IMPACT OF FOREST FIRES ON PORTUGUESE FOREST ECOSYSTEM AND ITS NATIONAL EMISSIONS BUDGET

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IMPACT OF FOREST FIRES ON PORTUGUESE FOREST ECOSYSTEM AND ITS NATIONAL EMISSIONS BUDGET. The study highlights the significance of the forestry industry in Portugal, and delves into the economic, social, and environmental ramifications of forest fires on this vital sector. With a specialization in forest services, the country's healthy and sustained growth is heavily reliant on this sector. The study is a literature review analysis of carbon sink-source relationships and related uncertainty in the Portuguese forest ecosystem. We found wide literature research that Portugal lost 4% of its total tree cover due to forest fires in 2016-2017. The study concludes that the drought and forest fires suffered by the country throughout the years have had a considerable impact on the national emissions budget. Forest fires have wielded a significant impact on the nation's overall carbon emissions, representing 10% during the years with the highest incidence and averaging 2.7% over 25 years. Prior to 2014, the country was making significant progress towards achieving its National Plan on Climate Change (PNAC) 2020 reduction target, with emissions projected to fall between 18-23% below 2005 levels. These factors are putting country in a non-compliance position with the PNAC 2020 commitment target (which is the same target as for the Kyoto Protocol 2nd Commitment Period).

Keywords: GHG emission, carbon flux, forest fires, climate mitigation and adaptation, and Mediterranean forest

DAMPAK KEBAKARAN HUTAN TERHADAP EKOSISTEM HUTAN PORTUGIS DAN ANGGARAN EMISI NASIONAL. Studi ini menekankan pentingnya industri kehutanan di Portugal, dan membahas dampak ekonomi, sosial, dan lingkungan dari kebakaran hutan terhadap sektor vital ini. Dengan spesialisasi dalam layanan kehutanan, pertumbuhan sehat dan berkelanjutan negara sangat bergantung pada sektor ini. Studi ini adalah analisis tinjauan literatur tentang hubungan penyerapan-karbon dan sumber-karbon serta ketidakpastian terkait dalam ekosistem hutan Portugal. Kami menemukan penelitian literatur yang luas bahwa Portugal kehilangan 4% dari total tutupan pohonnya akibat kebakaran hutan pada tahun 2016-2017. Studi ini menyimpulkan bahwa kekeringan dan kebakaran hutan yang dialami oleh negara selama bertahun-tahun telah memberikan dampak yang signifikan terhadap anggaran emisi nasional. Emisi dari kebakaran hutan telah memberikan dampak yang signifikan terhadap total emisi negara, dengan kontribusi sebesar 10% selama tahun-tahun dengan kejadian terbanyak dan rata-rata 2,7% selama periode 25 tahun. Sebelum tahun 2014, negara tersebut telah membuat kemajuan signifikan dalam mencapai target pengurangan Rencana Nasional untuk Perubahan Iklim (PNAC) 2020, dengan perkiraan emisi turun antara 18-23% di bawah tingkat tahun 2005. Faktor-faktor ini menempatkan negara dalam posisi yang tidak sesuai dengan target komitmen PNAC 2020 (yang merupakan target yang sama dengan Periode Komitmen Kedua Protokol Kyoto).

Kata kunci: Emisi GHG, aliran karbon, kebakaran hutan, mitigasi dan adaptasi iklim, dan hutan Mediterania

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I. INTRODUCTION

The concentration of carbon dioxide (CO2) in the atmosphere has steadily increased since the early stages of industrialization (Dlugokencky & Tans, 2019; Quéré et al., 2019). This is primarily due to the emissions from fossil fuels and changes in land use, which have caused an increase in atmospheric carbon concentrations (Ciais et al., 2013; Quéré et al., 2017). The definition of land use and land cover modifications should be broad and inclusive, taking into account all types of land management activities, including those caused by humans, such as shifting cultivation, fertilizer use, logging, and fire presence, among others (Houghton & Nassikas, 2012).

The decline in land coverage seems to be caused primarily by forest fire (Alencar et al., 2011). In tropical rain forests, fire scarcely occurs naturally; due to human activity, fire deals with extreme temperatures and drought (Goldammer, 2016). In 2017, the fire trend increased since El Niño's international impact would last for two years and triggered drought throughout the tropics belt (Silva et al., 2018). Human influences also make forest more vulnerable to burning by the local climate (WMO, 2018). El Niño is also active in boreal and humid forests, where fires are more common, but global climate change raises fire intensity and costs (Weisse & Goldman, 2017; Ribeiro-Kumara et al., 2020). Forest combustion will emit huge quantities of carbon into the atmosphere (Weisse and Goldman, 2017). Blazes in Brazil, California, Portugal and elsewhere have recently been shown that forest fires do not go away–they just intensify because the global warming (BBC, 2019). Over the last two years (2016-2017), Portugal has had half of all forest areas (approximate 165.8 thousand ha) burnt in the EU because of incorrect policies of forest management, poor land use management and fire prevention activities (Weisse & Goldman, 2017; BBC, 2019; GFW, 2023). During this context, our study is, therefore, to review the carbon sink-source relationship and related uncertainty within the Portuguese forest ecosystem; discuss what the economic, social, and environmental importance of forests for Portugal is; and consider the implications that forest fires are having in Portugal's CO2 reduction targets. The objective of this study is to know carbon sink-source relationships and related uncertainties within the local forest ecosystem in Portugal through the review of obtainable literature. Intending to guide us throughout the development of this study and fulfil the proposed objectives, we set the subsequent research questions: (a) What has been the carbon sink and source evolution in recent years within the Portuguese forest ecosystems by taking into consideration the relevant uncertainties (e.g., forest fires, drought, etc.)? (b) What are the CO2 emissions related to forest fires and consequent impacts on GHG reduction targets for Portugal?.

II. MATERIAL AND METHODS

The research has been explored supported literature search by combination of the specific keyword using "logical" AND "operator" with period between 2005-2020 on search engine by Google, Google Scholar, Scopus, and Web of Science for the peer-reviewed article, news, case studies, report, on the issues of carbon sinks and sources within the forest ecosystem of Portugal. For searching, we used keywords like "objective" AND "problem" AND "scale". We also administered a literature-screening focus in the target objectives. We have been found total 92 literature to be focused of our objectives, and we have been short listed 25 articles. We categorized literature supported the combinations of the used word. We have read the abstract and content of selected articles to critically identify the various approaches to treat carbon sinks and sources within the Portuguese forest ecosystem (Figure 1.). Our literature review was examined consistent with specific predefined objectives (Vieites-Blanco & González-Prieto, 2020).

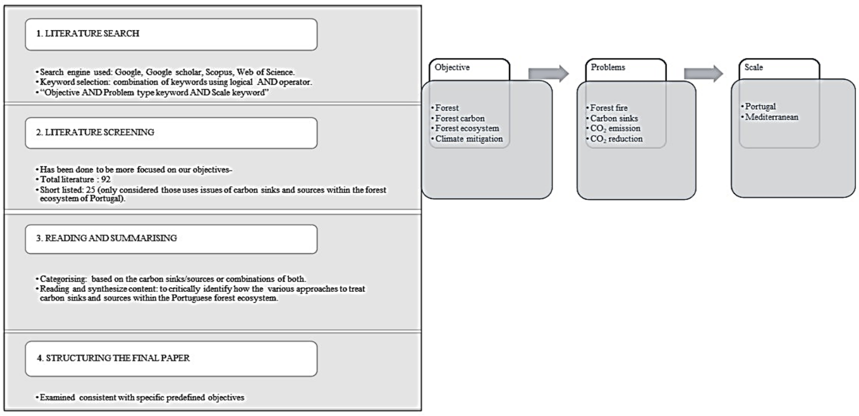


Figure 1. Sketched mapped for the literature review process.

III. RESULT AND DISCUSSION

1. Present Scenario of Portuguese Forests and their climate condition

Due to a group of important forest protection measures and impactful reforestation actions that were implemented during the past four centuries, Portugal has currently one among the most important forest areas in Europe – 35.4% or 3.2 million ha (Figure 2, Figure 3.) (ICNF, 2013a). The eucalyptus tree is the predominant specie in Portugal with a 26% occupation or 812 thousand hectares. The cork oak tree follows up with a 23% territorial presence, equivalent to 737 thousand hectares. In third place comes the pine tree with 22% or 714 thousand ha of forest areas (Figure 4.) (Nunes et al., 2019).

Geographically speaking, the eucalyptus species is primarily concentrated in the Beirã region (specifically, Baixo Vouga and Beira Interior Sul), as well as in Tâmega, Central Tagus, the West, and Alto Alentejo. The eucalyptus is comparatively recent in Portugal and coincides with the establishment and emergence of the paper industry (Figure 5.). The oak trees are abundant across Portugal, with various species found throughout the country. The cork oak tree dominates the south coast, while the holm

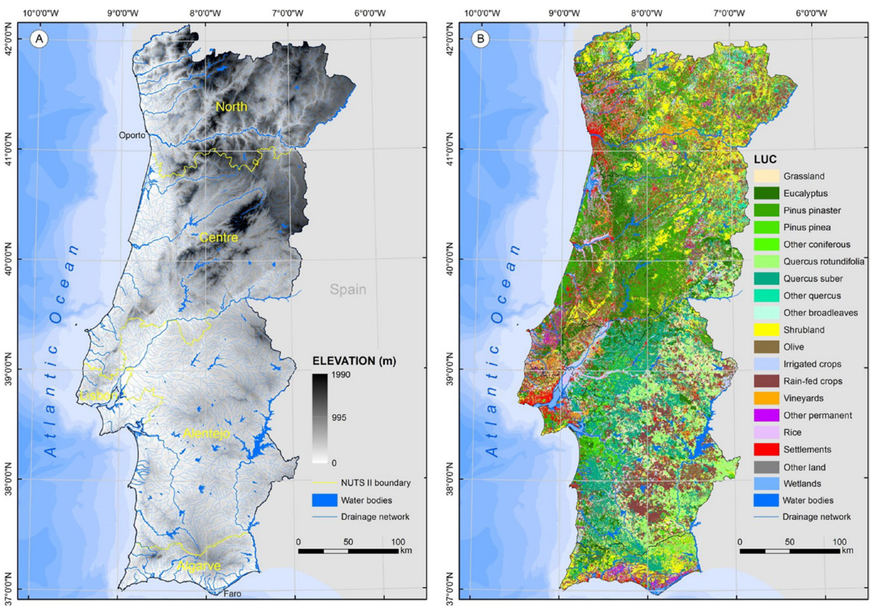


Figure 2. Elevation and land cover map of Portugal (Meneses et al., 2018).

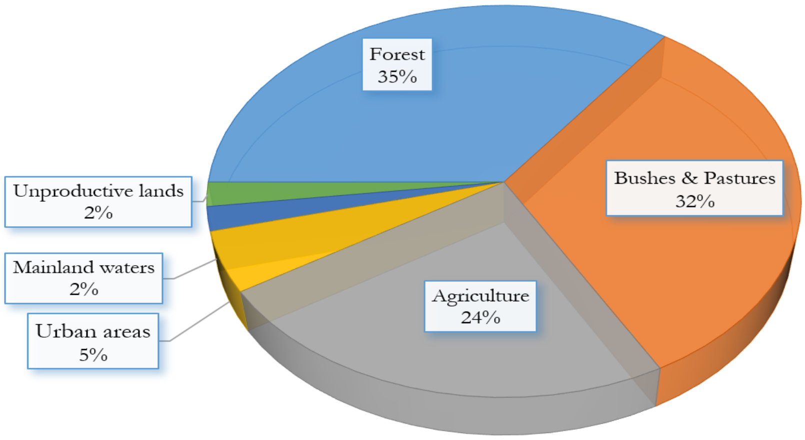


Figure 3. Landscape distribution in Portugal (Público, 2017).

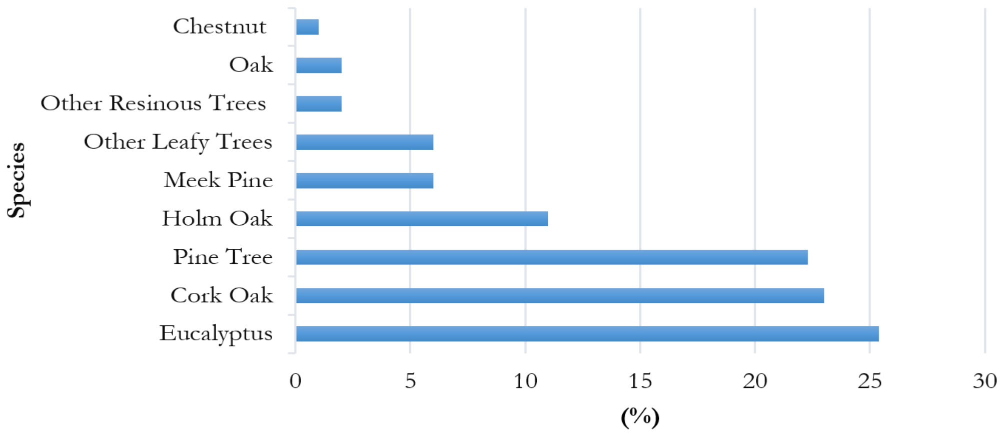


Figure 4. Forest areas distribution in Portugal (PEFC, 2017).

oak is frequently seen in the country's interior. The penduncalate oak is primarily concentrated in the north-east region, spanning throughout the Minho-Leiria coast band, which is known for its mild temperatures and high humidity. The black oak is located in the Beira Interior and Trás-os-Montes regions, and the meek oak is particularly present in the Setubal region, which is situated in the centre of the country.

Riparian species such as the pine-oak, willow, poplars, alders, elm, and ash trees are found within the northern part of the Tagus River and more rarely within the South in smaller agglomerates or sub-regions of the inner land (ICNF, 2013b). Most of the Portuguese forest property is owned by privately or entities. About 84.2% of the total forest area, equivalent to 2.8 million hectares, is owned by industrial businesses, while small household-level owners own the rest. The public ownership corresponds to 15.8% of the total forest of which 2% is owned by the state (lowest figure in the EU). It is estimated that in total there is the maximum amount as half a million forest owners (ICNF, 2013a). Despite the high number of forest owners and therefore the small dimension of forest properties, the resources that forests provide sustain an important and integrated industrial chain that is exports-based. Forestry is a significant contributor to Portugal's

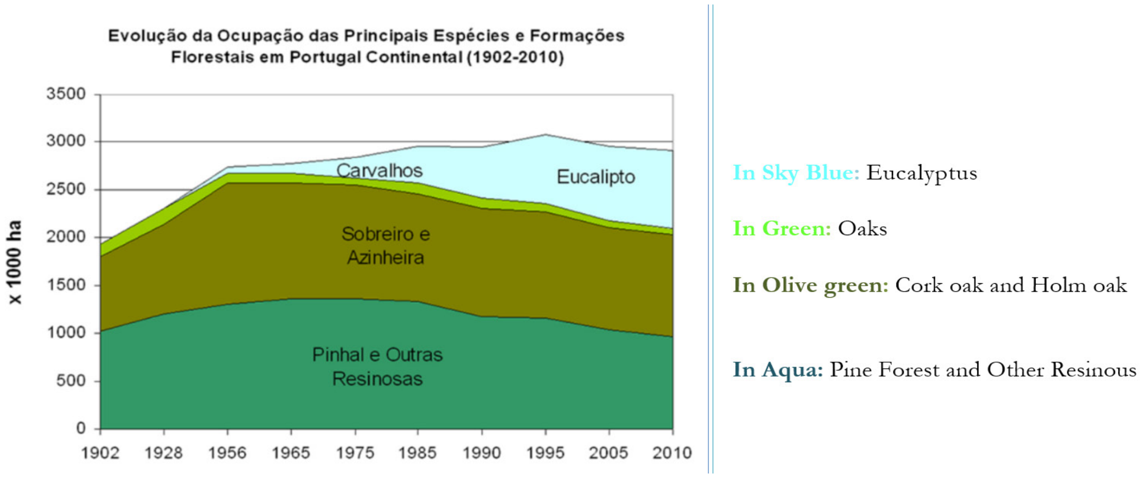


Figure 5. The main forest species occupation and forest formation between 1902-2010 in Portugal (Anonymous, 2014).

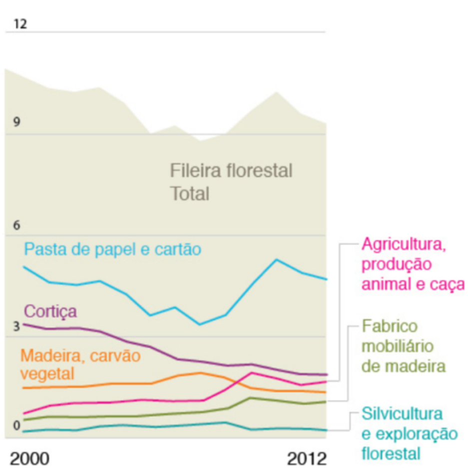
economy, and the country is well-known for its expertise in the industry. In comparison to the EU average, the forestry sector significantly contributes to Portugal's national GDP (PEFC, 2017). Despite its significant economic importance, the national forest in Portugal plays an equally crucial role in the environment and society more broadly.

The impact of climate change is significant in the region of the Atlantic Ocean and the Mediterranean Sea. This is due to the transition between the climatic conditions of the Mediterranean and the Atlantic. The amount of rainfall that falls in the region varies across the area. In the southern and north-eastern areas, the mean annual precipitation is less than 500 mm. In the northwest, however, it exceeds 2000 mm. The mean annual rainfall typically increases with higher latitudes, elevations, and proximity to the Atlantic Ocean. In the summer, the region experiences dry conditions, particularly in June, July, and August. Most of the rainfall is concentrated between October and March (Meneses et al., 2018).

2. Importance of Portuguese Forests

Forests play a crucial role in the Portuguese economy and society, as they contribute 10% of the country's total national exports and 2% of the Gross Domestic Product (GDP) (ICNF, 2017). The Portuguese forestry sector's most important products include paper and cardboard, paper folders, cork, wood, resin, and furniture products, which not only contribute significantly to the economy but also have environmental benefits, highlighting the multi-dimensional importance of Portuguese forests (Figure 6.). In addition to the significant economic benefits, Portuguese forests also provide valuable non-timber forest products such as dry fruits like chestnuts and pine nuts, support sport hunting, and facilitate outdoor activities such as tourism and recreation, further underlining the significance of forests in Portuguese society.

Portuguese forests also contribute significantly to the country's external trade, with a net value of the balance of payments representing a total of €2,267 million, which further emphasizes the economic importance of the forestry sector (ICNF, 2017). Portuguese forests play a critical role in the job market, providing employment opportunities to 101,700 direct workers, which corresponds to 1.8% of the active population, demonstrating the significance of the forestry sector for the country's workforce (Público, 2017). All these figures indicate that the sector is of greater importance in comparison with the EU (Table 1.). The strength of the Portuguese forestry



In Blue: Paper and cardboard pulp.
In Purple: Cork.
In Pink: Agriculture, livestock production and hunting.
In Yellow: Wood, coal, vegetal.
In Green: Wood furniture
In Turquoise: Forestry and forest exploration

Figure 6. The forest subsectors as a share of the total forest exports (Público. 2017)

Table 1. Contribution of employment, GDP, forest cover, and ownership in the forest sector of Portugal (Lopes and Cunha-e-Sá, 2014)

Forestry sector	Portugal (%)	Europe (%)
Contribution of Employment (2006)	1.6	1.1
Contribution of GDP (2006)	1.7	1.0
Forest Cover (2010)	38	45
Private Ownership	86	60

Carbon Sequestration	**Regulating services**	Climate regulation	Climate regulation	Mediation by biota, sequestration
Watershed Protection		Water regulation	Water purification	Mediation by ecosystems
Protection from Soil Erosion		Erosion regulation	Erosion prevention	Mediation of mass flows
Recreation	**Cultural Services**	Recreation	Recreation	Physical and experiential interactions
Landscape		Aesthetic values	Aesthetic information	Intellectual and representational interactions
Biodiversity		Supporting services	Habitat services (Gene pool protection)	Maintenance services (Gene pool protection)

Figure 6. Environmental importance of forests (Lopes and Cunha-e-Sá, 2014

sector is not only limited to the national level but also extends to the EU-wide level, as evidenced by its significant contribution to the economy and society, further cementing its position as a vital sector in the country.

Despite efforts to monetize forest services, the true value of Portuguese forests remains invaluable due to their unique, complex, and vulnerable nature, emphasizing the need to prioritize their preservation and protection for the benefit of both present and future generations. Portuguese forests offer numerous environmental benefits as listed (Figure 7.). Watershed protection is crucial for ensuring the quality of drinking water, balanced water and nutrient flow, and soil conservation (Postel &

Thompson, 2005). It involves keeping forests intact and investing in green infrastructures instead of building water treatment plants. This approach reduces property damage and future costs of providing clean water and treating wastewater, and it has become more cost-effective over time (EPA, 2012). The devastating fires of 2017 in Portugal have led to significant problems with water quality and contamination in certain regions, highlighting the urgent need for effective measures to prevent and mitigate the impact of future forest fires on the environment and communities. (Anonymous, 2017).

In recent years, the gradual forest cover decline in Portugal has also reduced biodiversity (Figure 8.). Some species are in danger and others have already disappeared from the country (Tomas, 2017).

The problem is that without an accurate human intervention in burnt forest areas, native species will not be able to reinstall themselves within the region because invasive tree species with rapid growth will tend to occupy these lands (i.e., eucalyptus). These same forest fires also created open-air and unprotect land areas. Raindrop splash makes soil particles detach in nutrient-rich lands. As a result of such fires, soils degrade and are unable to retain and purify water. This might considerably increase the risk of floods in surrounding communities (depending on location) and further reduce water quality. For instance, the dramatic forest fires during the summer of 2016 within the highlands of Funchal have significantly increased the risk of floods within the city. Funchal is surrounded by mountains that used to have forests widespread. Its tropical climate means that precipitation could also be intense sometimes. These surrounding forests served as water and land retainer-like thus prevented big floods and landslides. Since big parts of those forests were burnt in 2016, the city is today highly susceptible to inundation and rock collapse (Anonymous, 2016b). Finally, CO_2 emissions increase as a result of forest devastation. Because it is understood, forests are an important carbon sink and without them, the atmosphere would present much higher levels of greenhouse emission concentrations. The annual occurrence of fires has an impression of an impact on Portugal's national emissions target because it is discussed within the following section.

3. Impact of Fires in Portuguese Forests

Since the beginning of the new millennia, Portugal has suffered from a severe forest loss (Figure 9.). This is often mainly due to an increasing number of forest fires. The numbers are striking within the last 17 years, the country lists a total burnt forest area of 1.023 million ha (including the dramatic fires of 2017) (Assembleia da Républica, 2017). The numbers are not the same in every source. As an example, Global Forest Watch (GFW) states that for the

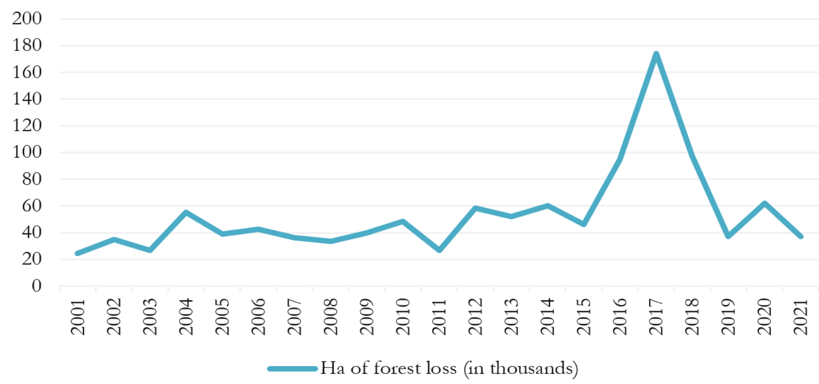


Figure 8. The gradually forest cover decline in last ten years (GFW, 2023).

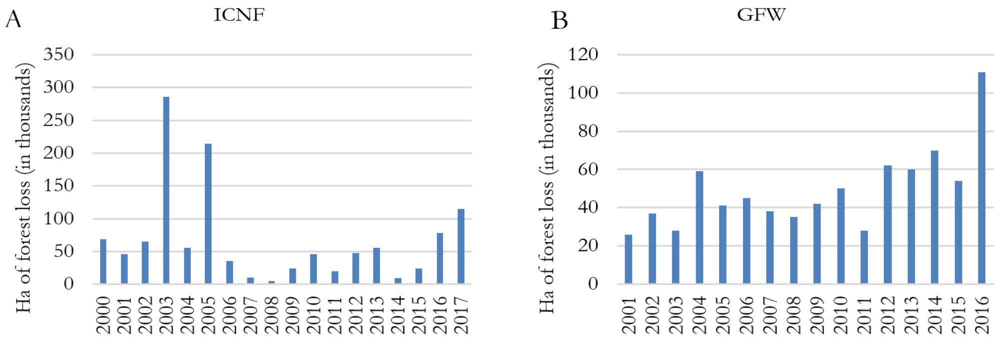


Figure 9. Burnt forest area in Portugal by ICNF (Institute for Nature Conservation and Forests) (A) and GFW (B).

same period a total of 0.79 million ha of forest were lost (excluding 2017 fires estimated at 0.12 million ha and including other sources of forest loss – logging and deforestation) (GFW, 2017); the national government stands for 0.15 million ha (excluding 2017 fire events) (Anonymous, 2016a). Altogether these three assertions, only forest loss is being considered as bush loss is outside the scope of this analysis. The previous two being the foremost independent sources.

Portugal has also made significant progress in increasing its tree cover, with a gain of 0.29 million hectares between 2001 and 2012, according to data from Global Forest Watch (GFW, 2017). Another report indicates that this same gain was about 0.2 million ha from 1995 to 2010 (Caetano et al., 2017). While it's important to note that the figures may not be entirely comparable due to variations in research methodology and content date, the overall trend suggests that losses in forest cover over the past two decades have outpaced gains. Forest fires are unequivocally the basis explanation for this outcome.

4. Impact of Forest Fires in Meeting National GHG Emission Targets

Over time, the frequency of forest fires has been on the rise. As previously discussed, these forest fires have pre-occupying effects on the economy, society, and environment. These effects are expected to aggravate over time due to global climate change. In Portugal, burnt forest area has increased in recent decades due to increasing dimension of forest fires (Figure 10.) (Assembleia da Républica, 2017).

When exclusively considering the impact of forest fires on the country's annual emissions, we can observe a noteworthy impact. Capable of significantly deviating Portugal's trajectory from achieving the ultimate GHG targets set under the National Plan on Climate Change (PNAC) 2020/2030 on an isolated year. The impact is lower when forest fire emissions are considered on average terms. As we can observe, emissions from forest fires can count at most with approximately 10% of the national total as it happened after the catastrophic years of 2003 and 2005 (expected to reach similar levels in 2017); and a minimum of with 0.2% like in 2008 and 2014 (Figure 11.). On average, from 1990 to 2015, forest fire emissions have contributed to 2.7% of Portugal's total emissions budget. This average figure is expected to increase after the 2017 events.

PNAC 2020/2030 has set a twin goal of reducing emissions by 18% to 23% by 2020, and 30% to 40% by 2030, having the 2005 emission levels as a baseline. When referring to the 2020 target (in line with the national target under the Kyoto Protocol 2nd Commitment Period), emissions from forest fires were not so important until 2014 when Portugal's emissions were at its lowest. Today, forest emissions (both on average and yearly) have the potential to vociferously undermine Portugal's commitments. Together may observe, in 2017 forest fires have abruptly

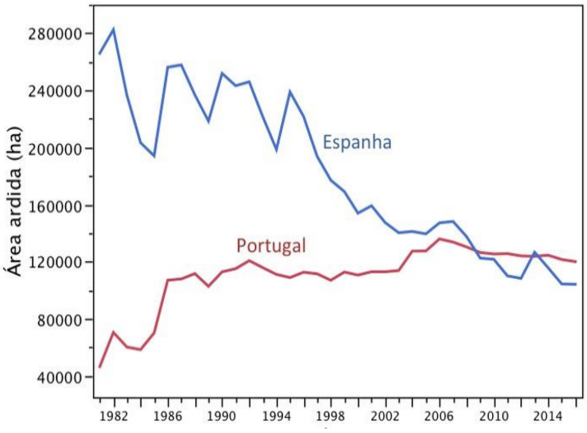
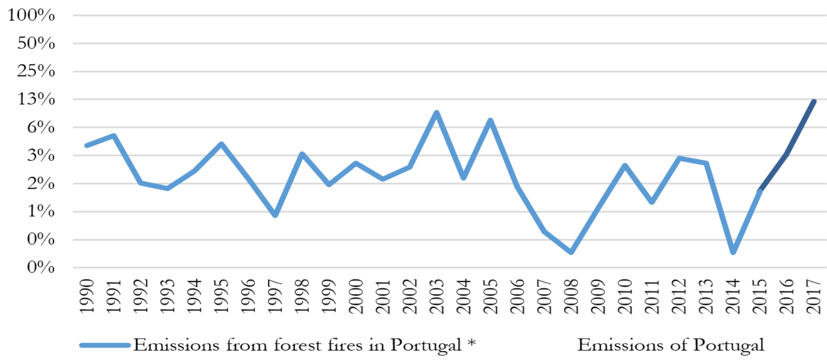


Figure 10. Evolution of forest fires over time in Portugal and Spain (Assembleia da Répubdica, 2017).



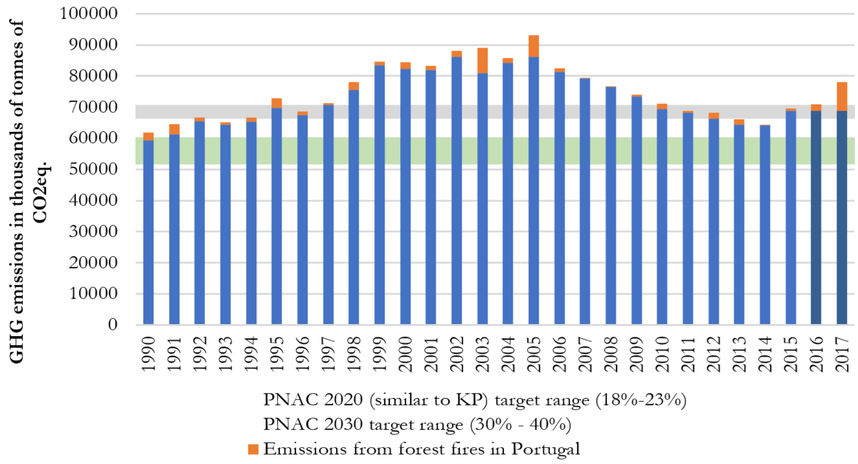
Note: *The ***dark blue*** line covering the 2016 and 2017 years is the forest fire emissions - published by the Portuguese Environment Agency (APA, 2017a, b) - as a percentage of the 2015 emissions since the figures for those years are not yet available. National emissions for 2016 and 2017 (excluding CO2 from forest fires) are expected to be higher than the 2015 reference due to the unprecedented droughts. This is an exercise intended to merely help the reader understand and have a clear view of the impact of 2017 forest fires.

Figure 11. Forest fire emissions as a (%) of total national emissions (APA, 2017a, b.

increased national emissions to levels that put Portugal in nonconformity regarding its reduction commitments (Figure 12.).

On the other hand, forest fires are not so relevant when considering that Parties under the Kyoto Protocol are allowed to leave 'abnormally high' emissions from natural phenomena unaccounted in their National Inventory Report (NIR) documents. This option can be pursued as long as regeneration and reforestation of the burnt areas are not used as negative emissions (sink) (APA, 2017a, b). For the time being, this seems to be a plausible possibility, and a decisive one is as long as the national emissions are increasing steadily since 2014. As an example, in 2017 the inclusion of forest fire emissions within the national total puts Portugal during a non-compliant position, but not any longer if equivalent emissions are excluded.

As to the PNAC 2030 goal, Portugal has committed to reducing its emissions by 30% to 40%. The foremost recent NIR report submitted by Portugal to the UNFCCC shows that Portugal has significantly increased its emissions in 2015 due to the severe droughts that the country has faced (APA, 2017a, b). These emissions are expected to further increase in 2016 and 2017 given the intensified droughts (Público, 2017). Due to these extreme events, Portugal is distancing itself from the



Note: *The two ***dark blue*** columns for 2016 and 2017 are the national emissions of the 2015 emissions given that the figures for the two most recent years are not yet available. National emissions for 2016 and 2017 (excluding CO2 from forest fires) are expected to be higher than the 2015 reference due to the unprecedented droughts. This is an exercise intended to merely help the reader understand and have a clear view of the impact of 2017 forest fires.

Figure 12. CO2 emissions and the impact of forest fires in Portugal (APA, 2017a, b).

2030 target (Figure 9.). Nevertheless, for this specific commitment, the state has enough time (13 years) to curb its emissions right down to promised levels with adequate investments in renewable energy, efficient technology, forest fire-prevention measures, and reforestation. Also, improve forest fire prevention measures and combat interventions (Weisse & Goldman, 2017; APA, 2022).

IV. CONCLUSION

Half all-forest areas (approximate 165.8 thousand ha) burned within the European Union occurred within the last two years (2016-2017) of Portugal which one of the most important forest areas in Europe (GFW, 2017; 2023). This is truly worrying given the economic, social, and environmental importance this sector has for the country. It concluded that these same forest fires have a considerable impact on the country's annual emissions. The impact of large-scale forest fires is significant, as they have the potential to significantly deviate Portugal from achieving its greenhouse gas (GHG) targets set under the National Plan on Climate Change (PNAC) 2020/2030 in a single year. Prior to 2014, Portugal was making good progress towards achieving its PNAC 2020 reduction target of reducing emissions by 18-23% below 2005 levels. In contrast, since that time, there has been an alarming increase in national emissions. The emissions' trajectory in the years of 2016 and 2017 is expected to be one of continued ascendance, up to levels that put Portugal in a non-compliance position with the PNAC 2020 commitment target (which is the same as the national target under the Kyoto Protocol 2nd Commitment Period). For the future, it is important to keep tracking the emissions growth trajectory and estimate what impact the increasing occurrence and intensity of forest fires and droughts may have in the years preceding the 2020 national CO2 reduction target. It is equally important to insist on a wide and broad discussion because of improving and upgrading adaptation plans and forest fire prevention and combat policies. To address the situation in Portugal effectively, it is crucial to focus on two key strategies (Weisse & Goldman, 2017; APA, 2022; GFW, 2023): controlling forest fire occurrences and reducing GHG emissions.

1. Controlling forest fire occurrences:
   - Enhance prevention efforts: Implement rigorous forest management practices, including regular monitoring, early detection systems, and firebreaks.
   - Improve firefighting capabilities: Invest in advanced firefighting equipment, enhance training programs for firefighters, and establish efficient coordination mechanisms among different agencies.
   - Increase public awareness: Educate communities about fire safety measures, promote responsible behavior in forested areas, and encourage the reporting of potential fire hazards.
2. Reducing GHG emissions:
   - Transition to renewable energy sources: Transitioning to renewable energy is vital not only in tackling the challenges of our dependency on fossil fuels but also in mitigating greenhouse gas emissions. Investing in renewable infrastructure, such as solar and wind power, will help achieve this goal.
   - Improve energy efficiency: Implementing energy-saving measures in buildings, industries, and transportation sectors can decrease energy consumption and associated emissions. Improving energy efficiency is a necessary step towards a sustainable future.
   - Promote sustainable practices: Encourage sustainable agriculture techniques, afforestation projects, and the use of cleaner technologies to reduce emissions from agricultural activities.
   - Support public transportation and electric vehicles: Improve public transportation systems, incentivize the use of electric vehicles, and develop charging infrastructure to reduce emissions from the transportation sector.

By prioritizing these strategies, Portugal can make significant progress in controlling forest fires and reducing GHG emissions, contributing to a more sustainable and resilient future. Additionally, international collaborations and partnerships can further support these efforts through knowledge sharing and resource mobilization.

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