v. 4, n. 1, 2024

International Journal of Biological and Natural Sciences

FOREST FIRES IN CHILE: EVALUATION OF THE ECONOMIC AND ENVIRONMENTAL IMPACT ON NATURAL CAPITAL

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Abstract: Forest fires are caused by intentional action or by natural reasons, and the degree of exposure has been increasing due to the combination of both. Climate change is exacerbating these events. The case of Chile is a good example: intentional factors are at the origin of 55% of fires, then are aggravated by heat waves and water stress among other climate-related factors. This document estimates the cost of the 2017 forest fire season, which affected 518,174 hectares, being the largest in the recent history of Chile. The cost of the fire is estimated in terms of natural capital, for plantations and native forest, and the effect on carbon fixation. Considering the replacement cost for plantations at non-productive ages and the potential productive volume for mature trees, losses of natural capital in plantations are estimated at US$ 1,046 million. On the other hand, the 68.2 million tons of CO_2eq emitted by the fire and the 547 million tons of CO_2eq of absorption capacity lost due to the fire, are valued at US$ 2,983 million and US$ 18,666 million respectively.
Keywords: Natural Capital, Forest Fires, Sustainable Development.
JEL codes: C13, E22, Q51

INTRODUCTION

In a world where climate change threatens to intensify natural disasters, it stands out that forest fires are becoming more frequent and harmful across the planet. By both devastating large areas of land and releasing high amounts of carbon into the atmosphere, forest fires are a growing threat to humanity and biodiversity. In this global context, Chile has experienced particularly severe episodes.

The recent 2022-2023 fire season severely damaged 431 thousand hectares of different land use. This event motivates the study of the quantification of the natural capital costs of fires in Chile, given that recent observed events indicate an increase in the number and intensity of fires due to intentional action, natural and climate factors. Since at this time there is no detailed information of the damages, we estimated the losses of forest capital caused by the 2017 megafire that affected 520 thousand hectares. During the months of January and February, 501,168 hectares were burned in total, of which half occurred in just 5 days.

In this work, we estimated the costs in natural capital and carbon emissions using data from the 2017 fire. The polygon data, which delineate the spatial boundaries of areas affected by the fire, are used to assess the extent of the damage. This data, along with information on land use types, is provided by the Corporación Nacional Forestal (CONAF). Additionally, most of the data regarding timber product prices were obtained from the Instituto Forestal (INFOR).

It is essential to address not only the extent and causes of these disasters, but also their impact on national wealth. Forest fires affect both produced capital, which includes housing, infrastructure and machinery, and natural capital. The latter refers to the value of ecosystems and the services they provide for human well-being. Its degradation has a significant impact on the reduction of ecosystem services, including carbon sequestration.

Quantifying natural capital is challenging due to difficulties in measuring the impacts of ecosystems, as well as in the valuation of the lost services, which are often not traded in traditional markets. In this document, the cost of the 2017 forest fires is estimated only in terms of forest capital, and its effect on carbon sequestration. Taking into account the replacement cost for plantations at non-productive ages and the potential volume for trees close to harvest age, losses of natural capital in plantations are estimated at US$

1,046 million. On the other hand, the 68.2 million tons of CO_2eq emitted by the fire and the 547 million tons of CO_2eq of absorption capacity lost due to the fire, are estimated damages of US$ 2,983 million and US$ 18,666 million respectively.

Considering the loss of natural capital stock, especially in forest-managed soils and native forests, has significant implications for industry and biodiversity. This study, therefore, highlights the need to address wildfires not only as an emergency management challenge, but also as a critical environmental sustainability and conservation issue. Finally, we seek to promote the development of management strategies and public policies that integrate a broader understanding of the economic and environmental costs associated with forest fires in Chile, taking into account the integrity of ecosystems and the various services they provide.

BACKGROUND

Motivated by the 2023 fire, we estimated the effect on natural capital with the best data available to date from the 2017 fire. In both fires, plantations and native forests suffered serious damage, with repercussions on the provision of ecosystem services, and consequently, on the economy and human well-being.

Formerly, in economics, the term capital was used mainly to refer to tangible assets. However, the concept has evolved to also encompass intangible and non-alienable assets, such as human and natural capital. Over time, methodologies have been developed to quantify their value for individuals and society.

It is vital to understand how wildfires affect natural capital and, consequently, ecosystem services. The services of ecological systems and the reserves of natural capital that produce them are critical to the functioning of the Earth's life support system. They contribute to human well-being, both directly and indirectly, and therefore represent a part of the total economic value of the planet (Costanza et al., 1997).

Given the importance of natural capital, particularly in areas affected by wildfires, it is essential to address the economic valuation of these resources. In the absence of market prices for natural capital, we have to estimate accounting prices or "shadow prices". These prices reflect a combination between what is socially desirable and what is socio-ecologically possible. Unfortunately, traditional macroeconomic theories that have shaped our beliefs about growth and development do not recognize or consider humanity's dependence on nature (Dasgupta, 2021).

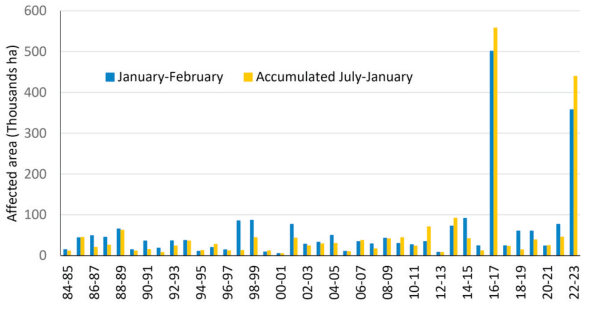
To address the intrinsic relationship between humanity and nature, the Common International Classification of Ecosystem Services (CICES) has been developed as a system that identifies the contributions that ecosystems make for human well-being[1]. The system classifies ecosystem services into three groups, provision services, regulation services and cultural services. Provision services include the supply of materials and energy, regulation and maintenance services are related to the regulation of ecosystem processes, and cultural services correspond to non-material benefits such as spiritual experiences and aesthetic values (Dasgupta, 2021).

In Chile, about 90% of forest fires are caused by human action (CONAF, 2023). These fires lead to significant economic losses, environmental damage, and loss of human life. Globally, it has been estimated that large tropical forest fires in one year could be equivalent to one-third of the emissions from burning fossil fuels (Rowell and Moore, 2000).

1. Based on the work of the Millennium Ecosystem Assessment.

Given the deep relationship between fires and climate change, analyzing fire data is crucial to understanding the magnitude of the problem and its impacts. The 2017 mega fire affected almost 100 thousand hectares (ha) more than the 2023 fire, which reached 431 thousand hectares of different land use. Figure 1 shows the affected area in hectares in January and February and the cumulative amount from July to January by season.

Figure 1. Affected area (ha) in January-February and accumulated July-January by season



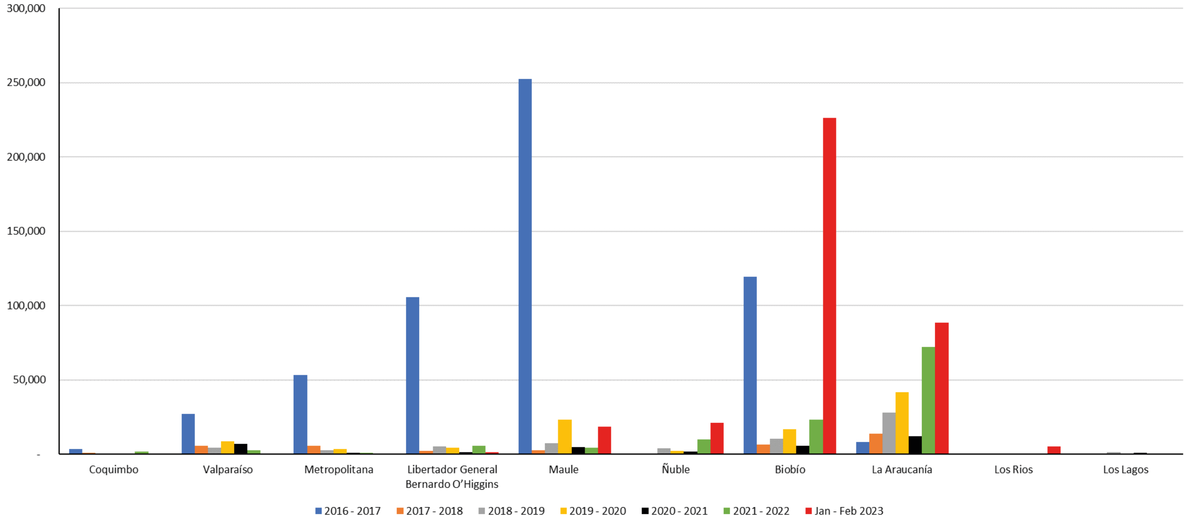
Source: Own elaboration with data from CONAF (2023).

When analyzing the damages by region, in 2023 the most affected regions were Biobío and La Araucanía, with 226,397 hectares and 88,487 hectares respectively. Other regions severely affected were Ñuble region, with 21,164 hectares and, Maule region with 18,583 hectares.

In 2017, the most affected region was the Maule region, with a damaged area of 244,289 hectares during January and February, as seen in Figure 2 . The Biobío region was widely affected, and only in January and February 2023 a larger surface area was burned than in the entire 2016-2017 season, reflecting the speed with which the incident occurred[2].

The analysis by region demonstrates highlights the need for solutions aimed at conserving natural capital and mitigating the impacts of wildfires on affected communities.

Figure 2. Hectares affected by season and region



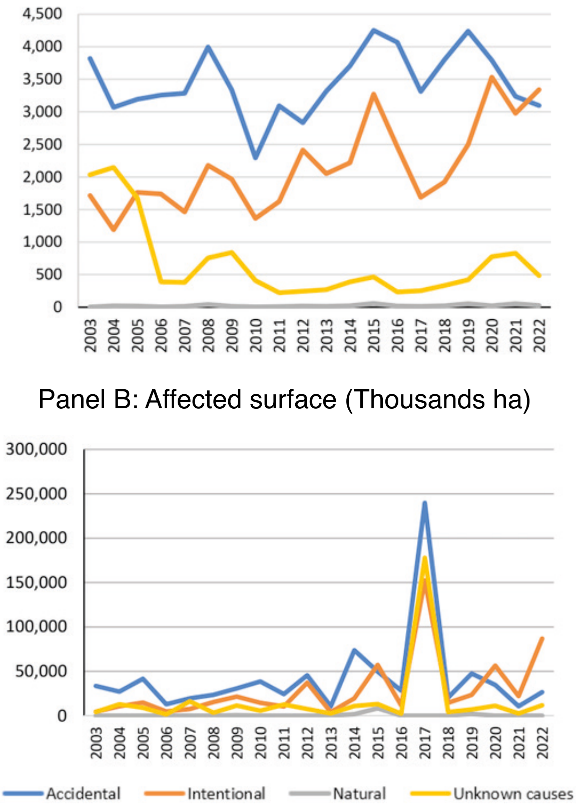
Source: Own elaboration with data from CONAF (2023).

A public policy concern is trying to understand and establish the causes of these events, to implement preventive and management measures. As can be seen in Figure 3, the most notable aspect is the systematic increase in intentional fires, which are also becoming more damaging.

2. See annexes Figure A1 for a comparison between the affected area in January-February by region and fire season.

Figure 3. Number of occurrences and hectares per cause of fire in each fire season

Panel A: Number of occurrences



Source: Own elaboration with data from CONAF (2023).

Beyond the immediate and historical causes, the geographic patterns of fires also deserve attention. The available evidence shows an important spatial correlation between fires and estimated areas with high vulnerability to climate risks (See annexes Figure A3). The enclosed map of the estimated future fire risk taken from ARCLIM[3], defined as the risk of native forest fires in the future climate (2035-2065 under the RCP 8.5 scenario), is quantified as the multiplication of the threat, sensitivity and exposure indices. As all the indices have been normalized, the risk presented in this map corresponds to a ranking among Chilean communes.

Table 1 shows the surfaces affected by the last two largest fires suffered in Chile in recent years (2017 and 2023) according to type of land use. The surfaces affected by the 2023 fire, correspond to the information available as of April 4, 2023.

Table 1. Area affected (ha) by the 2017 and 2023 fires by type of land use

Year / Type of land use	Plantations	Native forest	Grasslands and bushes	Agricultural land	Others	Total
2017	283,659	105,137	93,755	33,579	2,024	518,174
2023	242,798	58,312	37,090	57,057	3,561	398,818

Source: Own elaboration based on 2017 and 2023 data obtained from INFOR, 2018 and 2023 respectively.

There have been multiple attempts to quantify the costs of these types of fires. For the 2023 catastrophe, ClapesUC estimated the fiscal costs amounting to US$ 278 million and an impact on the regional GDP of US$ 197.7 million (Gonzales and Hernández, 2023). Then, private companies estimated losses of US$ 540 million. On the other hand, the Ministry of Finance updated estimates of accounting costs, which amount to US$ 309 million. These estimates refer to income flows from production losses, from higher expenses for fire control, and support for affected communities, particularly in the case of the Ministry of Finance. There are also some references to the effect on the flow of carbon emissions, but no attempts have been made to estimate the value of forests services lost.

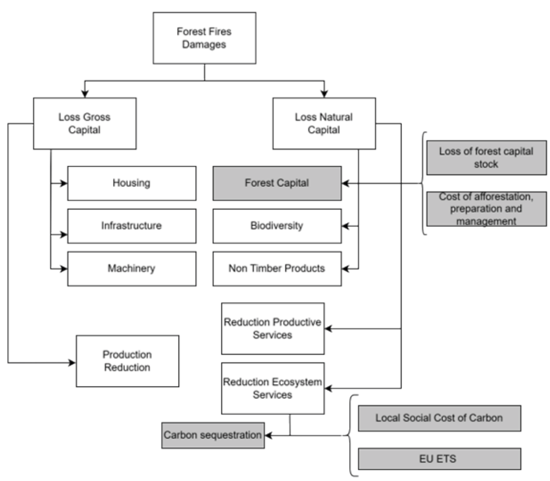
As mentioned above, the concept of capital has evolved to also encompass intangible and non-alienable assets such as human and natural capital, recognizing that human life depends on the integrity of ecosystems and the various services they provide. Natural capital is defined as the stock of natural ecosystems that produce a flow of valuable

3. Available at https://arclim.mma.gob.cl/atlas/view/incendios_bosques_nativos/

ecosystem goods or services into the future (Cleveland et al., 2008). It can also be defined as the discounted present value of these ecosystem services, which are valued at shadow prices that depend on the state of the ecosystem (Dasgupta, 2021). However, natural capital remains an abstract concept given the considerable practical measurement challenges it represents (World Bank, 2018, Vial, 2023).

Valuation challenges arise mainly due to difficulties in measuring and pricing ecosystem services, since these goods and services are not usually traded in traditional markets.

Figure 4. Scheme of capital losses associated with fires



Source: Own elaboration.

In the diagram (see Figure 4) it can be seen that, when there is a forest fire, it damages two types of capital, produced or traditional capital and natural capital. The loss in produced capital, which we usually measure in national accounts, corresponds to the traditional definition, which incorporates housing, infrastructure and machinery. This loss of the produced capital stock in turn generates a reduction in future production capacity, which can be represented by a reduction in the trend Gross Domestic Product (GDP).

On the other hand, the fire generates a loss in natural capital, composed of capital to produce wood, biodiversity and ecosystem services and non-wood goods. As with produced capital, this loss in natural capital in turn generates a loss of flows, which in this case can be represented as a reduction in productive services, but perhaps more important and of greater magnitude, a reduction in current and future ecosystem services. This study estimates the costs in timber capital, both in plantations and native forests, and the cost associated with the loss of a particular ecosystem service, carbon sequestration.

It is important to acknowledge that forest fires affect a range of ecosystem services. These include soil protection, watercourses protection, and the preservation of flora and fauna, among many other services provided by ecosystems. We are not evaluating these in this study.

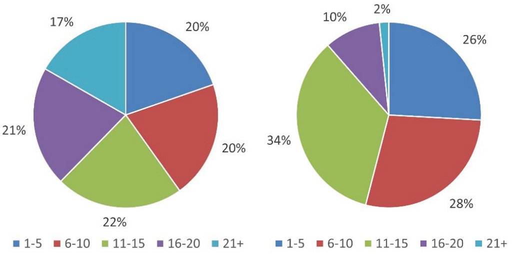
ESTIMATES

For plantations that do not yet have productive value, the costs of afforestation, preparation and management were used, and for plantations in productive age, their potential productive volume was valued at the prices of the same year. On the other hand, we estimated the damage in terms of emissions and the loss of carbon capture caused by the fire. For both valuations, the local social cost of carbon (LSCC) and the EU-ETS for 2017 and 2022 were used as the price for a ton of emissions.

FOREST CAPITAL COST ESTIMATES: 2017 FIRE – PLANTATIONS

Figure 5 displays the distribution of the surfaces that were affected by the 2017 fire by species and age. In the case of Pine, the distribution is quite homogeneous among ages. However, in the case of Eucalyptus there is a greater proportion of younger trees, 26% from 1 to 5 years old and 28% from 6 to 10 years old.

Figure 5. Distribution of area affected (ha) by fire 2017 by species and age



Panel A: Pine Panel B: Eucalyptus

Source: Own elaboration based on INFOR, 2018.

This is relevant, because in the estimation it is considered that trees from 0 to 5 years old have no productive value, and therefore their value is estimated according to the costs of afforestation, preparation and management, considering the following assumptions[4]:

1. General costs of afforestation of exotic species by region.
2. Preparation and handling costs by species.
3. Percentage of impact of 50% of total loss.

Table 2 shows that of the total of 41,690 hectares affected with trees between 0 and 5 years old, 75% were Pine and approximately 25% were Eucalyptus. Based on the assumptions mentioned above, the losses of forest capital in plantations are estimated at $USD 26.3 million.

Table 2. Afforestation, preparation and management costs for hectares affected by the 2017 fire (trees from 0 to 5 years old)

Species	Total 0-5 years (ha)	General afforestation cost (US$ million)	Additional prep. and management costs (US$ million)	Total (US$ million)
Pine	31,074	10.5	9.4	19.9
Eucalyptus	10,616	3.7	2.7	6.4
Total	**41,690**	**14.3**	**12.1**	**26.3**

Source: Own elaboration based on data from CONAF, 2011; INFOR, 2018; INFOR, 2022.

For trees 6 years old or older, the estimate is made according to the value of the potential productive volume of the affected hectares. Considering the following assumptions[5]:

1. Potential volume per hectare according to age range and region (m3ssc / ha)
2. 2017 distribution of products of wood origin
3. Percentage of impact = 50% total loss[6]
4. Average m3ssc price 2017[7]:

- Pine Pulp = CL$ 14,044
- Sawn Pine = CL$ 65,843

That is, for each species, age, and region, the volume of potential lost production is calculated and then aggregated. This total is valued at the average price of m3ssc/ha for the year 2017. Additionally, a total loss or impact percentage of 50%, as reported by INFOR in 2018, is considered.

$$(1) \qquad ha_{aer} * vol_{aer} * 0{,}5 = lost\ volume_{ear}$$

$$(2) \qquad \sum_{a=1}^{5} \sum_{r=1}^{6} ha_{aer} * vol_{aer} * 0{,}5 = total\ volume\ lost_{e}$$

$$(3) \qquad \sum_{s=1}^{2} total\ volume\ lost_{e} * Average\ price_{e} = total\ loss\ in\ plantations$$

4. See annexes Table A1: General costs of afforestation of exotic species by region and Table A2: Preparation and management costs by species.
5. See annexes Table A3: Potential volume per hectare by age range and region (m3ssc / ha) and Table A4: 2017 distribution of timber products.
6. Another study has been found with a percentage of affectation lower than that used in this study, around 30% affectation.
7. Average prices per m3ssc in 2017 based on INFOR, 2022.

Here, *s* corresponds to an index for each species, such as Pine and Eucalyptus; *a* is the index corresponding to the age; and *r* corresponds to the region index. The term ha_{aer} represents the number of hectares affected for each species, age and region, while vol_{aer} denotes the potential volume for each species, age and region. Table 3 presents the results, estimating the loss in forest capital stock in plantations, specifically in trees 6 years old or older, at $USD 1,019 million.

Table 3. Loss of productive forest capital stock caused by the 2017 fire

Species	Sub-total	Total (ha)	50% total volume loss (thousands m3ssc)	Total (US$ million)
Pine	Total pulp	50,894	4,163.1	90.0
	Sawed	26,268	2,148.7	217.9
	Other products	80,609	6,593.7	486.0
Eucalyptus	Total Eucalyptus	41,029	3,667.3	225.9
	Total	**198,800**	**16,572.7**	**1,019.8**

Source: Own elaboration based on INFOR data. For volume data per hectare, data were obtained from INFOR, 2017. Data on the 2017 distribution of products of wood origin and the percentage of impact with total loss were obtained from INFOR, 2018. Price data per m3ssc 2017 were obtained. obtained from INFOR, 2022.

Table 4 summarizes the results of the estimations of forest capital loss in plantations. The sum of the losses for trees without productive value (0 to 5 years) and with productive value (6 years or more) amounts to a total loss of forest capital of $USD 1,046 million due to the 2017 fire.

Table 4. Total losses of forest capital stock caused by the 2017 fire

Species	0 – 5 years (ha)	Afforestation, prep. and management costs (US$ million)	6 or more (ha)	Loss of productive forest capital (US$ million)	Total (US$ million)
Pine	31,074	19.9	126,697	793.9	813.8
Eucalyptus	10,616	6.4	30,413	225.9	232.3
Total	**41,690**	**26.3**	**157,110**	**1,019.8**	**1,046.1**

Source: Own elaboration.

COST ESTIMATES FOR CO_2eq EMISSION: FIRE 2017

In addition to the loss in forest capital, fires have a direct effect on carbon capture since burning trees releases the carbon stored in them. The 2017 fire generated an emission of 68.2 million tons CO_2eq.

The valuation of carbon emissions and CO_2eq is still discussed in the literature. In this study, three reference prices per ton of CO_2eq emission are used to perform a sensitivity analysis: the European Emissions Trading System (EU-ETS) for 2017, the local social cost (LSCC) and the EU-ETS for 2022.

In 2017, according to the World Bank (2023), carbon pricing systems, including taxes or tradable emissions permits, covered 12.03% of global emissions. The EU-ETS was the most extensive, with 3.05% of total emissions covered. We took the average price per year, which reached US$ 6.2 per ton CO_2eq in 2017. This price has increased significantly since the EU adopted more stringent criteria on emissions. Therefore, we also use the average EU-ETS price for 2022 (US$ 86.5 per ton CO_2eq) as a reference. It is important to note that the total carbon price systems in 2022 cover 22.3% of emissions[8].

Beyond market references, economic theory seeks to have a price that reflects the cost of the damages created by an extra ton of

8. The sharp increase in the price of carbon is largely due to the application of stricter emission control standards to align this market with the emission reduction targets of the Paris Agreement.

carbon dioxide emissions. According to Pizer (2014), Pindyck (2019), Tol (2011) and Cruz and Rossi-Hansberg, (2023) this price is the social cost of carbon. When a ton of carbon dioxide is emitted into the atmosphere, it remains in it for a time and causes warming that affects the economic and social activity of humanity. The social cost of carbon is the total damage that an additional ton of CO_2eq has on these activities, converted to dollars.

The social cost of carbon helps reveal how much society must sacrifice to avoid climate change. Based on the above and taking the evidence of the heterogeneity of the effects of climate change by geographical area in Cruz and Rossi-Hansberg (2023), the local price of the social cost of carbon for Chile from Ricke et al (2018) was taken, Tol (2019) and Cruz and Rossi-Hansberg, (2022) which is equal to US$ 43.7 per ton of CO_2eq.

The LSCC provides the information to determine how much to sacrifice to combat climate change. This is because the local social cost of carbon is the benefit, or in other words, the harm avoided, of reducing CO_2eq emissions in a specific locality[9].

Table 5. Emissions CO_2eq caused by the 2017 fire

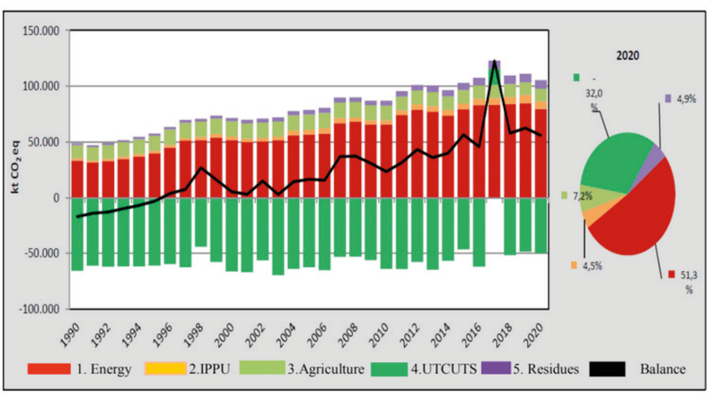
	Millions of tons of	EU-ETS value 2017 (US$ million)	LSCC value (US$ million)	EU-ETS value 2022 (US$ million)
		US$ 6.2 x ton.	US$ 43.7 x ton.	US$ 86.5 x ton.
Emissions	68.2	422.8	2,983.1	5,899.3

Source: Own elaboration based on data from the National Greenhouse Gas Inventory, 2022. EU-ETS data from the World Bank, 2022. LSCC data from Cruz and Rossi-Hansberg, 2022. Absorption loss data from Gilabert and Meza, 2023.

Table 5 shows the valuation of the 68.2 million tons of CO_2eq issued by the fire at different prices, reaching estimated damages between US$ 422.8 million and US$ 5,899.3 million. The LSCC value (almost 3 billion dollars) is not only an intermediate value, but is the best available representation of the loss of current and future income in Chile, as a consequence of the damages associated with climate change associated with these emissions.

Figure 6, shows how the usual emissions were exceeded due to the 2017 fire. The flow of emissions caused by the fires are directly related to carbon neutrality, since 68.2 million tons of CO_2eq were emitted, which corresponds to almost 8 times the total emissions by automobiles in 2017.

Figure 6. National Greenhouse Gas Inventory of Chile: GHG balance (kt CO_2eq) by sector, 1990-2020 series



Source: MMA Technical Coordinating Team, GHG Inventory (2022).

9. While the damage is global and therefore goes far beyond the damage in a particular country, this is a useful measure to assess the opportunity cost of carbon emissions (or sequestration) of devoting resources to this end.

COST ESTIMATES FOR LOSS OF ABSORPTION OF CO_2eq: FIRE 2017

To calculate the loss of future absorption capacity due to the trees lost by the fire, a weighted average of the age of the trees that were standing in the areas burned was calculated, reaching an average of 12 years old, which is compared to an average harvest age of 21 years. With this, we have that the affected hectares still had (not counting the year 2017) 9 additional years of capture of CO_2eq.

Considering that the capture loss for the year 2017 was 54.7 million tons of CO_2eq annually (Gilabert and Meza, 2023), for the entire period of 10 years there is a total absorption loss of 547 million tons of CO_2eq, which valued at the local social carbon price (LSCC) amounts to US$ 18,666 million. See estimates in Table 6.

Table 6. Loss of absorption capacity due to the 2017 fire

	Millions of tons of CO_2eq	LSCC value (US$ million)	EU-ETS value 2022 (US$ million)
		US$ 43.7 x ton.	US$ 86.5 x ton.
Loss of absorption	547	18,666	34,824.6

Source: Own elaboration based on Gilabert and Meza (2023).

FOREST CAPITAL COST ESTIMATES: 2017 FIRE – NATIVE FOREST

Preliminary estimates of the cost of afforestation and conservation of native forest species were made using the afforestation costs per hectare and coverage provided by Patricio Toledo Eco-Solutions (2023) and the information on affected surfaces provided by CONAF (2023). Table 7 shows that the cost of reforestation by forest type, for the total hectares of native forest affected, has a cost of US$ 143.3 million.

Table 7. Afforestation costs of native species in 2017

Forest type	Total (ha)	Afforestation cost (US$ million)
Austrocedrus chilensis	303	-
Sclerophyll	33,978	78.2
Chilean Palm	7	0.0
Roble Hualo	12,157	27.7
Roble-Raulí-Coihue	3,979	7.6
Evergreen	76	0.2
Native With Wild Exotics	16,233	29.6
Not classified	89	-
Total	**66,823**	**143.3**

Source: Own elaboration based on afforestation cost data obtained from Patricio Toledo Eco-Solutions, 2023. Categories "Austrocedrus chilensis" and "Not classified" were not valued due to the difficulty of assigning costs.

For the "Roble-Rauli-Coihue"[10] forest type, there is information on conservation costs, which depend on the coverage of the surface. There are a total of 3,979 affected hectares of Roble-Rauli-Coihue, for which the conservation costs would amount to US$ 19.1 million.

Table 8. Total losses of Roble-Raulí-Coihue capital stock caused by the 2017 fire

ROBLE-RAULI-COIHUE	Total (ha)	Conservation cost (US$ million)
Very open	-	-
Open	299	1.0
Semi dense	1,758	7.6
Dense	1,922	10.4
Total	**3,979**	**19.1**

Source: Own elaboration based on data from CONAF, 2023.

10. In the "Roble-Raulí-Coihue" forest type, 'Roble' refers to Nothofagus obliqua, 'Raulí' to Nothofagus alpina, and 'Coihue' to Nothofagus dombeyi.

ESTIMATED TOTAL DAMAGES: FOREST CAPITAL AND EMISSIONS OF CO_2eq

Table 9 presents a summary with the results of the estimates of this study. In capital stock, there are forest capital losses amounting to US$ 1,046 million and, on the other hand, the losses in capture capacity for the period amount to US$ 18,666 million valued at the LSCC. Additionally, the losses from emissions of CO_2eq[11] of that same year are US$2,983 million.

Table 9. Estimated damage to forest capital and CO_2eq emissions

Cost category	Value (US$ million)
Loss of forest capital in plantations	1,046.1
Loss of absorption capacity of **CO_2eq** at LSCC	18,666
Cost category	**Value (US$ million)**
CO_2eq emissions at LSCC	2,983.1

Source: Own elaboration.

CONCLUSIONS

The contribution of this study is to provide estimates of the costs associated with productive services of forest capital and the ecosystem service of absorption of greenhouse gas emissions (carbon fixation). In addition, we identified the need to improve the disaggregation of data, assumptions, and prices for a more accurate valuation.

Although only these two specific costs are estimated, very relevant cost magnitudes are reached. The loss of forest capital produced in 2017 corresponds to 7.8% of the capital produced in the agricultural, forestry and fishing sector.

Finally, it must be noted that in the future it is necessary to include a broader evaluation of the functions of other ecosystem services, which are not considered in this study due mainly to the difficulties in their identification and assessment.

The economic impact of the loss of forest capital and reduced carbon sequestration is considerable, even when only these two elements are considered. This underlines the importance of investments in conservation and restoration, and sustainable management of forests, as well as the need to improve methodologies for the evaluation of ecosystem services.

11. Considering the affected area of both plantations and native forest.

REFERENCES

Banco Mundial, 2018. The changing wealth of nations 2018: Building a Sustainable Future. Lange, Wodon & Carey, 2023. DOI: 10.1596/978-1-4648-1046-6

Betancor, et al., 2022. Estimaciones del Costo Fiscal Directo de la Propuesta de Nueva Constitución. Bentancor, A , Larraín, G , Martínez, C , Ugarte, G , Vergara, R , Valdés, R 2022. Instituto de Economía, Política Pública N°3.

Cleveland et al., 2008. Cleveland, C. J., Kubiszewski, I., & Endres, P. (2008). Energy return on investment (EROI) for wind energy. Publisher: The Oil Drum.

CONAF, 2023. Datos de estadísticas históricas. Corporación Nacional Forestal, Ministerio de Agricultura, 2023. https://www.conaf.cl/incendios-forestales/incendios-forestales-en-chile/estadisticas-historicas/

Costanza, R., d'Arge, R., de Groot, R. et al. The value of the world's ecosystem services and natural capital. Nature 387, 253–260 (1997). https://doi.org/10.1038/387253a0

Cruz y Rossi-Hansberg, 2022. Local Carbon Policy, 2022.

Cruz y Rossi-Hansberg, 2023. "The Economic Geography of Global Warming." Review of Economic Studies, forthcoming

Dasgupta, P. (2021), The Economics of Biodiversity: The Dasgupta Review. (London: HM Treasury)

Gilabert y Meza, 2023. Incendios forestales y la carbono neutralidad. La Segunda, 2023.

Gob.cl, 2023. Balance temporada de incendios 2022-2023: 431 mil hectáreas afectadas y 2.369 brigadistas movilizados. Gobierno de Chile, 2023. https://www.gob.cl/noticias/balance-temporada-de-incendios-2022-2023-431-mil-hectareas-afectadas-y-2369-brigadistas-movilizados/

Gonzales y Hernández, 2023. Informe: Costo económico y fiscal de incendios forestales de enero y febrero de 2023. Luis Gonzales Carrasco y Valentina Hernández, 2023.

Gonzales, Lara y de Solminihac, 2023. Informe: Desafíos de Resiliencia y Adaptación: Análisis preliminar del impacto de las inundaciones de junio de 2023 en Chile. Luis Gonzales Carrasco, Isidora Lara y Hernán de Solminihac, 2023.

INFOR, 2017. Informe Resumen: Cifras de plantaciones afectadas por los incendios forestales. Instituto Forestal, 2017.

INFOR, 2018. Disponibilidad de Madera de Plantaciones de Pino Radiata y Eucalipto (2017 - 2047). INFORME TÉCNICO Nº 220. Buchner, Martin, Sagardia, Avila, Molina, Rojas, Muñoz, Barros, Rose, Barrientos, Barrales y Guiñez, 2023.

Inventario Nacional de Gases de Efecto Invernadero, 2022. Inventario Nacional de Gases de Efecto Invernadero, 1990-2020: Resumen de Puntos clave. División de Cambio Climático, Ministerio del Medio Ambiente, 2022.

Moore, P.F., & Rowell, A.D. (2000). Global review of forest fires.

Pardo Velásquez, Evaristo; Bañados Munita, Juan Carlos (2022). Precios Forestales. Instituto Forestal, Chile. Boletín N° 183. 52p.

Pindyck, R. S. (2019). The social cost of carbon revisited. Journal of Environmental Economics and Management, 94, 140-160.

Pizer W, Adler M, Aldy J, Anthoff D, Cropper M, Gillingham K, Greenstone M, Murray B, Newell R, Richels R, Rowell A, Waldhoff S, Wiener J. Environmental Economics. Using and improving the social cost of carbon. Science. 2014 Dec 5;346(6214):1189-90. doi: 10.1126/science.1259774. PMID: 25477446.

Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018). Country-level social cost of carbon. Nature Climate Change, 8(10), 895-900.

SENAPRED, (2023). Consolidado de Incendios Forestales Relevantes, SENAPRED.

Tol, R. S. (2011). The social cost of carbon. Annu. Rev. Resour. Econ., 3(1), 419-443.

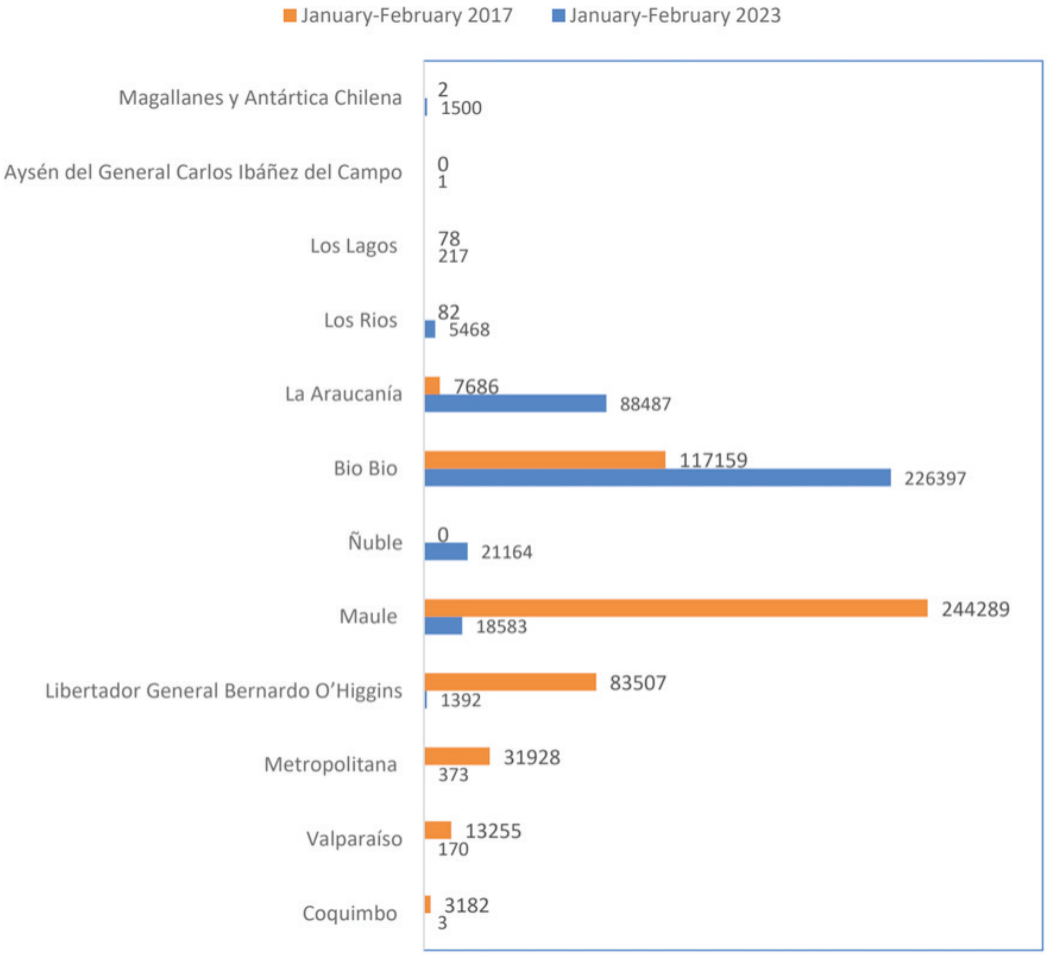
Tol, R. S. (2019). A social cost of carbon for (almost) every country. Energy Economics, 83, 555-566.

Toledo, P. (2023). Costos de forestación por hectárea y cobertura. Patricio Toledo Eco-Solutions (2023)

Vial, J. (2023). "Desarrollo sostenible y capital natural" Policy Paper N° 14. CAF https://scioteca.caf.com/handle/123456789/2030

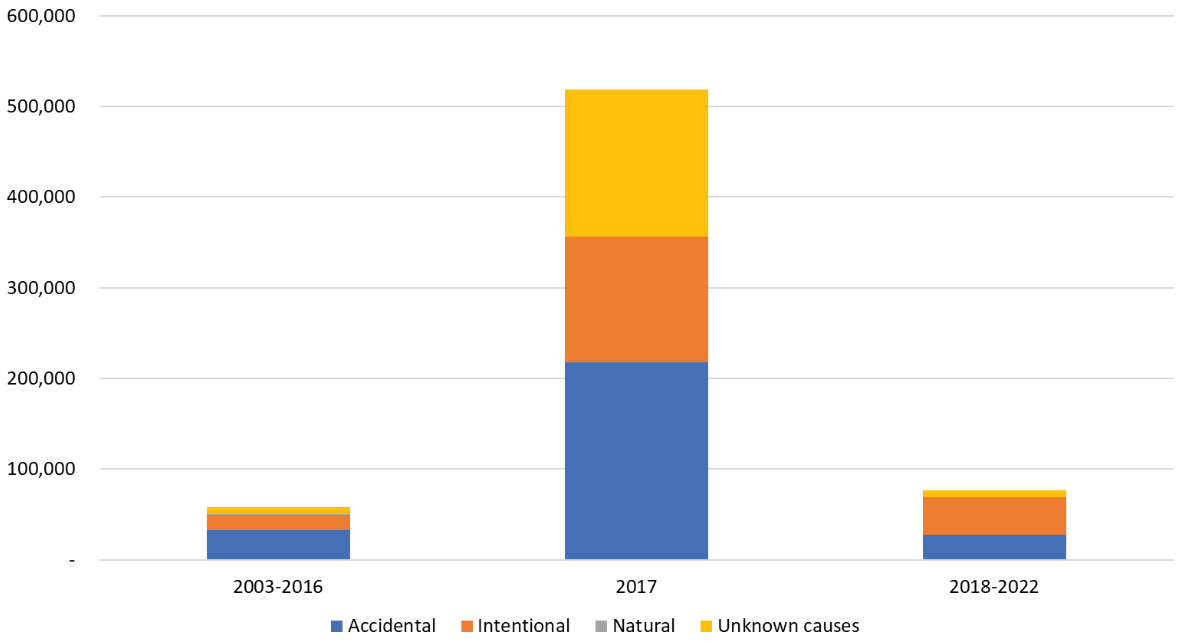
ANNEXES

Figure A1. Affected area (ha) in January-February by region and season



Source: Own elaboration with data from CONAF (2023).

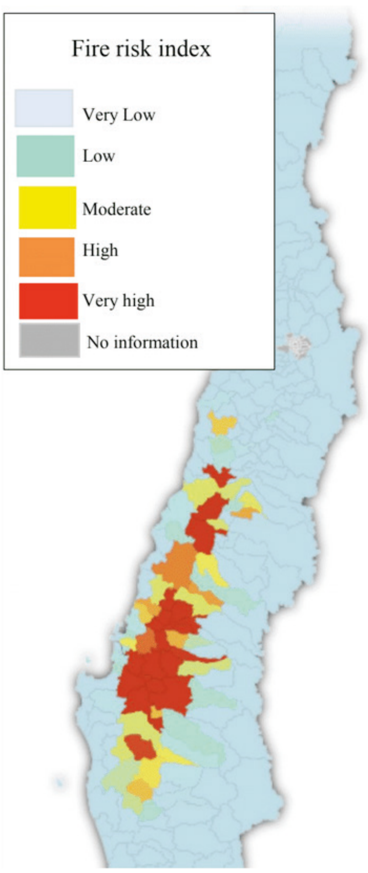
Figure A2. Area affected (ha) by forest fires by type of cause



Source: Own elaboration with data from CONAF (2023).

Figure A3. Comparison of estimated future fire risks and observed fire outbreaks

Future forest fire risk map (ArcClim MMA)



Forest fires February 2023 (NASA)

Source: Own elaboration based on ARCLIM data and NASA satellite images.

Table A1. General cost of afforestation of exotic species at 2017 prices (Chilean pesos)

Region	General cost of exotic forestry per hectare
Valparaíso	421,933
O'Higgins	490,690
Maule	436,497
Biobío	436,497
La Araucanía	466,330
Los Ríos	466,330

Source: Own elaboration based on data from CONAF, 2011.

Table A2. Preparation and management cost for exotic species at 2017 prices (Chilean pesos)

Item	Additional cost of preparation and management per hectare
Manual planting	59,482
Plowing with tractor	45,703
Moderate erosion	108,065
Management costs	
First pruning*	66,055
First thinning	37,432
Professional consulting	75,810
Total Pine	**392,548**
Total Eucalyptus	**326,492**

Source: Own elaboration based on data from CONAF, 2011. Note *: The costs of first pruning for Eucalyptus plantations are excluded.

Table A3. Potential volume per hectare according to age range and region (m3ssc / ha)

Panel A: Pine

Region/Age	1-5	6-10	11-15	16-20	21 or more
Valparaíso	0	30	71	200	289
O'Higgins	0	36	85	240	346
Maule	0	58	106	288	420
Biobío	0	67	117	304	446
La Araucanía	0	73	128	334	491
Los Ríos	0	77	135	351	515

Panel B: Eucalyptus

Region/Age	1-5	6-10	11-15	16-20	21 or more
Valparaiso	0	102	186	226	248
O'Higgins	0	122	223	271	298
Maule	0	134	244	295	325
Biobío	0	159	275	326	359
La Araucanía	0	175	303	395	395
Los Ríos	0	184	318	377	415

Source: Own elaboration based on data from INFOR, 2017 for the regions of O'Higgins, Maule and Biobío. For both species, it is assumed that the O'Higgins region produces 20% more than Valparaíso. Los Ríos 5% more than La Araucanía and in Araucanía 10% more than in Bio Bío.

Table A4. 2017 distribution of products of wood origin

Product	Pine	Eucalyptus
Pulp	32.3%	51.4%
Sawn Wood	51.6%	0.7%
Panels and Veneers	9.7%	1.7%
Chips	3.2%	45.5%
Other Products	3.2%	0.7%

Source: Own elaboration based on data from INFOR, 2018.

Table A5. Establishment cost per USD/ha, depending on forest type and coverage

Forest Type / Coverage	Very open	Open	Semi dense	Dense	Average
No. trees per hectare	100	300	600	1,200	-
Austrocedrus chilensis	-	-	-	-	-
Sclerophyll	704	1,578	2,889	5,512	2,671
Chilean Palm		3,027	5,787	11,306	6,706
Roble Hualo		983	1,700	3,133	1,939
Roble-Raulí-Coihue		983	1,700	3,133	1,939
Evergreen		983	1,700	3,133	1,939
Native With Wild Exotics		983	1,700	3,133	1,939

Source: Own elaboration based on afforestation cost data obtained from Patricio Toledo Eco-Solutions, 2023. Note: Number of trees per hectare estimated by coverage.