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Title of the Master Thesis: Mapping multiple-stressors of rural areas in Spain: identifying new geographical spots of vulnerability attention

Title of the master's degree: Master's Degree in Interdisciplinary Studies in Environmental, Economic and Social Sustainability

Major within the master's degree: Ecological Economics

Title of the journal used as the basis for the paper format criteria: Journal of Rural Studies

Name of the supervisors and the Institute where the research has been carried out: Esteve Corbera Elizalde (PhD) and Sergio Villamayor Tomás (PhD), in ICTA-UAB.

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Author: Gerard Pocull-Bellés

Description of how this project fits within the research of the research group the student has been working in:

This Master Thesis has been carried out within the project SEVERAS, which is leaded by the supervisors of this Master Thesis. This project aims to develop country-wide and regional indexes of Socio-Environmental VulnErability in RurAl Spain (SEVERAS) and use them to explore policies that can reduce said vulnerability. To do that, the project will assemble so far disconnected climatic, census, land-use and rural development data into a unique socio-environmental database.

In the case of my Master Thesis, it has grown out of working on already existing databases that served the development of a multiple stressor analysis using GIS techniques. It constituted the first steps towards the identification of hotspots of exposure based on municipal data to several components of vulnerability by developing a spatial analysis of exposure to climate change, depopulation and international trade. My Master Thesis has allowed the team: to better understand rural patterns in Spain, to highlight new geographical areas of vulnerability-related attention and to enhance the knowledge on the differences between the categories of remote rural and accessible rural in the Spanish context for vulnerability studies.

Guide for authors of Journal of Rural Studies

From https://www.elsevier.com/journals/journal-of-rural-studies/0743-0167/guide-for-authors

Manuscripts must be double-spaced with a wide margin (2.5cm or 1 inch). The normal maximum length for a contribution is 10,000 words. However, all papers should be written as concisely as possible.

- *Introduction*. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

- *Material and methods*. Provide sufficient details to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized and indicated by a reference. If quoting directly from a previously published method, use quotation marks and also cite the source. Any modifications to existing methods should also be described.

- *Theory/calculation*. A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis.

- *Results*. Results should be clear and concise.

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- *Conclusions*. The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

Abstract:

Rural Spain has undergone several changes in recent decades. The deagrarization of rural societies and agricultural intensification has spread throughout the territory and, with it, the abandonment of unproductive and mountainous lands, with the consequent socio-environmental impacts. This phenomenon has been coupled with a historical depopulation process continues to affect rural villages, especially in remote rural areas. Furthermore, Spain is one of the most vulnerable countries to climate change impacts, particularly in the agriculture sector. This study proposes an interpretation of rural vulnerability based on multiple-stressors framework accounting for climate change, depopulation and international trade. A spatial analysis is presented through a methodology based on Hot-spot analysis where the rural areas most exposed to the aforementioned stresses are identified, differentiating between remote rural and accessible rural contexts. This triple-exposure approach at the country level allows new vulnerable rural areas to emerge that until now could have been invisible by the single-stressor analysis. The resulting maps may have implications when designing and applying future rural policies that act on areas that experience interactions between various stresses.

Content

1. Introduction

The study of rural populations' vulnerability to environmental hazards and other types of stressors has been a subject of enquiry in the last decades, with special attention on the developing countries (Dasgupta et al., 2014). These analyses have been aimed at identifying mainly vulnerability to climate change and its associated risks, livelihoods sustainability (commonly food security, see Ericksen (2008)) and vulnerability of socio-ecological systems (see Berrouet et al. (2018)). They have often been conducted with the aim to devise development policy and approaches that may contribute to increase the viability of rural livelihoods, or their resilience to such experienced hazards and shocks.

Vulnerability has been understood from different perspectives and frameworks. Adger (2006) has one of the most accepted definitions of vulnerability as: "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt". In that sense, O'Brien et al. (2007) differentiated two different interpretations of understanding vulnerability in the climate change literature: outcome vulnerability, where climate change impacts and adaptive capacity follow a linear end-point approach; and contextual vulnerability, based on a multidimensional approach where different socio-economic, political and climate changes affect vulnerability (Appendix A).

Major literature body reveals a bias towards the study of single stressors alone, such as climate change impacts and related environmental hazards. However, O'Brien and Leichenko (2000) and Leichenko and O'Brien (2008), proposed a theoretical framework where vulnerability is not only explained by climate-related stresses, but through "double-exposure" of socio-economic (globalization) and climate-related pressures. Furthermore, the combination of "exposures" or simultaneous drivers of vulnerability may exacerbate the risk context, intensifying the vulnerability of the system or social groups, creating new "double losers" and "double winners" (O'Brien & Leichenko, 2000). Other researchers have used the concept of

"multiple stressors" when climatic and non-climatic stressors are studied together (Bennett et al., 2015; Eriksen & Silva, 2009; Freduah et al., 2019; Lele et al., 2018; McDowell & Hess, 2012; Nyantakyi-Frimpong & Bezner-Kerr, 2015; Shameem et al., 2014; Silva et al., 2010). Apart from terminology aspects, "multiple stressors" framework is a recent field and is gaining interest in the literature (Räsänen et al., 2016).

Rural areas in *developing* and *developed* countries show differences on the degree and main types of stresses, but at the same time present similarities that differentiate them from urban and peri-urban trends (Dasgupta et al., 2014). This dissertation is focused on rural context in the Global North. In *developed* countries, rural areas have peaked in population numbers, agriculture is no longer the main economic pillar and farm subsidies are under pressure due to new international trade agreements. Furthermore, climate change is a global issue, but rural areas are more vulnerable due to its higher direct climate-related interactions, such as agriculture (Dasgupta et al., 2014).

Spain is as a paradigmatic case for the study of multiple stressors. Spain is the most severely threatened country in Europe due to desertification processes (Prăvălie et al., 2017), causing land degradation. Simultaneously, land abandonment is taking place and will continue in several regions of the country (Perpiña Castillo et al., 2020). In addition, Spain has become an important world food producer during the last decades but starts to experience stagnation in agriculture production and in final production value with the loss of soil fertility due to fast intensification processes driven by market-related pressures (González de Molina et al., 2019).

This research is an empirical investigation at country-level of how vulnerable Spain's rural livelihoods may be to three drivers of agrarian change, namely climate change, international trade and depopulation. In doing so, the dissertation asks what the most common multiple-stressor combination in the rural Spain is and how it is distributed. To respond to these

questions, I develop a methodology based on spatial analysis at municipal level to draw a country-wide multiple stressors map showing the spatial distribution of three rural stressors in Spain. This study doesn't aim to identify the most vulnerable areas in Spain (to do so it would be needed to assess the adaptive capacity and resilience as well), but to spatially assess three-mentioned drivers of stress at country scale. The analysis here presented aims to identify *relative* exposure of each stressor (using words of Luers (2005)) and the distribution of spots with high probability of multiple stressors intersection, enabling to highlight areas for prioritization actions and future vulnerability assessments.

The dissertation is structured as follows. Section two reviews the literature on rural stressors in rural Spain to contextualize the three selected stressors of this analysis: climate change, depopulation and international trade. Section three presents the case study and the research methods developed to identify the spatial distribution of relatively high-exposed clusters and intersections between them. Section four presents the results and demonstrates that climate change and depopulation are the most common combination of stressors currently in rural Spain and that triple-exposure of the studied components of vulnerability may exist in the territory. Section five discusses these results in the light of the multiple stressors framework and its policy and management implications.

2. Background

2.1. Rural Spain

Rural areas in Spain have experienced different social and economic dynamics compared to urban areas. Camarero et al. (2009) published a research characterizing the current rural areas in Spain, highlighting: a decrease in direct dependence on urban development; an increase of difficulties in agricultural sector due to economic crises and globalization; the existence of a productivity-sustainability dilemma in rural environments, questioning the equilibrium between economic, environmental and social sustainability; and finally, rural areas' demographic trends are generally based on loss of population, over-aging, masculinization, gender inequalities and job vulnerability.

Nowadays, rural Spain is not agrarian-based society anymore where the economic activity was related almost exclusively to the primary sector. Alternative activities, including construction, industry and services (such as tourism) has emerged as employment engines and are employing three quarters of rural active population (BOE, 2010). However, socio-ecological system sustainability still depends on agriculture activities, that sustain several ecosystem services (Spanish National Ecosystem Assessment, 2014) and have a strong indirect influence on rural economies (Dasgupta et al., 2014).

Food and Agriculture Organization (FAO) publishes national reports stating socio-economic indicators of rural areas in the world (FAO, 2019). For Spain in 2018, employment in agriculture was 4,4% (2,3 % in the case of female employment), representing both percentages half of the values compared to 1997. Besides, Spain's share of land use dedicated to agricultural activities is 52,6% of country area, while forest lands cover the 37%. In demographic parameters, rural population reaches 9,1 million people (19,5% of total Spain's population) and

in economic lenses, Spain is a net exporter of fruits and vegetables (net trade of 11.838 M €[1])
and meat (4.267 M €[2]).

Finally, and looking at the Spanish agriculture in detail, it has experienced changes provoked
by internal and external pressures. In the case of endogenous drivers, rural exodus has been a
motor for land abandonment and agriculture intensification in Spain (Collantes & Pinilla,
2019). On the other side, external pressures in Spanish agricultural sector are sourced in
Common Agricultural Policy subsidies, Market-related pressures (particularly for small and
medium producers, see Figure 1) and climate-related stressors, for instance, water-limited
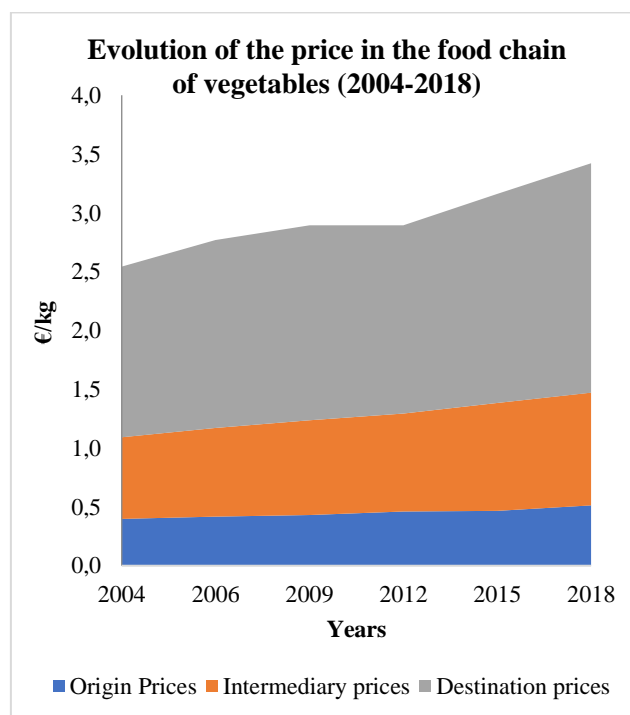production (MAPA, 2019b).

Figure 1. Average of prices for selected vegetables[3] in Spain stratified by the three main stages in the food chain. While prices in origin (those perceived by the farmer) have maintained stable during the last fifteen years, destination prices (based on prices for final consumers) have increased significantly. Source: Observatorio de la Cadena Alimentaria (Food Chain Observatory), Ministerio de Agricultura, Pesca y Alimentación (https://www.mapa.gob.es/es/estadistica/temas/estadisticas-alimentacion/observatorio-precios/)

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[1] Converted to euros following 1 USD = 0,85 €
[2] Ibid.
[3] Selected vegetables: Potato, Chard, Zucchini, Onion, Flat Green Bean, Romaine Lettuce, Italian Green Pepper, Smooth Round Tomato, Carrot, Lemon, Clementine, Navel Orange, Golden Apple, Water pear, Banana

2.2. Multiple stressors in rural Spain

Vulnerability of rural areas in Spain have been widely argued from agrarian pressures and demographic dynamics, among others. However, studies that combine two or more stressors from different lenses (i.e. social, environmental and economic) are scarce and focused on small study areas. However, new publications are trying to fulfill this lack with the multiple-stressors or double exposure framework. For instance, Albizua et al. (2019) studied farmer's vulnerability to global change, structuring their analysis into two main sources: climate-related shocks and economic shocks, which were determined by price volatility. In another study recent study Perpiña-Castillo et al. (2020), developed a country-wide land abandonment risk index based on demographic, biophysical and agroeconomic factors. All these analyses are part of a new literature body that emphasize the importance of multiple-stressors or drivers of change in the Spanish agrarian sector, that influence rural sustainability. In this dissertation, I included three sources of stress: climate-related stress based on aridity and climate change, depopulation as a demographic-related stress and international trade as a market-related stress.

2.2.1. Climate-related stressors: climate change

Climate conditions can be a stressor in rural areas, because rural livelihoods highly depend on climatic and environmental conditions (Dasgupta et al., 2014; Iglesias et al., 2012). In the agricultural sector, year-to-year variations in crop yields can be mainly explained by weather conditions, particularly due to changes in water availability (Frieler et al., 2017), impacting negatively on rural livelihoods. Changes in precipitation and temperature, parameters that determine aridity conditions (see more in Methods section), can provoke reductions in crop yields (Camps & Ramos, 2012; Iglesias et al., 2012). Thus, aridity, among other factors, is one of the drivers of land abandonment in Europe, and especially in the southern areas (Ustaoglu & Collier, 2018).

Increase in temperature, due to climate change[4], has been experienced in Spain during the last decades (Figure 2)(Moreno et al., 2005). Furthermore, climate change projections (based on different scenarios of anthropogenic gases emissions) and its impacts on agriculture sector show a decrease in crop productivity in the Southern Europe (Iglesias, 2012). The impacts of this phenomenon on the agriculture in the European Mediterranean region have been reported (EEA, 2019), concluding that the main climate change impacts on the agriculture production are the increase in water demand (due to decrease in precipitation, increasing risk of droughts and increase in heat extremes) and decrease in crop yields. In the case of Atlantic regions (located in the northern coastal areas in Spain), climate change impacts are mainly related with more severe precipitation events. Therefore, climate change (and its cascading effects), can impact on production (in price, quantity and quality changes) and, as consequence, agricultural livelihoods and food security (see FAO, 2016, p. 4).
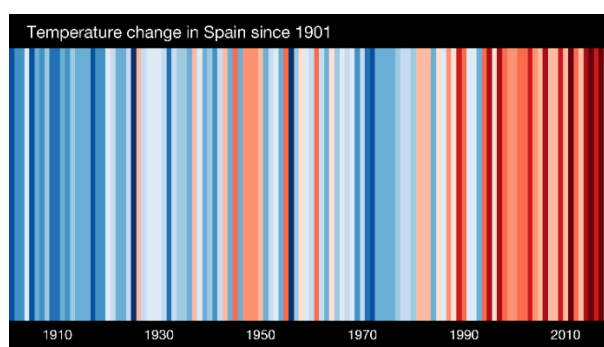

Figure 2. Temperature change in Spain (1901-2019) represented with Warming Stripes (each stripe represents the temperature in that country averaged over a year). The stripes turn from mainly blue to mainly red in more recent years, illustrating the rise in average temperatures in that country. Source: Ed Hawkings (University of Reading), https://showyourstripes.info/)

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[4] United Nations Framework Convention on Climate Change (UNFCCC, 1992) defined climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.". Intergovernmental Panel on Climate Change (IPCC, 2018) used in its last report the definition for climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use."

2.2.2. Depopulation: a historic phenomenon in rural Spain

Over the last century and specially during the second part of 20th century (1950-1990) most Spanish rural areas experienced a drastic loss in population, categorized as "rural exodus" by some authors. Populations living in rural areas have decreased in absolute numbers (from 13,3 million in 1950 to 9,4 million in 2000) and in relative numbers in total Spanish population (representing around 50% in 1950 and 24% at the beginning of the current century) (Collantes & Pinilla, 2019). 20th century depopulation was based on rural migration to cities but, in more recent rural population losses, the negative natural growth is one of the main causes (Pinilla et al., 2008). The demographic consequences of that phenomena (which had different causes and feed-back loops) can be seen in the current density population distribution through the country (Figure 3), in high degree of masculinization of rural villages and over-ageing processes (Camarero et al., 2009).
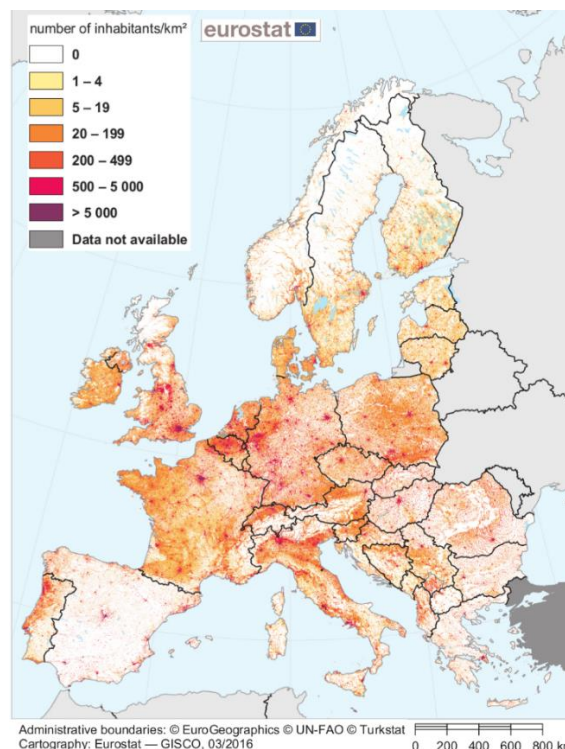

Figure 3. Population density based on the GEOSTAT population grid, 2011 (Number of inhabitants/km2)

Rural migration can be viewed with positive arguments (such as restoration of natural environments and people's capacity to find new job opportunities) or negative arguments (crop abandonment, rural depopulation and loss of local identity and traditional ecological knowledge) (Quintas-Soriano et al., 2016). In that last sense, the Spanish National Ecosystem Assessment (2014) stated that the rural abandonment caused an important loss of essential cultural services, such as local ecological knowledge, which maintained several ecosystems ecological integrity and resilience. All in all, demographic future scenarios, represented as changes in population density, migrations or distribution, are key factors to assess vulnerability in agricultural contexts (Iglesias et al., 2012).

2.2.3. Globalization and trade: socioeconomic and environmental stressors

Market-related pressures have been studied as drivers influencing the vulnerability of rural livelihoods. Agricultural trade and its market driving forces are factors that shape rural dynamics and can increase vulnerability in *developing* countries (O'Brien et al., 2004; O'Brien & Leichenko, 2000), and more in detail in European and Spanish context (Iglesias et al., 2012; Nainggolan et al., 2012). Furthermore, market-related stressors have already been studied together with climate-stress events in Spanish wine crops, testing its interactions (Bardaji & Iraizoz, 2015).

Market forces increase within a context of economic globalization (O'Brien & Leichenko, 2000), and international trade is one of its maximum exponents. Therefore, agrarian products that are oriented towards international trade are more exposed to changes that occur out of the internal market, for instance, international trade agreements, higher variability in consumers preferences and emergence of new producers, among others (Belliveau et al., 2006) causing price volatility and vulnerability (Clapp, 2009).

Competitiveness within international markets and policy-driven pressures, such as the Common Agricultural Policy (CAP), can bring socio-ecological changes in rural environments, such as agricultural intensification, loss of identity agricultural landscapes and mid-term productivity decreases (Cabello et al., 2015; Rodríguez Sousa et al., 2019). These socio-economic changes, driven at global and also at regional scale, produce contexts of vulnerability because economic viability of exploitations is being constrained. Rodríguez Sousa et al. (2019) stated two main causes of loss in viability in the olive orchards of southern Spain: uncertainty of production and volatility of prices. Particularly, price volatility is accentuated in the case of international trade because is exposed to low-price competitiveness.

Spanish agriculture has a significant importance in the international food trade. As an example, Spain is the first and fourth world producer of olives and grapes, respectively (FAO, 2020). One way of studying the international trade patterns is looking at the balance between exports and imports, showing the weakness among international markets or the export potential of a product (MAPA, 2019a). This balance based on exports and imports can be a major driver of economic impact on the agriculture sector (Iglesias et al., 2012). Thus, through the analysis of Spanish agriculture products balance and the crop specialization of different areas in Spain, it is possible to determine export-nature agrarian regions, allowing to identify where international trade exposure may be higher.

3. Methods

3.1. Study area

Spain is a South-western European country with a population of 47.329.981 inhabitants, one of the most populated countries in the European Union. However, its large surface (505.990 km²) and high concentration of citizens in large cities (such as the metropolitan areas of Madrid and Barcelona) has resulted in the existence of vast landscapes with low or very low population densities, i.e. less than 12,5 inhabitants/km2 and less than 8 inhabitants/km2, respectively.

The study area (Figure 4) is the peninsular territory of Spain and the Balearic Islands. Other territories that also joint the Kingdom of Spain (the Canary Islands and Ceuta and Melilla Autonomous Cities in the north of Africa) were excluded of the analysis due to significant geographical distance and lack of homogenized climate data.

Figure 4. Map of Spain with Peninsular territory and Balearic Islands (archipelago on the right).

3.2. Climate change and aridity: Climate Change Stress Index

In order to map climate-related pressures, I developed a Climate Change Stress Index (CCSI) at municipal level that define the spatial distribution of climate stressed areas that are experiencing and will experience an increase in climatic stress due to climate change. The

analysis of climate change in the Spanish context was based on the interpretation of O'Brien et al (2004) where climate change stress was determined by a biophysical exposure (the change in the climate due to Climate Change[5]) and a biophysical sensitivity (areas that, despite of climate change, suffer stressful climate characteristics). In that same sense and for methodological steps, I partially followed Closset et al. (2017), which developed a Physical Vulnerability to Climate Change Index (PVCCI) (see more about this index in the Appendix section 7.1.).

In the case of Spain, aridity has been studied in the literature as an important stress at the national and regional level, which can increase with climate change (Iglesias et al., 2012; Quiroga & Iglesias, 2009; Ronchail et al., 2014). Aridity can be defined as:

A nature produced permanent imbalance in the water availability consisting in low average annual precipitation, with high spatial and temporal variability, resulting in overall low moisture and low carrying capacity of the ecosystems. (L. S. Pereira et al., 2002).

This "imbalance in the water availability" can be measured with different formulas (Moral et al., 2016). The FAO (1989) proposed the Equation 1 to calculate the aridity at the global scale, determining thresholds that defined degrees of aridity.

$$Aridity\ Index = \frac{P}{PET}$$

Equation 1. Aridity Index proposed by Food and Agriculture Organization (FAO, 1989)*. P represents Precipitation (mm) and PET represents Potential Evapotranspiration (mm)*

Then, the Climate Change Stress Index (CCSI) considered in this study was composed by two components: current aridity distribution and the anomaly of one of the parameters that define

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[5] ibid

aridity, in this case the Potential Evapotranspiration[6], being the anomaly in climate terminology the difference of a future climate compared to the present climate. I have not used precipitation as the variable to represent the anomaly because it shows high variability depending on the projected Regional Climate Model (RCM) used (Lorenzo & Alvarez, 2020), although there is a general trend of annual precipitation decrease in the whole country (Gao & Giorgi, 2008; Lorenzo & Alvarez, 2020). In brief, the CCSI aims to identify areas that combine present aridity stress with a relative high increase in PET, being a proxy of climate change.

Climate raster data was collected from the national climate change adaptation platform called AdapteCCa (htpps://escenarios.adaptecca.es), which offers country-level projections of Regionalized Climate Models (RCM) (see section 7.2. in Appendix to find the complete details of the models used and the database characteristics). This database was used to download: the observed precipitation from the raster dataset Spain011 of Historic period (1971-2000), the Potential Evapotranspiration of Historic period (1971-2000) and the Anomaly of Potential Evapotranspiration of Mid Future (2041-2070) compared to the Historic period. Projected climate values are the result of the ensemble average of 16 RCM (Dezsi et al., 2018) of the EURO-CORDEX Initiative (https://www.euro-cordex.net/).

In my study, it was needed an Aridity Index where resulting larger values identified places with high aridity (in FAO's Aridity Index smaller values represent arid lands). Then, Aridity Index was transformed into Equation 2, as used in Dezsi et al. (2018):

$$AI = \frac{PET_{1971-2000}}{P_{1971-2000}}$$

Equation 2. Aridity Index, where PET is Potential Evapotranspiration and P is Precipitation of the Historic Period

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[6] Potential Evapotranspiration (PET) is defined as the water loss that takes place during a certain period of time from a given area due to evaporation from soil surface and plant transpiration if vegetation was "well supplied with water" (Kirkham, 2014).

Next, Aridity Index and PET Anomaly were normalized[7] into a [1,0] scale. Finally, it was used the quadratic mean[8] to combine both components (normalized Aridity Index and normalized PET Anomaly), as recommended by Closset et al. (2017). The resulting raster was finally joint to the layer of municipalities, where each municipality feature processed the average of pixels inside their boundaries.

3.3. Depopulation as a negative growth rate

Population projections in Spain are based on recent past and present demographic patterns, and they show unclear demographic projections[9]. To deal with this uncertainty and to develop a local scale analysis based on a growth rate, I used the base period 2011-2019 to calculate the population variation at municipal level. Growth rates have been used to study population trends, also in rural areas contexts (Collantes et al., 2014; Ghosn et al., 2012; Wittemyer et al., 2008). As mentioned previously, the study was focused on the peninsula and Balearic Islands. Thus, municipalities of Canary Islands and Autonomous Cities of Ceuta and Melilla were excluded. At the end, 8041 municipalities were accounted for the analysis, based on the existent local units in 2019 established by INE (Instituto Nacional de Estadística, *Spanish Statistical Office*). Population of each municipality was taken from INE database (htpps://www.ine.es) for the period 2011 and 2019 (see more details in Appendix D about data processing).

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[7] Normalization allows to compare different components that use different scales. This calculation was made with: NC = (c -min) / (max – min), where NC is Normalized Component, C is the value of the component. Maximum and minimum were defined as two times the Standard Deviation applied to the mean of each component of the index, to avoid outliers' interference.

[8] Quadratic mean was used instead of the arithmetic mean because it gives more weight to larger values. The suitability of quadratic mean in this analysis is because if a municipality has a high value (close to 1) at least in one of the two components, the resulting mean will be higher compared to arithmetic mean, showing that high stress of one component is significant (Closset et al., 2017).
Quadratic mean= $\sqrt{(x_1{}^2 + x_2{}^2 + ... + x_n{}^2)/n}$

[9] Population projections in Spain don't show a clear trend and demographic evolution will depend significantly on migrations. For instance, UN Population Prospects expects a decline in the total population (from 46,7 million in 2020 to 43,6 in 2030 and 36,7 in 2070) (UN, 2019). Similar demographic projections were accounted in a report developed by the Spanish Statistical Office (INE, 2014) were total population declined. On the other side, two years ago, INE published another demographic projection (INE, 2018) with an increase of Spanish population reaching 50 million people after 2030.

In this study, I used the Compound Annual Growth Rate (CAGR) that has already been applied in the Spanish case (Collantes et al., 2014). It is calculated with the Equation 3:

$$r = \left(\sqrt[n]{\frac{Endin\ Date\ Population}{Starting\ Date\ Population}} - 1 \right) x\ 100$$

Equation 3. Compound Annual Growth Rate formula

Where "r" is the Compound Annual Growth Rate and "n" refers to the number of years from start to end. This growth rate should be interpreted as a year-on-year growth measured as a percentage (%).

3.4. International Trade Stress Index

The commercial balance, also called balance of trade or net exports, is the difference between exports and imports in monetary value at national scale. Spain is a net importer accounting for the whole economy but is a clear net exporter in transformed and not-transformed agrarian products. The ICE (Instituto de Comercio Exterior, *Foreign Trade Institute*) publishes every year the commercial balance of Spain (MAPA, 2019a), resulting in 2018 that: exports reached 41.708 M€, while imports were accounted for 26.355 M€. The trade balance average of the last three years (2016-2018) has had a positive value of 15.256 M€. Furthermore, export-oriented nature of Spanish agriculture is following a positive trend, with a mean of 8% of annual growth in the commercial balance in the last 10 years.

I considered 4 crops[10] with a high export-oriented nature based on the commercial balance (Exports-imports): olive trees, vineyards, vegetables and fruit trees (see the Appendix section 7.3 for the detailed criteria used). The area (ha) of each crop at municipal level was collected

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[10] Pork production, despite of its high export trend (positive trade balance of 4.438.798.000 €), was not considered because the main measurement variable is Livestock Units (in contrast of surface for the crops) and is less directly dependent of environmental conditions. These characteristics made it unsuitable for the index explained later. However, pork industry could be an interesting case study seen its recent exporting trend.

from the national Agrarian Census from 2010 (which is the most recent published census at national scale and provides data for each municipality). First, I calculated the local proportion of each crop surface compared to the total country coverage of that crop. That is, for instance, a municipal vineyards area divided by the total country area covered by vineyards. This step aims to standardize the different productivities of the considered crops. In other words, one hectare of vineyards doesn't have the same productivity as one of vegetables, thus, cannot be compared directly. After summing the four proportions of each crop for each municipality, this value was divided by the total municipal area in order to correct the different municipal sizes. In Spain, northern municipalities tend to be smaller than the southern ones due to geographical and historical processes. Without this correction, southern municipalities would have systematic higher values of exposure and the spatial statistical analysis would show incorrect results for this stressor. The following equation (3) resumes the calculation process:

$$Index = \frac{\frac{Local\ Vines\ (ha)}{Spainsh\ vines\ (ha)} + \frac{Local\ olive\ trees\ (ha)}{Spainsh\ olive\ trees\ (ha)} + \frac{Local\ fruit\ trees\ (ha)}{Spainsh\ fruit\ trees\ (ha)} + \frac{Local\ vegetables\ (ha)}{Spainsh\ vegetables\ (ha)}}{Municipal\ area\ (ha)}$$

Equation 4. International Trade Stress Index

3.5. Multiple stressors analysis using Hot and Cold Spot Analysis

Spatial analysis tools of GIS allow the users to statistically delineate areas with significantly specific trends or characteristics that made them different from their surrounding areas. One of these tests is Hot Spot Analysis that is based on Getis-Ord Gi* test (Getis & Ord, 1992) that assess the degree of spatial association while defining statistically significant clusters of hot-spot (areas with relative high values) and cold-spot (areas with relative low values). In other words, for a given a data set, Getis-Ord Gi* test identifies clusters of spatial features with significant higher or lower values than those expected to be found by random chance. More details of the Hot-Spot Analysis methodology can be found in the respective section in Appendix.

In Spain, different studies have used Getis-Ord Gi* test in order to discuss topics such as the distribution of Rural Development Policy (Nieto & Cárdenas, 2018), hot-spots of rural tourism (Sánchez-Martín et al., 2019) and Ecosystem Services (Roces-Díaz et al., 2017). In this study, I used ArcMap from ArcGIS Desktop (ESRI, 2019) to run the test.

In order to discover areas with multiple-stressor, I considered only the Hot-Spot areas (with a minimum of confidence of 90%) of "International Trade" and "Climate Change" and the Cold-Spot areas (with a minimum confidence of 90%) of "Depopulation"[11] from the three maps created after running the Hot-Spot Analysis Test. Then, *Union Analysis* tool in ArcGIS 10.7.1 (ESRI, 2019), which is a layer overlapping technique, was applied to combine all three layers, being four new categories created: Climate Change-Depopulation, Climate Change-International Trade, Depopulation-International Trade and Triple stress.

In addition, in this study I applied the municipal categorization of Reig et. al (2016) to analyze multiple stressors coverage per degree of urbanization[12]. This classification at local scale is based on three pillars: demography, land coverture and accessibility. Accessibility is defined as the "time of travel" by car needed to reach the capital of the province and is a key parameter for differentiating the rural areas between "accessible" and "remote" (>45 minutes from the city).

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[11] In the case of Depopulation, Cold-Spot areas (areas in blue in the Figure 7b) are the ones that show negative values in the Equation 3, then experiencing the stress of population decline.
[12] Different local classifications of the degree of urbanization have been used in the Spanish context. For instance, UN have applied population threshold of 10.000 habitants to distinguish rural from urban (Dijkstra & Poelman, 2014) while OECD proposed municipalities with population densities lower than 150 inhabitants/km^2 (Jonard et al., 2009).
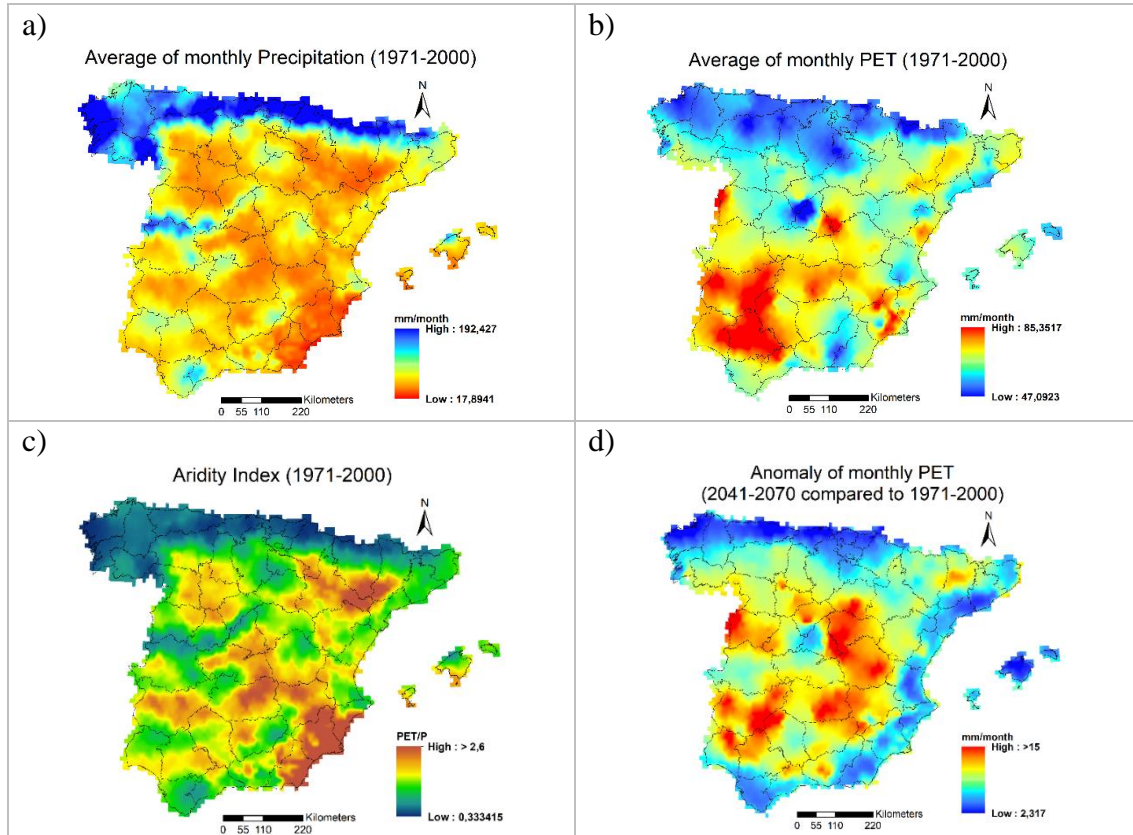
4. Results

4.1. Climate change

Figure 5. Maps of climate variables of (a) Average of monthly precipitation and (b) Potential Evapotranspiration of 1971-2000 period, (c) Aridity Index of 1971-2000 and (d) Anomaly of Potential Evapotranspiration for the period 2041-2070 compared to the period 1971-2000 with emissions scenario RCP 8.5.
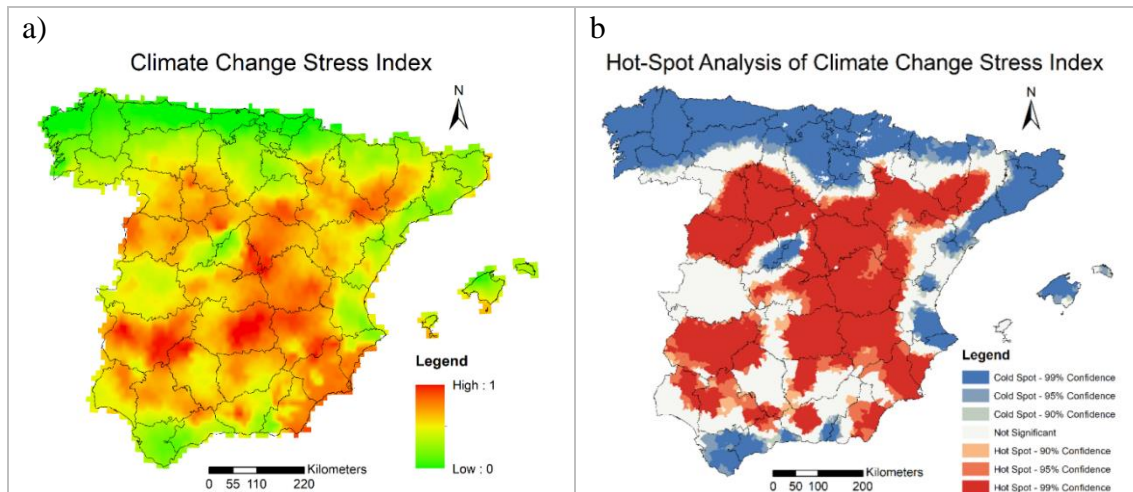

Figure 6. a) Map of Climate Change Stress Index, following the section 2.1. in Methods. b) Hot-Spot Analysis of Climate Change Stress Index

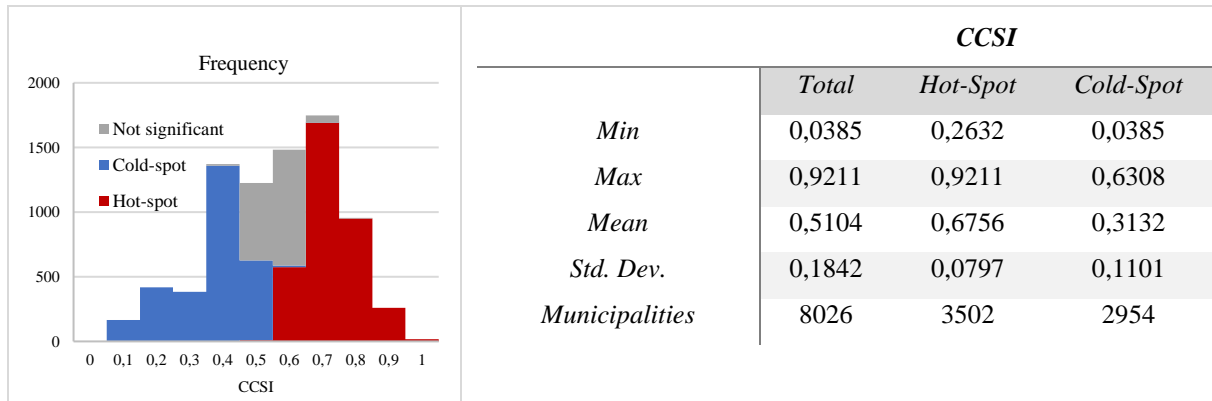|		CCSI	
	Total	*Hot-Spot*	*Cold-Spot*
Min	0,0385	0,2632	0,0385
Max	0,9211	0,9211	0,6308
Mean	0,5104	0,6756	0,3132
Std. Dev.	0,1842	0,0797	0,1101
Municipalities	8026	3502	2954

Table 1. Statistics of municipal CCSI with stacked bar chart of the frequency of municipalities by its CCSI value (left) and clusters statistics created with Hot-Spot Analysis for Climate Change Stress Index (right)

Figure 6a is the raster map resulted from the Climate Change Stress Index (CCSI) and Figure 6b shows the resulting Hot-Spot Analysis. Hot-Spot areas (red ones in Figure 6b) show the spatial-statistically significant areas with relative higher values in CCSI municipal database. Both *Mesetas* (*Septentrional* and *Meriodional*) in central Spain are mostly covered by hot-spot areas, as well as the Ebro Depression. In the southern Spain, hot-spot areas are more heterogeneously distributed, with smaller sizes. They are found in regions like the Guadalquivir Depression or Tierra de Barros, in the Province of Badajoz. This map shows also that Northern regions in Spain and close to Mediterranean coast areas (such as Catalan coast) are not relative spots of aridity-related stresses within the Spanish context.
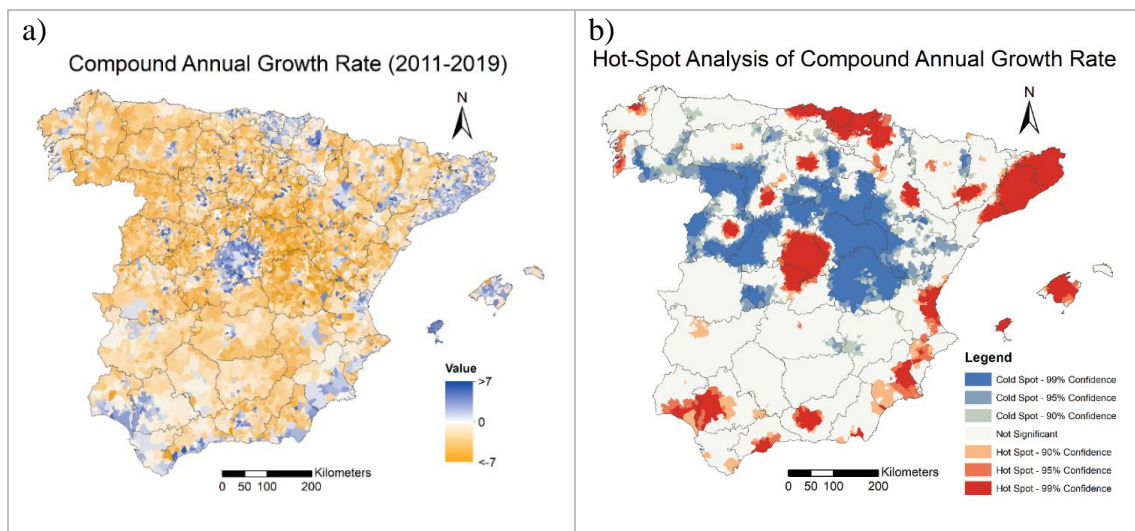
4.2. Depopulation

Figure 7. a) Map of Municipal Compound Annual Growth Rate between 2011-2019, calculated with Equation 3. b) Hot-Spot analysis of Compound Annual Growth Rate

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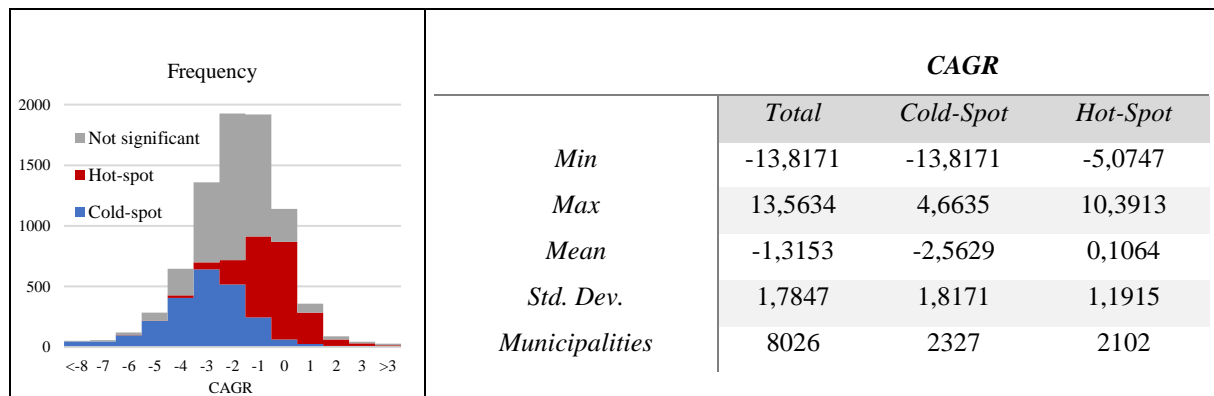|		CAGR		
		Total	*Cold-Spot*	*Hot-Spot*
Min		-13,8171	-13,8171	-5,0747
Max		13,5634	4,6635	10,3913
Mean		-1,3153	-2,5629	0,1064
Std. Dev.		1,7847	1,8171	1,1915
Municipalities		8026	2327	2102

Table 2. Statistics of municipal Compound Annual Growth Rate (CAGR) with stacked bar chart of the frequency of municipalities by its CAGR value (left) and clusters statistics created with Hot-Spot Analysis for the CAGR (right)

Figure 7a clearly differentiates two dynamism in the Spanish demography. The most part of the territory is losing population, with the lowest values of CAGR (higher depopulation rates) in the mid-northern part, where the orange is darker. Important metropolitan areas, such as Madrid (in the center), Barcelona (in the north-east) and Basque Country region (in the middle of the northern coast) are areas that are experiencing population growth in the last years.

Figure 7b is the result of the Hot-Spot analysis of the municipal Compound Annual Growth Rate. Cold-spots areas (blue ones) are those clusters that are experiencing depopulation, with an average CAGR of -2,56% (Table 2). They are distributed in the mid-north-inland of the peninsula. There is a compact cluster of depopulation in the provinces surrounding the region of Madrid, the capital city, and areas close to the Portuguese border. The southern Spanish areas, even if most part of them have negative values (Figure 7a), they are not considered spatial-statistically significant within the database and its spatial configuration.
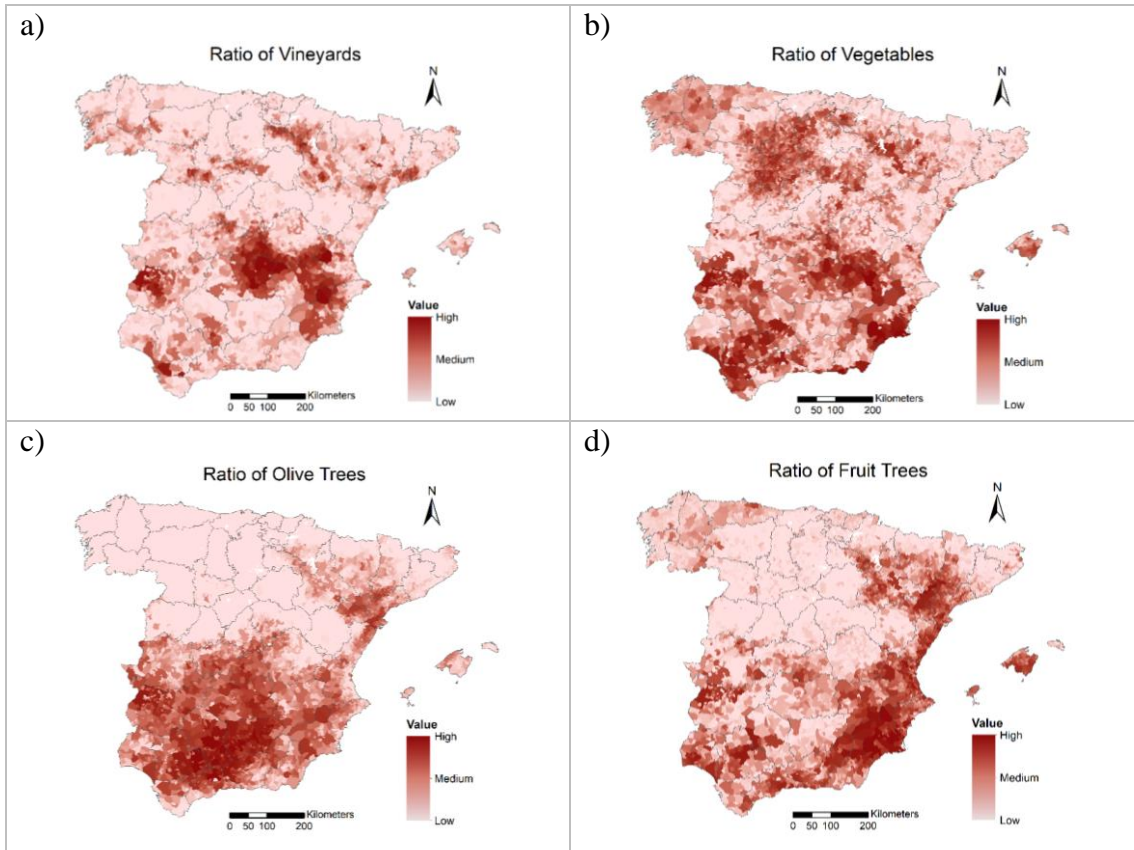
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4.3. International trade

Figure 8. Maps showing the ratio of each crop per Municipality following the Equation 4. a) Country ratio of vineyards surface for each municipality, b) Country ratio of vegetables crops surface for each municipality, c) Country ratio of olive trees surface for each municipality and d) Country ratio of fruit trees surface for each municipality

Figure 8 is composed by four maps that represent the distribution of four crop groups in Spain. These crops were selected following the criteria explained in the Methods section. Each map shows the local proportion of each crop compared to total country area covered by that crop. Figure 8a shows the spatial distribution of vineyards, which is distributed mainly in the region of Castilla-La-Mancha and several smaller areas in the Ebro Depression, Extremadura and some *comarcas* in Catalonia and Castilla-y-León. In the case of vegetables (Figure 8b), its distribution in the peninsular Spain is more homogenous, with higher values in the regions of Castilla y León, Castilla-La Mancha, Andalucía, Murcia and Extremadura. The area of olive trees in Spain (Figure 8c) has a clear distribution, where olive production is concentrated in the mid-south and in the Ebro Depression. Finally, the fruit trees production (Figure 8d) is located in Mediterranean areas of Spain and some significant spots in the south-west.
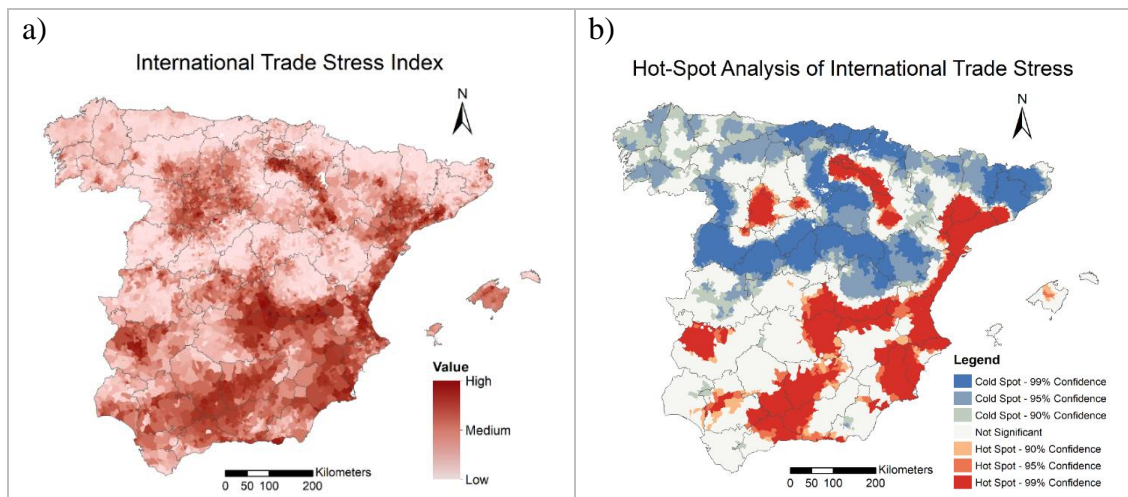
Figure 9. a) Map of International Trade Stress Index for each Municipalities. b) Map of Hot-Spot Analysis of International Trade Stress Index

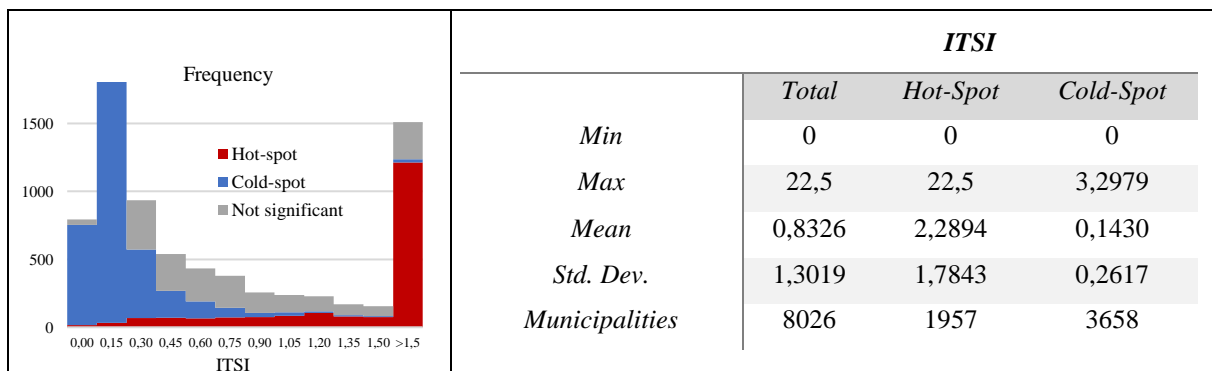|		ITSI		
		Total	Hot-Spot	Cold-Spot
Min		0	0	0
Max		22,5	22,5	3,2979
Mean		0,8326	2,2894	0,1430
Std. Dev.		1,3019	1,7843	0,2617
Municipalities		8026	1957	3658

Table 3. Statistics of municipal International Trade Stress Index (ITSI) with stacked bar chart of the frequency of municipalities by its ITSI value (left) and clusters statistics created with Hot-Spot Analysis for the ITSI (right)

The average of the four maps is shown in the Figure 9a. We can observe that south Spain and Mediterranean areas have higher proportional values of export-nature crop surfaces compared to the rest of the country. Furthermore, two more areas come up in the northern part, especially in Castilla y León and close areas to the Ebro Depression. The Hot-Spot Analysis of International Trade Stress Index (Figure 9b) shows a simplified result based on the map in Figure 9a.

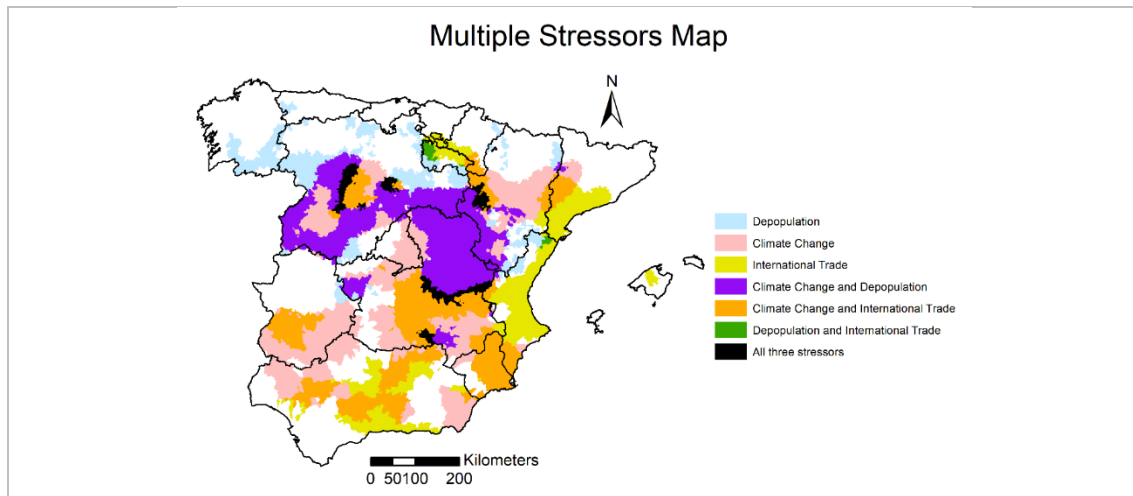## 4.4. Multiple stressors and coverage by degree of urbanization

Figure 10. Map showing the stressors analyzed in this study (Depopulation, Climate Change and International Trade) and the overlaps between them with a double or triple overlap.
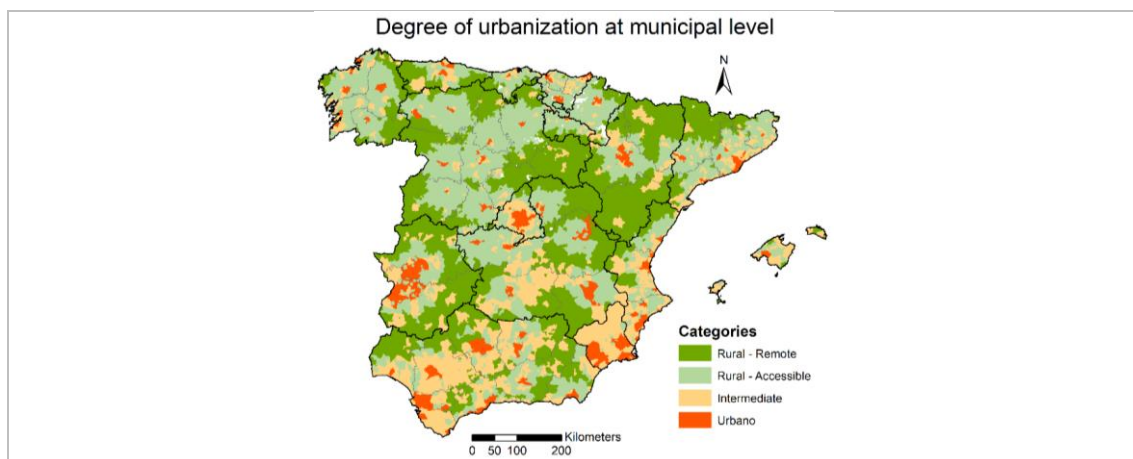

Figure 11. Map of the Degree of urbanization at municipal level based on the methodology proposed by Reig et al. (2016). They differentiated two types of rurality: Remote and Accessible, based on the time of travel to reach the closest province capital. In the case of Rural – Remote, time of travel is more than 45 minutes.

	Area (km²)	Percentage (%)	Population (in Millions)	Pop. Density (Inhab/km²)
Rural	365.167	73,44	5,960	16,34
Remote	186.779	37,57	1,698	9,11
Accessible	178.388	35,88	4,261	23,92
Intermediate	106.395	21,40	13,997	131,81
Urban	25.639	5,16	25,115	976,58
Total	497201	100	45,073	90,76

Table 4. Area, percentage of cover at country scale amd population harbored and population density in each degree of urbanization proposed by Reig et al. (2016) in study area of Spain (Peninsula and Balearic Islands)

	Climate Change	Depopulation	International Trade	Climate Change - Depopulation	Climate Change - International Trade	Depopulation - International Trade	All Three Stressors
Rural	17,47	9,09	6,35	17,48	7,90	0,39	2,17
Remote	16,94	12,69	2,94	23,23	4,47	0,26	2,39
Accessible	17,82	5,32	9,93	11,45	11,50	0,51	1,94
Intermediate	13,77	0,83	15,90	1,22	28,42	0,07	0,95
Urban	21,00	-	6,33	3,59[13]	22,65	-	-

Table 5. Table of coverage in % of single and multiple stressors per degree of urbanisation[14]. The first three columns represent the percentage of coverage only with a single stressor. That is, summing the first column (Climate Change) with the fifth, sixth and seventh (Climate Change–Depopulation and Climate Change – International Trade and All three stressors, respectivley), you will get the total surface that is covered at least by the Climate Change stressor.
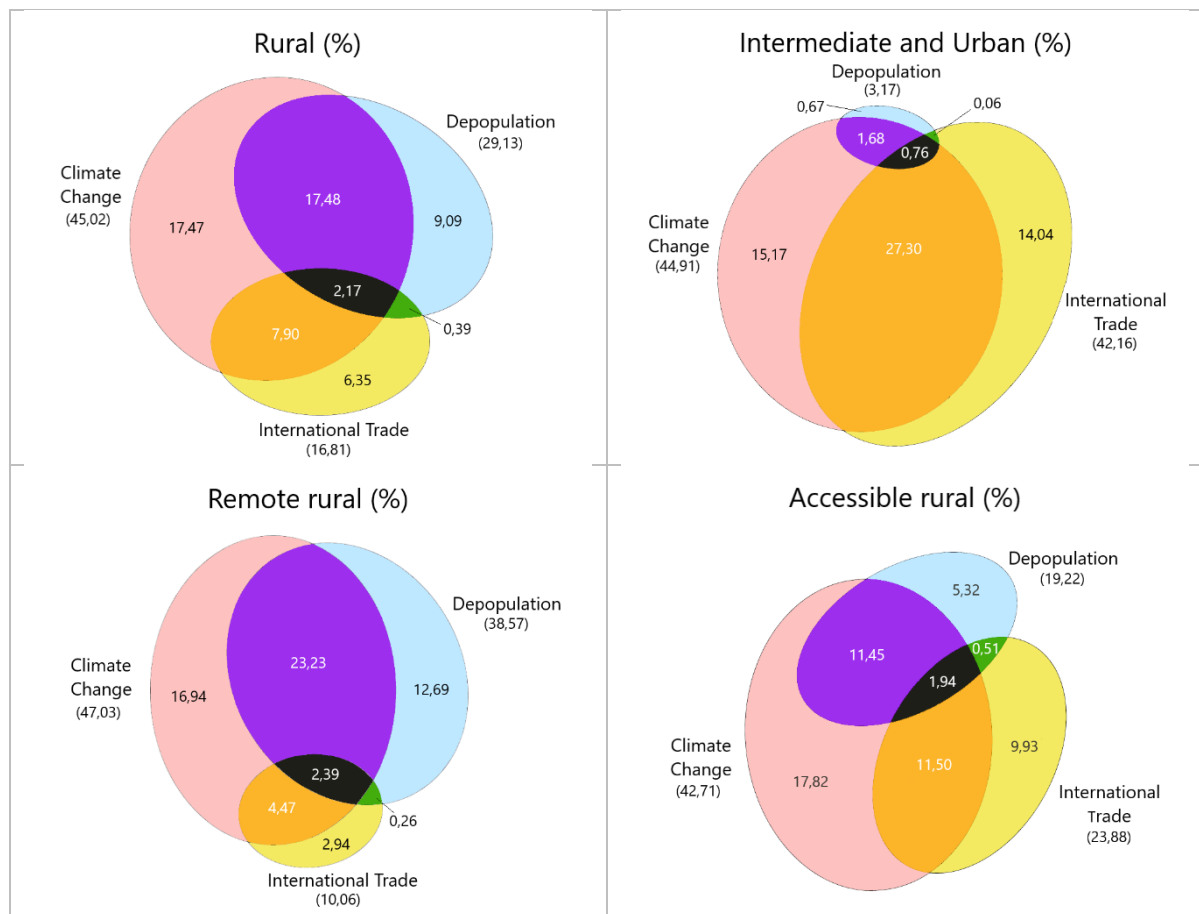

Figure 12. Venn diagrams (Micallef & Rodgers, 2014) based on coverage (area) of studied stressors for each degree of urbanization[15]. Rural (Figure 11a) represents Remote rural and Accessible rural together. Numbers in brackets show the total coverage (%) of the stressor (as single stressor and in combination with others). Black areas represent the combination of the three stressors.

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[13] Urban areas covered by Climate change and Depopulation doesn't mean that urban centers are being depopulated, but since their surroundings are suffering relative-high values of depopulation, somewhat the hot-spot analysis englobed also these urban municipalities inside the Depopulation Cold-Spot Clusters.

[14] Stablished by Reig et al. (2016)

[15] Ibid.

Figure 12 and Table 5 summarize the results of the combination of the analyzed stressors stratified by the degree of urbanization. In the single stressor view, *Depopulation* is mainly a stress of rural areas. Furthermore, within the rural context, Remote rural covered by *Depopulation* stress is more than two times higher than in Accessible rural (38,57% and 19,22% respectively). In the case of *International trade* stress, non-rural contexts are more exposed relatively to it (reaching 42,16%), while rural areas show a coverage of 16,81% to this stressor. However, there is a clear difference between Remote and Accessible rural, being the latest two times relatively more exposed to *International trade* than Remote rural (23,88% compared to 10,06%, respectively). Finally, for the aridity-related stress, there are similar percentages of exposure within the municipality-type classification.

In the multiple-stressor lenses, aridity-related stress (*Climate Change* stress) combined with *Depopulation* is the more common multiple stressor of the analysis in the rural context (17,48%). More in detail, Remote rural areas show a value of 23,23% for this combination, while in Accessible rural is the half (11,45%). Alternatively, *Climate change* and *International trade* combination shows higher values of exposure in the case of Accessible rural (11,50%) compared to Remote rural (4,47%). It is remarkable that this double exposure is the most common for non-rural environments (27,30%), considering that the analysis was focused on rural drivers of stress. The third double-exposure, *Depopulation* and *International trade*, is the least common combination of stressors of the analysis for all types of municipalities, not reaching the 1% in any case. Last but not least, our analysis show that triple-exposure (*All three stressors*) may exist in the study area. Rural areas show higher exposure to this triple combination (2,17%) compared to Intermediate and Urban areas (0,76%), being the Remote rural context the type of rural more exposed (2,39%). It must be said that three stressors combination has low coverage (i.e. is not widely present in the territory) but it represents areas with very high exposure.

5. Discussion and conclusions

This dissertation aimed to enhance already existing knowledge about Spanish rural areas and common rural stressors distribution. Thus, this section will be focused on the discussion of the results for rural areas, accounting for the categories of remote and accessible rural.

The analysis showed that the most severe depopulation processes are characteristic of rural environments, especially for remote areas. These areas high-exposed to population losses are generally constituted by small villages where decrease in small amounts of people have a significant impact in the territory. Figure 13 shows that most of the municipalities are found within low values of population density (which is based partially on municipal residents) and, at the same time, show larger negative values of Compound Annual Growth Rate (CAGR). In addition, low densities also show higher range of CAGR values, which implies that municipalities with low population densities are exposed to higher variability of depopulation phenomena.
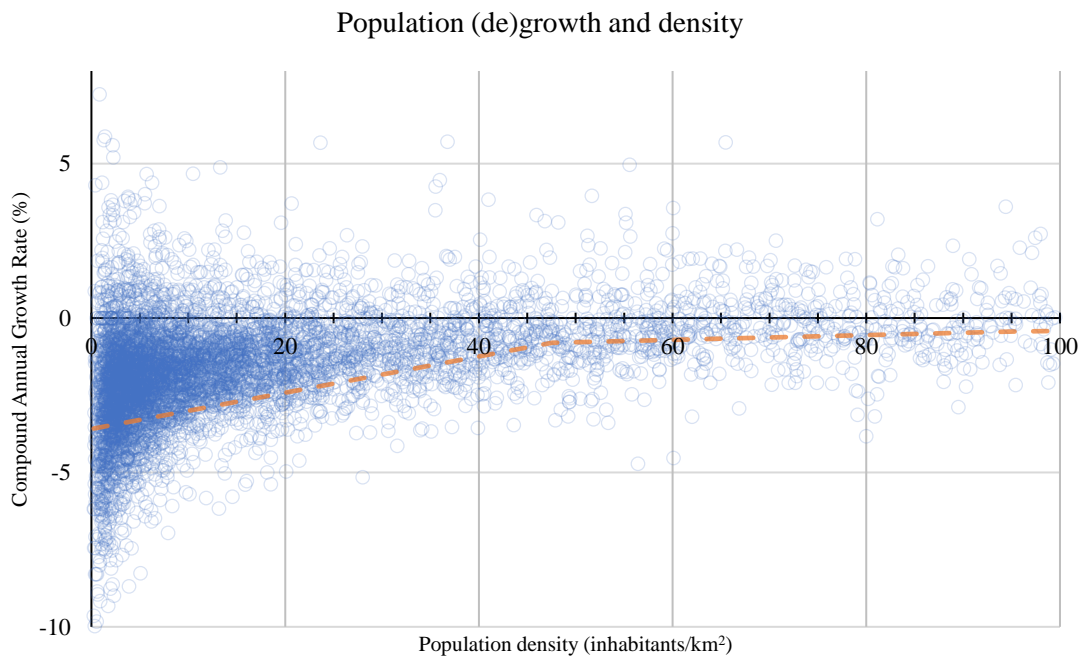
Population (de)growth and density

Figure 13. Dispersion graph showing the population density (horizontal axes) and population variation tax based on the compound annual growth rate (%) (vertical axes). Orange line represents a logarithmic trendline (R² = 0,2928)

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However, this depopulation phenomenon is not only explained by losses in population or decreases in population densities, but with other demographic changes, such as masculinization and over-ageing. These processes are at the same time causes and consequences of the general depopulation dynamics, creating internal feedback (Camarero et al., 2009) loops that increase the complexity of the phenomenon. Furthermore, remoteness can be a proxy of the shortage of public and private services (Reig et al., 2016) and investments, constraining the socio-economic possibilities of these territories, worsening the struggle of the so-called "places that don't matter" (Collantes & Pinilla, 2019).

Another single stressor of this study was International trade, and accessible rural areas were the ones with higher exposure compared to remote rural ones. Looking at the geography (Figure 4), peninsular Spain is quite mountainous compared to the rest of European countries and this relief determines the distribution of agricultural production. Spanish agriculture experienced an intensification process starting at the second half of twentieth century and productivity driven by export trend of national agricultural production which affected the management of lands, being the mountainous regions less economically profitable, thus, many of them being abandoned (Santini et al., 2013; Teodoro Lasanta Martínez & Purificación Ruiz Flaño, 2013). About the distribution of international trade exposure, we can see that is mainly found in areas between 0 and 400 m, were productivity and profitability are higher with intensification practices. This market-oriented agriculture is based on intensification, is heavily subsidized and energy inefficient (Spanish National Ecosystem Assessment, 2014). The subsidies from the Common Agricultural Policy (CAP) in the European context sustain the profitability of these exploitations, but this European program is constantly under debate and its future characteristics are uncertain. Furthermore, Mediterranean South European areas are predicted to be the most stressed by agricultural trade changes based on exports and imports balance (Iglesias et al., 2012). Rodríguez Sousa et al. (2019) studied different management techniques of olive orchard

with various socio-economic scenarios in Spain. They concluded that, if CAP subsidies were dismantled, intensively managed areas (driven by market pressures) would suffer the highest rate of land abandonment by farmers. This abandonment may compromise the sustainability of the landscape by increasing risk of wildfires or provoking soil degradation in steep slope areas.

Looking at the multiple-stressors outcomes, first it must be said that *intersection* of several stressors doesn't explicitly mean *interaction*. O'Brien et al. (2009) put in practice this theoretical framework in Southern Africa and concluded that there exist "hidden vulnerability" that can be explained by the specific interactions that go beyond linear relation between stressors. In the case of this study, it would be needed deeper and *in situ* researches of each multiple-exposure areas to put light on the vulnerabilities of particular groups. However, a first short-concluding literature revision about possible interactions in the Spanish context is presented.

In the case of rural areas with rural depopulation and international trade exposures, even if it is not the most common combination in this analysis, livability could be indirectly affected. Duarte et al. (2008) studied the olive orchards of remote areas in Spain concluding that whereas new traditional practices are based on intensification, availability of labor decrease and seasonal laborers are no longer employed. These seasonal laborers, that more and more are based on migrant population, are the ones that could "turn the omelet" of demographic trends. However, they no longer have job opportunities to settle their lives and bring social sustainability, apart from environmental-friendly practices. As said in the beginning of this paragraph, this combination of stressors is not the most common, although it exists. This fact could be explained partly because areas that are marked as International Trade hot-spots (in other words, that produce relatively more export-nature products) experience economic dynamism and, thus, they may have better adapt to market demands and are able to offer enough employment to their inhabitants, avoiding the exodus.

Depopulation and climate change stresses will be one of the main drivers of risk in the Spanish rural context, being as well the more frequent double exposure of this study. Its interactions can be of a great variety and intensity and local characteristics will be essential to determine them. What is important to note, is that several agricultural and forest land areas with high natural value are humanized systems (i.e. cultural landscapes) and its mid-term sustainability and ecosystems services depends on anthropogenic management (for instance, cleaning undergrowth from abandoned lands to avoid forest fires) (Fernández-Giménez & Estaque-Fillat, 2012; Seijo et al., 2018). These practices have been shaped with centuries of adaptation strategies within the local environmental conditions, which are currently in risk with the disappearance of entire villages due to the consequences of depopulation in small localities. In that sense, climate change impacts on "unvalued" rural places can have severe consequences on *wide* sustainability of these areas. For example, water-scarcity coupled with decreasing public investments in remote areas brings a "without-future" context. Advances in a country-wide revalorization of ecological traditional practices and better promotion of organic agriculture management with a focus on ecosystem services will be essential to bring new opportunities for climate change mitigation and adaptation.

Finally, the combination of the three stressors (triple-exposure) is not widely extended in the territory but, as said in previous sections, triple exposed areas should be taken seriously as very exposed areas. This triple combination allowed to put the light on areas that could have been invisible so far with the single-exposure framework. Thus, this combination of drivers may have socio-economic and political implications when determining geographical areas of vulnerability attention. Future rural policy and public development plans of these areas should account for triple-exposure spatial dimension. It is interesting to note that in some areas of rural Spain, the three stressors can be very close and can share similar landscapes. Consequential

future analysis should determine whether some particular types of landscapes are more frequently doubled or tripled exposed to these stressors.

To conclude, in this dissertation I aimed to deepen in the study of rural vulnerability in Spain. First, I proposed a methodology to identify hotspots where the three identified drivers of stress may be occurring in the Spain's rural context. It allowed visualize how aridity increase by climate change effects, depopulation processes and International Trade dynamics are distributed among the country, discovering landscapes where high exposure values of each stressor intersect and may interact. Secondly, it served to expand the knowledge about rural classification in Spain. Remote rural and accessible rural differed in stress coverages and, thus, are exposed differently to drivers of change. This may be of interest for developing rural policies that will tackle small scale stressing contexts, increasing the success of implemented projects. Ecosystems conservation and fight against rural depopulation have drawn attention of public administrations and a new national plan is close to be published by the recently created Ministry for the Ecological Transition and the Demographic Challenge and new policies should be focused on recovering the multifunctionality of rural landscapes.

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7. Appendix

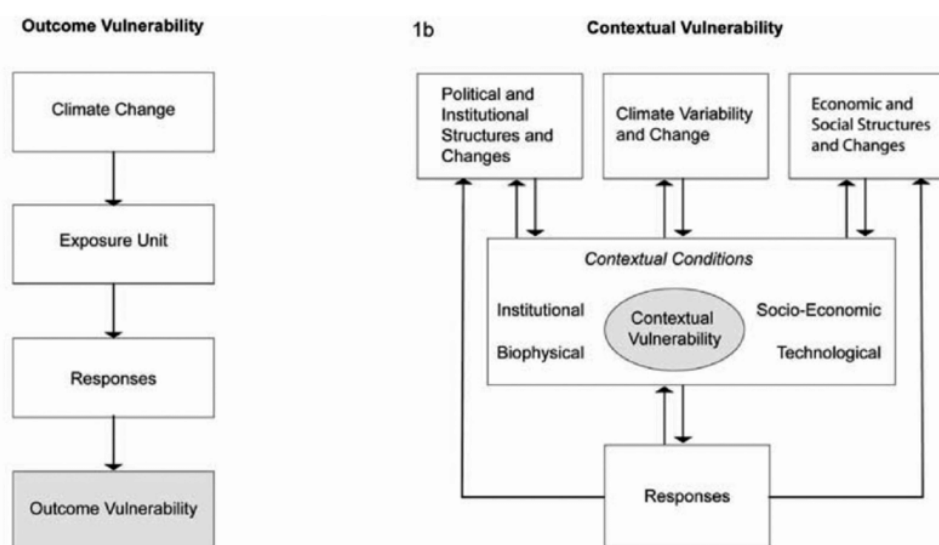## A. Vulnerability interpretations

Figure 14. Source: O'Brien et al., 2007

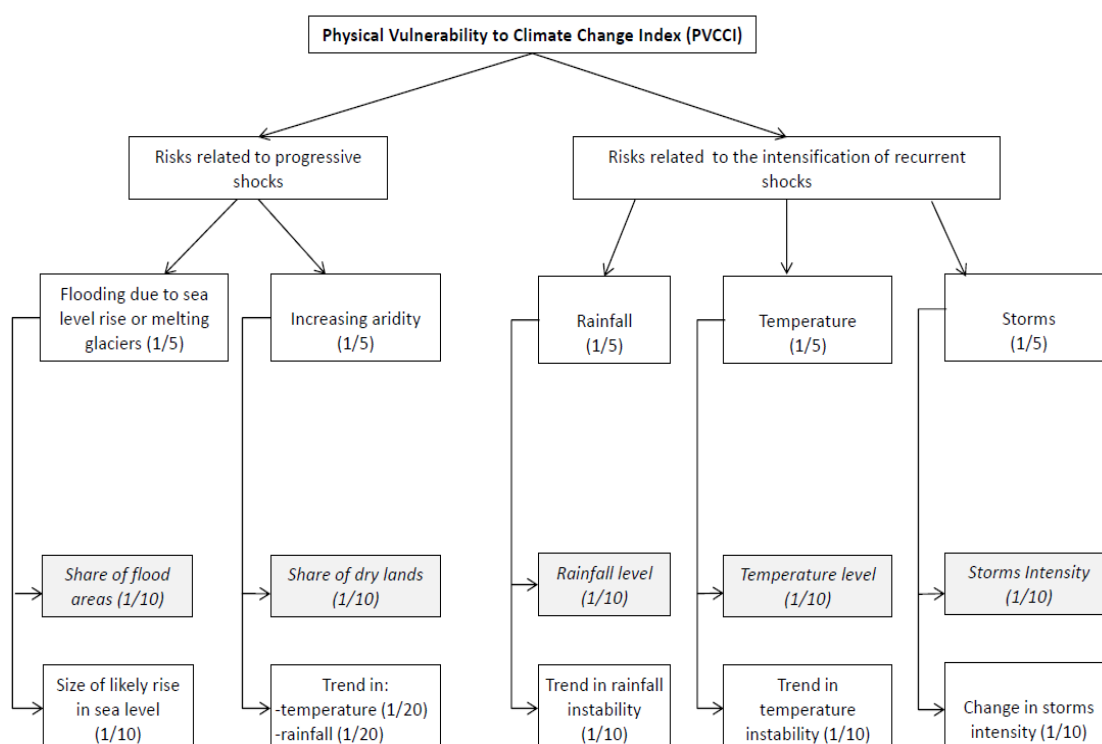## B. Physical Vulnerability of Climate Change Index

Figure 15. Note: The boxes corresponding to the two last rows of the graph respectively refer to exposure components (grayed-out, in italics) and to size of the shock components. For details on the philosophy, components, calculation

C. AdapteCCa Scenarios of Climate Change

Raster data offered by AdapteCCa is a grid of 10x10 km climate information. These projections have been adjusted by the EQM method of quantile adjustment (Gutiérrez et al., 2019). All the variables mentioned are the result of the mean of a several adjusted EUROCORDEX RCM with scenario RCP 8.5 (*Representative Concentration Pathway*s), that corresponds with the high emissions scenario during twentieth century (IPCC, 2014). Potential Evapotranspiration (PET) is calculated using the Thornthwaite method from the effective temperature as in Pereira & Pruitt (A. R. Pereira & Pruitt, 2004).

Regional Climate Models used to find the climate variables means

- EQM-CNRM-CERFACS-CNRM-CM5-CLMcom-CCLM4-8-17
- EQM-CNRM-CERFACS-CNRM-CM5-CNRM-ALADIN53
- EQM-CNRM-CERFACS-CNRM-CM5-SMHI-RCA4
- EQM-ICHEC-EC-EARTH-CLMcom-CCLM4-8-17
- EQM-ICHEC-EC-EARTH-SMHI-RCA4
- EQM-ICHEC-EC-EARTH-KNMI-RACMO22E
- EQM-ICHEC-EC-EARTH-DMI-HIRHAM5
- EQM-IPSL-IPSL-CM5A-MR-IPSL-INERIS-WRF331F
- EQM-IPSL-IPSL-CM5A-MR-SMHI-RCA4
- EQM-MOHC-HadGEM2-ES-CLMcom-CCLM4-8-17
- EQM-MOHC-HadGEM2-ES-KNMI-RACMO22E
- EQM-MOHC-HadGEM2-ES-SMHI-RCA4
- EQM-MPI-M-MPI-ESM-LR-CLMcom-CCLM4-8-17
- EQM-MPI-M-MPI-ESM-LR-SMHI-RCA4

- EQM-MPI-M-MPI-ESM-LR-MPI-CSC-REMO2009

- EQM-NCC-NorESM1-M-DMI-HIRHAM5

For the case of Precipitation raster of Historic Period (1971-2000), data is offered in mm/day. It was needed to multiply by the factor 30 (days/month) to equalize both parameters of the Aridity Index.

D. Population trends at municipal level

A total amount of 8022 municipalities had population data from 2011 and 2019 (99,76%). However, 19 local units (0,47%) had not data for the complete 8-year period due to more recently creation or new local aggregations. For these special cases, growth rate formula was adapted to the period of available data. For instance, the municipality of Tiétar, Extremadura was created in 2011 (DOE, 2011) and started to have population statistics in 2013, so the period of population analysis here was 2013-2019. Finally, 7 municipalities (0,09%) had only data for 2019, so "N/D" was stablished.

E. Trade balance and selection criteria of export-nature crops

	CUADRO 6 BALANZA COMERCIAL AGROALIMENTARIA POR SECTORES (MILES DE EURO					
Descripción	2017			2018		
	Exportación	Importación	Saldo	Exportación	Importación	Saldo
CÁRNICOS	7.076.188	2.308.487	4.767.701	7.084.741	2.287.401	4.797.340
- Bovino	958.881	1.014.449	-55.568	1.053.604	1.034.741	18.863
- Ovino-caprino	316.422	71.933	244.489	319.586	73.582	246.004
- Porcino	5.064.088	520.116	4.543.972	4.914.784	475.986	4.438.798
- Aves y huevos	606.893	622.759	-15.866	661.254	625.883	35.371
- Otros animales	129.904	79.230	50.674	135.513	77.209	58.304
LÁCTEOS	1.148.731	1.693.019	-544.288	1.117.215	1.703.478	-586.263
PESCA	3.989.190	6.995.865	-3.006.675	4.167.321	7.156.054	-2.988.733
CEREALES Y PRODUCTOS DE LA MOLINERÍA	622.340	3.009.412	-2.387.072	657.743	3.342.755	-2.685.012
RESIDUOS DE LA INDUSTRIA ALIMENTARIA Y PIENSOS	990.726	1.745.760	-755.034	1.037.643	1.807.631	-769.988
FLORES Y PLANTAS	358.376	218.130	140.246	407.028	230.615	176.413
HORTALIZAS Y LEGUMBRES	6.031.967	1.222.886	4.809.081	6.029.287	1.323.178	4.706.109
FRUTAS	8.388.508	2.771.402	5.617.106	8.447.667	2.973.571	5.474.096
CONSERVAS VEGETALES	2.753.542	1.227.564	1.525.978	2.734.493	1.219.577	1.514.916
VINOS, BEBIDAS Y VINAGRE	4.214.738	1.714.765	2.499.973	4.471.215	1.728.625	2.742.590
TABACO	244.014	1.616.345	-1.372.331	230.430	1.648.145	-1.417.714
GRASAS Y ACEITES	4.949.811	2.961.303	1.988.508	4.338.011	2.730.825	1.607.186
SEMILLAS OLEAGINOSAS, MANDIOCA Y FORRAJE	612.198	2.122.961	-1.510.763	700.301	2.090.428	-1.390.127
CAFÉ, TÉ, CACAO Y AZÚCAR	949.724	2.243.604	-1.293.880	944.116	1.946.793	-1.002.677
INDUSTRIAS AGROALIMENTARIAS	4.442.512	3.770.852	671.660	4.582.113	3.813.584	768.529
OTROS PRODUCTOS	755.970	2.768.236	-5.021.678	795.492	365.848	429.644
TOTAL	47.528.535	36.003.519	11.525.016	47.744.816	36.368.508	11.376.308

Table 6. Agri-food trade balance by sector in thousands of Euros of 2017 and 2018. It shows exports, imports and balance (exports-imports). Source: Ministerio de Agricultura, Pesca y Alimentación

Table 6 summarizes in sectors the trade balances of agri-food products of 2017 and 2018. There are 4 main sector products which have a clear export trend: oil products, drinks (wine), fruits and vegetables. All four sectors have two characteristics: overpass de threshold of 1.500 Million of euros of positive commercial balance and exports represent at least the double of the imports.

F. Hot-Spot Analysis

Methodology

Hot-Spot Analysis test proposed based on Getis-Ord Gi* test has peculiarities compared to other spatial hot-spot analysis tests (such as Moran's I). Gi* is a measure of high/low value concentration and Getis-Ord Gi* statistics tends to measure homogeneity more than Moran's I. Results using both technics don't differ significantly.

For the analysis of climatic and non-climatic variables, I ran the Optimized Hot Spot Analysis tool in ArcGIS 10.7.1 (ESRI, 2019) for the three indexes calculated for Climate Change, Depopulation and International Trade Stresses. This tool runs the Getis-Ord Gi* for each unit of analysis and enables to choose the input parameters of analysis. In the three variables I used: Field Analysis before running the test and automatically define the distance threshold (taking into account the size and distribution of units of analysis, i.e. municipalities). The distance threshold serves to establish a spatial limit for accounted neighbors for each unit of analysis.

Results

Climate Change Stress Index

```
   - Properties:
      Min:       0,0385
      Max:       0,9211
      Mean:      0,5104
      Std. Dev.: 0,1842
   - There were 109 outlier locations; these will not be used to compute
the optimal fixed distance band.
```

- Looking for an optimal scale of analysis by assessing the intensity of clustering at increasing distances: No optimal distance was found using this method.
- Determining an optimal distance using the spatial distribution of features: The optimal fixed distance band is based on the average distance to 30 nearest neighbors: 23322,0000 Meters
- There are 6456 output features statistically significant based on an FDR correction for multiple testing and spatial dependence.
- 2,2% of features had less than 8 neighbors based on the distance band of 23322,0000 Meters

Depopulation

- Properties:
    Min: -13,8171
    Max: 13,5634
    Mean: -1,3153
    Std. Dev.:   1,7847
- There were 109 outlier locations; these will not be used to compute the optimal fixed distance band.
- Looking for an optimal scale of analysis by assessing the intensity of clustering at increasing distances: No optimal distance was found using this method.
- Determining an optimal distance using the spatial distribution of features: The optimal fixed distance band is based on the average distance to 30 nearest neighbors: 23322,0000 Meters
- There are 4429 output features statistically significant based on an FDR correction for multiple testing and spatial dependence.
- 2,2% of features had less than 8 neighbors based on the distance band of 23322,0000 Meters

International Trade

- Properties:
    Min: 0,0000
    Max: 22,5000
    Mean: 0,8326
    Std. Dev.:   1,3018
- There were 109 outlier locations; these will not be used to compute the optimal fixed distance band.
- Looking for an optimal scale of analysis by assessing the intensity of clustering at increasing distances: No optimal distance was found using this method.
- The optimal fixed distance band is based on the average distance to 30 nearest neighbors: 23322,0000 Meters
- There are 5615 output features statistically significant based on an FDR correction for multiple testing and spatial dependence.
- 2,2% of features had less than 8 neighbors based on the distance band of 23322,0000 Meters