An Iberian Peninsula analysis of variation in forest area development

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Abstract

This research consists of an analysis of variation in forest cover development on the Iberian Peninsula, investigating both the variation and the underlying transitions and drivers. Within European context, there is a lot of variation in development of forest cover, with the differences between Spain and Portugal as the most striking results. Despite having very similar natural conditions and resources, these countries have experienced an opposite trend in forest development, with Spain as one of the biggest gainers and Portugal as the biggest loser of forest cover in the same period of 2000 to 2018. Therefore it is dominantly the human influence that makes the difference. This was quantified using Corine Land Cover data of 2000 and 2018 processed in QGIS and further handled using spreadsheet software, producing statistics on land-use changes per aggregated land-use type and transition matrices to reveal the transitions responsible. The underlying drivers of these transitions were further investigated through a literature review.

The results have shown that Spain has gained 1,5 mln hectares of forest, while Portugal has lost 600.000 hectares of forest. The net afforestation in Spain comes mainly at the expense of miscellaneous vegetation, while the net deforestation in Portugal was due to growth of miscellaneous vegetation. The same transitions were responsible for afforestation and deforestation in both countries: the main transitions responsible for afforestation were miscellaneous vegetation and agricultural area transitioning into forest, while the main transitions accounting for deforestation was forest transitioning into miscellaneous vegetation and agricultural area. The underlying drivers of net deforestation in Portugal are a combination of the fact that almost all of Portugal's forest is in fragmented private ownership combined with the fact that Portugal's forest owners took too little initiative in forest management and received too little support from the state.

The results from literature indicated that the transition of forest into burnt area was underestimated in the QGIS analysis, wildfires played a key role in the Portuguese trend of deforestation. The underlying driver of these wildfires was the absence of proper forest management due to a lack of participation of private forest owners in Portugal. Other underlying drivers that played a role in the observed transitions in both countries are agricultural abandonment and agricultural intensification.

Contents

1. Introduction

Since the beginning of the Holocene era, human civilisation is flourishing and its influence on the natural environment is ever increasing *(Rockström, 2009)*. In the timeframe of the 20th century up until now, human population has had more influence on their natural environment than ever before *(Dietz, 2017)*. Land use change is a major and global process as it has affected almost a third of the world's terrain since 1960, therefore it is seen as the world's biggest threat to global biodiversity *(Viglione, 2021; Ewers, 2006)*.

Within the continent of Europe, a great deal has happened in the past century in terms of change in forest cover, with sometimes great variation in this development of forest cover. There are countries that have seen their forest area double over the past century thanks to human choices, such as Sweden and Finland, while at the same time there are countries that are experiencing deforestation, also due to human activity. This variation isn't only evident on a long timescale. Much land cover has changed in the period of 1990 to 2020, with Ireland and Spain as the biggest gainers in this timespan and Portugal as the only country that has seen net forest cover loss *(Fernández-Nogueira, 2018; Eurostat, 2021)*. There is a lot of variation, and it is dominantly the human influences that make the difference, the way in which forests are being managed. Nowhere on the European map is this more evident than when you look at the differences in forest cover development between Portugal on the recent timescale of 2000 to 2018 as seen in the figure below. These countries are geographically connected to each other, have the same Mediterranean climate conditions, comparable soil conditions and average slope of terrain amongst other influential factors. Despites these similarities, it becomes very clear from the figure below that Spain and Portugal are at the two ends of the spectrum of forest area development in Europe.

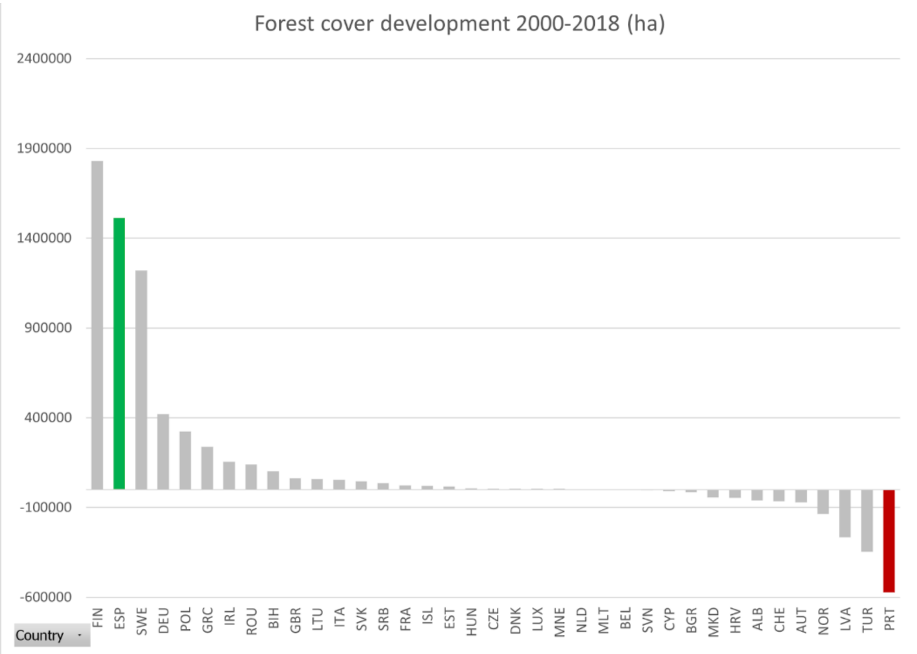

Figure 1: European Variation in Forest Cover Development (Source: Copernicus, 2018)

Therefore the difference lies in other factors than natural conditions and processes, the human factor. The way in which these countries manage their forests is apparently so different that in one country the trend over the past 30 years has been for the forest to decline, while in another country the trend has been for it to grow rapidly. Land use change in the Iberian Peninsula has been driven by human activities such as intensification of agriculture, urban expansion, tourism-related economic activity, forestry policy and abandonment of agricultural land (*Diogo, 2010)*. Being better able to understand the underlying reasons for these trends in both forestation and deforestation, will provide more insight and guidance in the planning of our landscapes.

The interdisciplinary nature of the study of Earth, Economics and Sustainability is well represented in this problem statement, as both ends of the spectrum and the interface between them are addressed. The human induced changes in landscape need to be understood from the social-economical perspective as well as from an environmental perspective, as both of these worlds collide in land use science, in which the processes of afforestation and deforestation play a large role. In the context of European land transitions, the iberian peninsula is an interesting research object because of the dualistic nature of forest development. This leads to the following main research question:

"To what extent does the development of forest cover differ between Spain and Portugal and which transitions and underlying drivers are responsible for these changes?"

To answer and support this main question, the following subquestions have been formulated:

- *"To what extent does the absolute forest cover differ between these two countries?"*
- *"Which transitions are responsible for these changes?"*
- *"How do the Iberian trends compare with the trends in Europe as a whole?"*
- *"What are the underlying drivers for the observed transitions?"*

2. Methods

2.1 Data selection and pre-processing

The main method used in this research consists of a GIS-analysis using Corine Land Cover data, downloaded from the European database Copernicus which collects data from an extensive satellite network. With the use of remote sensing technology in combination with other techniques,, the raw satellite data is transformed into the Corine Land Cover map, containing information on 44 different land use types in 37 European countries *(Ruggeri Et Al, 2021; Copernicus, 2022)* . For this research, the 2000 and 2018 editions were used, which are based on Landsat-7, Landsat-8 and Sentinel-2 satellites. The maps were downloaded in raster format with a spatial resolution of 100 m by 100 m and a minimum mapping unit of 25 ha (*Copernicus, 2022).*This data was processed in the geographical information software QGIS version 3.16 with the GRASS 7.8 plug-in. In order to be able to divide the results of the European CLC map into the different member states, a shapefile of European member states was used that originates from the Eurostat administrative unit database. For the reason that the 2018 edition of the CLC covered more countries, those countries who were not included in the 2000 edition were manually removed from the 2018 as well, to be able to compare the results.

2.2 Land use classification

The original classification of 44 land use types was aggregated to 8 major land use types, including forest, urban, agriculture, resource production, miscellaneous vegetation, water and rocks. As forest is the land-use type of main interest in this paper, all other vegetation types were aggregated into miscellaneous vegetation. As the aim of this research was to gather knowledge about the human influences on forest development, the classes urban, agriculture and resource production were selected. This centred the analysis on the human influences on land-use transitions that induced land-use change. The complete analysis also included the other three land-use types, to enable a complete analysis of the interplay between not only human types of land-use but also natural types. This classification of simple and broad classes made the results easier to interpret.

2.3 Quantification of Land Use Change & Land Use Transitions

The quantification of land use change in absolute numbers was performed by using both the Corine Land Cover 2000 and 2018 map. With the help of statistical raster software, the absolute count in hectares of the different classes in both time periods were quantified, on both a European scale as well as on the national scale of Portugal and Spain *(Meneses et al, 2017)*. Spreadsheet software enabled further calculations and allowed us to derive statistics on the absolute land use change. In order to quantify the land use dynamics during the time period of 2000 to 2018, substitution patterns were quantified according to the method of V. Diogo & E. Koomen (2010). A transition matrix of the 8 land-use classes was created and further handled using spreadsheet software.

2.4 Explaining Land Use Transition trends in Portugal and Spain

In order to explain the transitions observed in both Portugal and Spain, a literature review was carried out which covered the historical context related to the trends in land-use transitions and forest development, forestry policy and other spatial developments. In order to explain the transitions observed, documents of the European Forest Institute about forest ownership in both Spain and Portugal have been especially helpful, as it contained detailed information the history of forest management and policies in both countries. Furthermore, the work of Spanish geographer C. Montiel has been useful in describing the differences in policy-making between the two countries, together with a range of other scientific sources used.

3. Results

3.1 Land Use Change Analysis: Forest Cover

In this section, the outcomes of the GIS-analysis regarding absolute forest cover are discussed. The calculations are based on total hectares of land per aggregate land-use class. The results of the quantification of absolute land use changes in hectares per aggregated class are visualised below in figure x. The more detailed tables of land use change can be found in annex B, including the absolute numbers of the change in hectare per country, as well as the changes relative to the initial land use. The results of the analysis show that forest cover in Portugal has decreased significantly over the course of just 18 years, losing 570.000 hectares of forest cover, which amounts to nearly losing 20% of the total forested area. Another notable land use type that has lost ground in this time period is agriculture, losing roughly 3,5% of its total area. The class miscellaneous vegetation on the other hand, has seen an increase of 590.000 hectares meaning a 33% increase of this land-use type, and burnt area has also seen an increase of 40.000 hectares, which is an increase of 137% percent, making it the biggest change relatively seen. Urban land use has also seen an absolute and relative increase of 60.000 hectares and 23% respectively.

The results show that forest cover in Spain, in contrast to Portugal, has increased significantly in the same timespan, gaining 1.511.600 hectares of forest cover, which is almost a 13% increase of the total forested area. Urban area grew by 42.000 hectares, which is an increase of 64%.This growth in land uses came at the expense mostly of agricultural land use, suffering a loss of 1.056.977 hectares, which is a decrease of 4,63%. The land-use type burnt area has also experienced the opposite trend of Portugal, decreasing with 42.000 hectares, meaning almost a 60% decrease. The land use types resource production, water and rock have not experienced any significant land use changes in the chosen period.

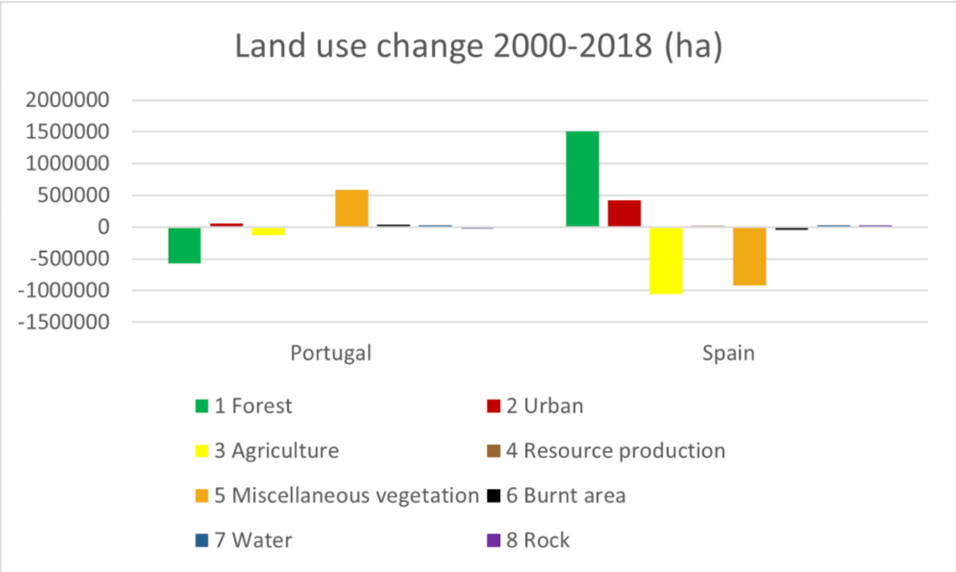

Figure 2: Absolute Aggregate Land Use change in Portugal and Spain

3.2 Land Use Transition analysis

This section discusses the results of the transition matrices that revealed the land use transitions in the Iberian Peninsula that induced the Land use changes. The transitions that have caused deforestation will be discussed first, followed by afforestation. The differences are visualised in the form of figures comparing the relative transitions leading to deforestation and afforestation per land-use class for both countries and figures that spatially visualise where these transitions have taken place. The more detailed transition matrices can be found in Appendix C.

3.2.1 Deforestation

On the deforestation side, the main land-use types that contribute toward this deforestation, or in other words, the land-use types that forest transitions into, consist mostly of miscellaneous vegetation, which is classified as any form of natural vegetation which is not forest. This transition is by far the most dominant transition on the deforestation side, with 23% of the original forest cover of 2000 having transitioned into miscellaneous vegetation in 2018 in Spain and around 17% of the original forest cover having transitioned in Portugal. In absolute terms, this is roughly 2 mln hectares of forest cover lost in Spain, and 700.000 hectares lost in Portugal. After that, the second important trend is the trend from forest to agricultural land, this amounts to a change of 3,48% of the original forest cover in Portugal and a 5, 43% change in Spain. The third and last notable transition is the transition of forest to burnt area, comparing 2000 and 2018. This transition is well visible on the Portugese map, where fires have turned forest into burnt areas. This transition is more present in Portugal than in Spain, transitioning 36.000 and 13.000 hectares of forest respectively. In relative terms, 1,19% of the Portugese forests have been transitioned due to wildfires, which is tenfold the impact that wildfires have had on Spanish forests, transitioning only 0,11% of initial forest cover. The other transitions to deforestation aren't as major as the ones previously mentioned. The transition from forest to urban is quite small in both countries, transitioning only 0,46% and 0,24% of Portugese and Spanish forests. The land-use types resource production, water and rock, have a negligible small share in the total deforestation. Of the initial forest cover in 2000, Portugal saw 29% transition into other land-use types, while Spain only saw 23% of their initial forest cover transition.

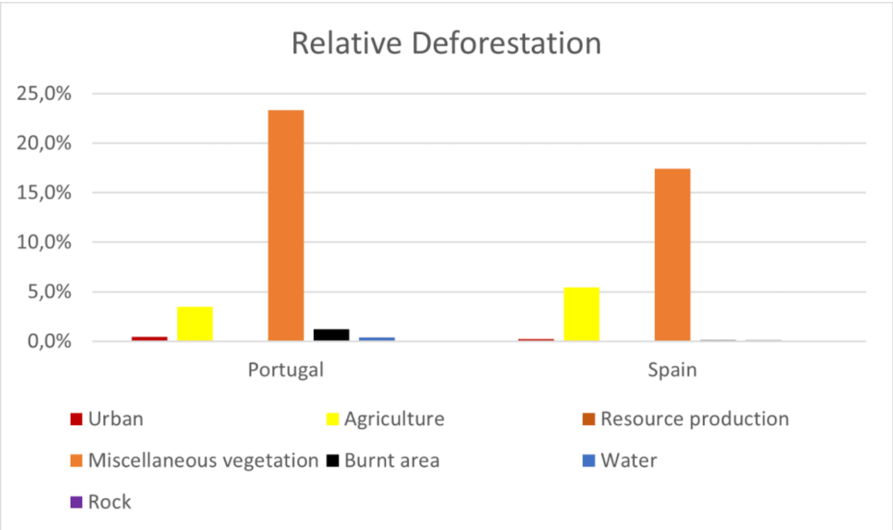

Figure 3: Deforestation relative to the initial forest cover per land-use type

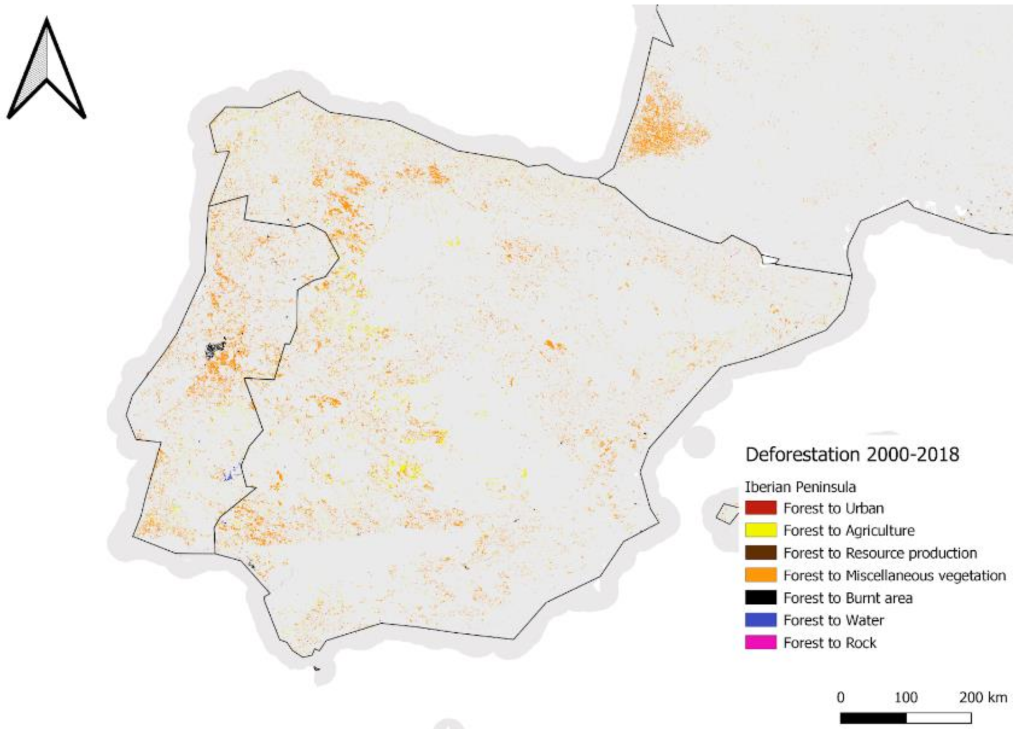

Figure 4: Deforestation on the Iberian Peninsula, 2000 - 2018

3.2.2 Afforestation

In terms of afforestation, the contrast between the two Iberian countries is very clear, in the matrices from Appendix C as well as the visual representation of figure x and x. The transition matrix includes important statistics, of which the most notable will be briefly discussed. The most dominant transition leading to afforestation is the transition from miscellaneous vegetation into forest, transitioning 22% of the initial miscellaneous vegetation into forest in Spain, meaning roughly 3 mln hectares of new forest. In Portugal, only 10% of this initial vegetation transitioned into forest, meaning roughly 190.000 hectares of forest gained. The second transition that stands out when expressing the transitions per land-use type as a percentage of the initial class in figure x, is the transition from burnt area to forest. The graph suggests that Spain has been much more committed to reforestation of burnt areas than Portugal, with Spain transitioning 13,75% of burnt area to forest while Portugal only transitioned 3,75% of their burnt area. However, this result alone cannot indicate such a causal relationship, as the underlying causes must be investigated. The relative graph is misleading in the sense that it portrays the transition as the second most dominant transition, but this is only the case when looked at from a relative perspective. The absolute figures of the transition matrices in annex C show that the area burnt is not close to being a large transition to forest, being in fact just a small transition in absolute terms: only 1,000 hectares were converted to forest in Portugal, in Spain this was limited to 10,000 hectares. On the visualised map of the transition matrix in figure x, it is clearly visible that besides the transition of miscellaneous vegetation to forest, the transition of agricultural land to forest is another dominant transition, especially in the north-western Galician part of Spain. This isn't as visible on the map in Portugal, but the results of the absolute matrices support this, as agriculture is the second largest transition to forest with Portugal having converted 100.000 hectares and Spain having converted 1.1 mln hectares. Another significant result is the fact that 5% of the land-use type rock has been converted to forest, which amounts to 12.000 hectares. The remaining land-use types have not contributed significantly to afforestation in Spain or Portugal. Overall, the relative percentages of afforestation per land-use type of Portugal are quite low across the board compared to Spain.

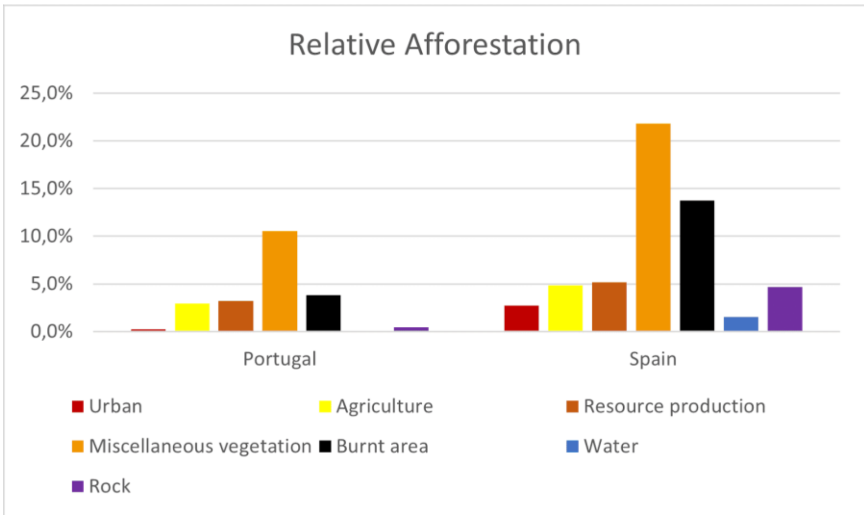

Figure 5: Iberian Afforestation relative to the initial class

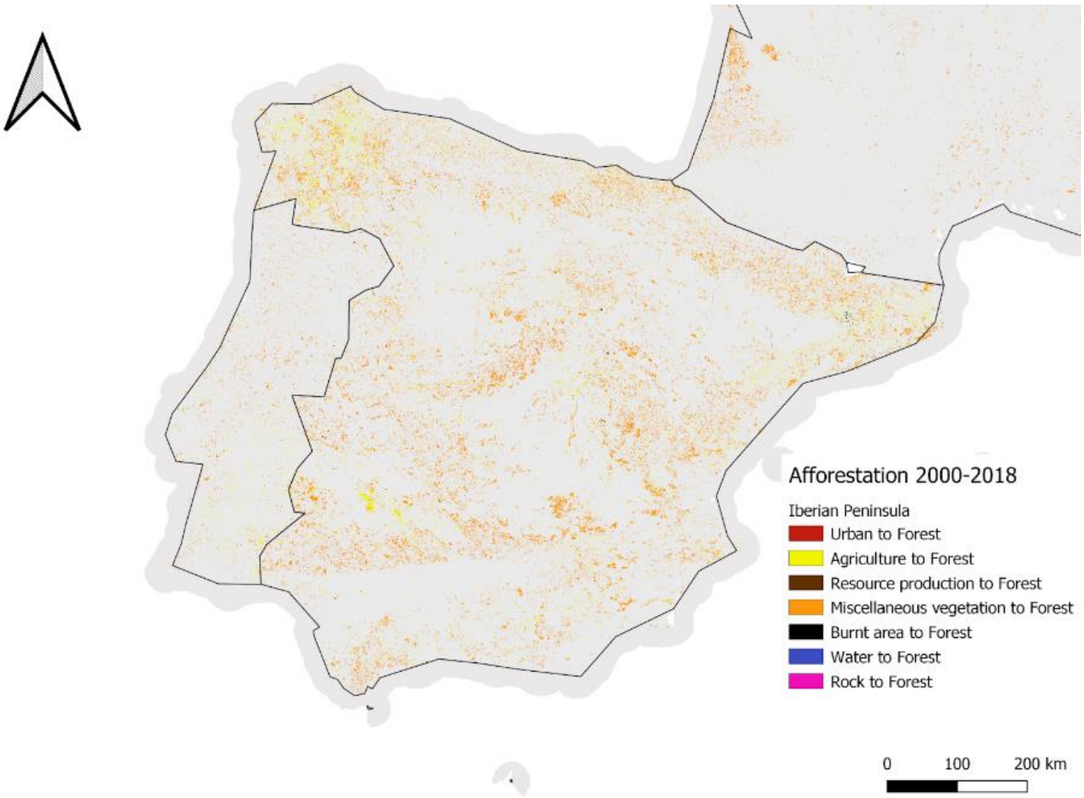

Figure 6: Afforestation on the Iberian Peninsula, 2000 - 2018

3.3 European trends

This section builds on the previous section, which dealt with differences in land use transitions on the Iberian Peninsula. The European trends in land-use transitions will be described. Subsequently, these trends will be compared to the trends of Portugal and Spain in the time period of 2000 to 2018. This has been done with the aim of providing a European context through which the trends in transitions can be better put into perspective. The results are visualised in figures comparing the relative transitions inducing deforestation and afforestation per land-use class for the three regions. More detailed results of the transition matrices can be found in annex C3.

3.3.1 Deforestation

The figure below immediately highlights that overall, the transitions as a percentage of the initial land use per class of the European average are much lower than the percentages on the Iberian Peninsula, meaning that the deforestation rate of the Iberian Peninsula is relatively high when compared to the European average. Regarding the most dominant land-use transition, forest to miscellaneous vegetation, only 7% of the initial forest area was converted, while Portugal and Spain converted 23% and 17% respectively. The second biggest transition, in absolute as well as relative terms, is the transition of forest to agricultural land, with 1,87% of the European forest having transitioned into agricultural land, which is much lower than the conversion rates of Portugal Spain. The results also show that forest transitioning into burnt areas is not a European trend, since the average conversion rate of the 37 European countries is as low as 0,06%. The European results also support the Iberian results that there is no trend of significant areas of forest being lost to urbanisation, as the conversion rate is quite low. The remaining transitions do not have a significant share in the transitions observed.

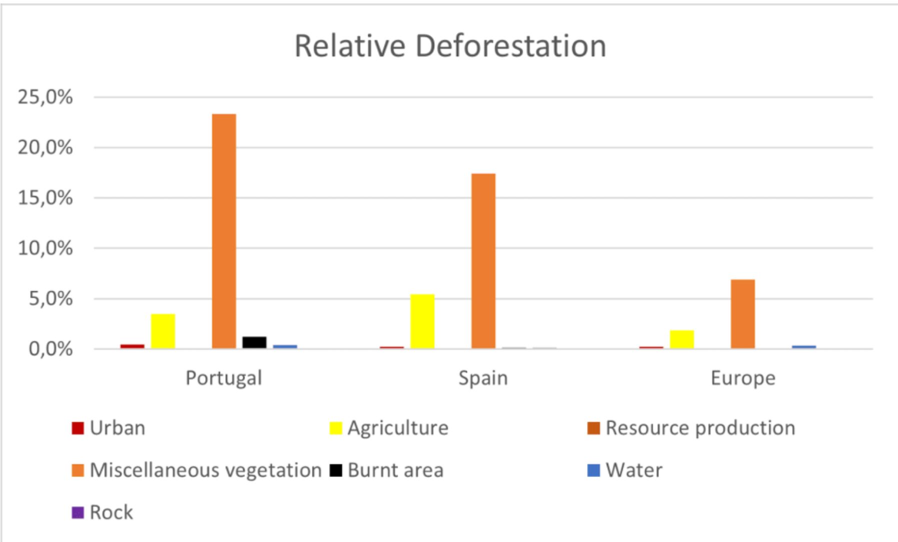

Figure 7: European Comparison of Deforestation relative to the initial Class

3.3.2 Afforestation

The results of European land-use transition matrices are visualised in the figure below as a percentage of the initial land use per class. In contrast to the trends in the transitions leading to deforestation, the trends in afforestation do not fall outside the Iberian Peninsula results, but rather in between, meaning that the Portugese afforestation rate is lower than the European average, while the Spanish afforestation is relatively high compared to the European average. The transition that stands out most on European scale is the dominant transition of miscellaneous vegetation into forest, converting 14% of the initial vegetation into forest.

The second relative transition that stands out in the figure is the reforestation of burnt areas, which amounts to roughly 13% on a European scale. As with the results for the Iberian Peninsula, this is a misleading statistic, as the absolute numbers of this transition are quite low, only 22,000 hectares, of which 10,000 hectares are accounted for by reforestation in Spain. Burnt area is by far the smallest land-use type in the whole of Europe, amounting to only 177.000 hectares in 2000, making the 13% transition to forest seem significant, when in fact it is not. Taking into account that the initial area burnt represents a larger share of total land use, Portugal is lagging behind in reforestation of this burnt area compared to both Spain and the European average. The second biggest transition in absolute numbers on European scale is agricultural land converting to forest, despite the fact that just 2% of agricultural land is converted. To put this into perspective, the initial agricultural area was 250 mln hectares, of which 2% means an area of 5 mln hectares. Furthermore, only 1% of initial urban land use was converted, in line with the Iberian results that afforestation does not come at the expense of urban areas. The remaining transitions are in line with the Iberian results, as these have insignificant results.

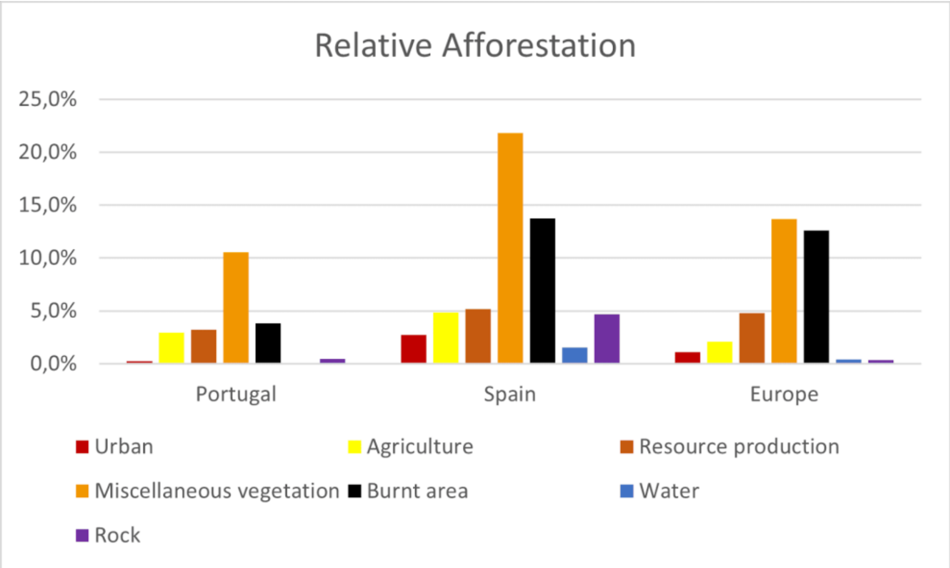

Figure 8: European Comparison of Afforestation relative to the initial Class

3.4 Literature Review of Underlying drivers

3.4.1 Drivers of Deforestation on the Iberian Peninsula

An Extensive discussion of possible drivers of deforestation of these transitions reviewing existing literature

Wildfires have a great impact on Portugal, and are directly related to fragmentation of ownership of forests, following a long history of dividing plots of land between heirs of landowners, as the vast majority of 93% of forest is privately owned *(EFI, 2013; EFI, 2015)*. Therefore, the forest owners are key actors in forest management, their participation is essential, while coordinating joint forest management with them comes with a number of challenges *(Gorriz et al., 2017)*. The policy instruments available to governments were limited to those that could only encourage owners to focus on managing forests, including subsidies and a limited support to Forest Owners Associations. After the second world war, national forest development plans promoted afforestation on private land, without much concern for wildfire prevention due to densification of forest. Due to this uncontrolled growth of forest, waves of wildfires started occurring in the 1970's *(Bento-Gonçalves, 2018)*. In the decades following, managing forest became even less economically attractive to forest owners, therefore forests in Portugal as well as Spain, while at their peak of total area, were abandoned between 1986 and 1996 with an increased risk of wildfires as a result (*IFN, 1995)*. Wildfires have had an impact on the development of forest cover beyond the results of the transition matrix, as only the burnt areas present in 2000 and 2018 have been measured, not taking into account a lot of forest fires in between. This recent history has shown that the Portuguese authorities did not take enough initiative in forestry policy to prevent forest fires *(Mendes, 2006)*.

In contrast to Portugal, Spain has had a forestry policy for a longer time. Until the Spanish constitution in 1978, a strongly centralised system was in place. After the constitution, the smaller governments were handed more responsibilities and freedoms, of which spatial planning and forestry policy. Within the European context, Regional Forest Programmes (RFP's) were written *(C. Montiel, 2003).* The forests in Spain are less often privately owned than the forests in Portugal, with at present 66% of Spanish forests being owned privately, and the remaining 34% being publicly owned by local authorities *(EFI, 2015).* The cadastral information of both Portugal and Spain unfortunately doesn't include much detailed information of forest ownership, as there is no legal requirement to register this *(EFI, 2015)*. Since forest areas consist of fragmented territories, local stakeholders defend their own interests, and therefore, de facto, a significant part of the population is opposed to more far-reaching measures in the field of forestry policy, which is one of the reasons why only limited measures have been taken outside publicly owned forest areas in the past 30 years. The initiatives that did take place came from associations of forest owners in both countries. The key difference that separates Spain from Portugal in this matter, is that among forest owners in Spain there was more awareness about their responsibility in managing forest to reduce the risk of forest fires, this awareness was not so widely supported in Portugal *(EFI, 2015; Oliveira et al, 2017).* This participation of owners was well encouraged by the Spanish Regional Forest Programmes, this has proven to be effective in the battle against deforestation *(Montiel, 2002)*.

3.4.2 Drivers of Afforestation on the Iberian Peninsula

An Extensive discussion of possible drivers of the transitions causing afforestation reviewing existing literature

The class of miscellaneous vegetation includes grassland, shrubland and other vegetation types. The transitions from this vegetation to forest cover and vice versa are the largest in absolute terms of both afforestation and deforestation. Deriving the direct drivers of the transition of miscellaneous vegetation into forested areas has proven to be difficult, as the class itself is so broad. Processes that are at play consist of natural succession of vegetation and land-use trends such as agricultural abandonment and agricultural intensification amongst others *(Vidal-Macua, 2017; Peña et al, 2007)*.

In both Spain and Portugal, the transition from agricultural land to has been a dominant transition, of which the underlying causes are historically rooted. During the mid-20th century in both Portugal and Spain, people started moving from the rural interior to industrially developing coastal cities, seeking jobs *(Iglesias & Garcia, 2013)*. Another factor that played a part was the intensification of agriculture. This trend of agricultural intensification was facilitated by technological and scientific developments, such as the emergence of artificial fertiliser and agricultural mechanisation, which led to a more efficient use of agricultural land and furthermore replaced traditional agricultural systems. The urbanisation of coastal areas combined with agricultural intensification, led to agricultural activity becoming increasingly unpopular amongst the younger generations. *(Bunce et al., 2000; Filho et al., 2016; Delgado et al, 2022)*. These drivers, amongst other socio-demographic changes, were main causes of agricultural abandonment, allowing natural revegetation and further succession into natural forest *(Munroe et al., 2013; Peña-Angulo et al., 2019)*. In addition to the abandonment of agriculture, previously managed forests were abandoned, colonising new areas and compacting their structures where they already existed, causing the Iberian forests to reach the greatest extent in known history *(EFI, 2015; Loidi, 2017)*.

Furthermore, like explained in paragraph 3.4.1, Spain has been more successful in involving owners of forest in management, which has had a positive impact on the afforestation rate. This is well represented in the results when you look at the relative percentages of afforestation in Spain compared to Portugal across the board.

4. Conclusion & Discussion

The aim of this study was to describe and explain the differences in forest area development between the countries Spain and Portugal, which have many similarities in natural factors, yet experience different trends in forest area development. The main question that has acted as a thread in this research was as follows:

“To what extent does the development of forest cover differ between Spain and Portugal and which *transitions and underlying drivers* are responsible for these changes?”

To conclude on this main question: the results of this research have shown that the difference between Spain and Portugal is quite large. In fact, Portugal and Spain have experienced opposite trends in forest area development during the period of 2000 to 2018. Whereas Spain gained 1.5 million hectares of forest in this period, Portugal saw its forest area decrease by almost 600,000 hectares. This net afforestation in Spain is due to agricultural land and miscellaneous vegetation transitioning into forest, outweighing forest conversion. The net deforestation of Portugal was driven by a large-scale transition into miscellaneous vegetation. The underlying drivers of net deforestation in Portugal are a combination of the fact that almost all of Portugal's forest is in fragmented private ownership combined with the fact that Portugal's forest owners took too little initiative in forest management and received too little support from the state. The underlying driver of net afforestation in Spain is agricultural abandonment in rural areas.

The land-use transitions inducing changes in forest cover have been analysed from the perspective of deforestation as well as afforestation. The most dominant transition in both of these processes has been the transition between forest and miscellaneous vegetation, having shown interesting interplay. The underlying factors driving these transitions are diverse, as the class miscellaneous is very broad. Therefore, it is not just accountable to one spatial development but rather the context of spatial developments influencing forest area development on the Iberian Peninsula as a whole. The second largest transition in both the process of deforestation and afforestation was agricultural. The conversion of agricultural land into forest, had as underlying driver the process of agricultural abandonment, which had densification and expansion of the forest cover in rural areas as a result, leading to afforestation. On the other hand, conversion of forest into agricultural was the second dominant transition in terms of deforestation, indicating forests have been cleared to provide space for agriculture. Although these two developments moved in two opposite directions, afforestation through agricultural abandonment outweighed deforestation due to agricultural expansion in both countries, especially in Spain. The last but not least important transition was from forest to burnt area, which has especially wreaked havoc in Portugal due to the lack of proper forest management. The literature review showed that wildfires had a negative impact on the development of forested area beyond the results of the transition.

The European comparison showcased that Iberian deforestation rates were very high compared to the European average, especially in Portugal. In terms of afforestation Spain has relatively converted more of their land to forest than the European average, while Portugal has been lagging behind in this matter.

The QGIS-based methods used in this research have proven to be effective in other land-use changes related studies *(Diogo & Koomen, 2010; Fernández-Nogueira, 2018).* The data from Copernicus, the Corine Land Cover map editions 2000, and 2018, have been proven to be valid. Research conducted by Maucha & Büttner in 2004 had as the main result that the Corine map had an overall reliability of ~87%, therefore the specified accuracy requirement of 85% was fulfilled. This was measured by performing a detailed comparison of Corine data with Eurostat's LUCAS data of higher spatial resolution. There is however one shortcoming of this method used, which is that calculating land-use change from two years 18 years apart, isn't the most effective method for the specific land-use type of burnt area. In contrast to other land-uses, it's the result of episodic events of wildfires, not some occupation that shifts gradually over time. The wildfires that have occurred between 2000 and 2018 are therefore grossly underestimated in this analysis, as only the burnt areas present in 2000 and 2018 have been taken into account, missing wildfires that have occurred in between this time period.

A recommendation for future research would be to include more reference years in this analysis, as the CLC database is also available for the years 2006 and 2012, for a more detailed analysis. Furthermore, this detailed analysis would benefit from an analysis of the study area that better outlines the natural and historical context related to forest development. In addition, the most useful result of this study is the understanding of how certain spatial developments have led to the development of the area of forest, which could be explored more extensively in a follow-up study. Another recommendation would be to include a more detailed classification of the miscellaneous vegetation class, to be able to better explain the observed transitions between vegetation and forest.

The results of this research imply that Portugal still has much to learn from its Spanish neighbours, especially in terms of involving forest owners in sustainable management through effective policies.

Literature

Bento-Gonçalves, A. (2018, 27 september). Changes in mainland Portuguese forest areas since the last decade. Open Editions Journals. Geraadpleegd op 20 juni 2022, from https://journals.openedition.org/mediterranee/10025

Bunce, R. G. H., Pèrez-Soba, M., Elbersen, B. S., Prados, M. J., & Andersen, E. (2000, juli). Examples of European agri-environment schemes and livestock systems and their influence on Spanish cultural landscapes. Wageningen University & Research eDepot. Consulted on 22 juni 2022, from https://edepot.wur.nl/81891

Copernicus. (2022). CORINE Land Cover — Copernicus Land Monitoring Service. Consulted on 8 juni 2022, from https://land.copernicus.eu/pan-european/corine-land-cover

Delgado-Artés, R., Garofano-Gómez, V., Oliver-Villanueva, J. V., & Rojas-Briales, E. (2022, 7 januari). Land use/cover change analysis in the Mediterranean region: a regional case study of forest evolution in Castelló (Spain) over 50 years. Elsevier. Consulted on 20 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S0264837721006906?casa_token=LsFvbuzChmgAAAAA:4KEj-DWmeK-9CH11w715joF1kpxXHWvyoH_y7igLFpct4UyB1F-3eKEbRQvd1wlMsVGWb2aweKI

Dietz, T. (2017). Drivers of Human Stress on the Environment in the Twenty-First Century. Annual Review of Environment and Resources. Consulted on 10 juni 2022, from https://www-annualreviews-org.vu-nl.idm.oclc.org/doi/pdf/10.1146/annurev-environ-110615-085440

Diogo, V., & Koomen, E. (2010). Explaining land-use change in Portugal 1990–2000.Academia. Consulted on 10 juni 2022, from https://www.academia.edu/download/53898646/Explaining_land-use_changes_in_Portugal_20170719-5251-12kpcf4.pdf

European forest institute & European cooperation in science and technology. (2015). Forest Land Ownership Change in Portugal. FACESMAP. Consulted on 20 juni 2022, from https://facesmap.boku.ac.at/library/FP1201_Country%20Report_PORTUGAL.pdf

European Forest Institute & European Cooperation in Science and Technology. (2015). Forest Land Ownership Change in Spain. E.F.I. Consulted on 20 juni 2022, from https://facesmap.boku.ac.at/library/FP1201_Country%20Report_SPAIN.pdf

European Forest Institute. (2013). Mapping the distribution of forest ownership in Europe. EFI. Consulted on 20 juni 2022, from https://efi.int/sites/default/files/files/publication-bank/2018/tr_88.pdf

Eurostat. (2021, december). Statistics Explained. Consulted on 10 juni 2022, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Forests,_forestry_and_logging

Eurostat. (2021a, maart 21). 39% of the EU is covered with forests. Consulted on 20 juni 2022, from https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20210321-1

Ewers, R. M. (2006, mei). Interaction effects between economic development and forest cover determine deforestation rates. ScienceDirect. Consulted on 21 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S0959378005000798?casa_token=RW2KBP7AjRoAAAAA:l76wJk-JKe7_clbCSy1liUqnuMYcwAoMNzYXZmNiQe_YWzFHd-G6JamusATu7iLu5a1q9E1VEis

Fernández-Nogueira, D. (2018). Land Use Changes in Iberian Peninsula 1990–2012. MDPI. Consulted on 9 juni 2022, from https://www.mdpi.com/2073-445X/7/3/99

Filho, W. L., Mandel, M., Al-Amin, A. Q., Feher, A., & Jabbour, C. J. S. (2016, 1 juni). An assessment of the causes and consequences of agricultural land abandonment in Europe. International Journal of Sustainable Development & World Ecology. Consulted on 22 juni 2022, from https://www-tandfonline-com.vu-nl.idm.oclc.org/doi/full/10.1080/13504509.2016.1240113?casa_token=G1Q_dEbfq74AAAAA%3A9m4MSl0eZY6lPRZEnV5AmSz_8-tncYni9jhvxEPQybu50_rwXLLq0JTPiCeQ3U-iW7hapxc_SJJhnA

Gorriz, E., Donazar, L. O., Eseverri, E. M., & Govigli, V. M. (2017, november). The challenges of coordinating forest owners for joint management. Forestry Policy and Economics. Consulted on 23 juni 2022, from https://www.researchgate.net/publication/321357922_The_challenges_of_coordinating_forest_owners_for_joint_management

Iglesias, E. L., & Garcia, F. S. (2013, oktober). Processes of Farmland Abandonment: Land use Change and Structural Adjustment in Galicia (Spain). Researchgate. Consulted on 22 juni 2022, from https://www.researchgate.net/publication/265467035_Processes_of_Farmland_Abandonment_Land_use_Change_and_Structural_Adjustment_in_Galicia_Spain

Loidi, J. (2017, 13 september). Introduction to the Iberian Peninsula, General Features: Geography, Geology, Name, Brief History, Land Use and Conservation. SpringerLink. Consulted on 9 juni 2022, from https://link-springer-com.vu-nl.idm.oclc.org/chapter/10.1007/978-3-319-54784-8_1

Maucha, G., & Büttner, G. (2004). Validation of the European CORINE Land Cover 2000 database. European Association of Remote Sensing Laboratories. Consulted on 22 juni 2022, from http://www.earsel.org/symposia/2005-symposium-Porto/pdf/055.pdf

Mendes, A. (2006). Private forestry and forest policy reforms in Portugal in the context of increasing forest fires. Legal Aspects of European Forest Sustainable Development. Consulted on 23 juni 2022, from https://www.researchgate.net/publication/299800752_Private_forestry_and_forest_policy_reforms_in_Portugal_in_the_context_of_increasing_forest_fires

Meneses, B. M., Reis, E., Pereira, S., Vale, M. J., & Reis, R. (2017, 27 februari). Understanding Driving Forces and Implications Associated with the Land Use and Land Cover Changes in Portugal. Researchgate. Consulted on 10 juni 2022, from https://www.researchgate.net/publication/314224234_Understanding_Driving_Forces_and_Implications_Associated_with_the_Land_Use_and_Land_Cover_Changes_in_Portugal

Montiel, C. (2003). Origen y evolución de la propiedad colectiva en España. Dialnet. Consulted on 22 juni 2022, from https://dialnet.unirioja.es/servlet/articulo?codigo=2978366

Munroe, D. K., From Berkel, D. B., Verburg, P. H., & Olson, J. L. (2013, oktober). Alternative trajectories of land abandonment: causes, consequences and research challenges. Current Opinion in Environmental Sustainability. Consulted on 22 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S1877343513000791?casa_token=Z3hWSt4d4BMAAAAA:vBsDUU86QZ50qop7fAP1YuWrWoYXrhR9E2f0EOVWzrQA8nA2OTupCSRxaNMy1IjHsK-ErYY47yI

Oliveira, T. M., Guiomar, N., Oliveira Baptista, F., Pereira, J. M. C., & Claro, J. (2017). Is Portugal's forest transition going up in smoke? Land Use Policy. Consulted on 20 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S0264837716314272

Peña, J., Bonet, A., Bellot, J., Sanchez, J. R., Eisenhuth, D., Hallett, S., & Aledo, A. (2007). Driving forces of land use change in a cultural landscape of Spain. Springer Link. Consulted on 20 juni 2022, from https://link-springer-com.vu-nl.idm.oclc.org/content/pdf/10.1007/978-1-4020-5648-2.pdf

Peña-Angulo, D., Khorchani, M., Errea, P., Lasanta, T., Martínez-Arnáiz, M., & Nadal-Romero, E. (2019, oktober). Factors explaining the diversity of land cover in abandoned fields in a Mediterranean mountain area. Elsevier. Consulted on 20 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S0341816219301985?via%3Dihub

Ruggeri, S., & Et Al. (2021, december). Optimized unsupervised CORINE Land Cover mapping using linear spectral mixture analysis and object-based image analysis. ScienceDirect. Consulted on 21 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S1110982321000867

Vidal-Macua, J. J., Et al. (2017, 15 december). Factors affecting forest dynamics in the Iberian Peninsula from 1987 to 2012. The role of topography and drought. ScienceDirect. Consulted on 10 juni 2022, from https://www-sciencedirect-com.vu-nl.idm.oclc.org/science/article/pii/S037811271730960X

Viglione, G. (2021, 11 mei). Land-use change has affected 'almost a third' of world's terrain since 1960. Carbon Brief. Consulted on 10 juni 2022, from https://www.carbonbrief.org/land-use-change-has-affected-almost-a-third-of-worlds-terrain-since-1960/#:%7E:text=%E2%80%9CLand-use%20change%E2%80%9D%20is,attempt%20to%20repair%20previous%20damage.

Appendix

Appendix A: Aggregation of CLC classes

***Table 1:** Aggregation of land use classes*

CLC classes	*Aggregated class*
1.1Agro-forestry areas 1.2 Broad-leaved forest 1.3 Coniferous forest 1.4 Mixed forest	Forest
2.1 Continuous urban fabric 2.2 Discontinuous urban fabric 2.3 Industrial or commercial units 2.4 Road and rail networks and associated land 2.5 Port areas 2.6 Airports 2.7 Green urban areas 2.8 Sport and leisure facilities 2.9 Construction sites	Urban
3.1 Non-irrigated arable land 3.2 Permanently irrigated land 3.3 Rice fields 3.4 Vineyards 3.4 Fruit trees and berry plantations 3.5 Olive groves 3.6 Pastures 3.7 Annual crops associated with permanent rops 3.8 Complex cultivation patterns 3.9 Land principally occupied by agriculture with significant areas of natural vegetation	Agriculture
4.1 Mineral extraction sites 4.2 Dump sites	Resource production
5.3 Natural grasslands 5.4 Moors and heathland 5.5 Sclerophyllous vegetation 5.6 Transitional woodland-shrub 5.7 Sparsely vegetated areas	Miscellaneous vegetation
6.1 Burnt area	Burnt area
7.1 Glaciers and perpeutal snow 7.2 Inland marshes 7.3 Peat bogs 7.4 Salt marshes 7.5 Salines 7.6 Intertidal flats 7.7 Water courses	Water

7.8 Water bodies 7.9 Coastal lagoons 7.10 Estuaries 7.Sea and ocean	
8.1 Beaches dunes sands 8.2 Bare rocks	Rock

Appendix B: Land Use Change Analysis: Forest Cover

Table 2: Land Use Change - Portugal

PORTUGAL	2018		2000		2018-2000		
Class	Area (ha)	% of total land	Area (ha)	% of total land	Change (ha)	Change/Class (%)	% of total LUC
Forest	2.426.490	26,71%	2.999.040	33,02%	-572.550	-19,09%	39,62%
Urban	318.791	3,51%	258.669	2,85%	60.122	23,24%	4,16%
Agriculture	3.479.076	38,30%	3.607.359	39,72%	-128.283	-3,56%	8,88%
Res. production	17.584	0,19%	18.058	0,20%	-474	-2,62%	0,03%
Misc. vegetation	2.373.372	26,13%	1.782.640	19,63%	590.732	33,14%	40,88%
Burnt area	69.237	0,76%	29.111	0,32%	40.126	137,84%	2,78%
Water	393.189	4,33%	361.004	3,98%	32.185	8,92%	2,23%
Rock	5.241	0,06%	25.884	0,29%	-20.643	-79,75%	1,43%

Table 3: Land Use Change - Spain

SPAIN	2018		2000		2018-2000		
Class	Area (ha)	% of total land	Area (ha)	% of total land	Change (ha)	Change/Class (%)	% of total LUC
Forest	13215268	26,05%	11703668	23,07%	1511600	12,92%	37,47%
Urban	1085862	2,14%	663865	1,31%	421997	63,57%	10,46%
Agriculture	21773310	42,92%	22830287	45,00%	-1056977	-4,63%	26,20%
Res. production	119262	0,24%	97658	0,19%	21604	22,12%	0,54%
Misc. vegetation	13292772	26,20%	14213231	28,02%	-920459	-6,48%	22,82%
Burnt area	30994	0,06%	73878	0,15%	-42884	-58,05%	1,06%
Water	923257	1,82%	895496	1,77%	27761	3,10%	0,69%
Rock	286034	0,56%	255198	0,50%	30836	12,08%	0,76%

Table 4: Land Use Change - Europe

EUROPE	2018		2000		2018-2000		
Class	Area (ha)	% of total land	Area (ha)	% of total land	Change (ha)	Change/Class (%)	% of total LUC
Forest	174798927	23,87%	170113127	23,22%	4685800	2,75%	21,92%
Urban	23624044	3,23%	19946007	2,72%	3678037	18,44%	17,20%
Agriculture	241820557	33,02%	247633369	33,80%	-5812812	-2,35%	27,19%
Res. production	1146804	0,16%	966987	0,13%	179817	18,60%	0,84%
Misc. vegetation	103128795	14,08%	107989917	14,74%	-4861122	-4,50%	22,74%
Burnt area	226982	0,03%	177038	0,02%	49944	28,21%	0,23%
Water	177915915	24,29%	175947779	24,02%	1968136	1,12%	9,21%
Rock	9699109	1,32%	9842894	1,34%	-143785	-1,46%	0,67%

Note: In these tables above, the land use change per class is stated in absolute terms as well as in terms relative to the initial land use. The far right column describes the share of the class represented in the total amount of absolute change.

Appendix C: Land Use Transition Matrices

Appendix C1: Land Use Transition Matrices of Portugal

Table 5: Transition Matrix of Portugal in absolute numbers

Land Use 2000	Land Use 2018: Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock	Total LU 2000
Forest	2.129.601	13.707	104.367	2.399	700.601	35.759	12.477	129	2.999.040
Urban	657	250.809	5.904	389	802	0	19	2	258.582
Agriculture	106.547	40.042	3.275.233	1.544	169.047	2.409	12.888	46	3.607.756
Res. production	577	4.975	508	10.143	1.607	35	178	0	18.023
Misc. vegetation	187.586	8.737	91.307	3.051	1.452.969	30.082	7.889	1.221	1.782.842
Burnt area	1.104	119	1.337	0	25.582	948	24	0	29.114
Water	271	269	732	33	1.400	0	357.792	128	360.625
Rock	121	42	61	24	21.645	0	271	3.696	25.860
Total LU 2018	2.426.464	318.700	3.479.449	17.583	2.373.653	69.233	391.538	5.222	

Table 6: Transition Matrix of Portugal in %

Land Use 2000	Land Use 2018: Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock
Forest	71,01%	0,46%	3,48%	0,08%	23,36%	1,19%	0,42%	0,00%
Urban	0,25%	96,96%	2,28%	0,15%	0,31%	0,00%	0,01%	0,00%
Agriculture	2,95%	1,11%	90,79%	0,04%	4,69%	0,07%	0,36%	0,00%
Res. production	3,20%	27,55%	2,81%	56,17%	8,90%	0,19%	0,99%	0,00%
Misc. vegetation	10,52%	0,49%	5,12%	0,17%	81,51%	1,69%	0,44%	0,07%
Burnt area	3,79%	0,41%	4,59%	0,00%	87,88%	3,26%	0,08%	0,00%
Water	0,08%	0,07%	0,20%	0,01%	0,39%	0,00%	99,11%	0,04%
Rock	0,47%	0,16%	0,24%	0,09%	83,62%	0,00%	1,05%	14,28%

Appendix C2: Land Use Transition Matrices of Spain

Table 7: Transition Matrix of Spain in absolute numbers

Land Use 2000	Land Use 2018: Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock	Total LU 2000
Forest	8.950.019	28.300	635.953	7.478	2.039.109	13.057	17.332	10.439	11.701.687
Urban	18.152	559.600	63.334	3.372	15.714	58	3.133	476	663.839
Agriculture	1.105.667	401.429	19.473.387	45.935	1.753.946	2.502	38.045	8.749	22.829.660
Res. production	5.049	22.677	15.203	37.605	14.596	8	2.274	246	97.658
Misc. vegetation	3.102.602	66.522	1.545.068	23.562	9.301.098	15.272	34.485	122.471	14.211.080
Burnt area	10.163	51	3.789	227	59.533	90	8	17	73.878
Water	13.538	4.135	30.270	889	19.737	10	823.974	1.579	894.132
Rock	11.976	2.269	6.152	192	89.178	1	2.607	142.231	254.606
Total LU 2018	13.217.166	1.084.983	21.773.156	119.260	13.292.911	30.998	921.858	286.208	

Table 8: Transition Matrix of Spain in %

Tabel 7: Transition Matrix of Spain in %

Land Use 2000	Land Use 2018: Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock
Forest	76,48%	0,24%	5,43%	0,06%	17,43%	0,11%	0,15%	0,09%
Urban	2,73%	84,21%	9,53%	0,51%	2,36%	0,01%	0,47%	0,07%
Agriculture	4,84%	1,76%	85,30%	0,20%	7,68%	0,01%	0,17%	0,04%
Res. production	5,17%	23,22%	15,56%	38,50%	14,94%	0,01%	2,33%	0,25%
Misc. vegetation	21,83%	0,47%	10,87%	0,17%	65,44%	0,11%	0,24%	0,86%
Burnt area	13,75%	0,07%	5,13%	0,31%	80,57%	0,12%	0,01%	0,02%
Water	1,51%	0,46%	3,38%	0,10%	2,20%	0,00%	91,92%	0,18%
Rock	4,70%	0,89%	2,41%	0,08%	34,96%	0,00%	1,02%	55,76%

Appendix C3: Land Use Transition Matrices of Europe

Table 9: Transition Matrix of Portugal in Europe in absolute numbers

		Land Use 2018								
		Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock	Total LU 2000
Land Use 2000	Forest	153.885.411	419.741	3.181.986	102.244	11.717.133	99.211	577.470	40.933	170.024.129
	Urban	217.881	18.282.316	1.269.243	35.534	85.195	98	40.195	3.750	19.934.212
	Agriculture	5.104.073	4.400.045	230.344.436	367.579	6.568.915	10.216	649.681	81.531	247.526.476
	Res. prod.	46.088	152.510	134.273	482.931	92.529	82	53.774	4.501	966.688
	Misc. Veg.	14.798.127	291.119	6.273.287	131.823	82.587.329	107.819	2.480.411	1.295.082	107.964.997
	Burnt area	22.331	331	9.430	375	141.132	3.165	206	68	177.038
	Water	673.355	61.639	491.233	16.902	566.768	6.157	173.838.496	208.553	175.863.103
	Rock	35.028	14.893	98.509	9.263	1.365.469	234	251.354	8.063.547	9.838.297
	Total LU 2018	174.782.294	23.622.594	241.802.397	1.146.651	103.124.470	226.982	177.891.587	9.697.965	

Table 10: Transition Matrix of Europe in %

		Land Use 2018							
		Forest	Urban	Agriculture	Resource production	Miscellaneous vegetation	Burnt area	Water	Rock
Land Use 2000	Forest	90,46%	0,25%	1,87%	0,06%	6,89%	0,06%	0,34%	0,02%
	Urban	1,09%	91,66%	6,36%	0,18%	0,43%	0,00%	0,20%	0,02%
	Agriculture	2,06%	1,78%	93,02%	0,15%	2,65%	0,00%	0,26%	0,03%
	Res. production	4,77%	15,77%	13,89%	49,94%	9,57%	0,01%	5,56%	0,47%
	Misc. vegetation	13,70%	0,27%	5,81%	0,12%	76,48%	0,10%	2,30%	1,20%
	Burnt area	12,61%	0,19%	5,33%	0,21%	79,72%	1,79%	0,12%	0,04%
	Water	0,38%	0,04%	0,28%	0,01%	0,32%	0,00%	98,80%	0,12%
	Rock	0,36%	0,15%	1,00%	0,09%	13,87%	0,00%	2,55%	81,92%