://www.earthdata.nasa.gov/data/catalog/esdis-ciesin-sedac-gpwv4-popcount-r11-4.11
		Short-term health risk coefficient		Risk ratio (RR) per 10 $\mu g/m^3$ daily fire smoke-related $PM_{2.5}$	Wang *et al*. (2025)
	Value of a statistical life		Value of a statistical life	US$ per statistical life	Estimates based on Viscusi (2021), Viscusi and Masterman (2017), and World Bank Group and IHME (2016).

Dust column mass density: $PM_{2.5}$ *(*$DUST_{2.5}$*); sea salt column mass density:* $PM_{2.5}$ *(*$SS_{2.5}$*); black carbon surface mass concentration (*BC*); organic carbon surface mass concentration (*OC*); and* SO_4 *surface mass concentration (*SO_4*).*

Source: Original table for this publication.

Assessing the cost of damage to productive activities

For this category, the combined impact of fires on agricultural crops and livestock were valued.[11] It was assumed that the main driver (that is, the "quantity" variable) was represented by the number of burned hectares that would have been destined for either activity (such as cropland or pastures).

To estimate the area of burned land that would have been used for productive activities, the following data was used:

- Burned area data from MODIS (MCD64A1v061) (Giglio *et al*., 2021), which is available at a 500 m spatial resolution and measured in hectares per year
- Burned area data from the Amazon Regional Observatory (ARO), which is available at a 30 m resolution, but only for 2024
- Land cover data from MapBiomas Amazonia, which is available at a 30 m resolution (see Appendix C).

To identify land destined for agricultural or livestock production, three land-cover classes were considered: Pasture, agriculture, and a mosaic of uses.[12] For 2024, the land cover data available for 2023 was used.

Unit values were estimated by combining the gross value of production per hectare in each of the countries (in current US$ per year) (FAO, 2025a) with the number of hectares destined for agricultural and livestock production (FAO, 2025b). Two sources were used to determine this area: (a) area harvested (in hectares) according to the FAO, and (b) the total agricultural, pasture, and mosaic-of-uses area estimated using MapBiomas land-cover maps. Four unit values were identified for use as inputs in the probabilistic sensitivity analysis. The resulting figures were adjusted to constant 2024 US dollars.

Table 3 summarizes the final unit values for 2024 by country used for the valuation.

Table 3. Estimated unit values for productive activities (agriculture + livestock) in 2024 (2024 US$ per hectare)

Measure		**Bolivia**	**Brazil**	**Colombia**	**Ecuador**	**Guyana**	**Peru**	**Suriname**	**Venezuela, RB**
Unit value (FAO only)	Trend	460	2,555	8,169	2,401	7,678	3,898	2,632	12,500
	Mean	621	1,812	8,740	3,171	4,009	3,609	2,521	11,717
Unit value (FAO plus MapBiomas)	Trend	148	872	1,175	665	5,545	996	1,010	145
	Mean	217	579	1,291	918	3,221	950	1,417	170

Unit values for French Guiana are excluded due to lack of estimates for gross production value. This does not affect French Guiana's valuation because no productive areas were burned in the territory. See Appendix D for more on how country values were estimated. Source: Estimates for this report based on FAO and MapBiomas data. See Appendix D for more detail on how these values were estimated for each country.

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[11] The impact of fires on forest plantations (silviculture) was not assessed due to data limitations. However, it is unlikely that this damage would be substantial given that the total silviculture area for the Amazon, based on MapBiomas data, is less than 0.06 percent of the total area (about 395,000 hectares), of which only 23,100 hectares of forest plantations were burned (less than 0.15 percent of total burned area).

[12] The land cover class "3.3. Mosaic of uses" from MapBiomas corresponds to a mix of livestock and agricultural activities.

Assessing the cost of damage due to increases in GHG emissions

Greenhouse gas emissions from fires were estimated by multiplying the total CO_2e emitted due to the burning of biomass by the carbon price.

CO_2e emissions include the CO_2, CH_4, and N_2O emitted by the burning of biomass, assessed in terms of their global warming potential values—which for CO_2 is 1, for CH_4 is 27, and for N_2O is 273—as recommended by the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) (Forster et al. 2021). Emissions of each substance were estimated using data from the Global Fire Assimilation System (GFAS) (Kaiser *et al*. 2012).

Several alternatives could have been used for CO_2e values per ton (/tCO_2e), each with different implications:

- **The shadow price of carbon** is the carbon market value needed to limit global warming to 2 degrees Celsius (ºC), as captured in the Paris Agreement. The World Bank's recommended lower bound is 2017 US$44/$tCO_2e$ for 2024 (World Bank 2024a).
- **The social cost of carbon** is the estimated present discounted value of present and future worldwide economic damages from emitting one ton of CO_2e into the atmosphere today. The mean estimate of the social cost of carbon is US$185/$tCO_2e$ (Rennert *et al*. 2022).
  The market prices of carbon can be determined from compliance and voluntary carbon markets. The market price of carbon in voluntary credit markets in Latin America was US$6.52/$tCO_2e$ in 2024 (Forest Trends' Ecosystem Marketplace, 2025).

For the purposes of this valuation, a conservative carbon price of between US$5/$tCO_2e$ and US$15/tCO2e, with a mean of US$10/$tCO_2e$ (all in 2024 US dollars) was selected. This range reflects the opportunity cost of losing carbon to fire. It is important to note that for countries not actively engaged in carbon markets, even this conservative assumption may not be perceived as such.

Assessing the cost of damage to ecosystem services

This valuation follows the example of the World Bank's The Changing Wealth of Nations report, which considers the value of three key ecosystem services: (a) recreation, hunting, and fishing; (b) non-wood forest products; and (c) watershed protection (World Bank, 2024c.[13]

Some ecosystem services require people to have access to forests ("accessible forests"), while other services, such as non-wood production, rely on having the right to perform a particular type of activity in the forest; only certain sustainable activities are allowed in International Union for Conservation of Nature (IUCN) Category V and Category VI protected forests.[14]

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[13] Watershed protection encompasses all natural processes and functions that contribute to the regulation of water flow, the purification of water, and the supply of clean water for various uses, including household consumption. These services also include the maintenance of rainfall patterns through sustained vegetation, the control of soil erosion, and the mitigation of flood impacts by absorbing, storing, and gradually releasing water.

[14] IUCN Category V refers to protected landscapes with an explicit natural conservation plan, which allows some developments such as ecotourism and sustainable agricultural practices. IUCN Category VI allows for a low level of human occupation. Local communities and their traditional practices have had little environmental impact on such areas (IUCN 2002).

Accessible forests are those forests that are within 10km or less of roads or navigable waterways (World Bank, 2024c). Amazonian forests affected by fire were identified by determining the intersection between: (a) the “natural forest” land cover class in the MapBiomas Amazonia land cover maps; (b) the 10km “accessible forests” area around roads, rivers, and lakes, (c) IUCN category V and VI protected areas; and (d) burned areas.

While various approaches exist to assign monetary values to ecosystem services, it is widely accepted that these methods are fundamentally imprecise when it comes to assessing the value of non-market benefits (Damania *et al.* 2023).

This assessment uses the country-specific unit values for ecosystem services used in the World Bank Group’s The Changing Wealth of Nations 2024 report. These values are based on a combination of empirical data from various global regions—including the Amazon—and machine learning that allowed for extrapolation of data based on local ecological and socioeconomic conditions (World Bank 2024c). These unit values were adjusted to constant 2024 US dollars using the compounded annual inflation rate for the United States between 2020 and 2024.[15]

Table 44 summarizes the unit values applied per country in this valuation. The highest values of forest ecosystem services are for Ecuador (US$173 per hectare) and Venezuela (US$154 per hectare). However, given the Amazon’s natural richness and the fact that the water valuation is limited to accessible forests,[16] it is likely that the value of the region’s ecosystem services has been underestimated. By comparison, Brander *et al*. (2024)—based on a review of 2,000 study sites in more than 140 countries—estimate that the value of more than 20 ecosystems services for tropical and sub-tropical forests is US$8,166 per hectare (US$ 2020). However, this estimate is not done on a per-country level. Note that for our analysis we use the value of ecosystem services for the country, not for the Amazon region of the respective country.

Table 4. Ecosystem services assessed, potential forest area considered, and unit values by country

Services	Areas considered	Bolivia	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela, BR
		Unit values (2024 US$/ha)								
Recreation, hunting, and fishing	Accessible forests	6.1	33.2	71.0	118.5	8.6	2.7	10.3	2.4	78.3
Non-wood forest services	Accessible forests and IUCN Category V and VI protected forests	7.0	7.9	7.0	10.5	12.5	5.0	7.5	1.8	13.0
Watershed services	Accessible forests	47.0	54.5	38.8	44.2	57.8	27.9	27.5	15.2	62.7
Total		**60.1**	**95.6**	**116.8**	**173.3**	**78.9**	**35.5**	**45.3**	**19.4**	**153.9**

Corresponds to total forest unit values in World Bank (2024c). Water services from forests could also derive from non-accessible ones, but this valuation follow the procedure used in The Changing Wealth of Nations.
Source: World Bank 2024c.

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[15] The World Bank Group’s United States inflation data since 2019 can be viewed here: https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?end=2024&locations=US&start=2019

[16] As stated in World Bank (2024b), water services valuation is assigned only to accessible forests, even if forests further away from population and waterways can also produce valuable water ecosystem services. This has to do with the fact that available water services valuation studies for the region are restricted to areas of accessible forest.

Mortality burden from fire smoke-related $PM_{2.5}$

Exposure to $PM_{2.5}$, including that originating from landscape fires, has been consistently linked to increased risks of adverse health outcomes such as respiratory infections, cardiovascular diseases, and premature mortality (Héroux *et al.* 2015, Karanasiou *et al*. 2021, Reid *et al*. 2016). Several studies have quantified the health burden and associated costs of $PM_{2.5}$ exposure—both from all sources and specifically from fire-related emissions—highlighting substantial impacts on mortality and morbidity (Johnston *et al*. 2020; Matz *et al*. 2020; World Bank 2022).

Although fires affect morbidity, with implications for the increased use of healthcare services, when it comes to valuing the impacts of fires, most of the damage typically stems from mortality. As an example, the 2019–2020 bushfires in southeastern Australia resulted in short-term exposure to fire smoke-related $PM_{2.5}$ that cost the country about $A1,948 million. Of this total, $A1,923 million (98.7 percent) were attributed to mortality alone (429 deaths), with the remaining $A25.5 million (1.3 percent) was linked to 1,138 hospital admissions for cardiovascular disease, 2,092 admissions for respiratory diseases, and 1,523 emergency department visits for asthma (Johnston *et al*. 2020). A similar trend was observed in Canada, where acute mortality due to fire smoke-related $PM_{2.5}$ exposure between 2013 and 2018 accounted for about 85 percent of total acute health costs, while chronic mortality costs accounted for about 95 percent of total chronic health costs (Matz *et al*. 2020). A World Bank study (2022) also found that the cost of global $PM_{2.5}$ associated mortality accounted for 85 percent of the total health costs, whereas morbidity contributed 15 percent.

While there is some variation in how mortality and morbidity impacts are valued, there is consensus that the costs tied to mortality substantially exceed those from morbidity when it comes to air pollution exposure. Given that this report focuses on estimating economic damages attributable to fires, and considering time and resource constraints, this analysis therefore concentrates on mortality impacts only. This approach captures the dominant share of health-related costs while remaining feasible.

The mortality burden attributable to short-term exposure to fire smoke-related $PM_{2.5}$ uses the approach outlined by Anenberg *et al*. (2010). First, the attributable number (AN) of deaths was calculated. This represents the excess mortality linked to elevated $PM_{2.5}$ concentrations from fire smoke. To quantify the economic impact, AN was multiplied by the value of a statistical life (VSL).

The equation used is:

$$HealthCosts_y = AN_y \cdot VSL_y \tag{1}$$

Where:

- AN_y represents the attributable number of deaths for year y
- VSL_y is the value of the statistical life, expressed in constant 2024 US dollars.

For each country, the attributable number of deaths for a given year *y* (AN_y) was calculated using the following formula:

$$AN_y = \left(IR \cdot Pop_y \times \left(1 - e^{(-\beta \times \Delta C_y)}\right) \cdot 365\right) \tag{2}$$

Where:

- IR represents the daily baseline mortality incidence rate (deaths per 100,000 people per day). This is calculated as the mean daily rate of all-cause mortality between 2015 and 2019, based on data from the Global Burden of Disease study provided by IHME (2025). This period was chosen to exclude potential distortions from COVID-19.
- β is the health risk coefficient for short-term mortality associated with $PM_{2.5}$ exposure.
- ΔC_y is the mean daily population-weighted concentration of fire smoke-related $PM_{2.5}$ for year y in each country within the Amazon region.
- Pop_y is the estimated population for year y, derived from the Gridded Population of the World (GPWv4) dataset for 2015 and 2020.[17] This dataset has a 1 km resolution. Annual values for 2019–2024 were interpolated using a linear trend.

Relative risk

As explained in Appendix E, the health risk coefficient (β) was calculated using the formula:

$$\beta = \frac{\ln{(RR)}}{10} \tag{3}$$

Where:

- RR is the risk ratio for a 10 microgram per cubic meter ($\mu g/m^3$) increase in daily $PM_{2.5}$ concentrations.
- ln is the natural logarithm

For this analysis, an RR of 1.02 per 10 $\mu g/m^3$ was used (95 percent CI, range 1.01–1.03). This is based on a recent meta-analysis by Wang *et al*. (2025), which examines short-term exposure to fire smoke-related $PM_{2.5}$ and all-cause mortality.

To account for uncertainty, the 95 percent confidence interval of the RR was incorporated into the probabilistic sensitivity analysis. This range aligns with other estimates in the literature:

- The World Health Organization recommends an RR of 1.0123 (95 percent CI, range 1.0045–1.0201) for all-source $PM_{2.5}$ (Héroux *et al.,* 2015)
- Orellano *et al*. (2020) report a lower RR of 1.0065 (95 percent CI, range 1.0044–1.0086)
- Karanasiou *et al*. (2021), in a systematic review and meta-analysis of biomass-related related $PM_{2.5}$, estimate an RR of 1.0192 (95 percent CI, range 0.9981–1.053), based on three studies.
- Ye *et al*. (2022) estimate an RR of 1.031 (95 percent CI, 1.024–1.039) for all-cause mortality in Brazil between 2000–2016.

The RR of 1.02 per 10 $\mu g/m^3$ was uniformly applied across all years and countries in the Amazon region, on the assumption of short-term (24-hour mean) exposure.

Fire smoke-related $PM_{2.5}$

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[17] Gridded Population of the World (GPWv4) dataset for 2015 and 2020 can be accessed here: https://www.earthdata.nasa.gov/data/projects/gpw

Distinguishing routine air pollution levels from those specifically attributable to individual wildfires presents a significant challenge. To address this, daily fire smoke-related $PM_{2.5}$ (ΔC_y) was estimated using $PM_{2.5}$ data drawn from three distinct sources:

- **The Copernicus Atmospheric Monitoring System (CAMS) Global Reanalysis (EC4) dataset** provided daily $PM_{2.5}$ concentrations for 2003–2024 at a 0.75° spatial resolution (Inness *et al*. 2019)
- **The second Modern-Era Retrospective analysis for Research and Applications (MERRA-2)** dataset[18] provided aerosol diagnostics and estimated daily $PM_{2.5}$ for 2003–2024, following Buchard *et al*. (2016).[19]
- **The global fire-$PM_{2.5}$ dataset** developed by the Finnish Meteorological Institute, which specifically isolates fire smoke-related $PM_{2.5}$ concentrations (Hänninen *et al*. 2025), was also incorporated.

For the CAMS and MERRA-2 datasets, daily fire smoke-related $PM_{2.5}$ concentrations were estimated using a combination of a seasonal trend decomposition using loess (STL) analysis and fire activity indicators (Figure F1 in Appendix F). This method, previously applied to identify severe pollution events (Borchers-Arriagada *et al*. 2024a; Borchers-Arriagada *et al*. 2024b; Morawska *et al*. 2021) decomposes the $PM_{2.5}$ series into three components: seasonal, trend, and remainder. The sum of seasonal and trend components represents the estimated background $PM_{2.5}$, while the remainder potentially represents the $PM_{2.5}$ component associated with extreme pollution events (Morawska *et al*. 2021).

To refine the background estimate, the following steps were applied:

1. **Outliers were removed.** Values greater than the 95th percentile were excluded.
2. **Imputation of values.** Missing values (that is, removed outliers) were interpolated using a spline function via the "na_interpolation" function in the "imputeTS" package in *R*[20] (Moritz and Bartz-Beielstein 2017).
3. **Smoothing.** The seasonal + trend component (with imputed values) was smoothed using the "ksmooth" function from the "stats" package in R (R Core Team 2018).

We then recalculated the remainder as the difference between daily $PM_{2.5}$ and the smoothed seasonal + trend component.

To identify fire-affected days and locations, $PM_{2.5}$ emissions from burning biomass were obtained from GFAS (Kaiser *et al*. 2012). On any given day, a grid cell (0.75° x 0.75°, approximately 86 x 86 kms on the equator) was flagged as a candidate fire-smoke day if:

- Fire activity was detected on the same day or up to two days prior
- The activity occurred within a 300 km radius of the grid cell
- The remainder exceeded two standard deviations, following Borchers-Arriagada *et al*. (2024b).

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[18] The second Modern-Era Retrospective analysis for Research and Applications (MERRA-2) dataset can be accessed here: https://disc.gsfc.nasa.gov/datasets/M2T1NXAER_5.12.4/summary

[19] $PM_{2.5} = DUST_{2.5} + SS_{2.5} + BC + 1.4 \times OC + 1.375 \times SO_4$, *with Dust column mass density* $PM_{2.5}$ ($DUST_{2.5}$)*; sea salt column mass density:* $PM_{2.5}$ ($SS_{2.5}$)*; black carbon surface mass concentration* (BC)*; organic carbon surface mass concentration* (OC)*; and* SO_4 *surface mass concentration* (SO_4)*.*

[20] R is a free, open-source programming language and software environment for statistical computing and graphics.

This report defines fire smoke-related $PM_{2.5}$ as the positive remainder values on candidate days for fire smoke. Appendix G (Figure G1 and Table G1) shows how estimates of fire-$PM_{2.5}$ exposure vary depending on the source of data and methodological approach. This variability is captured through the probabilistic sensitivity analysis conducted for this assessment.

The value of a statistical life

For this study, the VSL is estimated for each country by transferring the United States VSL value of US$10.4 million (2019 US$) reported by Viscusi (2021), and adjusting it by the differences in income per capita and the elasticity of the VSL with respect to income. Viscusi (2021) was chosen because it is one of the most updated estimates for VSL.

For the adjustment, the following formula was used:

$$VSL_p = \left(\frac{GDPpercapita_p}{GDPpercapita_s}\right)^{\eta} \cdot VSL_s \tag{4}$$

Where:

- s refers to the study site (for example, the United States)
- p refers to the policy site (for example, a country within the Amazon region) to which the study site's value is transferred to
- η refers to the VSL to GDP per capita (proxy for income) elasticity (i.e., $\frac{\partial VSL}{VSL} / \frac{\partial GDPpercapita}{GDPpercapita}$).

Income disparities significantly influence individuals' willingness to pay for mortality risk reductions. Therefore, an income elasticity of VSL, which captures the proportional change in VSL in response to changes in income, was applied. This adjustment is particularly important when transferring VSL estimates from high-income to lower-income countries, because the VSL typically decreases with income—but not proportionally.[21]

Given the lack of consensus on the appropriate elasticity value, this parameter was incorporated into the probabilistic sensitivity analysis. The World Bank Group and IHME recommend a central elasticity of 1.2 for low- and middle-income countries, with a range of between 1.0 and 1.4 for sensitivity testing (World Bank Group and IHME 2016). For high-income countries, a central value of 0.8 is recommended, with a range of 0.6 to 1.0 for sensitivity analysis. The higher the income elasticity, the lower the resulting VSL when transferring the VSL from a high-income country to a lower income country. Here, different elasticities for different countries are used, depending on the World Bank's income classification.

Table 5 summarizes the GDP per capita for the United States and each of the countries or territories in the Amazon in 2020 (the base year), the income category of each country or territory, and the corresponding elasticities. These values were then adjusted to 2024 US dollars to determine the low, high, and mean VSL for each country or territory.

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[21] When income elasticity is zero, the VSL remains constant regardless of income level, resulting in the same VSL value for both poorer and richer countries. If the elasticity is 1, the VSL in the poorer country solely reflects income differences across countries. A value smaller than 1 indicates that willingness-to-pay estimates become a larger fraction of income for poorer countries, while a value greater than 1 lead to estimates that decrease as a fraction of income. The latter scenario could be explained by the fact that individuals in countries with lower mean incomes may prioritize spending on meeting basic needs rather than making marginal improvements in survival probability, thus resulting in a relatively lower VSL.

Table 5. Transferred value of a statistical life for each Amazon country or territory

	United States		**Bolivia**	**Brazil**	**Colombia**	**Ecuador**	**French Guiana**	**Guyana**	**Peru**	**Suriname**	**Venezuela, BR**
Income level FY2020*	*High*		*Lower-middle*	*Upper-middle*	*Upper-middle*	*Upper-middle*	*High*	*High*	*Upper-middle*	*Upper-middle*	*Not available*
GDP per capita current US$, for 2019**	65,561		3,591	9,011	6,540	6,199	17,618	6,594	7,252	6,716	2,625
VSL income elasticity (η)		Low	1	0.8	0.8	0.8	1	1	0.8	0.8	0.8
		Middle	1.2	1	1	1	1	1	1	1	1
		High	1.4	1.2	1.2	1.2	1	1	1.2	1.2	1.2
Converted to 2024 US$ million using US inflation ***		Low	0.7	2.6	2.0	1.9	3.4	1.3	2.2	2.1	1.0
		Mean (Low and High)	0.5	1.9	1.4	1.3	3.4	1.3	1.6	1.4	0.6
		High	0.2	1.2	0.8	0.8	3.4	1.3	0.9	0.8	0.3
Viscusi 2021 (2019 US$ milion)	10.4										

** Income level is as defined by the World Bank.*

*** GDP per capita is based on World Development Indicators (Metreau, Young, and Eapen 2025).*

Source: Original table for this publication.

**** US inflation - https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?end=2024&locations=US&start=2019*

Source: Estimates for this report

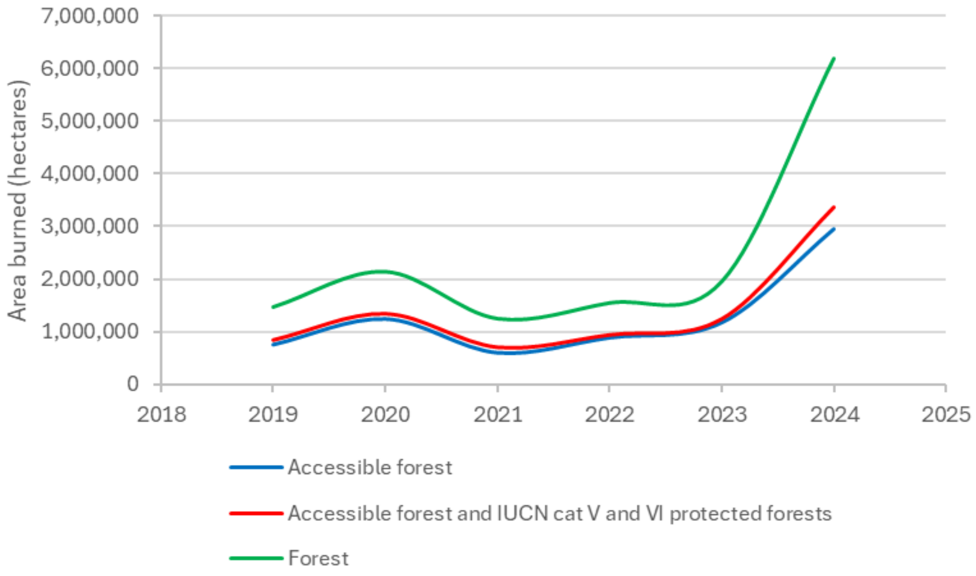
This approach approximates the VSL in the region. VSL is influenced by factors including age, education, having or not having dependents, risk level, or type of death (Sweis 2022). Time and resources limit further adjustments based on specific population affected by smoke from fires in the Amazon countries.

4. Key Findings

The year 2024 was indeed a catastrophic one in terms of fire activity in the Amazon, which was the highest in the region since 2011 and the fourth most intense since 2001. In total, almost 16 million hectares of land were burned, including:

- **About 4.2 million hectares of pasture and agricultural land**
- **Almost 6.2 million hectares of forest**, a 287 percent increase compared to the 2019–2023 average. Of this, nearly **3 million hectares were accessible forest**, representing a 223 percent increase compared to the 2019–2023 average (Figure 4), underscoring the exceptional scale of ecosystem disruption during the 2024 fire season.

Figure 4. Forest areas burned, 2019–2024



Source: Original figure developed for this report using MODIS for burned area.

Table 6, on the following page, provides a detailed breakdown by types of areas considered in this valuation, of the total area, the burned area (as per MODIS data in 2024, and the share of burned area, by country. For example, in Bolivia, nearly 2.3 million hectares of forest burned in 2024, representing 7.2 percent of the total forest coverage in that country.

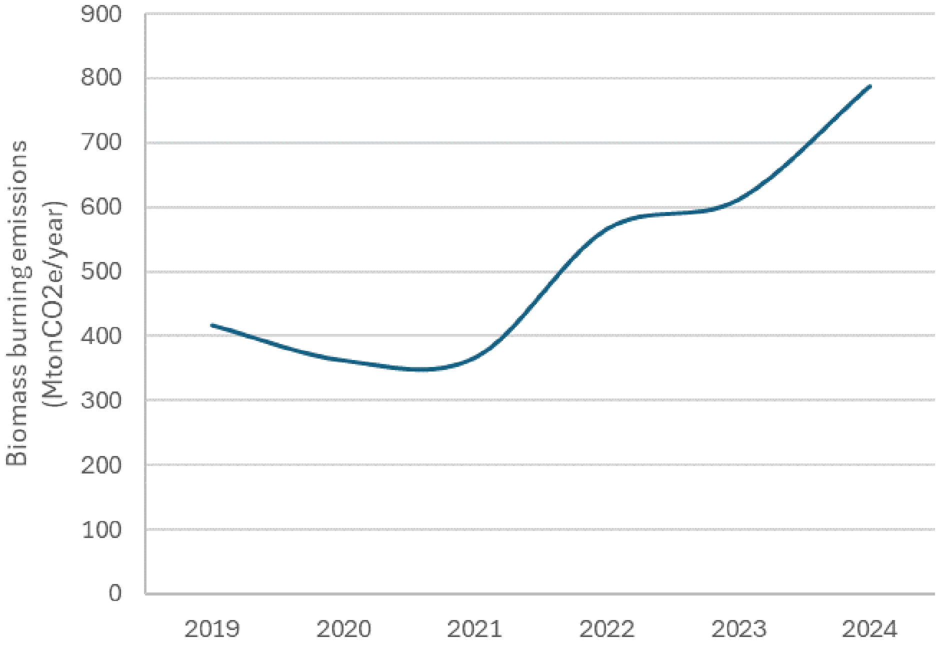
Table 2. Size estimates of the area considered and area burned during 2024 (hectares and %)

Indicator	Area considered	Bolivia	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela, RB	Amazon
Area (ha)	**Total**	**49,454,170**	**424,897,392**	**50,731,652**	**10,354,135**	**8,315,192**	**21,258,509**	**79,497,387**	**14,668,557**	**47,262,417**	**706,439,411**
	Forest	31,637,945	330,819,359	42,362,515	8,821,003	8,110,322	18,737,183	70,177,695	13,662,203	39,452,903	563,781,126
	Accessible forest	20,523,367	100,927,566	13,723,525	5,622,954	3,136,125	6,638,108	20,687,535	3,297,168	9,271,141	183,827,489
	Accessible forest and Cat V/VI protected areas	20,523,367	158,514,333	16,109,823	6,208,349	4,210,895	7,934,576	29,088,047	3,307,014	26,932,024	272,828,429
	Pasture and Agriculture	4,840,073	67,637,317	5,484,683	1,252,818	44,137	292,208	5,690,334	124,744	1,269,908	86,636,222
Burned area (ha)	**Total**	**6,108,389**	**8,086,928**	**154,368**	**1,196**	**296**	**232,100**	**189,240**	**49,086**	**926,889**	**15,748,492**
	Forest	2,286,304	3,409,679	21,609	823	231	42,345	73,096	16,200	347,593	6,197,881
	Accessible forest	1,262,995	1,458,857	16,484	608	187	13,910	46,308	11,216	148,457	2,959,022
	Accessible forest and Cat V/VI protected areas	1,262,995	1,810,677	16,484	779	187	14,438	47,949	11,421	188,155	3,353,084
	Pasture and Agriculture	526,056	3,387,178	20,025	292	0	43,940	78,377	7,690	130,112	4,193,669
Sharea of burned area (%)	**Total**	**12.4%**	**1.9%**	**0.3%**	**0.0%**	**0.0%**	**1.1%**	**0.2%**	**0.3%**	**2.0%**	**2.2%**
	Forest	7.2%	1.0%	0.1%	0.0%	0.0%	0.2%	0.1%	0.1%	0.9%	1.1%
	Accessible forest	6.2%	1.4%	0.1%	0.0%	0.0%	0.2%	0.2%	0.3%	1.6%	1.6%
	Accessible forest and Cat V/VI protected areas	6.2%	1.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.3%	0.7%	1.2%
	Pasture and Agriculture	10.9%	5.0%	0.4%	0.0%	0.0%	15.0%	1.4%	6.2%	10.2%	4.8%

Source: Original table based on MODIS Data.

The 2024 fires emitted an estimated 787 million tons (Mton) of CO_2e, which is 69.3 percent higher than the average emissions estimated for 2019–2023 (Figure 5).

Figure 5. GHG emissions from biomass burned in the Amazon, 2019–2024



Source: Original figure developed using GFAS data.

In 2024, fire smoke-related $PM_{2.5}$ concentrations in the Amazon were exceptionally high, with a population-weighted average of more than 3 µg/m^3—almost three times the 2019–2023 average (Table 3, Figure G1b in Appendix G). Population weighting better reflects exposure, because impacts vary significantly across the region (Map 2). The highest concentration exposure was estimated for Bolivia, with a mean of 12.1 µg/m^3, followed by Brazil, with a mean of 3.7 µg/m^3.

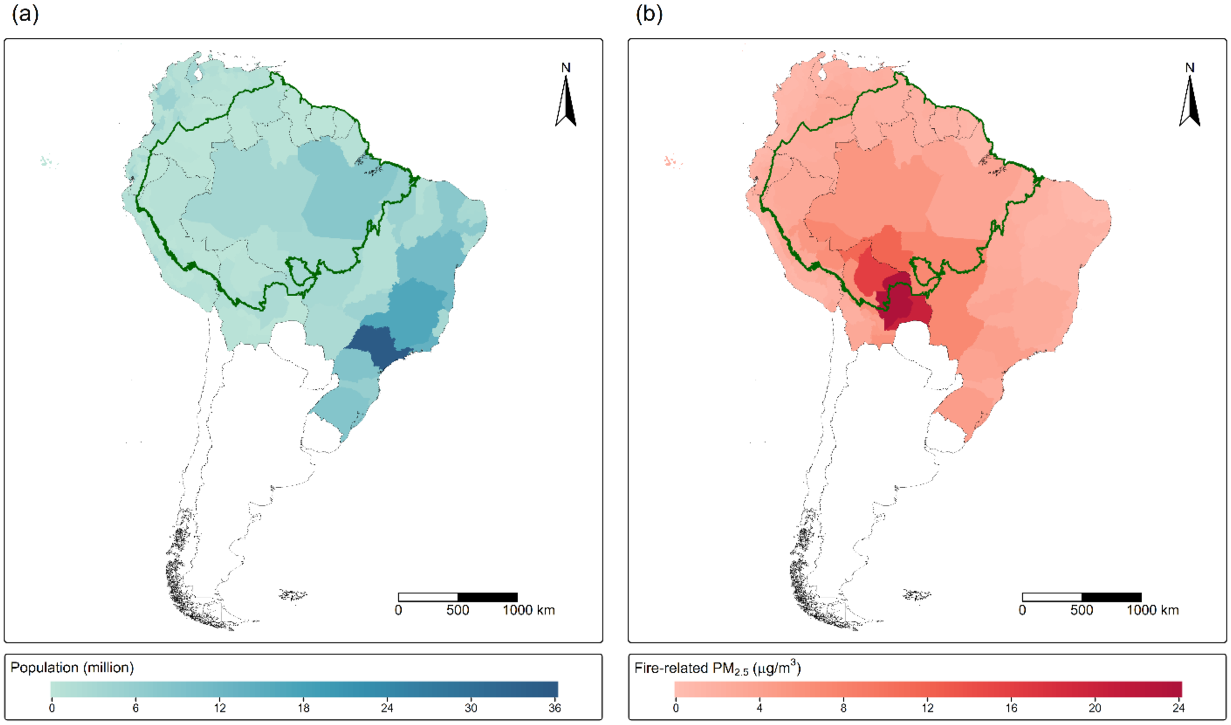
We estimate about 14,622 attributable deaths due to exposure to fire-smoke related $PM_{2.5}$ in 2024, representing 0.67 percent of all-cause mortalities for that year. This is triple the average number of fire smoke-related attributable deaths in 2019–2023 (Table H1 in Appendix H).

Table 3. Daily population-weighted fire-smoke related $PM_{2.5}$ concentrations, by country

Scenario for probabilistic sensitivity analysis	Bolivia	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela, RB
Minimum	7.3	1.6	0.7	0.6	0.5	0.7	0.9	0.5	0.8
Mean	12.1	3.7	1.6	1.9	1.2	2.5	2.1	1.9	2.1
Maximum	16.8	5.8	2.4	3.3	1.8	4.3	3.2	3.3	3.3

Source: Original table based on UN Gridded Population and $PM_{2.5}$ data.

Map 2. (a) population and (b) Mean daily population-weighted fire- $PM_{2.5}$ concentrations for 2024



The green border represents the boundary of the Amazon region used in this analysis. However, for mortality attributable to fire-related $PM_{2.5}$ concentrations, the whole population of countries/territories in the Amazon region and their exposure were considered.
Source: Original maps based on Gridded and fire-$PM_{2.5}$ data.

The total economic damages from fires in the Amazon during 2024 totaled US$43.1 billion, broken down as follows: [22]

- **Productive losses to agricultural crops and livestock** totaled about US$11.7 billion (27.2 percent of total)
- **Additional GHG emissions** totaled about US$7.9 billion (18.3 percent of total)
- **Decreases in other forest ecosystem services** totaled US$0.3 billion (0.6 percent of total)
- **Increases in short-term mortality risk due to fire smoke-related $PM_{2.5}$** caused damage of about US$23.2 billion (53.9 percent of total), corresponding to about 14,622 attributable deaths.

Overall fire damage in 2024 was equivalent to about 1.3 percent of the region's GDP, with a range between 0.6 percent and 2.4 percent.

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[22] Given ARO's high resolution burned area data is only available for 2024, comparisons of burned area in the previous section are done solely using MODIS burned area data. In addition to the uncertain parameters for 2024 already discussed (namely, the unit value of agriculture and livestock land use per hectare, the price per ton of carbon, the fire $PM_{2.5}$, the relative mortality risk related to $PM_{2.5}$, and the value of a statistical life), this valuation also considers uncertainty over the scale of the burned area. Considering uncertainty implies that the true burned area lies somewhere between MODIS and ARO estimates. This is what is reported here. Appendix I details the differences between MODIS and ARO burned areas and their consequent damages if, instead of considering uncertainty over the two sources, only one of them was used for the base estimate.

See Table 8 for a more detailed breakdown of these damages by category and country.

Table 4. Estimated annual damages, by category, per country/territory (2024 US$ million)

Category	*Bolivia*	*Brazil*	*Colombia*	*Ecuador*	*French Guiana*	*Guyana*	*Peru*	*Suriname*	*Venezuela, RB*	*Amazon*
Ecosystem services	*61*	*138*	*8*	*1*	*0*	*2*	*5*	*0*	*58*	*273*
Health: short term mortality	*803*	*19,203*	*1,095*	*477*	*11*	*42*	*1,014*	*23*	*555*	*23,224*
Agriculture and livestock	*288*	*7,568*	*762*	*7*	*0*	*454*	*488*	*45*	*2,128*	*11,740*
Carbon emissions	*1,893*	*5,291*	*147*	*6*	*7*	*66*	*219*	*23*	*215*	*7,867*
TOTAL (2024 US$ million)	*3,044*	*32,200*	*2,012*	*492*	*18*	*563*	*1,727*	*91*	*2,956*	*43,103*
Country GDP (2024 US$ million)	*48,404*	*2,171,337*	*418,542*	*121,728*	*4,985*	*24,659*	*289,070*	*4,458*	*119,808*	*3,202,991*
Damages as % of GDP	*6.3%*	*1.5%*	*0.5%*	*0.4%*	*0.4%*	*2.3%*	*0.6%*	*2.0%*	*2.5%*	*1.3%*
Shares with respect to the Amazon										
Damages	*7.06%*	*74.70%*	*4.67%*	*1.14%*	*0.04%*	*1.31%*	*4.01%*	*0.21%*	*6.86%*	*100.00%*
Forest area	*5.61%*	*58.68%*	*7.51%*	*1.56%*	*1.44%*	*3.32%*	*12.45%*	*2.42%*	*7.00%*	*100.00%*
Total area	*7.00%*	*60.15%*	*7.18%*	*1.47%*	*1.18%*	*3.01%*	*11.25%*	*2.08%*	*6.69%*	*100.00%*
Burned area	*27.46%*	*51.81%*	*3.01%*	*0.06%*	*0.02%*	*3.12%*	*2.61%*	*0.38%*	*11.54%*	*100.00%*

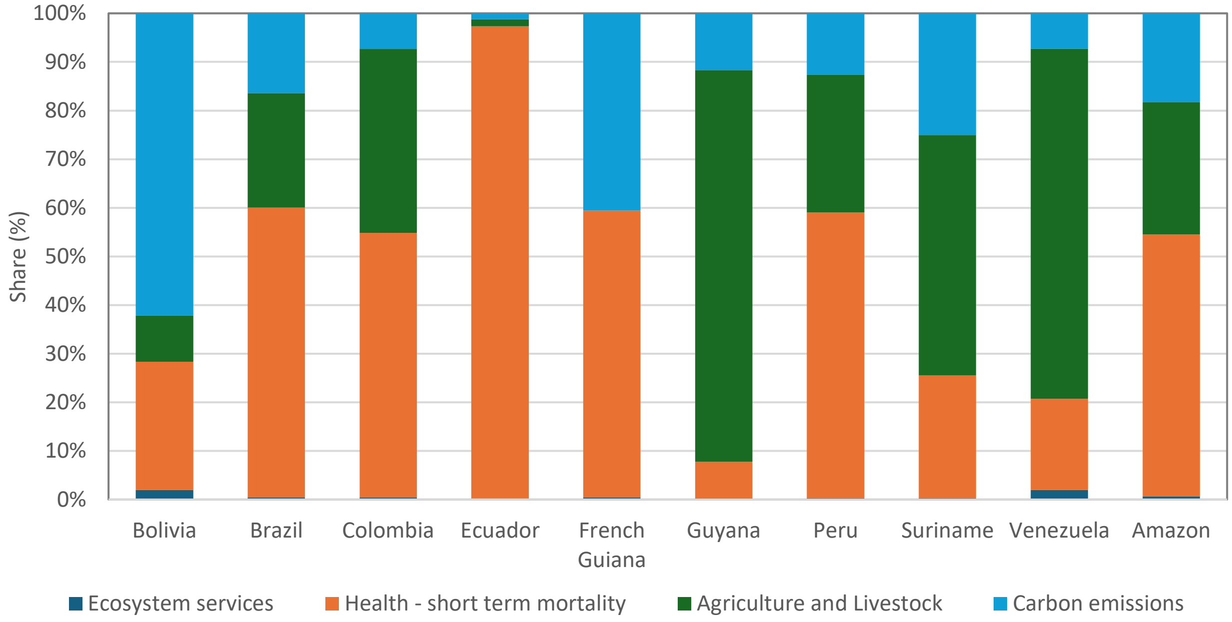
Damages are for the Amazon region of each country of territory, except for health, which considers the whole country or territory. GDP is per country since there is no information on the GDP generated in the Amazon portion of each one of them. GDP for French Guiana is for 2022 as per https://www.insee.fr/en/statistiques/serie/010751772
Source: Original table developed for this publication.

The estimates show that Brazil accounts for about 74.7 percent of the total damages, Bolivia accounts for 7.1 percent of the total damages due to fire, and Venezuela account for 6.9 percent of Amazon fire losses in 2024. After Brazil, Bolivia, and Venezuela, the remaining damages are split between Colombia (4.7 percent), Peru (4 percent), Ecuador and Guyana (1 percent each) and Suriname and French Guiana (collectively less than 0.22 percent of total damages). Brazil accounts for 60.1 percent of the amazon and 58.7 percent of the region's forests, while Bolivia accounts for 7 percent of the amazon and 5.6% of the region's forests. This implies that the share of their damage surpasses their share of the whole Amazon territory and the Amazonian forest. This is linked to the fact that, together, these countries account for more than 79 percent of the overall area burned along the Amazon in 2024 (51.8 percent for Brazil and 27.5 percent for Bolivia).

In terms of the fraction of damages relative to each country or territory's GDP, Bolivia is an outlier in the region with a relatively high 6.3 percent. For the remaining countries fire damages are equivalent to less than 3 percent of GDP, at about 2.3 percent of GDP for Suriname, Guyana, and *República Bolivariana de Venezuela*; about 1.5 percent in Brazil; and less than 0.6 percent in Peru, Ecuador, French Guiana, and Colombia.

As Figure 1 shows, the relative contribution of each damage category to total fire-related losses differs significantly from country to country. For instance, Bolivia exhibits the highest proportion of damages from carbon emissions, while productive losses in agriculture and livestock dominate in Guyana and *República Bolivariana de Venezuela*. Health-related costs represent the largest share of fire damages in the remaining countries and territories.

Figure 1. Estimated share of fire damages by category assessed for each country/territory (and total)



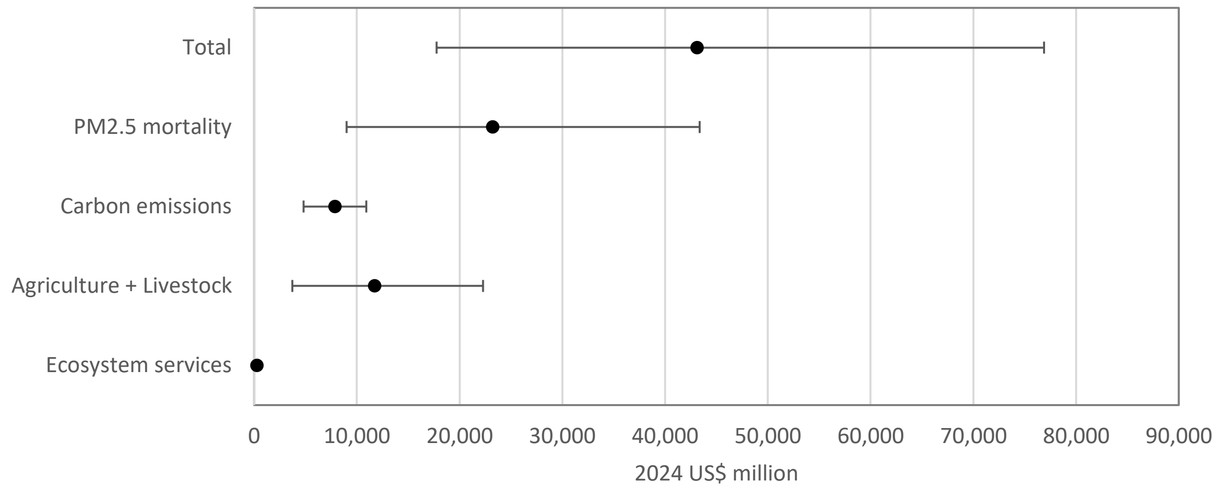
Source: Original figure developed for this report.

The total economic damage from fire in 2024 is equal to about 1.3 percent of GDP, with a range between 0.6 percent and 2.4 percent. This comparison serves only as a benchmark for scale and does not imply that Amazon countries' GDP was reduced by this percentage due to the fires. This percentage aligns with damages reported for other countries and regions, where fire-related damage was typically equal to between 0.5 percent and 3.4 percent of GDP.

How uncertainty affects this valuation

The 95 percent confidence interval means that total fire-related economic damage in the Amazon during 2024 ranges from US$17,761 million to US$76,887 million (2024 US dollars) (Figure 7). The greatest uncertainty stems from the valuation of health impacts, driven by uncertainties relating to the data source for fire-$PM_{2.5}$, the RR, and the VSL (see Section 3 "Data and methodology"). After health, the greatest uncertainty stems from the area burned and the number of hectares used for agriculture and livestock affected. A lower uncertainty comes from the price of carbon.

Figure 2. Range of damages values considering uncertainty of five variables



The line displays the 95% confidence intervals when accounting for uncertainty, while the black dot represents the mean.
Source: Original figure developed for this report.

Limitations

This report presents an assessment of fire damage across the Amazon region. However, there are substantial disparities in fire activity and exposure within the region that are not captured in this valuation's aggregated estimates.

While the primary objective of this work is to quantify total damages from fires, it does not include distributive analyses—such as identifying which populations or sectors may be disproportionately affected from fire events[23]—nor does it account for long-term impacts that extend beyond the 2024 calendar year.

The damage estimates presented in this report also do not capture the full spectrum of fire impacts, primary due to data limitations and time constraints. Several significant categories of damage were excluded from the analysis, including:

- **Direct fatalities** from exposure to flames or heat for both local populations and firefighters.
- **Morbidity impacts (other than from exposure to air pollution)**, including physical injuries, illnesses, and mental health conditions due to the potential trauma of the loss of loved ones, destruction of property, or damage to essential infrastructure. People who have experienced the effects of wildfires, for example, can face elevated risks of post-traumatic stress disorder, depression, and insomnia (To *et al*. 2021).[24] These impacts were not assessed for either the affected communities or firefighters.
- **Indigenous communities' intangible socio-cultural losses.** Social identities, traditions, and livelihoods are closely tied to forests and biodiversity in the Amazon. Fires threaten the survival

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[23] For example, fires in Chiquitanía, Bolivia, primarily affected Indigenous territories and communities (Painter 2020).

[24] As already noted, there is evidence that mortality is responsible for most of the total economic damage, at least when it comes to health damages associated with smoke.

of traditional architecture, medicinal knowledge, and cultural practices that have been passed down from generation to generation. The resulting loss can erode the unique expressions of identity and spiritual connections that Indigenous communities maintain with their lands and ecosystems.

- **Loss of homes and infrastructure**, including residential, commercial, and public assets.[25]
- **Indirect economic impacts** such as short-term business interruptions, disruption of public services (such as electricity, water, public safety, and education), and displacement-related effects (that is, migration and job losses).
- **Emergency response and recovery costs**, including aid relief, evacuation services, fire suppression, and immediate road and landscape stabilization.
- **Biodiversity and wildlife impacts**, such as animal mortality from fire and smoke, among other examples, are not valued in this report.[26]
- **Environmental degradation**, including soil quality deterioration, which may affect future agricultural productivity.
- **Changes in agricultural emissions**, such as reductions in the emission of methane due to a decline in livestock numbers due to fires.
- **Market disruptions**, including price increases due to product scarcity.

In addition, the following technical limitations should be noted:

- **Temporal resolution.** This report does not consider intra-annual variations in burned area or the timing of harvesting. For example, a crop harvested early in the year may have been unaffected by a fire that occurred later on. In this analysis, any burned pixel was assumed to result in total crop loss, regardless of when the fire took place. Incorporating finer temporal detail could improve accuracy.
- **Uniform ecosystem service values.** Forest ecosystem service values were applied uniformly across each country. More precise estimates would be possible if the Changing Wealth of Nations releases geospatially differentiated values.
- **VSL transfer limitations.** The transferred VSL values were adjusted only for income differences. Further refinements could include adjustments for age, health status, and other demographic factors, as well as spatial variations in income across Amazon countries.
- **Unit value availability.** Some unit values, such as those for agriculture, were only available for some years (for example, data for Bolivia was only available from 2020 to 2022, and data for

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[25] Housing, non-residential buildings, and infrastructure losses could be assessed using the Global Rapid Post Disaster Damage Estimation (GRADE) methodology (World Bank 2025). GRADE was applied to 66 cases, and could be used for fires, even if until now it has only been used for other disasters (earthquakes, tropical cyclones, floods, and volcanic eruptions). However, such an assessment requires 15 experts working seven to 21 days each (World Bank 2025), which exceeds the time and resources available for this valuation. In future, satellite imagery could be used to identify damaged buildings (Galanis *et al*. (2021), Du and Feng (2025), ideally as part of a smaller case study with a longer time frame.

[26] Wildfires can cause major biodiversity losses, damage ecological networks and cause significant declines in sensitive vertebrate populations, especially at forest edges and in fragmented habitats. There is evidence of these effects in the Amazon, even if generally they are not valued. In Bolivia, for example, fires occurring between 2001 and 2020 have observably impacted dozens of threatened and endemic species, with the most severe effects seen in the Amazon rainforest (Maillard *et al*. 2022).

Guyana and Suriname were only available for 2019 to 2021). For years without data, values were based on interpolation and average years with data.

- **Cross-validation with national data.** Further validation using unpublished or subnational data from each government—such as unit values, fire impacts, and sectoral losses—would strengthen the robustness of the estimates in this report.

These limitations should be considered when interpreting the results of this valuation. Further research may be needed to enhance the precision and policy relevance of fire-related damage assessments in the Amazon.

5. Conclusion

This study estimates total damages for 2024 at US$43,103 million (2024 US dollars), with a 95 percent confidence interval that ranges between US$17,761 million and US$76,887 million. This is equivalent to about 1.3 percent of the Amazon countries' GDP for the year, with a range of 0.6 percent to 2.4 percent. These results are within the range of existing evidence from other regions and countries, where damages range from 0.5 percent to 3.4 percent of GDP.

Total economic damages from fires can be broken down as follows:

- **Productive losses to agricultural crops and livestock** totaled US$11,740 million (17.9 percent of total; 95 percent CI: US$3,719 million–US$22,283 million), affecting nearly 4.2 million hectares of agricultural and pastureland
- **Additional GHG emissions** totaled US$7,867 million (18.25 percent of total; 95 percent of total CI: US$4,814–US$10,920 million)
- **Decreases in other forest ecosystem services** totaled US$273 million (0.63 percent of total; 95 percent CI: US$227 million–US$318 million)
- **Increases in short-term mortality risk due to fire smoke-related $PM_{2.5}$** totaled US$23,224 million (53.88 percent of total; 95 percent CI: US$9,002 million–US$43,366 million), corresponding to an estimated 14,622 deaths (95 percent CI: 6,184–25,421 deaths).

Most Amazon fire-related damages occurred in Brazil and Bolivia, which accounted for 74.7 percent and 7.1 percent of the region's total losses, respectively. This is a higher share than their share of land and forest in the Amazon. Roughly 15.5 percent of damages were distributed among *República Bolivariana de Venezuela*, Colombia, and Peru, while Guyana and Ecuador accounted for about 1.3 percent and 1.1 percent, respectively. Suriname and French Guiana contributed the smallest portion, at 0.2 percent and 0.4 percent of the overall fire losses, respectively.

When viewed as a percentage of each country or territory's GDP, Bolivia stands out as a regional exception, with losses equivalent to 6.3 percent of GDP. For Suriname, Guyana, and *República Bolivariana de Venezuela*, fire damages were equivalent to about 2.3 percent of each country's GDP, while in Brazil, the figure was roughly 1.5 percent. Meanwhile, in Peru, Ecuador, French Guiana, and Colombia, the impact was smaller, with fire damages accounting for less than 0.6 percent of national GDP.

The share of fire-related losses apportioned to each of the four categories of damage assessed differs from country to country. In Bolivia, for example, GHG emissions accounted for the largest portion of losses, while agricultural and livestock losses were the most significant category of loss in Guyana and *República Bolivariana de Venezuela*. In other countries, health-related expenses made up the greatest share of fire damage.

Due to data limitations and time constraints, several key categories of fire-related damage were not included in this assessment. These omissions include direct mortality, morbidity impacts (other than from exposure to air pollution from fires), socio-cultural damage to Indigenous communities, the loss of homes and infrastructure, indirect economic effects, emergency response costs, wildlife and biodiversity impacts, environmental degradation, agricultural emissions, and market disruptions, among others. The results presented here also do not account for the uneven regional impacts of fires across the Amazon. Given that only four impacts among many have been assessed, the overall estimate of damages may be conservative.[27]

If climate change continues to drive increases in the frequency and intensity of fires, future damages may not rise in direct proportion. Adaptation measures could mitigate some impacts: for example, awareness-raising efforts could teach people to avoid exposure to smoke, among many other possible actions. However, damages could also escalate significantly, especially in the absence of effective policy and planning.

If allowed to escalate, fires could push the Amazon region across a pivotal ecological threshold beyond which vast stretches of Amazon rainforest may transition into more open, savanna-like landscapes that, while ecologically distinct and sometimes valuable in their own right, represent a significant loss of the rainforest's unique biodiversity and ecosystem functions (Flores *et al* 2024). The estimates presented in this report offer a snapshot of fire impacts within a single year and do not account for such potential long-term, cumulative consequences.

Despite limitations, this report offers a valuable estimate of fire damages, underscoring the urgent need for greater investment and improved efficiency in fire management. It links the implications of fires with fiscal consequences, highlighting contingent liabilities and the need for better budget planning, particularly for governments but also for private actors.

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[27] Some of the impacts that were estimated could also be overestimated. For example, because this valuation regards any burned area as being unproductive for the whole year, it would not capture instances where the affected area recovered and value-generating activities resumed.

6. A Way Forward

The management of fires is a complex and multifaceted challenge that demands attention to:

- Shifting away from responding to emergencies to holistically investing in the Five Rs
- Conducting detailed cost-benefit analyses
- Strengthening enforcement, coordination, and local capacity
- Explore opportunities for regional cooperation.

These are discussed in greater detail below.

1. Invest in the Five Rs

The five phases of strategic fire planning, commonly known as the “Five Rs”, are review and analysis, risk reduction, readiness, response, and recovery (see box). Each phase plays a crucial role in mitigating the impacts of fires and ensuring the safety and resilience of communities and ecosystems. These phases relate to the “Three Is” needed for effective fire management: information; institutions—including responsible agencies, coordination mechanisms, and regulatory frameworks; and infrastructure—encompassing both human resources and physical equipment. Enhancing all these aspects is essential not only to reduce future damage but also to build resilience in the face of a changing climate.

This report emphasizes the need for legal reforms to support effective fire management. Despite the allocation of budgets and special funds, financial resources are often insufficient to manage growing threats such as fires. Responding to emergencies as they happen—a common approach—limits the gains in efficiency and cost-effectiveness from making more balanced investments across all phases of the Five Rs (Heines *et al*. (2018). It is crucial to understand how to maximize the impact of limited financial resources. In doing so, funding can be directed toward policies and interventions that yield the greatest benefits relative to their costs.

Box 1. The "Five Rs" of strategic fire planning

Developing effective strategies to manage fires requires attention to these five aspects.

1. **Review and analysis (monitoring)**

This involves the systematic gathering and examination of data on past fire events to understand the factors that influence fires, such as fuel, weather conditions, fire behavior, ecological responses, management strategies, and public reactions.

2. **Risk reduction**

This focuses on implementing various actions to decrease the likelihood and consequences of potential fires. This phase includes managing fuel at different scales (ranging from individual plots to entire landscapes), designing resilient buildings, effectively planning land use, and reducing the incidence of arson and accidental fires.

3. **Readiness**

Readiness involves preparing communities and fire departments to respond efficiently when fires occur. For residents, this preparation may include developing and practicing evacuation plans or having a considered plan for confinement if evacuation is not possible. Fire departments should also be equipped with trained personnel and appropriate technologies, and should have established systems and procedures in place.

4. **Response**

This encompasses the actions taken to manage a fire once it has ignited, and includes the allocation and management of resources, such as personnel and equipment, to suppress the fire. Effective incident management requires clear communication, coordination, and decision-making to ensure that resources are deployed where they are needed most. Providing timely fire alerts and fire-status updates to the public is essential for keeping communities informed and safe. Organized evacuations may be necessary to protect residents from the immediate danger of fires.

5. **Recovery**

Recovery involves efforts to mitigate the ecological, social, and economic impacts of a fire after it has been controlled. This phase includes activities such as restoring damaged ecosystems, rebuilding infrastructure, and providing support to affected communities.

2. Conduct detailed cost-benefit analyses

There are few existing studies that apply cost-benefit analysis to prioritize more appropriate fire-related policies, and most existing evidence focuses on developed countries.[28] This lack of available research also applies to the Amazon at both the biome and the national level.

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[28] Buckley *et al*. (2014), for example, found that in a California watershed, the benefits of fuel treatment are between 1.9 and 3.3 times higher than the costs. Similarly, Jones *et al*. (2022) examined fire mitigation activities—mainly mechanical thinning—in

Cost-benefit analyses—or at least cost-effective analyses that, for example, compare the costs of fire-management programs with outcomes (like reduced burned area)—would be valuable for guiding fire management across the Amazon. Such evaluations are essential for guiding the allocation of resources and improving policy design even as countries and economies work to address the widespread impacts of forest fires.

3. Strengthen enforcement, coordination, and local capacity

Stronger enforcement, coordination between agencies, improved local capacity for fire management, and engagement with affected communities are crucial for effective fire management.

4. Explore opportunities for regional cooperation

The Amazon is an interconnected ecosystem, transcending national borders. Its rivers, forests, and biodiversity form one vast, shared biome. Similarly, fire is a shared threat that is best managed in a collective fashion.

Countries in the Amazon would benefit from sharing data, harmonizing monitoring and response strategies, and developing best practices tailored to the region's unique ecological and social context. Such collaboration would complement country efforts to pool expertise, align methodologies, and generate a more comprehensive understanding of both the costs and the wide-ranging benefits of fire interventions, including for ecosystem services and climate regulation.

Such cooperation could be enhanced through regional organizations like the Amazon Cooperation Treaty Organization and the Amazon Network for Integrated Fire Management (RAMIF). Ultimately, regional collaboration leverages collective knowledge and resources, ensuring that investments in fire management are not only more efficient but also more impactful for the Amazon's ecological integrity and the well-being of its people.

How development funders can help

Support from international donors could focus on: (a) data improvement; (b) cost-benefit analyses; (c) the financing of integrated fire management, including by developing innovative financing mechanisms such as disaster risk insurance and results-based funding for prevention, readiness, and recovery; (d) building local capacity by supporting the development of early warning systems and strengthening the ability of public agencies, local communities, and Indigenous groups to prevent and respond to fires; and (e)

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areas supplying municipal water to Denver, Colorado, during the 2011–2019 period. Their research showed a benefit-cost ratio greater than 1 when a fire was encountered within a 25-year period and when other co-benefits, beyond watershed protection, were included. However, under alternative assumptions, the benefit-cost ratio fell below 1. More recently, Hjerpe *et al*. (2024) estimated a benefit-cost ratio of 7.04 for thinning and burning alternatives in the western United States. Yet the evidence supporting fire management extends beyond fuel treatment. Prestemon *et al*. (2010), for example, found that fire education from 2002 to 2007 aimed at preventing ignition in Florida yielded statewide benefits that averaged 35 times the costs. Studies of the efficiency of fire management alternatives also exist outside the United States. In southeastern Australia, Venn and Quiggin (2017) evaluated three policies: landscape-scale prescribed fires, bushfire defense sprinklers for home ignition zones, and early evacuation. Of these, only early evacuation resulted in net economic benefits. Additionally, Hope et al. (2024) conducted a cost-benefit analysis for an Earth observation mission (FireSat) designed to gather satellite data essential for fire monitoring. Under pessimistic and conservative assumptions, the mission's costs exceeded expected benefits by 1.16 to 1.59 times. However, with more optimistic assumptions, benefits surpassed costs by 8.72 to 10.48 times.

targeting vulnerable populations by supporting health, housing, and livelihoods interventions for those communities most affected by fires.

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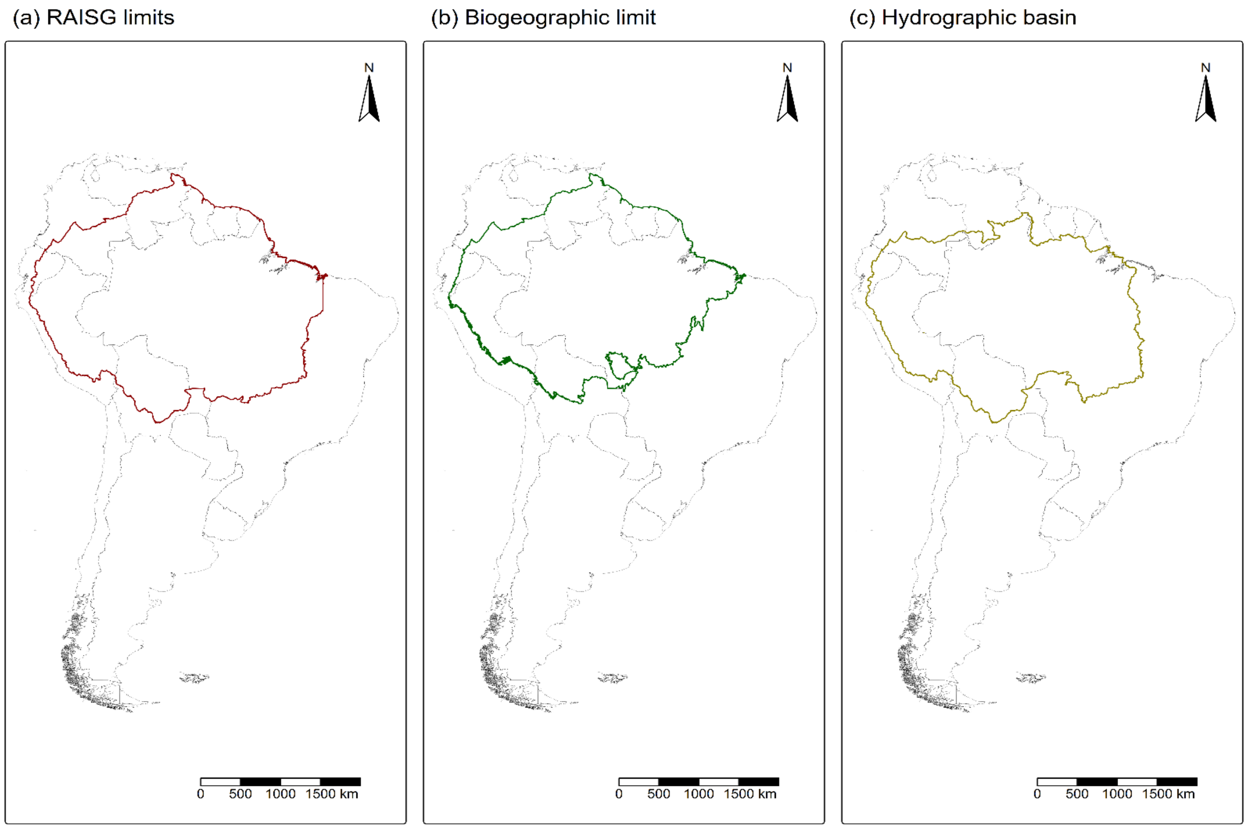
Appendixes

Appendix A. Alternative definitions of the Amazon

Map A1. Alternative definitions of the Amazon


(a) RAISG limits

(b) Biogeographic limit

(c) Hydrographic basin

(a) corresponds to Amazon maximum limit: biome + administrative regions + hydrographic basins.
(b) Map (b) is the one used in this report.
Source: https://www.raisg.org/en/infographic/

Appendix B. Fire-related indicators

Besides MODIS active fire hot spots (**Error! Reference source not found.**), the following indicators (Figures B1 and B2) related to either fire activity or weather conditions that would promote fire activity were considered:

- **VIIRS active fire hot spots:** The cumulative total of active fire hot spots was obtained using data obtained from the VIIRS NRT 375 m active fire products (Schroeder *et al*. 2014), with fire detections available since January 2012 (Figure B1a and B1b).
- **MODIS burned area.** The total annual burned area was calculated using the MODIS product (MCD64A1v061) burned area (hectares/year) (Giglio *et al*., 2021) available at a 500 m x 500 m spatial resolution (Figure B2c and B2d).[29]
- **Drought.** The percentage of land experiencing at least six months of drought was calculated, following the methods presented by the Lancet Countdown Report (2024) (Figure B2e and B2f). This indicator used the six-monthly Standard Precipitation and Evapotranspiration Index (SPEI6) to capture changes in extreme drought (SPEI ≤–1·6).
- **Fire-related $PM_{2.5}$.** The annual mean fire-related $PM_{2.5}$ concentration was calculated using daily estimates developed by Hänninen *et al*. (2025) from the Finnish Meteorological Institute (Figure B2 g and B2h).
- **Fire risk.** The number of days experiencing very high or extremely high risk of fire were calculated following the methods presented by the Lancet Countdown Report (2024). This indicator used the Canadian Fire Weather Index to identify days with a very high or extremely high risk of fires (Figure B2i and B2j).

During the early 2000s, the Amazon region suffered substantially higher levels of deforestation than the observed nowadays, with levels peaking in 2003.[30] This fact could bias the interpretation of long-term trends—mainly in relation to the contribution of climate change to these changes—of the previous indicators presented in Figure B2. Given this, each indicator was presented for two time periods: the trend from the beginning of this century (for instance, 2001, 2002, or 2003), mostly depending on when data was available, and the trend from 2011 onwards, where a clear increasing trend across all variables assessed could be observed.

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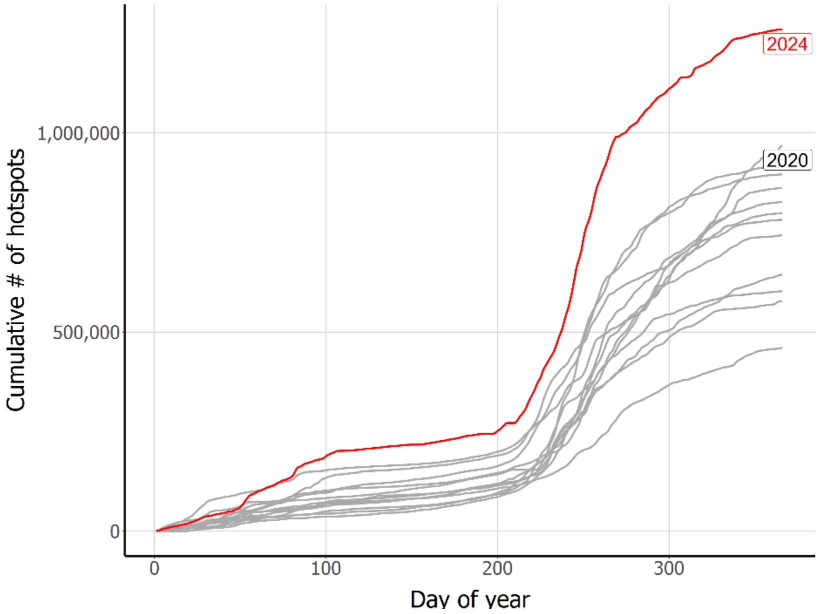
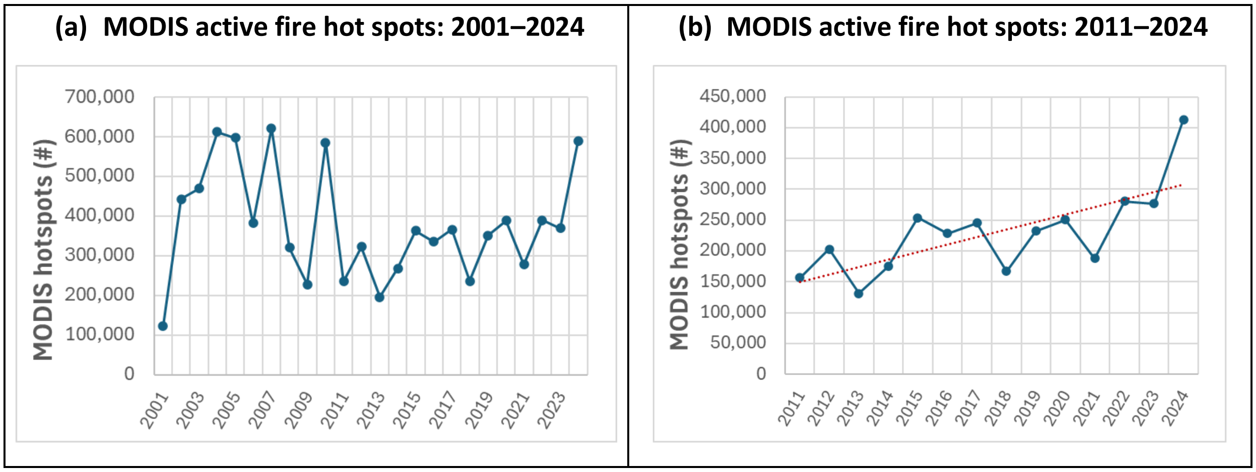
Figure B1. Cumulative number of VIIRS hot spots by day of the year for 2024 (red) and 2012–2023 (gray)



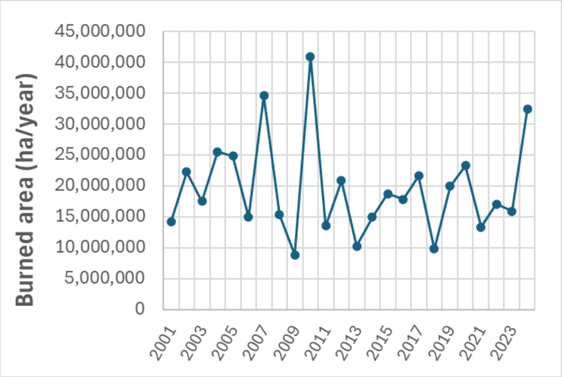
Source: Original figure developed using VIIRS data.

Figure B2. Temporal trends of fire-related indicators, 2001–2024

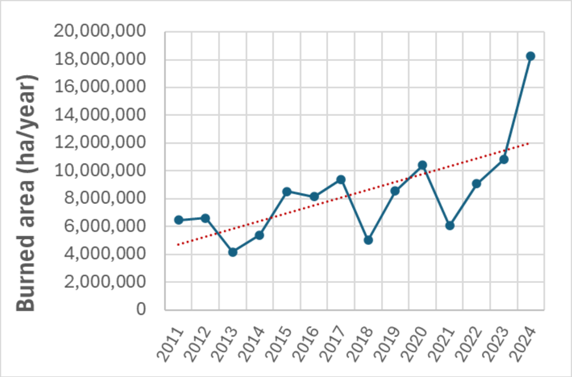

(a) MODIS active fire hot spots: 2001–2024

(b) MODIS active fire hot spots: 2011–2024

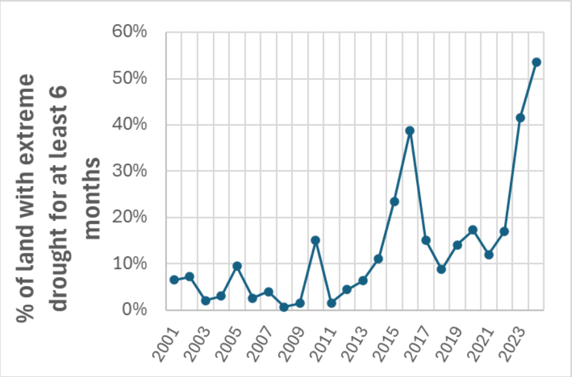
(c) MODIS burned area: 2001–2024



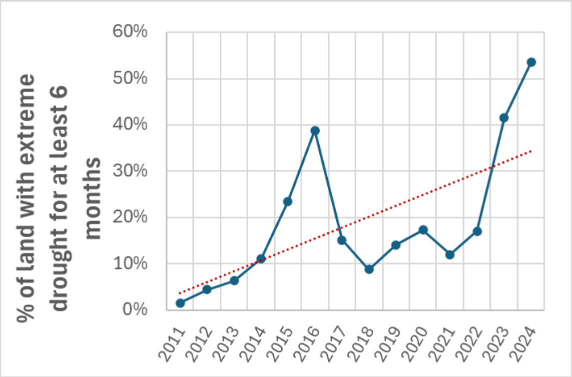
(d) MODIS burned area: 2011–2024



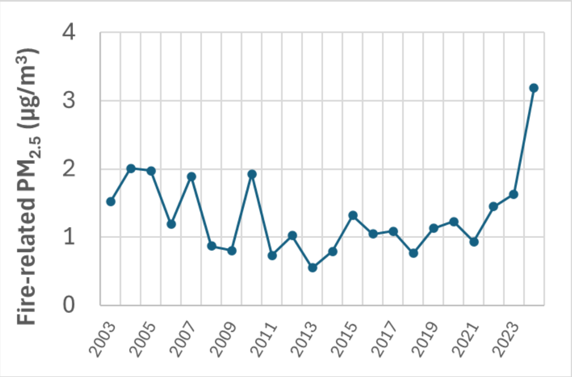
(e) Drought: 2001–2024



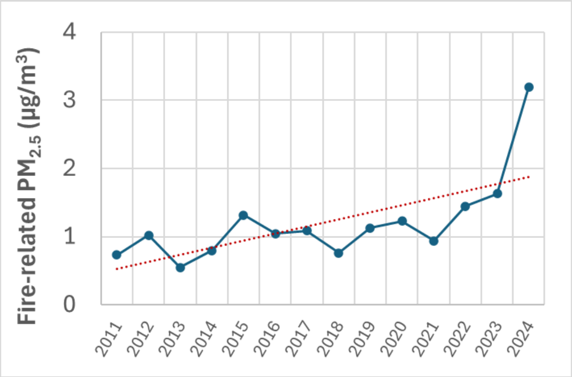
(f) Drought: 2011–2024

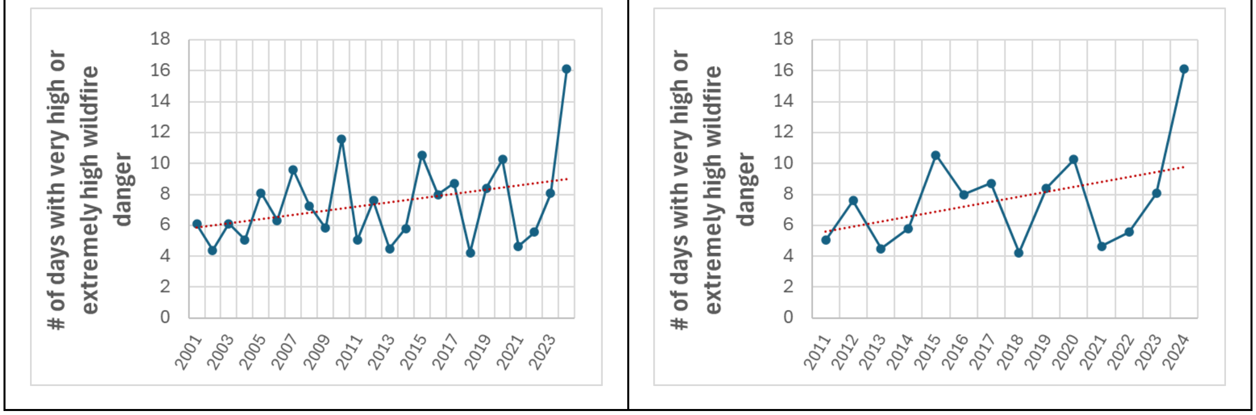


(g) Fire smoke-related $PM_{2.5}$: 2003–2024



(h) Fire smoke-related $PM_{2.5}$: 2011–2024





(i) Fire risk: 2001–2024

(j) Fire risk: 2011–2024

Source: Original figures developed for this report.

Appendix C. Geographical scope and land cover data

This assessment uses the biogeographic limits used by the Amazon Regional Observatory (ARO). MapBiomas Amazonia land cover data was used at a 30 m x 30 m spatial resolution (Map C1). The area of analysis covers parts of nine countries: Brazil, Bolivia, Peru, Ecuador, Colombia, *República Bolivariana de Venezuela*, Guyana, Suriname, and French Guiana. This dataset considers the 21 level-2 land cover classes presented in Map C1. Table C1 summarizes the total land cover area for each of these land cover classes for 2019 to 2023, estimated for the biogeographic limits used for this study.

Map C1. Land cover classes from MapBiomas Amazonia (2023) within the biogeographic limits

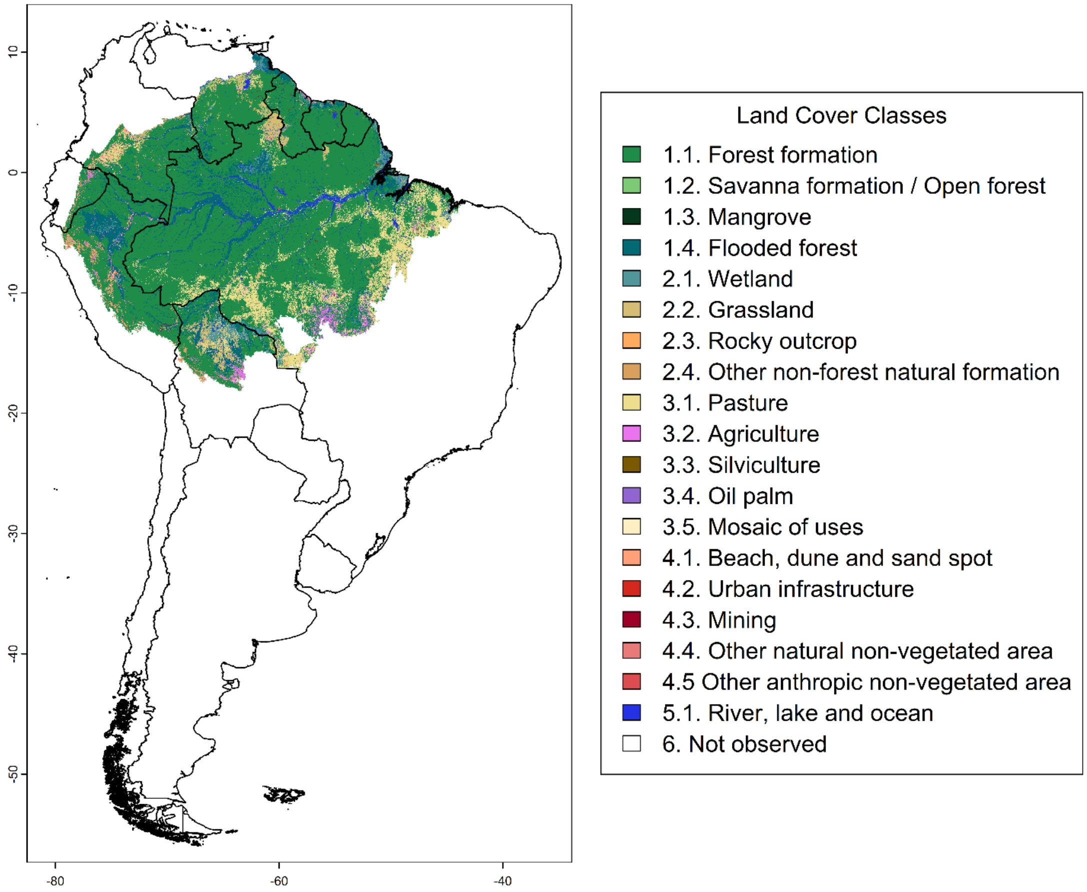


Table C1. Total area in hectares by land cover classes from MapBiomas Amazonia within the biogeographic limits: 2019–2023

Land cover class	2019	2020	2021	2022	2023
1. Natural forest	**573,630,126**	**572,195,725**	**569,720,869**	**566,830,186**	**563,781,126**
1.1. Forest formation	511,241,059	509,840,132	507,549,206	504,869,413	483,288,429
1.2. Savanna formation/open forest	1,717,450	1,715,582	1,715,569	1,714,270	2,120,593
1.3. Mangrove	767,262	761,997	766,618	753,788	783,790
1.4. Flooded forest	59,904,354	59,878,014	59,689,476	59,492,715	77,588,315
2. Non-forest natural formation	**42,218,883**	**42,231,008**	**41,742,055**	**39,419,334**	**39,393,323**
2.1. Flooded grassland/shrubland	15,332,201	15,029,420	14,389,922	13,277,804	17,255,183
2.2. Grassland	24,608,018	24,951,706	25,071,802	23,863,189	19,461,165
2.3. Rocky outcrop	696,468	696,794	697,133	700,040	1,044,175
2.4. Other non-forest natural formation	1,582,196	1,553,089	1,583,198	1,578,300	1,632,799
3. Farming and silviculture	**75,826,498**	**77,345,259**	**79,910,721**	**84,043,853**	**87,031,581**
3.1 Pasture	58,492,615	59,523,727	61,634,724	65,310,983	67,219,124
3.2 Agriculture	10,179,910	10,376,763	10,466,655	10,676,046	10,787,883
3.3 Silviculture	345,689	348,724	362,379	363,337	395,359
3.4 Oil palm	438,686	463,586	461,585	484,961	368,456
3.5 Mosaic of uses	6,369,598	6,632,460	6,985,378	7,208,526	8,260,759
4. Non-vegetated area	**1,628,816**	**1,678,326**	**1,764,515**	**1,898,132**	**2,339,024**
4.1. Beach, dune, and sand spot	38,774	37,829	37,486	43,397	233,204
4.2. Urban infrastructure	587,057	595,470	602,350	631,026	697,769
4.3. Mining	461,003	484,819	540,009	588,535	739,608
4.5. Other natural non-vegetated area	-	-	-	-	219,829
4.6. Other non-vegetated anthropic area	541,982	560,207	584,670	635,174	448,614
5. Water	**13,136,796**	**12,990,808**	**13,302,695**	**14,250,128**	**13,894,178**
5.1. River, lake, and ocean	13,136,796	12,990,808	13,302,695	14,250,128	13,894,178
6. Not observed	900	892	1,164	385	179
6. Not observed	900	892	1,164	385	179
Total	**706,442,018**	**706,442,018**	**706,442,018**	**706,442,018**	**706,439,411**

Because a different definition for the Amazon region was used, these aggregate surface areas do not correlate with statistics published by MapBiomas Amazonia. For example, for 2023, MapBiomas Amazonia declares a total of 842,441,896 hectares for the whole country, while this valuation estimates a total of 706,439,411 hectares. These differences relate to using different definitions for the Amazon region (see Appendix A).

Source: Original table for this publication.

Appendix D. Estimation of unit values for productive activities

To estimate the unit costs (2024 US dollars per hectare) of burned areas dedicated to productive activities, we combined gross value of production (GVP) from FAO (current US dollars per year) with burned area estimates from two sources:

- FAO area harvested (hectares per year)
- MapBiomas Amazonia land cover maps, covering total agricultural, pasture, and mosaic of uses area.

These datasets were available for selected years between 2019 and 2023. Using this data, we calculated unit values for 2024 (US dollars per hectare) using two approaches, namely:

- A trend-based extrapolation for available years
- Mean values of available years.

This was done for each country within the Amazon biome, resulting in four unit-cost estimates per country:

- FAO only (trend)
- FAO only (mean)
- FAO + MapBiomas (trend)
- FAO + MapBiomas (mean).

These four estimates were used to derive minimum, mean, and maximum values, which were then applied in a triangular distribution in a probabilistic sensitivity analysis to account for uncertainty in cost estimates. See details by country in Table D1 below.

Table D1. Estimation of unit values for productive activities

Country	Variable	2019	2020	2021	2022	2023	2024
Bolivia	FAO – Gross production value (current US$ thousand)		2,155,648	2,061,613	2,214,348		
	FAO – Gross production value (2024 US$ thousand)		2,612,726	2,386,632	2,373,499		
	FAO – Area harvested (hectares)	3,817,462	3,827,436	3,958,475	4,119,917	4,513,081	
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	10,266,977	10,736,450	11,375,645	11,990,160	13,243,503	
	Unit value – FAO only (2024 US dollars/ha)		683	603	576		
	Unit value – FAO + MapBiomas (2024 US$/ha)		243	210	198		
	Unit value – FAO only (trend) (2024 US$/ha)						460
	Unit value – FAO only (mean) (2024 US$/ha)						621
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						148
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						217
Brazil	FAO – Gross production value (current US$ thousand)	106,663,060	105,595,813	150,163,835	182,611,894		
	FAO – Gross production value (2024 US$ thousand)	130,874,399	127,986,083	173,837,553	195,736,715		
	FAO – Area harvested (hectares)	81,557,881	84,055,137	86,775,682	91,810,405	97,278,070	
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	266,177,860	268,364,498	271,523,190	275,262,774	279,250,333	
	Unit value – FAO only (2024 US$/ha)	1,605	1,523	2,003	2,132		
	Unit value – FAO + MapBiomas (2024 US$/ha)	492	477	640	711		
	Unit value – FAO only (trend) (2024 US$/ha)						2,536
	Unit value – FAO only (mean) (2024 US$/ha)						1,816
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						868
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						580
Colombia	FAO – Gross production value (current US$ thousand)	35,311,377	32,289,103	36,887,749	34,307,388	35,949,196	
	FAO – Gross production value (2024 US$ thousand)	43,326,671	39,135,603	42,703,198	36,773,155	37,009,527	
	FAO – Area harvested (hectares)	4,561,104	4,375,305	4,393,003	4,434,451	4,595,344	
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	29,635,559	29,931,485	30,256,690	30,574,148	30,971,009	
	Unit value – FAO only (2024 US$/ha)	9,499	8,945	9,721	8,293	8,054	
	Unit value – FAO + MapBiomas (2024 US$/ha)	1,462	1,308	1,411	1,203	1,195	
	Unit value – FAO only (trend) (2024 US$/ha)						7,834
	Unit value – FAO only (mean) (2024 US$/ha)						8,902
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						1,124
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						1,316
Ecuador	FAO – Gross production value (current US$ thousand)	6,234,790	6,240,500	6,472,767	6,252,341	4,904,681	
	FAO – Gross production value (2024 US$ thousand)	7650018.633	7563719.872	7493215.492	6701714.006	5049345.802	
	FAO – Area harvested (hectares)	2,163,253	2,203,174	2,236,733	2,160,414	2,077,684	
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	7,450,590	7,481,264	7,512,000	7,516,002	7,601,262	
	Unit value – FAO only (2024 US$/ha)	3,536	3,433	3,350	3,102	2,430	
	Unit value – FAO + MapBiomas (2024 US$/ha)	1,027	1,011	997	892	664	
	Unit value – FAO only (trend) (2024 US$/ha)						2,407
	Unit value – FAO only (mean) (2024 US$/ha)						3,170
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						666
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						918
Guyana	FAO – Gross production value (current US$ thousand)	665,601	659,399	984,192			
	FAO – Gross production value (2024 US$ thousand)	816,685	799,216	1,139,352			
	FAO – Area harvested (hectares)	234,698	242,675	215,550			

Country	Variable	2019	2020	2021	2022	2023	2024
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	283,993	285,128	284,041			
	Unit value – FAO only (2024 US$/ha)	3,480	3,293	5,286			
	Unit value – FAO + MapBiomas (2024 US$/ha)	2,876	2,803	4,011			
	Unit value – FAO only (trend) (2024 US$/ha)						7,627
	Unit value – FAO only (mean) (2024 US$/ha)						4,020
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						5,496
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						3,230
Peru	FAO – Gross production value (current US$ thousand)	10,040,798	9,872,992	10,203,982	12,112,390	13,179,926	
	FAO – Gross production value (2024 US$ thousand)	12,319,949	11,966,436	11,812,666	12,982,941	13,568,671	
	FAO – Area harvested (hectares)	3,436,586	3,389,336	3,495,397	3,521,802	3,460,385	
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	12,719,516	12,938,600	13,100,078	13,369,599	13,556,686	
	Unit value – FAO only (2024 US$/ha)	3,585	3,531	3,379	3,686	3,921	
	Unit value – FAO + MapBiomas (2024 US$/ha)	969	925	902	971	1,001	
	Unit value – FAO only (trend) (2024 US$/ha)						3,859
	Unit value – FAO only (mean) (2024 US$/ha)						3,621
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						984
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						953
Suriname	FAO – Gross production value (current US$ thousand)	255,586	169,890	184,273			
	FAO – Gross production value (2024 US$ thousand)	313,601	205,913	213,324			
	FAO – Area harvested (hectares) (*)	83,000	83,000	83,000			
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	140,296	139,257	165,749			
	Unit value – FAO only (2024 US$/ha)	3,778	2,481	2,570			
	Unit value – FAO + MapBiomas (2024 US$/ha)	2,235	1,479	1,287			
	Unit value – FAO only (trend) (2024 US$/ha)**						
	Unit value – FAO only (mean) (2024 US$/ha)						2,943
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)**						
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						1,667
Country	**Variable**	**2010**	**2011**	**2012**	**2013**		**2024**
Venezuela, RB***	FAO – Gross production value (current US$ thousand))	17,863,498	14,356,637	15,062,537	16,756,498		
	FAO – Gross production value (2024 US$ thousand)	25,697,952	20,021,043	20,579,594	22,563,496		
	FAO – Area harvested (hectares)	2,045,999	2,033,879	1,743,164	1,782,359		
	MapBiomas – Agriculture, pasture, and mosaic of uses (hectares)	130,036,569	130,519,832	130,910,385	130,910,563		
	Unit value – FAO only (2024 US$/ha)	12,560	9,844	11,806	12,659		
	Unit value – FAO + MapBiomas (2024 US$/ha)	198	153	157	172		
	Unit value – FAO only (trend) (2024 US$/ha)						12,500
	Unit value – FAO only (mean) (2024 US$/ha)						11,717
	Unit value – FAO + MapBiomas (trend) (2024 US$/ha)						145
	Unit value – FAO + MapBiomas (mean) (2024 US$/ha)						170

** FAO area data for Suriname was only available for the year 2012 (and applied to 2019-2021) and was obtained from the country profile report published by FAO* [31]

*** The unit values for Suriname using the trend alternative were not considered because they were negative values and did not make sense.*

**** Unit values for* República Bolivariana de Venezuela *were estimated based on available data for 2010–2013.*

Source: Original table for this publication.

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[31] FAO (Food and Agriculture Organization). 2015. AQUASTAT Country Profile – Suriname. Rome, Italy. https://openknowledge.fao.org/server/api/core/bitstreams/972d0f28-da70-4314-a907-2a9969ba29ed/content

Appendix E. A brief explanation of the health losses formula

The attributable function (AF) aims to estimate the portion of deaths that can be attributed to a risk factor. In this case, air pollution is the risk factor, measured by $PM_{2.5}$ concentration in $\mu g/m^3$. First, it is important to understand what relative risk (RR) is, using a contingency table as presented in Table E1:

Table E1. Contingency table

		Deaths due to $PM_{2.5}$ exposure	
		Yes	*No*
People exposed	*Yes*	a	b
	No	c	d

Source: Original table for this publication.

This table implies that the relative risk can be thought of as the quotient between the rates of disease in exposed and in non-exposed individuals or:

$$RR = (a/a+b)/(c/c+d) \qquad (E1)$$

Therefore, if RR > 1, the disease (and the death of the person from it) is more frequent among the exposed than among the non-exposed and is, therefore, a risk factor.

The attributable fraction is then the difference between this RR and 1, which is when the numerator and denominator of (E1) are the same. So:

$AF=RR-1/RR= 1-1/RR$
(E2)

The RRs are derived from epidemiological studies that link deaths with exposure to $PM_{2.5}$ (X). For instance, Wang *et al.* (2020) uses a log-linear function:

$$Ln(RR)=\beta \bullet X \qquad (E3)$$

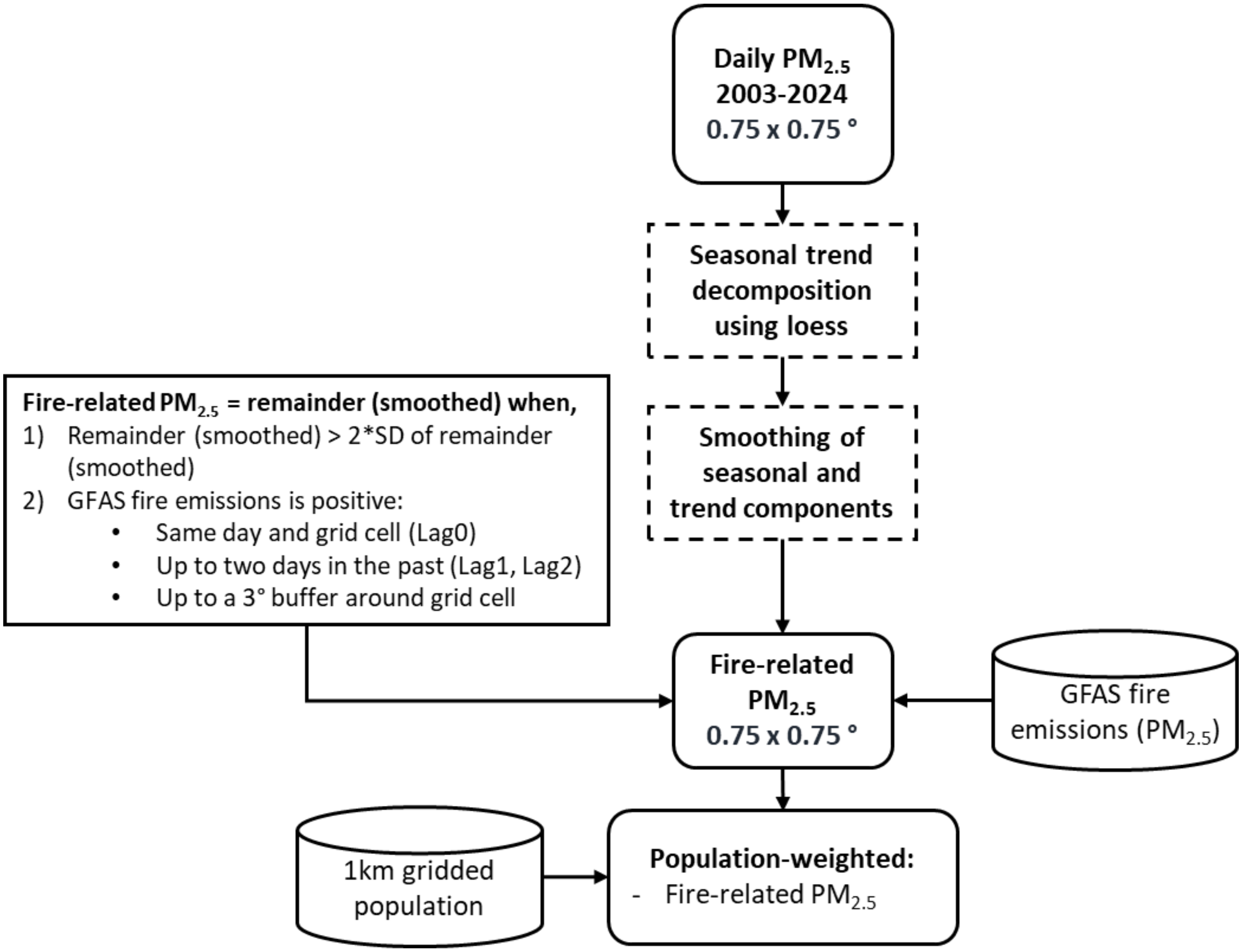
Hence, by the property of logarithms,

$$RR=exp(\beta \bullet X) \qquad (E4)$$

Combining (E2) and (E4) and multiplying the total by the baseline mortality rate (IR) and size of the exposed population (Pop) yields an estimate of the excess mortalities attributable to air pollution, that are then multiplied by the value of a statistical life (VSL).

Appendix F. Seasonal trend decomposition using loess

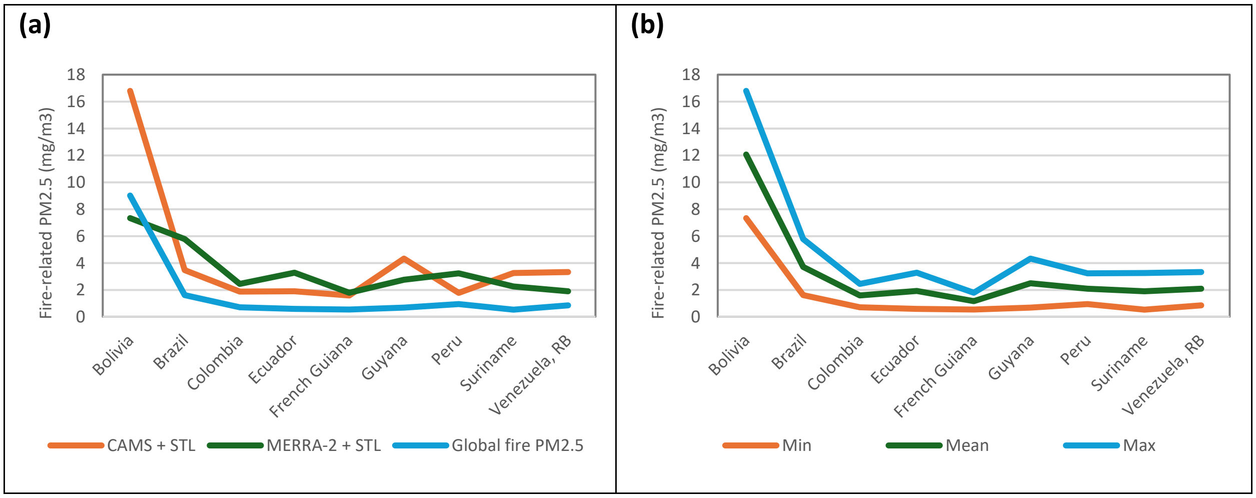
Figure F1. Application of Seasonal trend decomposition using loess approach and GFAS fire emissions to estimate fire smoke-related PM2.5



Source: Original figure developed for this report.

Appendix G. Estimates of daily population-weighted fire-PM$_{2.5}$

Figure G1. Predicted means daily population-weighted fire-related PM$_{2.5}$ for 2024 by country and data source (a) or scenario for probabilistic sensitivity analysis (b)



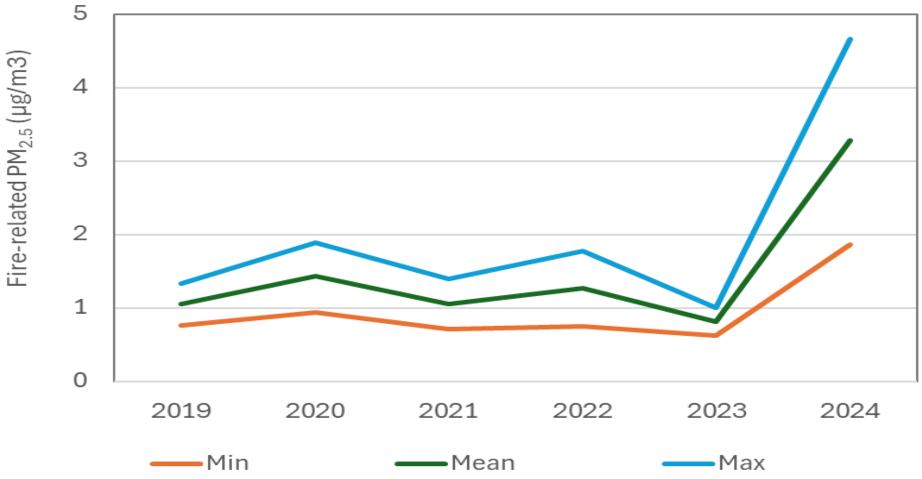
Source: Original figures developed for this report.

Table G1. Predicted mean daily population-weighted fire-related PM$_{2.5}$ (μg/m^3) for 2024 by country, data source and values used for sensitivity analysis

	Bolivia	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela, RB
CAMS + STL	16.8	3.5	1.9	1.9	1.6	4.3	1.8	3.3	3.3
MERRA-2 + STL	7.3	5.8	2.4	3.3	1.8	2.8	3.2	2.2	1.9
Global fire PM$_{2.5}$	9.0	1.6	0.7	0.6	0.5	0.7	0.9	0.5	0.8
Minimum	7.3	1.6	0.7	0.6	0.5	0.7	0.9	0.5	0.8
Mean	12.1	3.7	1.6	1.9	1.2	2.5	2.1	1.9	2.1
Maximum	16.8	5.8	2.4	3.3	1.8	4.3	3.2	3.3	3.3

Mean is estimated as the average of minimum and maximum.
Source: Original table for this publication.

Figure G2. Predicted mean daily population-weighted fire-related $PM_{2.5}$ by year for 2019–2024 across all countries within the Amazon region



Source: Original figure developed for this report.

Appendix H. Estimates of mortality attributable to fire smoke-related $PM_{2.5}$

Table H1. Estimates of attributable numbers, total deaths, and attributable fraction by country and year

Metric	Country	2019	2020	2021	2022	2023	2024
AN	Bolivia	219	326	236	385	337	1,750
	Brazil	2,697	3,612	3,452	4,027	2,240	10,140
	Colombia	441	658	303	261	272	776
	Ecuador	171	231	84	212	82	355
	French Guiana	2	2	1	0	2	3
	Guyana	13	12	13	6	16	33
	Peru	287	302	123	328	228	654
	Suriname	9	8	7	2	7	16
	Venezuela, RB	572	910	425	331	409	895
	Total	**4,412**	**6,059**	**4,642**	**5,553**	**3,592**	**14,622**
Deaths	Bolivia	69,120	70,120	71,121	72,121	73,122	74,122
	Brazil	1,338,852	1,349,010	1,359,167	1,369,325	1,379,483	1,389,640
	Colombia	239,830	241,758	243,686	245,614	247,542	249,470
	Ecuador	87,346	88,565	89,784	91,003	92,222	93,441
	French Guiana	1,234	1,264	1,294	1,325	1,355	1,385
	Guyana	6,479	6,512	6,545	6,577	6,610	6,643
	Peru	150,194	151,967	153,740	155,513	157,286	159,059
	Suriname	4,080	4,112	4,144	4,176	4,208	4,240
	Venezuela, RB	204,434	206,934	209,433	211,933	214,432	216,932
	Total	**2,101,569**	**2,120,242**	**2,138,914**	**2,157,587**	**2,176,260**	**2,194,932**
AF	Bolivia	0.32%	0.46%	0.33%	0.53%	0.46%	2.36%
	Brazil	0.20%	0.27%	0.25%	0.29%	0.16%	0.73%
	Colombia	0.18%	0.27%	0.12%	0.11%	0.11%	0.31%
	Ecuador	0.20%	0.26%	0.09%	0.23%	0.09%	0.38%
	French Guiana	0.20%	0.13%	0.11%	0.04%	0.12%	0.23%
	Guyana	0.20%	0.18%	0.20%	0.09%	0.23%	0.49%
	Peru	0.19%	0.20%	0.08%	0.21%	0.15%	0.41%
	Suriname	0.22%	0.20%	0.16%	0.05%	0.18%	0.37%
	Venezuela, RB	0.28%	0.44%	0.20%	0.16%	0.19%	0.41%
	Total	**0.21%**	**0.29%**	**0.22%**	**0.26%**	**0.17%**	**0.67%**

AN = attributable number
AF = attributable fraction
Source: Original table for this publication.

Appendix I. Effects on damage estimates from using MODIS versus ORA burned area data as the base case: sensitivity analysis over the other five parameters

Burned area data from ARO comes in a smaller grid (30 m x 30 m) and, when adding the pixels, has a 33 percent higher total burned area than the MODIS data, which has a 500 m x 500 m spatial definition (Table I1). When that larger burned area is overlapped with roads and lakes as well as categories in protected areas, the difference from using one source of data or the other is not substantial (between 2 and 6 percent). However, when overlapping with land used for agricultural and livestock activities, the burned area increases by 100 percent.

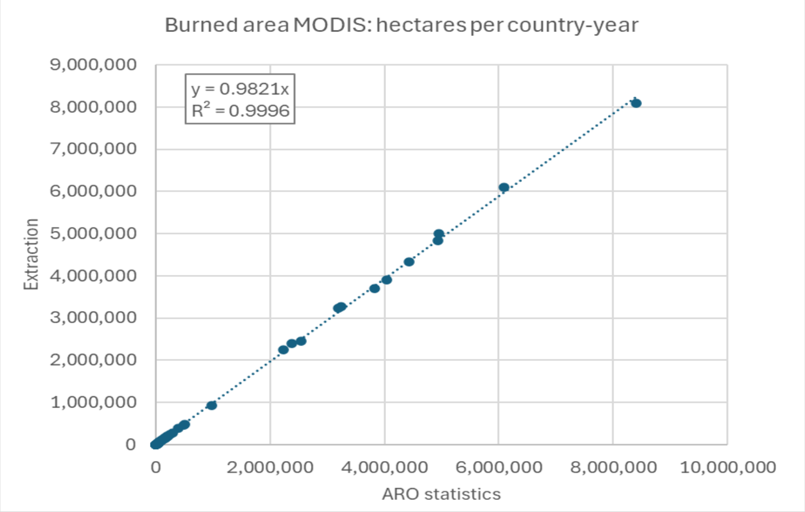
Table I1. Differences in burned area between MODIS and ORA ARO databases for the Amazon in 2024

Indicator	Area considered	MODIS	ARO
Burned area (ha)	**Total**	**15,748,492**	**21,014,762**
	Forest	6,197,881	7,314,149
	Accessible forest	2,959,022	3,136,596
	Accessible forest and Cat V/VI protected areas	3,353,084	3,423,013
	Pasture and agriculture	4,193,669	8,616,678
		Difference ARO to MODIS (%)	
Burned area	**Total**	**33%**	
	Forest	18%	
	Accessible forest	6%	
	Accessible forest and Cat V/VI protected areas	2%	
	Pasture and agriculture	105%	

Source: Original table for this publication.

It is common to find differences in burned areas when using different data products. For example, Pessôa *et al*. (2020) contrasted estimates of burned area for the Amazon biome using four different burned area products (including a previous version of the MODIS product used here) and found substantial differences, with estimates for burned forest ranging between 1,745,000 and 8,994,000 hectares (Pessôa *et al*. 2020). Given this, and to corroborate that this valuation's extraction process was correct, the analysis compared extraction estimates with statistics of burned area from MODIS published by ARO.[32] Slightly lower estimates (an approximate 10 percent difference) with a very high spatial correlation were obtained (Figure I1).

Figure I1. Comparison of estimated burned area using the MODIS data product



Source: Original figure developed for this report.

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[32] MODIS statistics on the burned area in the Amazon region are available at: https://otca.maps.arcgis.com/apps/instant/portfolio/index.html?appid=9f12f7b358194012a1a8659c7161c38a

This difference in burned area also translates into changes in damage estimates. Table I2 shows these differences, considering the central value when the sensitivity analysis is run on the remaining five parameters for which there is uncertainty.

Table I2. Central values for 2024 damage in Amazon using MODIS or/and ARO as base case

Category	**MODIS**	**ARO**	**Both sources***
Health - short term mortality	23,224	23,224	23,224
Agriculture and Livestock	6,848	16,633	11,740
Carbon emissions	7,867	7,867	7,867
Ecosystem services	246	299	273
TOTAL 2024 US$ million	**38,184**	**48,022**	**43,103**
Damages as share of GDP	*1.2%*	*1.5%*	1.3%

** Both sources mean that burned area is considered uncertain, and takes values between MODIS and ARO.*
Source: Original table based on MODIS and ARO data.