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MSc Internship

report

Observatory of the mountains

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Period of Internship:
10.10.2025 - 10.02.2026

WUR supervisor:
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Date final report:
23.01.2026

February, 2026

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Acronyms

CREAF Center for Ecological Research & Forestry Application

SDGs Sustainable Development Goals

SDG Sustainable Development Goal

SoP Strategy of Pyrenees

EF Ecological Footprint

IDESCAT Institut d'Estadística de Catalunya

1 Introduction

1.1 Internship organisation background

Center for Ecological Research & Forestry Application (CREAF) is a public research center situated in Catalonia. It exists as a consortium between different public entities such as universities, research centers and administrations. CREAF's research focuses on four fundamental areas: biodiversity, functioning of ecosystems, global change and earth observations. Integrating these four themes, CREAF aims to guide ecosystem management and environmental policies to contribute to adaptation and mitigation strategies of global change.

1.2 Scientific context of the research project

Catalonia is characterized by a highly variable landscape, from the Pyrenees mountain range in the north and the Serra de Collserola in the east, to the low-lying Catalan Central Depression in the south-west (Luna and Mendizàbal, 2004). This diverse geography is associated with the persistent territorial inequalities between the highlands and the lowlands. The Catalonian counties in the Pyrenees mountain range often face economic, social and demographic disadvantages compared to the rest of Catalonia (Claramunt-López et al., 2025; Generalitat de Catalunya, 2023; Luna and Mendizàbal, 2004; Pallares-Barbera and Casellas, 2019).

As a response to this issue the Department of Territory (Department de Territori) of the Government of Catalonia (Generalitat de Catalunya) developed a territorial development strategy called The Strategy of Pyrenees (SoP) (Generalitat de Catalunya, 2023). The SoP identifies several key issues and needs that the Catalonian government aims to tackle. Among these are: a) **demographic challenges**: the Pyrenees counties are faced with lower population density, higher rate of population aging and significantly slower population growth; b) **economic disparity**: they show generally lower economic wealth with a lower GDP per capita and lower Disposable Family Income per capita; c) **housing crisis**: access to housing is difficult due to scarce supply and high prices; d) **knowledge and education deficit**: in the Pyrenees counties, specialized education centers are scarce contributing to further depopulation; e) **mobility and connectivity**: there is a lack of comprehensive public transport system leading to a private vehicle dependence; and f) **forest management**: there is a need to move toward multifunctional forest models and find viable commercial outlets for wood and forest products. In addition, the report also proposes projects which can aid in tackling the issues present.

The narrative of the SoP incorporates the Sustainable Development Goals (SDGs) as a tool to guide the territorial development methods toward a just, prosperous and sustainable future. It states that one of the SoP objectives is "to take advantage of the values and territorial singularities of the Pyrenees in all areas so that it becomes a pioneering territory aligned with the sustainable development goals (SDGs), which include **absolute respect for the environment** and the purpose to reduce the impact of climate change in each of the actions that are intended to be carried out" (*translated from Catalan*) (Generalitat de Catalunya, 2023). Inspecting the SoP, we can observe that the strategy defines well the needs for socio-economical development which we can also observe in the key territorial issues listed above. However, when evaluating the environmental sustainability, the inclusion of the environmental perspective in the proposed projects is often strongly limited.

Even though the SoP report incorporates the environment related SDGs, such as SDG 13 and SDG 15 into the narrative of the report, when naming the proposed projects it lacks the inclusion of the planet's boundaries and the proposed ways of how they will be respected so that the territorial development will be sustainable (UN, 2015).

This phenomenon is not novel and several researchers have brought attention to this existing lack of environmental sustainability inclusion in territorial development planning even when framing the developmental plan around the SDGs. In his paper Economics without ecology: How the SDGs fail to align socioeconomic development with environmental sustainability, Hametner (2022) investigated the progress of SDGs where he concludes that composite SDG indices risk to solely reflect the trends in socio-economical development while neglecting the environmental dimension. Similarly, Zeng et al. (2020) warn about the lack of environmental priorities integration in countries' developmental plans and Jain and Jain (2020) support these claims by finding a negative correlation between the SDG Index and the Ecological Footprint (EF) score.

On the other hand, there are also numerous researchers who highlight ways how to incorporate the environmental dimension in the developmental plans. Rockström et al. (2009) defined the concept of **Planetary Boundaries** which are earth systems' limits within which humanity must operate to maintain sustainable future. Building on this idea, Kate Raworth proposed the **Doughnut Economics model** which combines socio-economical needs (inner circle) with planetary boundaries (outer circle) that should not be exceeded (Ross, 2019). These frameworks highlight the importance of inclusion of both environmental boundaries and human well-being to design sustainable developmental strategies.

With that being said, there is a need for a holistic territorial evaluation which does not only include the socio-economical perspective, but also incorporates the environmental dimension - an approach that can foster territorial development balancing economic growth, social justice and planetary boundaries (East, 2020).

Recognizing and understanding territorial inequalities is essential for combating them. It is a first step to designing effective policies that will advocate for a well-balanced territories and to improving the well-being of the disadvantaged communities (Mehlbye et al., 2019). However, we cannot design developmental strategy of a territory without considering its environment. In the age of Anthropocene, marked by a collapse of Earth's ecosystems (Freeman, 2018), it is a must to adequately incorporate the environmental dimension in the territorial development planning methodology. In that way, we can ensure that our generation does not erode the natural capital necessary to sustain the future generations (Hametner, 2022).

In order to address the problem stated above, this research builds upon two existing frameworks. One is the SoP developed by the Government of Catalonia to guide the future development of the Pyrenees region of Catalonia (Generalitat de Catalunya, 2023) and the other one is the Doughnut Economics model built by Kate Raworth (Ross, 2019) to guide developmental strategies. By combining these two frameworks, the project incorporates the *so*-needed environmental perspective into the developmental framework of the SoP which major focus is socio-economical state of the region. Therefore, this research project addresses two gaps:

1. **Conceptual gap**: The gap between the environmentally sustainable narrative of the territorial developmental strategy and the practical inclusion of the environmental limits in the methodology. While current strategy (SoP) emphasizes the socio-economic progress and its alignment with the SDGs, it often lacks the integration of ecological boundaries in the evaluation.

2. **Methodological gap**: The gap between the existing data that is fragmented and which references are often missing in the SoP and a visual dashboard built on transparently referenced data offering a comparison of the highland and lowland regions for an objective evaluation of the territorial dispute.

1.2.1 Research objectives

The aim of this research project was to integrate the environmental perspective into the evaluation of regional inequalities between the highland and the lowland counties of Catalonia to contribute to a more just picture of the situation not only for society and economy, but also for the environment. Therefore, the following questions were investigated:

1. What **socio-economic** and **environmental** variables are **available** at a county level to characterize the highland and lowland areas of Catalonia?
2. Which **environmental** variables can be included in evaluation of the **regional inequality** between these two regions to better represent the territorial dispute?
3. Do **environmental** and **socio-economic inequalities** follow the **same spatial pattern**?

2 Methods

2.1 Study area

The geographical focus of this research project was the Spanish province of Catalonia situated in the northeast corner of the Iberian Peninsula (fig. 1). The area was divided into two regions: the highlands concentrated around the Pyrenees mountain range and the lowlands, the non-Pyrenees area of Catalonia. The following counties belong to the representative region:

- **Highlands:** Aran, Alta Ribagorça, Pallars Jussà, Pallars Sobirà, Alt Urgell, Solsonès, Cerdanya, Ripollès, Berguedà;
- **Lowlands:** Alt Camp, Alt Empordà, Alt Penedès, Anoia, Bages, Baix Camp, Baix Ebre, Baix Empordà, Baix Llobregat, Baix Penedès, Barcelonès, Conca de Barberà, Garraf, Garrigues, Garrotxa, Gironès, Maresme, Moianès, Montsià, Noguera, Osona, Pla d'Urgell, Pla de l'Estany, Priorat, Ribera d'Ebre, Segarra, Segrià, Selva, Tarragonès, Terra Alta, Urgell, Vallès Occidental, Vallès Oriental, Lluçanès.

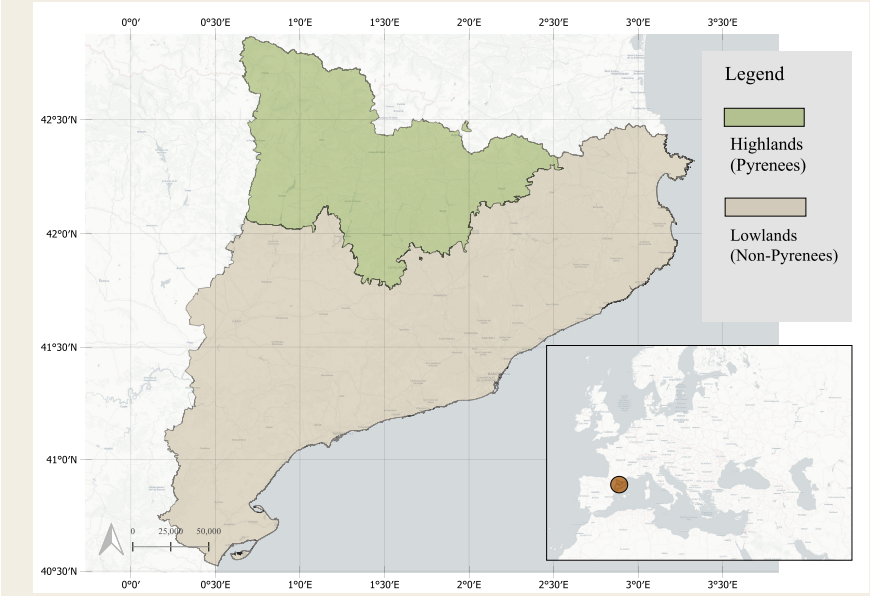

Figure 1: *The study area.*

2.2 Data & data pre-processing

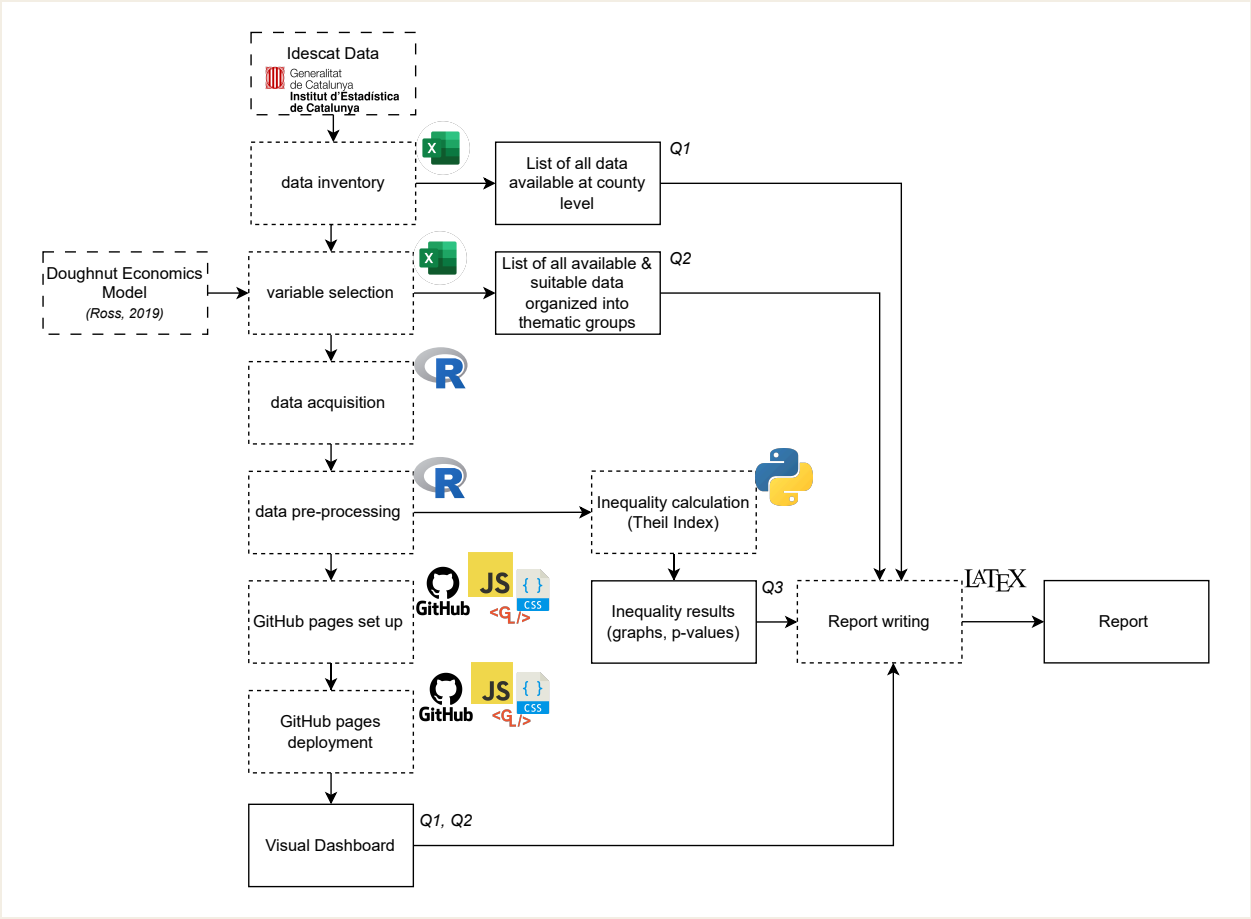

Figure 2: *Flowchart of the methodology. Line styles indicate flow type: dashed = input, dotted = process, solid = output. Logo of software indicates the software used in the given step. The Q1 - Q3 superscripts indicate the question with which the output is associated with.*

The data used in this research project were sourced from Catalan Institute of Statistics (Institut d'Estadística de Catalunya (IDESCAT)) operating under the purview of the Catalan government.

To collect an inventory of all the socio-economical and environmental variables available a systematic review of the IDESCAT data repository was done (fig. 2). This data repository can be found at idescat.cat. Initially, all the main categories and subcategories of variables available at the data repository were identified and recorded in a sheet. Subsequently, variables of each category were screened and searched for the term *Counties and Aran, areas and provinces* which determines whether these variables are available per county. All variables that were found to have this term were recorded in the initial sheet.

To select variables, a list of all the domains of the Doughnut Economics was made (fig. 2) (Ross, 2019). These domains belong to either the **social foundation**, hence, the socio-economical variables or to the **ecological ceiling**, hence, the environmental variables. Subsequently, the variables from the IDESCAT list were assigned to the thematic domain of the Doughnut Economics. If they fit in none of the domains, they were not used (fig. 3). To cover the SoP framework as well, the

main SoP axes were overlaid with the Doughnut Economics domains.

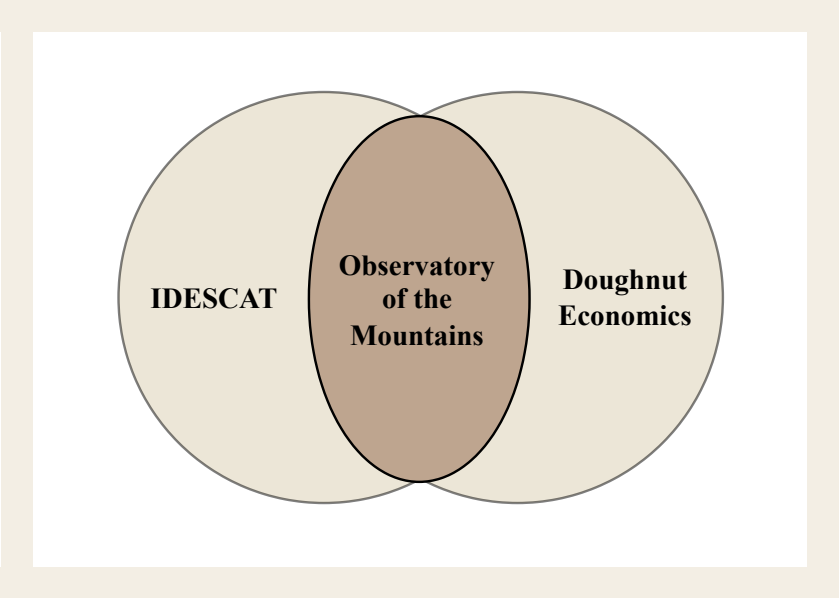

Figure 3: *The location of the variables selected in respect to available data soured from IDESCAT and the Doughnut Economics framework (Ross, 2019).*

The selected variables were subsequently downloaded from the IDESCAT data repository and pre-processed in RStudio (Team, 2020). The data were collected for the period 2015 - 2025, as this time range provided the highest availability across all variables considered. The pre-processing steps included: filtering and aggregating variables by year and region, calculating comparable variables between regions such as percentages and variables per capita, computing estimates for variables and exporting data into desired formats (tab. A1 and A2 detail the pre-processing steps per variable). All scripts and data produced in this research project can be found at GitHub repository Observatory of the Mountains.

2.3 Dashboard

To provide a visualization of the chosen variables and their respective values for highlands and lowlands, an online dashboard was made using html, js, and css languages. It was deployed through GitHub and can be found on bianky.github.io/Observatory-of-the-Mountains together with all scripts produced and stored on GitHub repository Observatory of the Mountains.

2.4 Inequality evaluation

Based on the calculated variables, the **Theil index T**, an entropy-based measure, of inequality was computed on each variable (Theil, 1967).

The Theil index T expresses how unevenly a variable is distributed across observations by comparing the distribution of observed values to a perfectly equal distribution (eq. 2). The T index ranges from 0, indicating perfect equality, to ln(m) indicating maximum inequality. Therefore, the higher T the greater the inequality (Theil, 1967; Gaboardi, 2025).

$$T = \sum_{i=1}^{n} \left(\sum_{j=1}^{n} y_j y_i \ln \left[n \sum_{j=1}^{n} y_j y_i \right] \right) \tag{1}$$

The Theil index T equation for a variable $\boldsymbol{y}$*; where* $\boldsymbol{n}$ *is the number of observations.*

To evaluate the regional inequality, we leveraged the Theil's T decompositional trait. This procedure separates the overall inequality into *within-group* and *between-group* components. The within group inequality represents the inequality among all the counties of Catalonia, whereas the between-group inequality expressed as **BG** reflects the inequality of the lowland and highland regions of Catalonia. This allows for an evaluation of the contribution of the between-group inequality to total inequality expressed as **BGshare** (Theil, 1967; Gaboardi, 2025). The Theil index T can be decomposed such that:

$$T = T_{between} + T_{within} \tag{2}$$

Where T between captures inequality between groups and T within captures inequality within groups.

To determine the significance of the regional inequality a pseudo $\boldsymbol{p}$-value of the between regions inequality was calculated via a permutation test in which the variable values were randomly reassigned across observations ($\boldsymbol{p}$ value ≤ 0.05 was considered significant).

The T index was chosen due to its decompositional property which enables to quantify between regions inequality adding a spatial dimension to the index (Theil, 1967; Gaboardi, 2025). Additionally, it has been also proved to be a robust index for evaluating socio-economical (Rey and Sastré-Gutiérrez, 2010; Marchetti and Tzavidis, 2021) as well as environmental variables (Duro, 2012; Remuzgo Pérez and Sarabia Alegría, 2015; Harper et al., 2013). It was implemented using the PySAL-inequality library in Python (Rey et al., 2023).

To see the workflow of this research project see figure 2.

3 Results

3.1 *Question 1*

There were five main categories of data identified with two to six distinct subcategories and two to fifteen variables per each subcategory. Table 1 details all recorded variables from the IDESCAT data repository.

3.2 *Question 2*

There are nine domains belonging to the **ecological ceiling** category of the Doughnut Economics which are the following: climate change, land conversion, chemical pollution, freshwater withdrawals, biodiversity loss, nitrogen and phosphorus leaching, air pollution, ozone layer depletion, ocean acidification (Ross, 2019). The first five domains were found to have representative variables from the IDESCAT data repository:

- **Climate change:** *temperature, precipitation*;
- **Land conversion:** land use;
- **Pollution:** industrial waste, municipal waste;
- **Water withdrawals:** industrial water consumption, domestic water consumption;
- **Biodiversity loss:** *forest fire.*

The variables written in italics were not included in the inequality evaluation due to their non standard distribution or high occurrence of zeros.

Table 1: *Variables collected from the IDESCAT data repository.*

DEMOGRAPHICS AND SOCIETY	
population	population density, population as of Jan 1, total crude growth rate, population structure by sex and age group, population structure by sex and marital status, population by place of birth, population by nationality, population residing abroad by sex, population resident abroad by continent
culture	broadcasting FM stations, cinemas, screens and capacity, cinemas, screening, spectators and takings, theatre and dance, libraries by type, museums, sports facilities, youth facilities, centres of worship
education	foreign students, foreign students, infant, primary, special education, secondary, special, adult training centres, level of education attained
voting	EU parliament, Spanish parliament, Catalan parliament, municipal elections
justice	operational judicial bodies, local police
health	voluntary termination of pregnancy, diseases of compulsory numerical declaration, treatments of drug addiction, non hospital centres, hospital beds, pharmacies, active population, inactive population, persons in employment, persons in employment, persons in employment, persons in employment, affiliation ot social security general regime, registered unemploymentt, registered work contract
QUALITY OF LIFE	
housing and dwelling	buildings by destination, buildings designed mainly as dwellings by level of conservation, buildings designed mainly as dwellings by year of construction, family dwellings by type, main homes by useful surface area, average selling price of newly built housing, average selling price of second-hand housing
social protection	persons legally recognised as being disabled, persons legally recognised as being disabled by degree and sex, social services facilities for disabled people by facility, facilities for elderly by ownership, facilities for the children and adolescents, basic social services, contributory social security pensions, contributory social security pensions by type of pension, non-contributory social security pensions
ECONOMY	
main aggregates	GDP and GDP per inhabitant, GVA by sector, GVA of the industry by branches, GDHI, GDHI by main components
companies finances	foundations by type of activity, associations by type of activity
public sector finance	ICT equipment in households, use of computer and internet
research and tech	ICT equipment in households, use of computer and internet
ECONOMIC SECTORS	
agriculture	agricultural surface by type, used agricultural area by type of tenancy, farms (count), farms with UAA by size, persons in employment, cultivated land (dry and irrigated), cultivated land (herbaceous crops) by type, cultivated land (woody crops) by type, surface of organic farming by type, farms of organic farming by type
livestock	livestock operations by species, livestock units by species
construction	started buildings by destinations, surface area of started buildings by destination, housing starts by type of building, housing starts by project area, housing starts with state subsidy, housing completion by type of building, rehabilitated and subsidised homes, intensity of construction
transportation	fleet of motor vehicles by type, traffic accidents with victims
tourism	tourism accommodations by type, hotel establishment by type, campsites, rural tourism
ENVIRONMENT AND TERRITORY	
environment	meteorology, precipitations, temperature, forest fires, forest clearing, reforestation, plan for spaces of natural interest, water consumption, quality of bathing water, industrial waste, municipal waste by destination, municipal waste selective collection
territory	heighest peaks, land uses, surface area and slopes, altitude, surface area and population

3.3 *Question 3*

To evaluate the presence and distribution of regional inequality the following variables were chosen:

- **Social foundation**: % of population with higher education degree, GDHI per capita (€), GDP per capita (€), average price of newly built house (€/m²), average price of second hand house (€/m²), average income per capita (€), taxable base of rural estate tax per capita (€), taxable base of urban estate tax per capita (€), real investment budget per capita (€), % of unemployed population;
- **Ecological ceiling:** land conversion (%), industrial waste per capita (kg), municipal waste per capita (kg), domestic water consumption per capita (m³), industrial water consumption per capita (m³).

From the category **social foundation**, average price of newly built house, real investment budget per capita and percentage of unemployed population variables showed significant ($\boldsymbol{p} \leq 0.01$) regional inequality (tab. 2).

The average price of newly built house demonstrated a regional inequality share of 0.194, meaning that inequality between regions accounts for 19% of the total inequality (tab. 2). The price of the newly built house has a higher distribution values in the highlands where in 2015 the highest occurrence of prices ranged from 1 676 to 2 970€ per m². In the same year the most frequent values in the lowlands ranged from 885 to 1 617€ per m² (fig. 4).

The regional inequality of real investment budget accounted for 21 - 50% of the total inequality (tab. 2) with, similarly to average price of newly built house, higher distribution values in the highlands. In 2020, real investment budget ranged from 135 to 1 020€ per capita in the highlands and 18.5 to 1 020€ in the lowlands (fig. 4).

The regional inequality of unemployment accounted for 25 - 36% of the total inequality (tab. 2). The distribution of values were lower in the highlands (fig. 4) with 1.55 to 4.22% of population in 2023 being unemployed in the highlands as oppose to 1.55 to 5.96% range in the lowlands (fig. 4).

From the category **ecological ceiling**, land conversion, industrial waste and domestic water consumption variables showed significant ($\boldsymbol{p} \leq 0.05$) regional inequality (tab 2).

Regional inequality of land conversion accounted for 13 - 15% of the total inequality (tab. 2) with a lower distribution of values in the highlands than in the lowlands. The absolute percentage of land converted from one land cover class to another in 2022 in the highlands ranged from 3.11 to 32% where most counties stayed within the lowest range of 3.11 to 6.25%. In the lowlands, the percentage ranged from 3.11 to 111% (fig. 4). Here, it needs to be taken into account that land conversion was calculated as the sum of the absolute rates of change across all land-use classes, capturing the total magnitude of land-use change regardless of direction (tab. A2).

The regional inequality of industrial waste accounted for 20 - 23% of the total inequality (tab. 2) with lower distribution values in the highlands. In 2016 highlands were represented by 589 to 43 477 kg of industrial waste per capita whereas lowlands ranged from 589 to 1 821 425 kg per capita (fig. 4).

The regional inequality in domestic water consumption accounted for 31 - 39% of the total inequality (tab. 2). Domestic water consumption had higher distribution values in the highlands with range of 32.5 to 134 m³ of water used per capita with most regions being represented by the highest interval, 48.5 to 134 m³. Lowlands had the same range however most counties were represented with the lowest intervals of 32.5 to 39.1 m³ (fig. 4).

The socio-economical and environmental categories do not follow the same spatial pattern; the regions are not uniformly advantaged in either socio-economical nor environmental perspective.

Table 2: *Summary of inequality evaluation for socio-economical and environmental variables. Reported values correspond to the range (minimum–maximum) across statistically significant years.*

Variable	Significant years	p-value	Theil (min–max)	BG (min–max)	BGshare (min–max)
Social Foundation (socio-economical variables)					
Average price of newly built building (€/m^2)	2015	≤ 0.01	0.088	0.017	0.194
Real investment budget (€)	2017, 2020–2023	≤ 0.01	0.219–0.326	0.051–0.159	0.210–0.505
Unemployed population (%)	2015–2023	≤ 0.01	0.019–0.029	0.005–0.010	0.247–0.355
Ecological Ceiling (environmental vairables)					
Land conversion (%)	2017, 2022	≤ 0.05	0.404–0.442	0.059–0.060	0.133–0.147
Industrial waste (kg)	2015–2020	≤ 0.01	0.294–0.393	0.060–0.080	0.199–0.234
Domestic water consumption (m^3)	2015–2023	≤ 0.01	0.052–0.069	0.016–0.027	0.312–0.387

4 Discussion

This research project was set out to re-evaluate the regional inequality of the highlands and the lowlands of Catalonia on which the current developmental plan SoP is built (Generalitat de Catalunya, 2023). This need stemmed from two motifs: (1) the necessity to include the environmental perspective in the evaluation ensuring sustainable regional development for all; and (2) the need for evaluation that is founded on transparently referenced data securing the accountability of the results.

We have identified a high number of variables describing the counties of Catalonia. However, majority of these belonged to the socio-economical category defining the demographics, housing market, social protection and economy. Nonetheless, there were a few variables associated with the environment as well. These mostly defined the climate, water use and waste disposed.

Using the Doughnut Economics, waste disposal, water consumption and land conversion were found to be suitable environmental variables for regional inequality evaluation.

Regarding socio-economical variables, analysis showed significant regional inequality in price of a new house, the percentage of unemployed population and the real investment budget. The regional inequality of higher average prices for a new house in the highlands of Catalonia is in-line with the statements of SoP (Generalitat de Catalunya, 2023) and literature (Franquesa, 2025). This is due to the high demand from holiday home buyers and tourists who drive prices beyond local incomes (Franquesa, 2025). It is important to mention that the inequality between the two regions accounts only for ≈20% of all inequality, meaning that majority of inequality is sourced from a different spatial composition. The percentage of unemployed population was demonstrated to be significantly lower in the Catalan Pyrenees in comparison to the Catalan lowlands. The SoP does not elaborate on the unemployment, however, report from the Redera+ project confirms that the unemployment rate is lower in Catalan Pyrenees (Redera+, 2021). Though, there might be

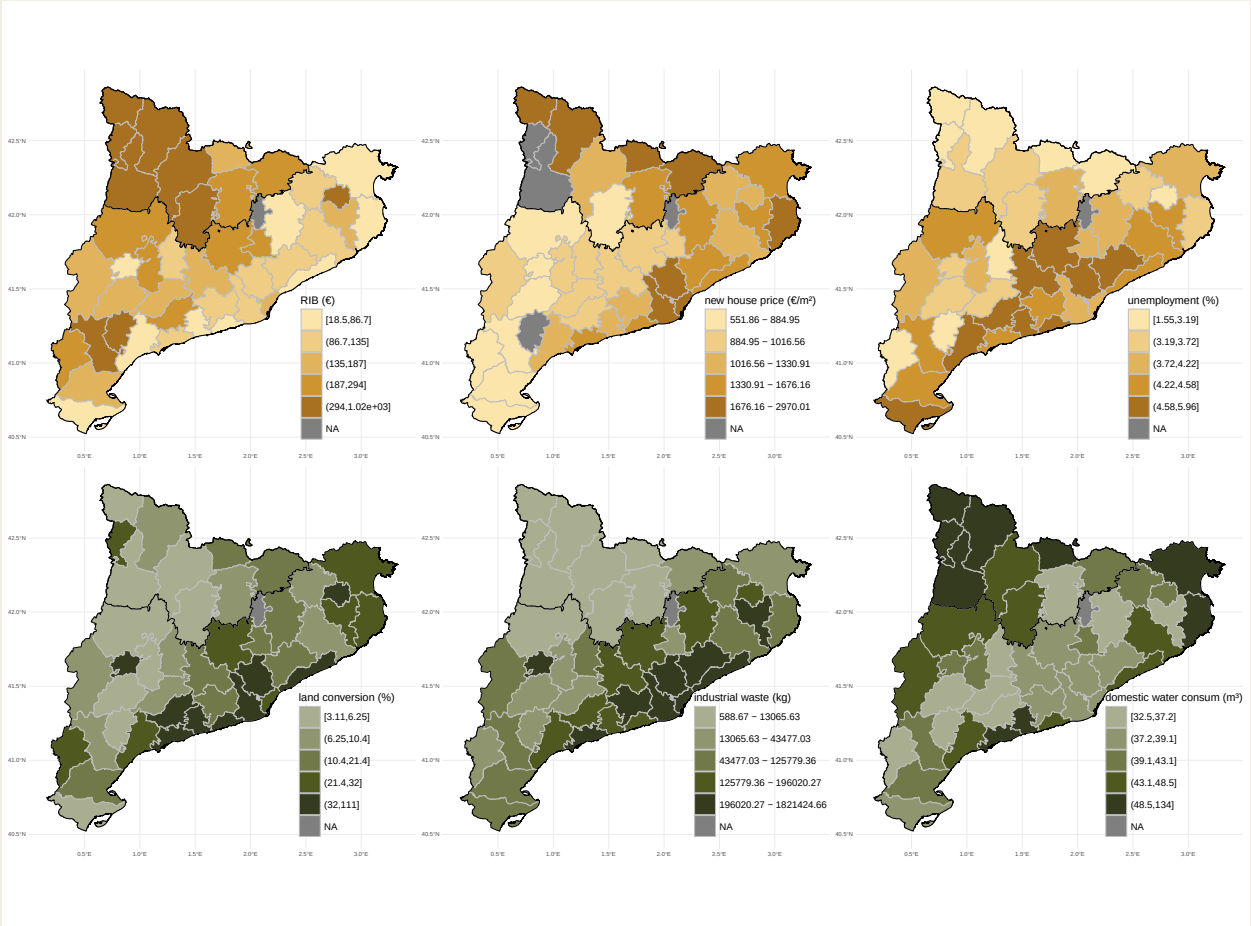

Figure 4: *Distribution of significant socio-economical and environmental variables. The distribution is a representative of the following years for a respective variable: real investment budget (2020), new house price (2015), unemployment (2023), land conversion (2022), industrial waste (2016), domestic water consum (2023).*

an existing bias due to the nature of employment in the Pyrenees which is mainly focused on seasonal hospitability leading to a potential higher long term unemployment rate (Redera+, 2021). Regarding unemployment, the regional inequality represents up to 36% of all inequality. The real investment budget, reflecting the proportion of public finance spent per inhabitant showed significantly higher distribution values in the Catalan highlands. Even though, there has been no recent literature found, this finding seems to go contrary to the SoP's narrative of under-valued mountain region. This might be due to the time range investigated which spans from 2015 to 2025. Within this time frame there has already been another development projects such as the Pyrenean Strategy (2014-2018) (of the Pyrenees, 2014). Therefore, this regional inequality might reflect an already changed public finance division. From the socio-economical variables, the share of regional inequality is the highest for real investment budget accounting for up to 50% of all inequality.

Among the environmental variables, the following showed significant regional inequality: land conversion, industrial waste and domestic water consumption. Land conversion showed significant regional inequality with the Catalan highlands having lower land conversion than the lowlands corresponding with the expectations due to the higher land cover change in urban versus rural areas

(Liu et al., 2015). The share of regional inequality is however considerably small accounting for up to 15% of all inequality. Therefore, in terms of land conversions the regions contribute little to the inequality. Industrial waste similarly demonstrated regional inequality with lower distribution of waste in the highlands. The share of regional inequality in relation to industrial waste is moderate accounting for up to 24% of all inequality. This is in line with expectations, as most of the industry in Catalonia concentrates outside of the Pyrenees region (Tapiador, 2020). On the contrary to the first two environmental indicators, the domestic water consumption showed significant regional inequality with higher consumption of domestic water resources in the Pyrenees. This, however, is also expected as the Pyrenees face significantly lower water stress year round leaving the population with high availability of resources (Benet Bayo, 2017). Domestic water consumption showed the highest regional inequality share accounting for up to 39% of all inequality.

The results demonstrate that socio-economic and environmental inequalities do not follow a uniform spatial pattern between the two regions investigated. This confirms the limitations of developmental strategies that are built solely on socio-economical indicators (Zeng et al., 2020). While a socio-economical indicator reveals disadvantages (higher house price) in the highlands region, environmental indicators show both relative advantages (lower land conversion and industrial waste) and potential emerging pressure (higher domestic water consumption). Interpreted through the Doughnut Economics framework, these findings indicate that Catalonia's highland and lowland regions occupy different positions with respect to both the **social foundation** and **ecological ceiling** (Ross, 2019). Consequently, policies aimed solely at closing socio-economic gaps risk overlooking environmental overshoot or underutilizing existing ecological advantages. By explicitly integrating environmental inequality into the evaluation of territorial disparities, this research utilizes the Doughnut Economics framework at a regional scale and exposes a critical gap in the SoP, which emphasizes sustainable development in its narrative but insufficiently accounts for ecological boundaries in practice.

4.1 Relevance and limitations

The Observatory of the Mountains, a project coordinated by the Mountain Lab under the supervision of Dr. Bernat Claramunt-López, aims to assist in the governance of the Pyrenean mountain region of Catalonia to contribute to sustainable development, regional balance, and improved quality of life. This research project contributes to the overarching Observatory of the Mountains project in the following ways: (1) it offers a transparent evaluation of the regional inequality using referenced data; (2) presents a decision support tool, the dashboard, which enables an interactive access to insights about the socio-economical and environmental state of the Pyrenees per county, per year and compares it to the rest of the Catalonia; and (3) it incorporates, within the limited availability, environmental perspective into the regional inequality narrative of the SoP. Given this, this project contributed to the Observatory of the Mountains with a practical technological tool and a conceptual analysis of the SoP.

There are numerous limitations of this research project which need to be considered. Among these are data limitations, temporal range, computational power and deployment platform. Even though, there has been many variables recorded, there is only about half of the domains in each social foundation and ecological ceiling represented with at least one variable. Therefore, a higher representation of domains could offer a more holistic evaluation of the regional inequality giving insights into where does each region stand when it comes to social foundation as well as ecological ceiling. Additionally, the data used in this analysis had a temporal range of 10 years spanning from 2015 to 2025 as most of the data had the highest occurrence in this range. However, longer temporal range could further improve the understanding of the regional inequality as many variables often

show more complex development over longer period of time. Furthermore, as there were limited computational power resource, the land conversion map was calculated based on the percentages of land being covered with a representative land cover class instead of land cover maps. This decreases the quality of the land conversion variable significantly. Lastly, the dashboard is now deployed through a personal GitHub profile which further limits the long term use of the dashboard and its maintenance.

4.2 Recommendation

Based on the findings of this research project, several recommendations can be formulated for the Observatory of the Mountains. First, the SoP framework should be expanded to systematically incorporate environmental indicators alongside socio-economic ones. This ensures the alignment between the SoP's sustainable narrative and its methodological implementation. Second, it is advised to make efforts toward data gathering whether it is primary or secondary data. The current analysis represents only three domains from the total of nine in the ecological ceiling category; and only three domains from the total of 12 in the social foundation. Therefore, increased data availability representing more domains of the Doughnut Economics model could significantly improve the evaluation of the regions's state both economically and environmentally. Thirdly, to ensure up-to-date data source in the dashboard, it is advised to connect the scripts to an API key for an automated data flow. Lastly, to ensure long-term usability of the dashboard should be migrated to an institutional platform.

Appendix

Table A1: Overview of variables' pre-processing steps belonging to the **social foundation** distinction of the Doughnut Economics

Domains	Idescat variables	Pre-processing steps	Final variable (per county)	Source
housing	**average selling price of newly build building**	import, filter Catalan counties, select variable average value, reshape data frame, add region column based on county, export	average price of newly-built housing (€/m² built)	https://www.idescat.cat/indicadors/?id=aec&n=15706&tema=habit&lang=en
	average selling price of second hand building	import, filter Catalan counties, select variable average value, reshape data frame, add region column based on county, export	average price of second-hand housing (€/m² built)	https://www.idescat.cat/indicadors/?id=aec&n=15707&tema=habit&lang=en
education	**level of education attained**	import, filter Catalan counties, sum Bc M PhD level of education into University education, calculate percentage of people attaining university education per county, reshape data frame, add region column based on county, export	percentage of population aged 15+ that attained university education	https://www.idescat.cat/indicadors/?id=aec&n=15743&tema=educa&lang=en
income and work	**GDP**	import, filter Catalan counties, select variable GDP per capita (€), reshape data frame, add region column based on county, export	GDP per capita (€)	https://www.idescat.cat/indicadors/?id=aec&n=15336&tema=macro&lang=en
	GDHI	import, filter Catalan counties, select variable GDHI per capita (€), reshape data frame, add region column based on county, export	GDHI per capita (€)	https://www.idescat.cat/indicadors/?id=aec&n=15917&tema=macro&lang=en
	real investment budget	import, filter Catalan counties, calculate per capita real investment budget in €, reshape data frame, add region column based on county, export	real investment budget per capita	https://www.idescat.cat/indicadors/?id=aec&n=15647&tema=finan&lang=en
	personal income tax	import, filter Catalan counties, select taxable base per contributor, reshape data frame, add region column based on county, export	income per capita (€)	https://www.idescat.cat/indicadors/?id=aec&n=15905&tema=finan&lang=en
	rural estate tax	import, filter Catalan counties, select tax base, calculate tax base per capita, reshape data frame, add region column based on county, export	rural estate tax per capita (€)	https://www.idescat.cat/indicadors/?id=aec&n=15656&tema=finan&lang=en
	urban estate tax	import, filter Catalan counties, select tax base, calculate tax base per capita, reshape data frame, add region column based on county, export	urban estate tax per inhabitant (€)	https://www.idescat.cat/indicadors/?id=aec&n=15657&tema=finan&lang=en
	registered unemployment	import, filter Catalan counties, select total unemployed population, calculate percentage of population that is unemployed, reshape data frame, add region column based on county, export	percentage of population that is unemployed	https://www.idescat.cat/indicadors/?id=aec&n=15303&tema=treba&lang=en

Note: The following domains of the Doughnut Economics were excluded as there were no representative/not suitable IDESCAT variables for these domains: networks, food, health, energy, peace and justice, political voice, social equity, gender equality.

Table A2: Overview of variables' pre-processing steps belonging to the **ecological ceiling** distinction of the Doughnut Economics

Domains	Idescat variables	Pre-processing steps	Final variable (per county)	Source
land-use change	**land cover**	import, filter Catalan counties, calculate land-cover change by computing the annual rate of change of each land-cover class and summing the absolute values across classes (adapted from (Horn, 2008)), reshape data frame, add region column based on county, export	land conversion (% per year)	https://www.idescat.cat/indicadors/?id=aec&n=15180&tema=terri&lang=en
chemical pollution	**industrial waste**	import, filter Catalan counties, select total industrial waste, calculate industrial waste per unit area, reshape data frame, add region column based on county, export	industrial waste per area (kg/km^2)	https://www.idescat.cat/indicadors/?id=aec&n=15219&tema=media&lang=en
	municipal waste	import, filter Catalan counties, select total municipal waste, calculate municipal waste per capita, reshape data frame, add region column based on county, export	municipal waste per capita (kg)	https://www.idescat.cat/indicadors/?id=aec&n=15221&tema=media&lang=en
freshwater withdrawals	**domestic water consumption**	import, filter Catalan counties, select domestic water consumption, calculate domestic water use per capita, reshape data frame, add region column based on county, export	domestic water consumption per capita (m^3)	https://www.idescat.cat/indicadors/?id=aec&n=15209&tema=media&lang=en
	industrial water consumption	import, filter Catalan counties, select industrial water consumption, calculate industrial water use per capita, reshape data frame, add region column based on county, export	industrial water consumption per capita (m^3)	https://www.idescat.cat/indicadors/?id=aec&n=15209&tema=media&lang=en

Note: The following domains of the Doughnut Economics were excluded as there were no representative/not suitable IDESCAT variables for these domains: biodiversity loss, nitrogen and phosphorus loading, air pollution, ozone layer depletion, ocean, acidification, climate change

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