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Future economic cost of large wildfires linked to climate projections

Resiliencia frente a los Riesgos de Inundaciones y Sequías derivados del impacto del Cambio Climático en las Cuencas Internacionales de los ríos Miño y Limia

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1. Aim

To provide a quantitative estimate of future wildfire-related economic losses associated to climate change, explicitly linking projected climatic conditions to wildfire probability and economic damage.

2. Historical Burned Areas in Ourense

2.1. Wildfire Data

- The Ministry for the Ecological Transition and Demographic Challenge (MITECO) (https://www.miteco.gob.es/es/biodiversidad/temas/incendios-forestales/estadisticas-datos.html)

This national database documents all recorded wildfires since **1968** up to the year **2021** identifying the administrative county (comarca) of origin, the start and extinction dates of each event, and the associated burned forest area.

- Xunta de Galicia (https://mediorural.xunta.gal/gl/recursos/estatisticas/estatisticas-forestais/incendios-forestais)

This regional databases extend the national time series up to **2024**.

2. Historical Burned Areas in Ourense

2.2. Annual Burned Areas

- Mean annual burned area for the periods 1985–2004 and 2005–2024, along with the normalized increment (second minus first period, relative to the first period), for the Galician provinces.

Province	Burned area (ha/year) 1985-2004	Burned area (ha/year) 2005-2024	Increment (%)
Coruña	8219	3912	-52.4
Lugo	9389	2723	-71.0
Ourense	15794	11114	**-29.6**
Pontevedra	8463	5055	-40.3

Despite increasingly hazardous climate conditions burned area has declined overall. Fire-management policies implemented in recent decades have been effective enough to counterbalance, and in some cases reverse, the expected increase in wildfire activity driven by climate and land-use changes.

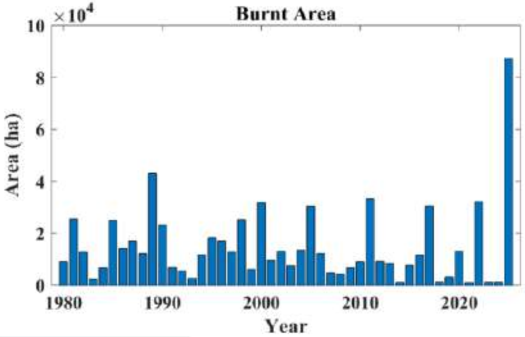
The comparatively modest reduction observed in **Ourense**, despite shared policies and operational structures, underscores the influence of structural regional factors such as:

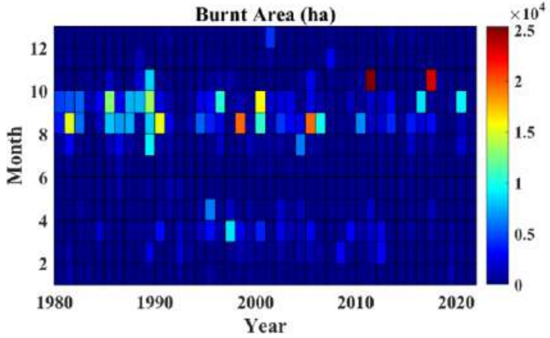
– sustained rural depopulation leading to increased fuel loads and reduced landscape management and

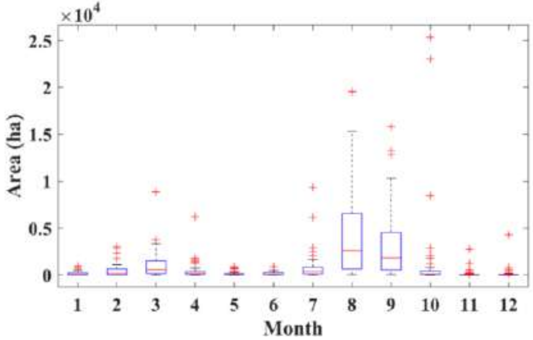
– enhanced climatic stress in inland areas, where the absence of maritime moderation exacerbates summer dryness and amplifies the impact of warming

3. Wildfire Dynamic in Ourense

- Annual burned area in the province of Ourense for the period 1980–2025. The time series reveals an alternation between years with very low impact and episodic extreme events (notably 2000, 2005, 2011, 2017 and 2022), culminating in the exceptionally high preliminary value for 2025.







Monthly burned area in Ourense (1980–2021) highlights the concentration of large fire events between August and October and the exceptional late-season episodes of October 2012 and October 2017.

Boxplots of monthly burned area show median values, interquartile ranges and extreme outliers, with **August–October** dominating wildfire activity.

Large wildfires, those > 500ha, and wildfire season, from August to October

4. Future probability of future large wildfires

4.3. Logistic Regression

Downscaling CMIP6 climate projections using the Weather Research and Forecasting (WRF) model (to 10 km). Estimates the future probability of large (> 500ha) wildfires through a logistic regression derived from observed fire events using ERA5 atmospheric data and evaluated using Receiver Operating Characteristic (ROC) based skill metrics for the historical period (1985-2014).

$$\log\left(\frac{p}{1-p}\right) = c_0 + \sum_{i=1}^{n_v} c_i AV_i$$

where, p is the probability of a large wildfire (≥ 500 ha), c_0 and c_i are the regression coefficients, AV_i represents the i-th atmospheric variable (T and Pr), and n_v is the total number of predictors. The logistic model coefficients were obtained using ERA5 data (0.25° × 0.25°) for the historical period (1985–2014).

Predictive performance analized by means the Receiver Operating Characteristic (ROC) curve, and skill by the Area Under the Curve (AUC).

The AUC metric provides a robust measure of the model's discriminative ability, with higher values indicating improved skill in distinguishing between days with and without large wildfire events.

4. Future probability of future large wildfires

4.3. Skills of the Logistic Regression

- Estimated coefficients and skill scores for a multivariate binomial analysis (logistic regression) using **T and Pr as predictors**.

	Estimate	t-statistic	p-value
(Intercept)	-6.8828	-7.7	1.6e-14
T	0.2267	6.5	9.0e-11
Pr	-1.1813	-6.9	3.9e-12

Both predictors exhibit **high statistical significance**, with p-values < 0.001, confirming their robust contribution to explaining the probability of large-fire occurrence.

Global goodness-of-fit statistics indicate that the binomial model displays **no overdispersion** (dispersion = 1) and that the selected climatic variables significantly improve predictive skill relative to a null model without predictors ($\chi^2 = 249$, $p \approx 8.2 \times 10^{-55}$).

The Area Under the ROC Curve (AUC) equals **0.83**, reflecting strong discriminative ability: in probabilistic terms, if one selects at random a day with a large wildfire and one without, the model assigns a higher probability to the fire day 83% of the time.

4. Future probability of future large wildfires

4.4. Future Probabilities

- Mean annual number of days with a predicted probability exceeding 50% for large wildfires (>500 ha) under historical and future scenarios.

	Historical	SSP2-4.5	SSP5-8.5
1985-2014	1.7	–	–
2026-2050	–	5.2	5.2
2051-2075	–	7.3	14.5
2076-2100	–	8.4	30.2

- Increases markedly under both emissions pathways with pathway-dependent amplification toward mid- and late-century.

5. Future economic cost associated to large wildfires

5.1. Actual (Historical) Annual Suppression Cost

- The actual annual cost (M€/year) for the historical period based directly on the observed burned area in large wildfires was calculated as follows:

$$C_A = \frac{C_{ha}}{10^6 N} \sum_{j}^{N_{Le}} S_j$$

where S_j is the burned area of large wildfire event number j, as recorded in the historical wildfire dataset; N_{Le} is the number of wildfire events with a burned area larger than 500 ha, and N the number of years analysed. The parameter C_{ha} represents the wildfire **suppression cost** per hectare (= 2115 €/ha), provided by Consellería do Medio Rural (https://mediorural.xunta.gal/es).

The actual (historical) cost is about **€14.1 million per year**.

This cost only reflects direct public expenditure on wildfire management. Do not account for broader economic losses such as damages to private assets, ecosystem services, and long-term socio-environmental impacts.

5. Future economic cost associated to large wildfires

5.2. Estimated Annual Suppression Cost

- The estimated annual economic cost, C_E, expressed in million euros per year, was computed as:

$$C_E = \frac{C_{ha}}{10^6 N} \frac{E}{D} \sum_{j}^{N_d} p_j(\overline{AV_1^j}, \dots, \overline{AV_k^j})$$

where p_j denotes the probability of occurrence of a future large wildfire on day j, which depends on the daily mean values of the k-th atmospheric predictors $\overline{AV_k^j}$.

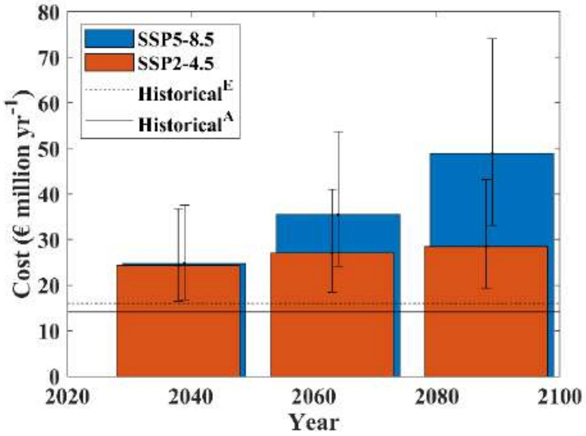
N_d is the total number of days between August and October (wildfire season) for the period under consideration (historical or future), and N is the number of years analyzed.

E represent the average burned area (ha) and D the average duration (days) of large wildfires.

5. Future economic cost associated to large wildfires

5.3. Historical and Future Estimated Annual Suppression Costs

- Projected annual suppression cost (€ million per year) of large wildfires under the SSP2-4.5 and SSP5-8.5 scenarios for three future periods: near future (2026–2050), mid-century (2051–2075), and late century (2076–2100).



- **Median historical estimated cost (~€16.0 million per year)**
- **Actual historical cost (~€14.1 million per year).**
- **13% between actual and estimated cost**

5. Future economic cost associated to large wildfires

5.3. Historical and Future Estimated Annual Suppression Costs

- Estimated wildfire suppression costs (€ million per year) for the historical and future periods.
- Projections are provided for different scenarios (SSP2-4.5 and SSP5-8.5) and time horizons.
- Reported values correspond to the median (second column) and the 25th and 75th percentiles (third and fourth columns, respectively).

	Median	P_{25}	P_{75}
Historical period* (1985-2014)	16.0	10.9	24.2
SSP2-4.5 (2026-2050)	24.3	16.5	36.8
SSP2-4.5 (2051-2075)	27.1	18.4	41.0
SSP2-4.5 (2076-2100)	28.5	19.4	43.2
SSP5-8.5 (2026-2050)	24.8	16.9	37.6
SSP5-8.5 (2051-2075)	35.5	24.1	53.8
SSP5-8.5 (2076-2100)	48.9	33.3	74.1

€14.1 million per year (actual value)

3 times de historical median

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