Land Use Impact of Maritime Pine and Eucalypt: A Life Cycle Assessment Study

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The forestry sector in Portugal faces important challenges, resulting in an increased incidence of fires and the action of pathogens, which puts the sustainability of forest resources at risk. Due to the economic, social, and environmental importance of forests, this work assessed the land use environmental impact of maritime pine and eucalypt standing in Portuguese forests. SimaPro software was used to translate the inventory table results into land use impact category. The ILCD 2011 Midpoint+ method was chosen to assess the "land use" environmental impact that focuses on soil quality and its indicator (kg carbon deficit), which describes the changes in soil organic matter associated with land interventions. The results showed that for the first rotation time, the land use impact category per cubic meter of maritime pine is 18423 kg C deficit and 23430 kg C deficit for eucalypt, which means that the land use impact category of eucalypt is 27% higher than the impact of maritime pine.

Keywords: Forest; Land occupation; Land transformation; Soil organic matter

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INTRODUCTION

The forestry sector faces important challenges worldwide in the climate change scenario. The major challenges are the sustainability of forest resources and the conservation of biological diversity. Due to climate change, an increase in the incidence of fires and the action of pathogens has been observed in recent years.

The forestry sector in Portugal has a high economic, social, and environmental value. In economic terms, in 2015, its gross value added (GVA) represented more than 10 billion euros, corresponding to 13% of industrial GVA and 3% of national gross domestic product (GDP) (ICNF 2020a). Forest products exports have been among the country's main exports, accounting in the current millennium for an average of 9% of the total exports, while the sector is only responsible for 4% of the imports (ICNF 2019). In social terms, the forestry sector is responsible for creating about 94.3 thousand jobs (ICNF 2020a). In environmental terms, it contributes significantly to mitigating the effects of global warming by capturing a total of 333.92×10^6 tons CO_2 (data from 2015) (ICNF, 2020b).

The forest is the main use of mainland Portuguese soil (36%) with maritime pine (*Pinus pinaster* Ait.) and eucalyptus (*Eucalyptus globulus*) the two main species whose main function is the production of wood (Table 1).

According to National Forest Inventory (ICNF 2020b), in 2015, eucalypt occupies the most forest land (845 kha), representing 26.2% of the total Portuguese forest area. The Maritime pine with an occupation of 713.3 kha represented 22.1% of the total forest area.

Table 1. Forest Soil Occupation by Species in Mainland Portugal (Kha) in 2015 (adapted from ICNF 2020 b)

Eucalypt	Maritime pine	Cork-oak *	Holm-oak *	Stone pine	Other species	Total
845	713.3	719.9	349.4	193.6	403	3224.2

* The main function is not the production of wood

Between 2005 and 2015, the occupation of the soil by eucalypt had grown about 7.5%, but the existing volume increased slightly 0.2%. During this time, maritime pine was the forest ecosystems that presented the largest reduction in soil occupation (-84.7 kha) and in the volume of growing wood (*i.e.*, from live trees) (-15 million m^3). This decrease in land-use area and growing wood volume was mainly due to fires and pests, the most important being the nematode (*Bursaphelenchus xylophilus*). During this period, 228,284 forest fires were recorded, which were responsible for a forest burnt area of more than 492 kha (Pordata 2020). The nematode is responsible for huge economic impacts related to wood loss, restriction/reduction of trade in wood/related products, and costs associated with phytosanitary procedures and control actions. According to Sousa *et al.* (2015) the accumulated value of the loss of forest stock in Europe, over a period of 22 years (2008-2030), if there are no control and regulatory measures of nematode, is estimated at 22 billion euros.

Furthermore, the severity of wildfires in Portugal in 2017, with a total burnt area of more than 539 kha (ICNF 2019), certainly caused an important degradation on the existing volume of eucalypt and maritime pine. Forest fires as well as land conversion, tillage, overgrazing, and soil erosion are anthropogenic causes of soil organic matter (SOM) loss (Brandão and Milà i Canals 2013).

Under the European Land Use, Land Use Change and Forestry (LULUCF) Regulation (EU 2018), an essential component of the EU 2030 climate and energy framework, EU Member States must ensure that their carbon sink will not be smaller than the one that would occur if current management practices are continued. Portuguese LULUCF were estimated as an average sink of -7.34 Mt CO_{2eq} in the period 1990 to 2015 with a tendency for increasing net-sequestration over time (APA 2017), but in 2017 greenhouse gas emissions of LULUCF were estimated at 7.3 Mt CO_{2eq} (INE 2020) in opposition of the goal of a net zero carbon footprint by 2050.

Life cycle assessment (LCA) is a technique that addresses the environmental aspects and potential environmental impacts (*e.g.* land use) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal (*i.e.* cradle-to-grave) (ISO, 2006a).

LCA has been applied to evaluates the environmental impacts associated with the production of eucalypt and maritime pine wood in Portugal (Lopes *et al.* 2003; Dias *et al.* 2007; Vieira *et al.* 2010; Dias and Arroja 2012; González-García *et al.* 2014; Ferreira *et al.* 2020), but no one of these earlier studies assessed the land use impact category. Lopes *et al.* (2003) compared the environmental impact of the use of two kinds of fuels in the pulp and paper production processes. Dias *et al.* (2007) assessed the potential environmental impacts associated with the entire life cycle of the printing and writing paper produced from eucalyptus pulp. Dias and Arroja (2012) evaluated the environmental impacts associated with the production of eucalyptus and maritime pine wood. González-García *et* *al.* (2014) estimated the environmental profile associated with maritime pine wood production in Portugal and France. Ferreira *et al.* (2020) evaluated the potential environmental impacts associated with different commercial outputs of maritime pine wood (round, industrial, and residual). Vieira *et al.* (2010) compared the environmental impacts of the production of printing and writing paper based on eucalyptus with those from the production of paper from industrial hemp having been the only study that accounted for direct land use (ha) per 1 ton of paper produced from eucalyptus wood.

According to achievements of Working Group 2 "Land Use" of COST Action E9 "Life Cycle Assessment of Forestry and Forest Products" (Doka *et al.* 2002), far more than for other products, the assessment of impacts caused by land use is essential for the full assessment of forest products. Two different kinds of land use impact were identified: land use change (also called land use transformation); and land occupation. Land use change (transformation) is a man-made change of the land use from one type to another (*e.g.*, from natural forest to intensive forest), and land occupation is the continuous use of some area for a certain period for specified land use type (Doka *et al.* 2002; Perminova *et al.* 2016).

The impact category 'land use' describes, in LCA methodology, the environmental impacts of land occupation and transformation for human purposes. Extensive research has been done on the impact category land use to quantify impacts of land occupation and land transformation on biodiversity, biotic production, and soil quality (Hauschild *et al.* 2011; Faragò *et al.* 2019). In the International Reference Life Cycle Data System (ILCD) Handbook (Hauschild *et al.* 2011), 3 midpoint models (ReCiPe, Milà i Canals, and Baitz) and five endpoint methods (EPS2000, Eco-Indicator 99, ReCiPe, LIME, and Swiss Ecoscarcity) were evaluated. At the endpoint level, no method is recommended by ILCD; therefore, the ReCiPe method was suggested as an interim solution. At the midpoint level, the method by Milà i Canals is considered the most appropriate among the existing approaches for Life Cycle Impact Assessment in the European context (Hauschild *et al.* 2011). This method focuses on soil quality, and its indicator describes the changes in soil organic matter (SOM) associated with land interventions (Milà i Canals *et al.* 2007).

This study aims to apply the life cycle assessment to evaluate the land use impact category of maritime pine and eucalypt standing in Portuguese forest. The results of this study can be important to support future decision-making regarding the best management options for Portuguese forest planning.

EXPERIMENTAL

The methodology adopted in the study is the Life Cycle Assessment method following the ISO 14040/44 (ISO 2006a; ISO 2006b) standards and used in similar studies (Laurent *et al*. 2016; Ratnasingam *et al*. 2017).

Description of the System under Study

Maritime pine and eucalyptus standing in Portuguese forest are used to account for the land on which trees grow. Attention was placed on the living tree before harvesting. Trees compose their biomass from carbon dioxide (CO_2), water, and several nutrients using solar energy.

The majority (80%) of maritime pine stands in Portugal do not require forest activities before the final cutting; *i.e.*, they grow under low intensive conditions. There is no planting or sowing because natural regeneration is performed. By contrast, the eucalyptus stands grow under highly intensive conditions.

Forest intensity and CO_2 assimilated by the trees does not contribute for the land use impact category; therefore, they are not in the scope of this study.

Functional Unit

In this study, the functional unit (FU) is given as 1 m^3 of maritime pine, standing in a pine forest and 1 m^3 of eucalypt, standing in eucalypt forest. The function of the system being studied is to produce maritime pine and eucalypt trees for different uses.

System Boundary

Figure 1 represents a simplified way of defining the system boundary (gate-to-gate) for the product systems being studied. The process included in the boundary is related to the regeneration of the trees in the forest. The output is maritime pine and eucalypt, standing in forest, and the inputs are those related to the occupation and transformation of land.

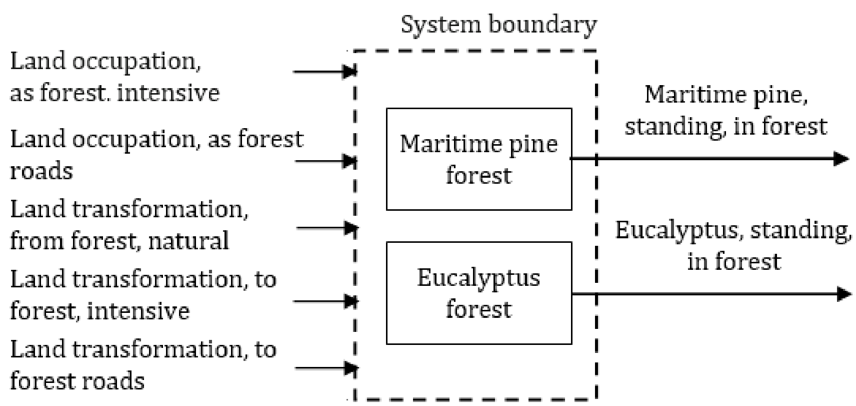

Fig. 1. Gate-to-gate product system boundary

Life Cycle Inventory (LCI) / Data Collection

Inventory data on maritime pine and eucalypt from managed natural forests in Continental Portugal was based on the National Forest Inventory (IFN) (ICNF 2020b) and other sources, as illustrated in Table 2. The National Forest Inventory (IFN) is a process of statistical and cartographic nature, which allows assessing the temporal evolution of the state and the use of forest resources in Portugal. Below is the IFN6 report forest data for 2015.

Allocation

Forests are multifunctional, providing environmental services including carbon sequestration, water storage, soil erosion prevention, landscape structuring, a place for recreation, *etc.* However in this study, like in Werner *et al.* (2007), the total forest area is allocated only to the main function that is the production of maritime pine and eucalypt. Uses other than for establishing, tending, and harvesting of wood are not considered.

All impact of land transformation is allocated to the first harvest, so the time for which land is used as forest (after transformation to forest) is the same as rotation length (time from birth/plantation to final tree harvest).

Table 2. Datasets for Land Use/Occupation and Production of Maritime Pine and Eucalypt

Nr.	Portuguese forest	Mean value		Units	Source
		Eucalypt	**Maritime pine**		
1	Land occupation (IFN6) (x10^3)	845	713.3	ha	ICNF 2020 b
2	Volume (growing) (IFN6) (x10^6)	43.31	66.52	m^3	ICNF 2020 b
3	Rotation length (time from birth/plantation to final tree harvest)	12*	35**	yr	*Almeida 2008, **AIFF 2013
4	Forest road length	71.3		m/ha	Faias *et al.* 2007
5	Forest road width	3.50		m	IC-EQUAL 2007
6	Forest road area	0.024955		m^2/m^2	Calculated [1]
7	Yield (including forest roads)	0.005125	0.00933	m^3/m^2	Calculated [2]
8	Yield (excluding forest roads)	0,005256	0.00957	m^3/m^2	Calculated [3]
9	Land use, forest	190.253	104.55	m^2/m^3	Calculated [4]
10	Land use, forest roads	4.869	2.676	m^2/m^3	Calculated [5]
11	Time for which land is used as forest (after transformation to forest)	12	35	yr	= Rotation length
11	Land occupation, forest	2283	3659	$m^2.yr/m^3$	Calculated [6]
12	Land transformation, forest	190.253	104.551	m^2/m^3	Calculated [7]
13	Land transformation, forest road	4.869	2.676	m^2/m^3	Calculated [8]
14	Land occupation, forest roads	58.431	93.65	$m^2.yr/m^3$	Calculated [9]

[1] Forest road area = (Forest road length × Forest road width) / 10000
[2] Yield (including forest roads) = volume (growing) / Land occupation / 10000
[3] Yield (excluding forest roads) = Yield (including forest roads) / (1 - Forest road area)
[4] Land use, forest = Yield (excluding forest roads)$^{-1}$
[5] Land use, forest roads = Forest road area / Yield (including forest roads)
[6] Land occupation, forest = Land use, forest × Time for which land is used as forest
[7] Land transformation, forest = Land occupation, forest / Time for which land is used as forest
[8] Land transformation, forest road = Land occupation, forest roads / Time for which land is used as forest
[9] Land occupation, forest roads = Land use, forest roads × time for which land is used as forest

Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment was performed by using SimaPro 9.1 software (PRé Consultant 2020). LCIA translates the inventory table results into a limited number of environmental impact scores, where one of them is land use. This is done by utilizing so-called characterization factors (CF) that indicate the environmental impact per unit of stressor (*e.g.*, per m^3 of resource used). The method chosen for the impact category land use was ILCD 2011 Midpoint+ V1.11 available in the SimaPro 9.1 software (PRé

Consultant 2019) that uses the model by Milà i Canals *et al.* (2007). It is considered the most appropriate among the existing approaches by the European Commission-Joint Research Centre - Institute for Environment and Sustainability (Hauschild *et al.* 2011) for Life Cycle Impact Assessment in the European context. This method focuses on soil quality, and its indicator describes the changes in soil organic matter (SOM) associated with land interventions. Indicator results are thus expressed as kilogram-C, reflecting changes in soil organic carbon (Sala *et al.* 2012).

RESULTS AND DISCUSSION

The data from Table 2 were used to build the inventory table. The results are illustrated in Table 3.

Table 3. Inventory Table per Functional Unit (1 m^3 of Tree, Standing, in Forest)

Activity/Substance	Compart-ment	Sub-compart-ment	Unit	Eucalyptus, standing, in forest	Maritime pine, standing, in forest
Occupation, forest, intensive	Raw	land	m^2.yr	2283.0	3659.3
Occupation, traffic area, rail/road embankment	Raw	land	m^2.yr	58.4	93.7
Transformation, from forest, natural [1]	Raw	land	m^2	195.1	107.2
Transformation, to forest, intensive	Raw	land	m^2	190.3	104.6
Transformation, to traffic area, rail/road embankment	Raw	land	m^2	4.869	2.676

[1] Transformation, from forest, natural = Transformation, to forest, intensive + Transformation, to traffic area, rail/road embankment.

The land-use impact assessment results (characterization) per functional unit (1 m^3 of tree, standing, in forest) for 2015 are presented in Table 4. From the table, the total carbon deficit attributed to 1 m^3 of maritime pine, standing in pine forest was 18423 kg C deficit and to 1 m^3 of eucalypt, standing in eucalypt forest was 23430 kg C deficit. Thus, the land use impact category of eucalypt was 27% higher than the impact of maritime pine.

Table 4 shows that for both products, the land use impact category was mainly due to the transformation of forest land into forest roads (transformation, to traffic area, rail/road embankment (TTTA)) representing 54% in the case of maritime pine and 78% in the case of eucalypt. Occupation, forest, intensive (OFI) is the second most important activity representing approximately 40% of maritime pine land use and 19% of eucalypt land use. The sign minus in the activity TFFN (transformation from forest natural) means that maritime pine and eucalypt receives a credit of 2145 kg C deficit and 3902 kg C deficit, respectively.

The results presented in Table 4 consider that transformation of land takes place, and all impacts are allocated to the first harvest. However, if the impact is allocated over several subsequent harvests, the impact of transformation and occupation becomes more similar. For example, in the case of Maritime pine, the occupation is higher than the transformation of land for the second harvest (2x35=70 years is the time for which

Maritime pine land is used as forest) and for the fourth harvest (4x12=48 years is the time for which eucalypt land is used as forest) in the case of eucalypt. Identical behavior was observed by Sandin *et al.* (2013) in the LCA study focusing on the biodiversity loss of bio-based textile fibers. They conclude that the biodiversity loss due to land transformation was much higher than biodiversity loss due to land occupation.

Table 4. Land Use Impact (Characterization) Per Functional Unit Using ILCD 2011 Midpoint+ Method

Activity /Substance	Compartment	Sub-compart-ment	Unit	Eucalyptus	Maritime pine
Occupation, forest, intensive	Raw	Land	kg C deficit	4566	7319
Occupation, traffic area, rail/road embankment	Raw	Land	kg C deficit	701	1124
Transformation, from forest, natural	Raw	Land	kg C deficit	-3902	-2145
Transformation, to forest, intensive	Raw	Land	kg C deficit	3805	2091
Transformation, to traffic area, rail/road embankment	Raw	Land	kg C deficit	18260	10034
Total			kg C deficit	23430	18423

The results of this study are compared with the results of other studies in Table 5 for Inventory Table. For land use impact category, the results are compared in Table 6 using the same software (SimaPro) and method (ILCD 2011 Midpoint+).

Table 5. Inventory Table per 1 m^3 of Tree, Standing, in Forest

Activity/ Substance	Unit	Eucalyptus, (Portugal)	Maritime pine, (Portugal)	Parana pine (Brasil) (1)	Eucalyptus (Thailand) (1)	Spruce (Swiss) (2)	Beech (Swiss) (2)
Occupation, forest, intensive	m^2.yr	2283.0	3659.3	3060	300	977	2120
Occupation, traffic area, rail/road embankment	m^2.yr	58.4	93.7	Not inven-toried	Not inven-toried	9.7	20.7
Transformation, from forest, natural[1)]	m^2	195.1	107.2	16	15	8.221	14.238
Transformation, to forest, intensive	m^2	190.3	104.6	16	15	8.14	14.1
Transformation, to traffic area, rail/road embankment	m^2	4.869	2.676	Not inven-toried	Not inven-toried	0.081	0.138

(1) Source: Althaus *et al.* (2007)
(2) Source: Werner *et al.* (2007)

Eucalyptus from Thailand is the species with the lowest land occupation (Table 5) due to the short rotation time (3 years). Contrarily maritime pine is the one that presents the highest land occupation due to the moderate yield (95.6 $m^3.ha^{-1}$) and rotation time (35 years). The species with the highest yield is spruce (1215 $m^3.ha^{-1}$) which is why it has relatively less land occupation.

The land use impact category of Portuguese eucalyptus and maritime pine can be compared with spruce and beech (Table 6). The greater impact of the maritime pine and eucalyptus land use compared to spruce and beech is mainly related to the higher land occupation on forest roads (traffic area) and land transformation into forest roads.

Table 6. Comparison of Land Use Impact Per 1 m^3 of Tree, Standing, in Forest Using ILCD 2011 Midpoint+ Method

Impact category	**Unit**	**Eucalyptus (Portugal)**	**Maritime pine (Portugal)**	**Paraná pine (Brasil) (1)**	**Eucalyptus** (Thailand) **(1)**	**Spruce** (Swiss) **(2)**	**Beech** (Swiss) **(2)**
Land use	kg C deficit	23430	18423	6120	600	2370	5000

(1) Calculated from Althaus *et al.* (2007)
(2) Calculated from Werner *et al.* (2007)

As Paraná pine (6120 Kg C deficit) and Thailand eucalyptus (600 Kg C deficit) don´t consider land occupation and land transformation of forest roads (see Table 5), they can only be compared with 4566 Kg C deficit and 7319 Kg C deficit of Portuguese eucalyptus and maritime pine, respectively (Table 4).

CONCLUSIONS

1. The land use impact measured in deficit in carbon per 1 m^3 of eucalypt is 27% greater than the impact of maritime pine.
2. The study showed the relative importance of land occupation and transformation in the total carbon deficit attributed to the functional unit. It depends on the time for which the eucalypt or maritime pine land is used as forest.
3. Land occupation on forest roads and land transformation into forest roads play an important role in the land use impact category of the forest trees studied when compared to other forest species.

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