Czech University of Life Sciences Prague

Faculty of Economics and Management

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Master's Thesis

The effects of drought management on farmers revenues in France

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DIPLOMA THESIS ASSIGNMENT

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Thesis title

The effects of drought management on farmers revenues in France

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Objectives of thesis

Investigate the quantitative effects of emergency restriction of irrigation on the supply of water, on agricultural output and financial health of farmers as well as remediating ways to damaged farmers.
Including:
- Extensive description of the irrigation water public policies in France.
- Describe emergency irrigation restrictions processes.
- Weight the effect on farms output and farmers financial stability.
- Map the existing remediating solution for farmers and water supply.
- Provide ways to fairly compensate.

Methodology

The first part of the diploma thesis will discuss the theory to assess the effect on the water availability for agriculture and on farmers output and revenues, as well as a legal background behind the management of water in France.

The second part will be empirical, combining a quantitative data analysis from the French information system on water and database on agriculture provided by the FAO, OECD, FADN and the French government. On the qualitative side a public policies evaluation will be run, for this purpose we will use reporting from French ministry of agriculture and ministry of ecological Transition through the French office of biodiversity (OFB). As well as report form the French and European court of auditors.

The proposed extent of the thesis

60 – 80

Keywords

Drought, water management, farmers revenue, food security

Recommended information sources

Cours de compte France (2023) LA GESTION QUANTITATIVE DE L'EAU EN PÉRIODE DE CHANGEMENT CLIMATIQUE. Cours des comptes.

Drysdale, K.M. and Hendricks, N.P. (2018) 'Adaptation to an irrigation water restriction imposed through local governance', Journal of Environmental Economics and Management, 91, pp. 150–165. Available at: https://doi.org/10.1016/j.jeem.2018.08.002.

Morardet, S. et al. (1998) 'Sécheresse et demande en eau d'irrigation : éléments de réflexion', Sciences Eaux & Territoires, (13 Ingénieries-EAT), pp. 15–28.

Palka, M. and Hanger-Kopp, S. (2020) 'Drought risk and drought risk management strategies among Austrian crop farmers', IIASA Working Paper, p. WP. Available at: https://doi.org/10.3929/ethz-b-000461745.

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Declaration

I declare that I have worked on my master's thesis titled "The effects of drought management on farmers revenues in France" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 31/02/2024 ______________________________

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The effects of drought management on farmers revenues in France

Abstract

Global warming is pressuring water supply and demand all around the world. France does not constitute an exception, facing water shortages more often, which create conflicts around the reparation of the water resources. Farmers are the most concerned as they are the biggest consumers of water. Thus, questioning the effects that drought have on agricultural production thus on their revenue.

The prolific literature on the subject offered a proper idea of the differences between metrological, hydrological, agricultural, and socio-economical droughts and the ways to assess the phenomenon.

To have a good understanding of the questions, three databases were compiled into a panel database covering twelve years and ten variables. After an analysis showing the growing prefectural reaction and a comparison with metrological data, different linear regressions were computed. Providing results on the relationship between maximum temperature and the fall of revenue of farms.

Keywords: Drought, Agricultural Water Management, Farmers Revenue, FADN, Prefectural Decrees, Econometric Modelling

Table of content

1 Introduction

Global climate change put a growing pressure on water resources around the world. Agriculture using 70 percents of the global freshwater in 2017 (Khokhar, 2017) is at the vanguard of this situation. Facing a double constraint, a supply of water decreasing and the demand in food growing. On the supply side, there is less and less water along the year prolonging the low flow periods. On the demands side evapotranspiration being higher during pick of temperature, leading to need supplementary irrigation demand for farmers to keep the crop alive. All farms activity can be touched, from crop to livestock. More high temperature will mean more decease livestock or more water consumed. Winter crops will be affected to by the rise of winter drought. Affecting the recharge of underground water resources and putting pressure on water resource all year.

This kind of problematics will be more visible as the global change in temperature will create tension on farmer and agricultural output. Therefore, setting dangerous situation for the steady supply of food in many parts of the world.

France is quite affected; some regions of France are experiencing continuous lack of water from year to year. Water in the rivers, ice caps and underground water, renew less. Forcing the French state to react. This reaction is made through local decision called prefectural decree, forbidding the irrigation locally. Made to preserve the resource of water, it affects the farmers that are dependent on this source for crops development.

This thesis will investigate the relations between, the rise in drought, the state actions and the revenue of the famers answering the question: *What are the consequences between drought state polices and the farms revenues?*

To do so, we will first analyse the literature, questioning the diversity of definition for droughts, look into the variety of indicators existing to categorize drought. Followed by an analysis of the legal framework for the state action around the quantitative management of water. In a second part we will investigate three databases on weather, decrees taken and farmers revenue, to cross the different results and asses for the effect of the restriction on crops.

2 Objectives and Methodology

The first part of this text will analysis of the literature. Especially the point of view from different academic fields on droughts. The diversity of views from agronomy to economics will help us to better understand the topic. To this extent a thorough legal exploration of the framework of French water management laws and regulations was done.

The second part consists of a practical part. Expanding on the research question - data from three different sources were combined to analyse their content and to create an econometric model.

The first database is an annual records of drought decrees, passed at the prefecture level, provided by the government, detailing their level of severity. These levels range from 1 to 7, where 1 is "vigilance" and seven is "All unnecessary withdrawal stops". Each decree taken by the prefecture is recorded and often covers the under-basin level. This database was of the form of a collection from 2011 to 2022, combined using power query. The unnecessary entries like the identification number were removed. This leading to a clean dataset, which assembled:

- Years
- Identification of the zone affected from which was decided the area of the decree.
- The department (French administrative local authority) and the region (which is above the department, of which there are thirteen in metropolitan France)
- Start and end date of the decree, from which we derived the duration.
- The strength of the decree as descried above.

Following this work, a few indicators were developed, like the mean duration per region, the mean area per region, etc.

The second data set combines weather data. Available by department, with monthly weather recorded from each local station, from five hundred different meteorological stations, provided by "Météo France" the French weather authority. The period extends from 1958 to 2022 with 160 dimensions (from precipitation to winds). These heavy datasets were combined into one using only three dimensions, monthly average of maximum temperature, yearly absolute maximum temperature, and monthly precipitation. Creating a unified dataset was too heavy for power query so an excel function was designed to extract the yearly means of temperature and the precipitation and the maximum of absolute temperature. All these data were compiled by departments and regions from 2011 to 2022 to follow the date length of the first dataset.

The last data set is named "Réseau d'information comptable Agricole" (RICA) in French and is the French application of the Farm Accountancy Data Network (FADN). Combining three hundred types of entries - structural, economical and accountability- for around seven thousand respondent every year. Available each year, a single dataset from 2011 to 2022 was created. The FADN does not allow for a departmental view without accessing confidential data therefore only the regional level is coded. This limitation is the reason the other datasets were compiled yearly and not monthly as it was impossible to access monthly data in the FADN due to the accountability nature of the data. From this database yearly indicators were gathered for each region, among which:

- Yearly mean of the turnover
- Total of climatic subvention in a year
- Mean cost in irrigation water and mean cost in public water
- The yearly mean of the production in euros of vegetal, farm animals, maize, and other crops.
- Livestock unit
- Irrigated surface total and irrigated surface of maize

Combining the three datasets gave a balanced panel dataset (the form can be seen in Table 1) from 2011 to 2022 which combines all the variables mentioned above for all the region in France. This is the main tools of analysis of the practical part. It is important to mention that due to the differences in the datasets it was impossible to do a more precises analysis. The department or local level would have been more relevant due to the local nature of the weather, but the FADN does not allow for this kind of investigation and does not account any weather data. Thus, the panel type was used due to the lack of cross-sectional information, joining weather, restriction, and accountability. Moreover, the regional analysis is not irrelevant since there are weather disparities among the region in France. This work gives a dataset with 144 entries for seventeen dimensions, resulting in 2304 individuals points on 12 years.

Table 1 Form of the panel database

Region	Dates	Variables
Ile-de-France	2011	
Ile-de-France	...	
Ile-de-France	2022	
Centre-Val de Loire	2011	
Centre-Val de Loire	...	
Centre-Val de Loire	2012	

Source: Original work

In the section 4 the description of the data set and the visual analysis of the different points are presented. To further analyse the dataset few methods were assessed with different ways to set up variables. Linear regressions of different nature were used, Ordinary Least Squares (OLS), Least Squares Dummy Variables (LSDV) and Weighted Least Squares (WLS).

For the reproducibility of the results, the datasets use is accessible here (to be open on excel):

https://docs.google.com/spreadsheets/d/1QDa07dFoFT8fQlZSX52sG81VzDncMeOE/edit?usp=sharing&ouid=106069990806195154600&rtpof=true&sd=true

For the original database, you can contact: Zwartjes.maxime@gmail.com

3 Literature Review

This section is dedicated to the different aspects underling the questions of drought management in France. Starting with questioning the literature on the relation between farmer revenue and drought. Seeking the reaction and remediation as well as how to model the different stages of drought effects, focusing on the question of the economic effect of irrigation water restriction. Then an audit of the legal definitions of the question, exploring the different policy framework and laws around water withdrawal and the quantitative management of water.

3.1 Elements of definition for drought and the effects of water scarcity

Before exploring different features of drought, and the effect on farms, we need to make three important definitions: blue water, green water and evapotranspiration. Evapotranspiration is the consumption of water used by plants that will be released in the environment. In other terms: *"Evapotranspiration (ET) is the process by which liquid water becomes water vapor and energetically this accounts for much of incoming solar radiation"* (Zhang *et al.*, 2016, p. 1). It is closely related to blue and green water. Green water will be the resources of water contained in plants, soils. Or as the FAO (1996) phrase it: *"that is, the water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rainfed crops."* Blue water will be the water contained in rivers, lakes, and water tables. Main part of the blue water is inaccessible because in remote region like the Amazon river (FAO, 1996). Green water will be the main source of water for rainfed crops and blue water is closely linked to irrigation.

Last definition the concept of crop yields, the OECD defines it as: *"are the harvested production per unit of harvested area for crop products. In most of the cases yield data are not recorded but are obtained by dividing the production data by the data on area harvested."*(OECD, 2021)

There are other types of definitions depending on the scientific field. Agronomists have definitions that are based on plants need, where sociologists see more the harvested yield or the theoretical yield. Economist are interested in the quantities actually sold. (Kapsambelis, 2022, p. 55)

3.1.1 Stakes around the definition of drought

Drought is highly debated in the literature and the definition can emphasise different features of the question of water scarcity. The IPCC (2022, p. 547) definition, used in their last report defines drought as: *“A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term, therefore any discussion in terms of precipitation deficit must refer to the precipitation-related activity that is under discussion.”*. However, we can go further, Wilhite et Glantz (1985) defined four types of drought: meteorological drought, agricultural drought, hydrologic drought, and socio-economic drought. Below, we will also make an extensive use of the Lincoln declaration on drought indices (Hayes *et al.*, 2011), which is a key and highly cited expert declaration on the different indicators to use to asses drought.

Meteorological droughts are centred on the level of dryness and evaluated through a reference point and oriented locally. In other words, it is the deficit of rainfall in a certain area. It is difficult to generalize this definition of drought as it is tight to local meteorological conditions (Wilhite and Glantz, 1985).

Multiple indicators exist to asses this kind of drought, among them the Palmer Drought Severity Index or PDSI (Palmer, 1965), is one of the crucial indicators of such drought. It computes different methods to approximate meteorological data. Giving results from -10 being dry and 10 being wet. A good idea is given on the severity of the drought over time. However the methodology does have some weaknesses such as not including snow cap or ice. (Keyantash and NCAR Staff, 2023).

Other indicators have been developed with the Standardized Precipitation Index (SPI) being the most widely used and recommended by the Lincoln Declaration (Hayes *et al.*, 2011). Official drought databases like the Copernicus European Drought Observatory produce data with this statistical tool using satellites imagery. The SPI provide data on certain times coded as SPI-3, SPI-12, etc. on a range from 2 being the wettest to -2 being the dryest (European Drought Observatory, 2020). It can better compare multiple regions than the PDSI and is less complicated to calculate (Keyantash and NCAR Staff, 2023).

Hydrological droughts, unlike meteorological drought, focus on the river's levels. The process of focusing on flows is an analysis of the consequence rather than the source of it. This means it will analyse anomalies in river basins like prolonged low flows. Low flow does have a classical definition by the World Meteorological Organisation *"flow of water in a stream during prolonged dry weather."* But as V.U. Smakhtin (2001, p. 29) points out, this definition does not include water scarcity times. Low flow is used to define droughts by multiple authors in the literature. Therefore, we can add multiple indexes to characterise hydrological drought. The Lincoln declaration (Hayes *et al.*, 2011, p. 448) cite the SPI and can be used but other indicators exist like the surface water supply index (SWSI), which at the level of the basin analyses reservoir storage, stem flow and precipitation. (IDMP, 2020). The declaration also mentions the aggregate dryness index (ADI), which is a defined as a *"multivariate regional drought index that looks at all water resources across many timescales and impacts. It was developed to be used across uniform climate regimes."*(IDMP, 2023)

Agricultural droughts are droughts through the lens of crop development, analysing the development of the plant regarding the different level of moisture linked to climatic condition taking into account the development stages of the plants. (Wilhite and Glantz, 1985, p. 6). The Crop Moisture Index is mentioned by Wilhite and Glantz, but the Lincoln declaration also mentions precipitation, heat, low-flows, and water balance. There is also the normalized difference vegetation index (NDVI), which is a ratio between near-infrared and visible light, with the near infrared being reflected more on the greener plants. In consequence, this ratio can analyse the difference in coloration which is symptomatic of damaged vegetation. This can be analysed by satellites equipped with infrared sensors. (GISGeography, 2017).

Socio-economic droughts analyse droughts through the societal effect that human activities can have on the supply and demand of water (Wilhite and Glantz, 1985). We are interested into the disparities between supply and demand will create. Calls for multiple authors has been made to better asses the human impact on droughts and account for the

Anthropocene (Van Loon *et al.*, 2016). They argue that we need to have a better understanding of how human actions impact droughts and the socioeconomic impacts of droughts.

Tentative attempts to make indicators are found around the literature, the main one being the Multivariate Standardized Reliability and Resilience Index (Mehran, Mazdiyasni and AghaKouchak, 2015, p. 7530; Guo *et al.*, 2019, p. 990). It is a combination of two distinct indexes- the inflow demand reliability index and the water storage index. The first one is composed of the demand in water and water inflow and is a "top down" method, analysing the inflow regardless of the water in storage. The second computes the reservoir storage, and the filling and emptying of the reservoir, thus is the "bottom-up" part of the index, focussing on the storage weighted by the demand.

There is diversity of indicators used by different institutions around the world. In Table 2 there is listed all the indicators complied by satellites with Copernicus through the European Drought Observatory. They are computing different aspects of the question - the precipitation, wetness of soil and low flow. The Combined Drought Indicator (CDI) is the most complete as it is a composite of the SMA, FAPAR and SMA indicators.

Table 2 Indicators used by Copernicus European Drought Indicators

Standardized Precipitation Index (SPI)	Soil Moisture Anomaly (SMA)	Anomaly of Vegetation Condition (FAPAR Anomaly)	Low-Flow Index (LFI, only available for Europe)
Heat and Cold Wave Index (HCWI)	Combined Drought Indicator (CDI; only for Europe)	Risk of Drought Impact for Agriculture (RDrI-Agri; only on Global Drought Observatory)	Indicator for Forecasting Unusually Wet and Dry Conditions

Drought is normally a part of the climate variability. Regardless of the type of drought we can link the growing frequency and severity of droughts to climate change. For this section we will make extensive use of the major study of Aiguo Dai (2011). He demonstrates that dryness levels are bound to increase even though we will have difficulty in assessing exactly the scale. In the days to come there will be dryness growth in many parts of the world, *"a very large population will be severely affected in the coming decades over the whole United States, southern Europe, Southeast Asia, Brazil, Chile, Australia, and most of Africa." (Dai, 2011, p. 60)*

Human induced climate change due to greenhouse emission is now undisputed fact as the IPCC points out (Calvin *et al.*, 2023, p. 3). « Coupled climate models used in the IPCC AR4 project increased aridity in the 21st century » (Dai, 2011, p. 59). Climatic future will be made of more and more extreme events. Soon, we will see a more arid world facing more droughts that will impact drastically agricultural production and therefore food security. It will be the subject of our next section.

3.1.2 Interdependency between farm and water

In the earlier part we have seen the difference way to analyse, compute, and assess droughts. Consequently, we can better understand the stake around the definition of drought and have an overview of what these terms can hide. And we shown that drought is a daily reality for many countries due to climate change. In this part we will examine the consequences that drought have on agriculture and farmers. However, we will make a more precise depiction of the economic consequences later. Afterward we will investigate the impacts that famers have on drought. *« measured by quantifying the amount of water given to a plant and the plant's increase in biomass during the experiment. »* (Brendel, 2021, p. 1)

The question of impact of drought on agriculture starts with the two ways that land receives water. According to MICRA 2000 a dataset on rainfed land, the non-irrigated land in 2000 stand for 9.9 million km2 yr−1 which is roughly 70 percent of the total harvested land in the world. The differences in exposure to drought of rainfed and irrigated land can depend on the endowment of both types of land. (Meza *et al.*, 2020, p. 14). Exposure will also rely on the quantity of rain for the rainfed land and for irrigation to hydrological drought. Irrigation technologies and farming habit will also play a key role in the risk assessment. (Downing and Bakker, 2000 as cited in; Meza *et al.*, 2021, p. 2)

Drought has major effects on the plant's development, but the scale of this effect depends on numerous factors. Seleiman et al. (2021) did an interesting compilation of all the effects that plant might face when exposed to stress. We can mention the yellowing of the leaf that we study earlier when characterising agricultural drought. However plants can respond to drought in diverse ways. (Seleiman *et al.*, 2021, p. 4)

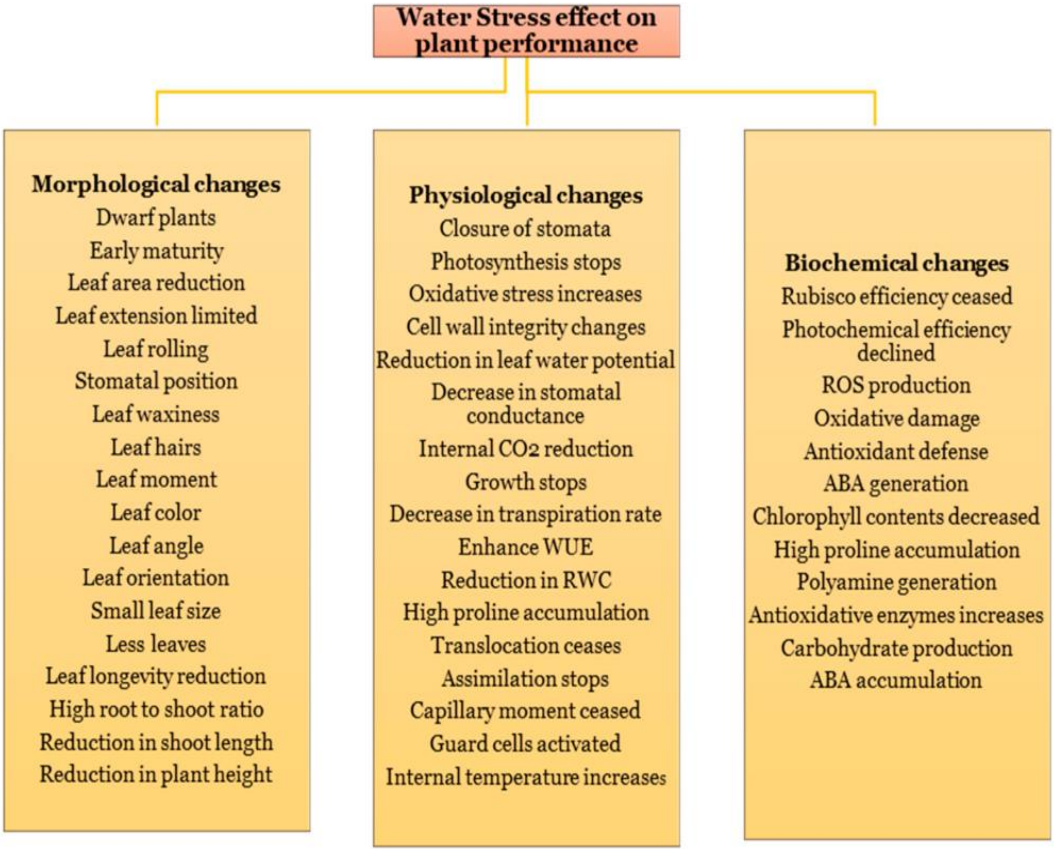


Figure 1 Morphological, physiological, and biochemical dynamics of plants affected by water stress. Source: Seleiman et al., 2021

We will not spend a long time summing up the difference effect of droughts on plants as they are multiple and complex. We will exclusively focus on yield and quality effect as it the main part connected to our subject, focusing on consequences rather than the exact responses.

Crops are not affected the same way by scarcity as they are not sensitive at the same time of development, nor they have the same need in water, as you can see in Table 3.

Table 3 Sensitivity of various field crops to water shortages

SENSITIVITY	LOW	LOW-MEDIUM	MEDIUM-HIGH	HIGH
CROPS	cassava	alfalfa	beans	banana
	cotton	citrus	cabbage	fresh green
	millet	grape	maize	vegetables
	pigeon pea	groundnuts	onion	paddy rice
	sorghum	soybean	peas	potato
		sugar beet	pepper	sugarcane
		sunflower	tomato	
		wheat	(water) melon	

Source: Allan, Pereira and Smith, 1998

Also, water needs and are highly dependent on many different climatic conditions like soil moisture, sunshine, temperature, humidity, windspeed. To better see through this complex question the FAO provided guidelines into computing water need in regions of the world to compute the Crop Water Requirement, to access a more precise calculation. (Allan, Pereira and Smith, 1998, p. 6) The FAO provides a calculation tool to assess Crop Water Requirements called CROPWAT.

Pfister et al. (2011) conducted an interesting study combining the land stress and an indicator called Relevant for Environmental Deficiency water or REDwater. As we can see in Table 3, maize, rice, etc put a high pressure on the land worldwide. Meaning they are concentrated in water stress regions.

Different indicators exist to make such assessment, like the Water Use Efficiency (WUE). It is « measured by quantifying the amount of water given to a plant and the plant's increase in biomass during the experiment. » (Brendel, 2021, p. 1) It held defined supplemental irrigation which is the quantity of water needed to keep a steady quantity of biomass. (Pereira, Oweis and Zairi, 2002) To further water definition Preira Oweis and Zairi (2002) proposed to use Water Productivity (WP) to assess the Yield in regards to irrigation performance.

It is where we touch the heart of the question of the consequences of drought on farms. Rainfed against irrigation will face diversity of consequence and especially diversity of ways to cope with the problem it will highly depend on the coping capacities especially in rainfed land (Meza *et al.*, 2020, p. 12).

3.1.3 Estimating the economic effect of drought on agriculture.

The economic effects of drought in agriculture are significant, impacting various aspects of the economy. Drought leads to crop failure and pasture losses, affecting farmers' incomes and increasing food prices for consumers (NIDIS, 2024) Livestock farms also suffer due to water scarcity, poor grazing conditions, and increased feed costs, leading to surplus supply initially but eventual price hikes on meat products.

The agricultural sector is hardest hit by the economic impact of drought, due to crop failure and loss of grazing land, leading to higher consumer prices or dependence on government aid. In addition, indirect effects ripple down the supply chain, affecting downstream industries such as food processing and reducing demand for inputs such as fertilizers and labour. Also, the intangible consequences on farmers' mental health due to production losses add to the non-market effects of drought. (‘Economic Impacts of Drought’, 2024). In addition, less water in the river lead to a fall in quality of the water and there is a probable impact on the rise of sickness among farm animals.

Finaly, drought affects energy production, particularly hydropower, resulting in energy shortages, increased prices, and high carbon emissions. Overall, drought's economic impact on agriculture is large, causing losses in crop and livestock productivity, destruction of property, and significant financial burdens on the economy. As well as disrupting global market leading to a winner-loser situation where the agricultural commodities skyrocket in price. Drought affected area will therefore be less productive when non affected will benefit from the rise in price of goods. As well as creating tension on financial markets due to the rise of insurance coverage (Ding, Hayes and Widhalm, 2011, p. 8)

One might ask how the scholars tried to estimate the economic effects of drought on famers. The first approach is through direct cost losses. This method analyses the immediate effects on expenditure or losses of revenue that farmer will face in a case of a drought. (Logar and van den Bergh, 2013) To that kind of cost we can add the damages to buildings due to ground subsidence. It is more present in the public debate but is hard to evaluate. Moreover, indirect cost exists also, they are environmental impacts. The effect on famers can be in the form of reduced biodiversity which can in return also impact future yield, especially when facing long term scarce situations (Logar and van den Bergh, 2013).

The extensive analysis provided by Logar and van den Bergh (2013) give us a good idea of the different approaches we can use to asses economic effects of droughts. They provided several different methods, to which one was added.

Market prices, production costs: The first mentioned is the market prices, production costs and avoided cost. It is extensively used in economics. We will compare losses in quantity and the prices effect. For the production function, we will compute different mix of input and output. Lastly, avoided cost analysis focuses on the cost not used in one's action. Logar and van den Bergh (2013, p. 1711) take the example of water paid for irrigation.

Assessing GDP and Agricultural production: Change in Gross Domestic Product and agricultural production can give an idea of the effect of drought on the sectors. However, it will be harder to assess the specific effects of drought compared to other effects.

Input-Output (I-O) Analysis: This is a sector wide method that will investigate the changes in key economic indicators like the value added on other sectors of the economy. In the case of drought, it allows for an economy wide assessment. Such a use of the I-O model has been done by Jenkins et al. (2021) recently establishing a link between droughts in the United Kingdoms and the economic impacts of the events.

Computable General Equilibrium Analysis (CGE): Used like the I-O model to assess sector wide impact the CGE is complementary to the earlier methodology. CGE models are a development of Leontief I-O view and the general equilibrium theory. It is still used recently in the literature to assess impact of drought. (Shahpari *et al.*, 2022)

Biophysical-Agroeconomic Modelling: Theses models will use the effects of drought on crops and crops output to calculate the socio-economic effects of the drought. As we mentioned in the previous part, we can measure the crop stage of development and therefore see the effects on yields.

Coupled Hydrological-Economic Modelling: Hydrological modelling is a highly discussed topic in the literature, these models link between hydrological events and economic changes. N. Englezos et al. (2023) made a link between stochastic modelling of water resources and the diverse costs along the way, distinguishing upstream, downstream and cooperative non-cooperative components.

Ricardian Hedonic Price Modelling: Originally it is used in environmental economics, it links the price of land to its characteristics. In the case of drought, it can provide a link between climatic conditions and environmental hazard like drought.

Winer/Looser: Is analysing those benefiting for higher prices and those loosing because they are not able to produce (Fleming-Muñoz, Whitten and Bonnett, 2023)

Non-Market Valuation: Few other technics exist using a mix of qualitative and quantitative analysis, like the contingent valuation, that will use scenarios and evaluate the response, choice experiments that will give a set question, or life satisfaction analysis that will mix life satisfaction study and quantitative data to make econometrics modelling.

Several other methods can be imagines assessing the economic effects of drought on agricultural output and farmers. This section discusses few of them. None stand out as the core method as the impacts of drought are multifactorial and complex. The nature of the events mix weather, hydrological, environmental, economic factors that was grasped in this diploma thesis.

3.2 Quantitative water management in France

After analysing the implication of water scarcity for farmers we need to research the ways France manage its quantitative resources in water. As mentioned in the introduction we will not question the qualitative framework for water management as well as public water. However, we will analyse frameworks about quantitative water management through international cooperation agreements, European directives, and French laws.

3.2.1 Legal framework evolutions

On the international scene France has signed the "convention on the protection and use of transboundary watercourses and international lakes" in Helsinki in 1992. The convention provides a definition for transboundary water as well as rules about transboundary pollution. On the quantitative side we are interested in two articles, 1.c that defend the fair sharing of the resources in water and 5.c that stipulate that the future demands in water should be preserved. The rest of the convention invites parties to cooperate and harmonize international cooperation.

France shares few rivers with its neighbours and there for as signed multilateral agreements with its neighbours. We can cite the Agreement around the Escaut river 1994, the one protecting the Rihn or the International Meuse Agreement (Ghent Agreement) in 2002.

The European Union has been leading multiple directives on the protection of water. The main is the Water Framework Directive (WFD). About the quantitative management the WFD defines clearly what a good quantitative status means "The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction." Annex five.

The WFD is key to rule the organization of water basin in Europe. It imposes to the state to name a competent administration to manages river basin. (Article 3) The states are urged to make an assessment if the human activities on the river basin and review of the economic use of water. (Article 5.1) In article 8 we find endeavours to monitor the quantity and quality of groundwater and surface water. The states must also provide instructions for a management plan that needs to be reviewed every 15 years. (Article 13). This directive had a huge impact on the way to management water in France after the transposition.

The French legislative framework evolved multiple time from 1964 to today. Although there were multiple laws on water before 1964, the "Loi n° 64-1245 du 16 décembre 1964" introduced a basin wide management. Dividing France in six different basins (see Image 1) and creating the "Agence de l'eau" and the "Comité de basin" (CB). The first one as the executive power in the basin, the second one is in a consultive committee. Originally the committee was supposed to fix the water fees for punctions. This part of the law was abrogated by "Conseil Constitutionnel" in 1982.

In 1992 a new important legislation is voted in the parliament. It stipulates that water is common patrimony of the nation and introduces new regulations tool. The most important being the « schémas directeurs d'aménagement et de gestion des eaux » (SDAGE) or water development and management plans. This plan regulates the quantity and the quality of the water use basin wide. It is the responsibility of the CB to draft it under the prefect responsibility. The ninety-two's law also introduces the "communauté local de l'eau" (CLE) or local water community, these are the equivalent of the CB but at the local level.

In 2006 is voted the transposition of the WFD in French law. For agriculture it introduces a unique entity to manage the different irrigators. In the absence of such groups, it will be the administration. The law also gives guidelines for the equilibrium of usage between different actors (industries, agriculture, public water, etc.) and biological life.

3.2.2 Institutional Ecosystem

The institutional ecosystem of water management in France is complex. However, in this part we will make an overview of the different actors and their responsibilities. At the national level, there are multiples ministries involved in the process of water management, the main one however will be the “Minsitère de la Transition Ecologique" (Ministry of Ecological Transition) that have the responsibility over the “Comission nationale de l’eau” (CNE) or national commission on water. This committee has the responsibility to provide guidelines for the ministries about water management at a national level. They are composed 160 members from different field, research, local authorities etc. The ministry of ecological transition is also the supervising authority for the “Office Français de la Biodiversité” (OFB), French office of biodiversity, that has the charge to monitor biodiversity issues in France notably the water resources. Regarding water, they are the authority for the “Police de l’eau” or water police. They oversee following infraction on pollution, but in our case, they enforce rules on punction point.

As stated above, at the basin scale the “agence de l’eau” are the executive branch, there are six agencies distributed around the territory (see Image 1). They are collecting different taxes about the usage of water and redistributing the resource to local actors. With an overall budget of two billion euros. Reading the famers they will collect revenue from the tax on water punction. At the same level is the CB oversees drafting the SDAGE. Each basin as plan attached to it and will manage the resources in water accordingly. It is revised every years according to the WFD (Cours des comptes, 2023). Each basin has a reference prefect (prefects are the representatives of the state locally), which is called prefect de basin.

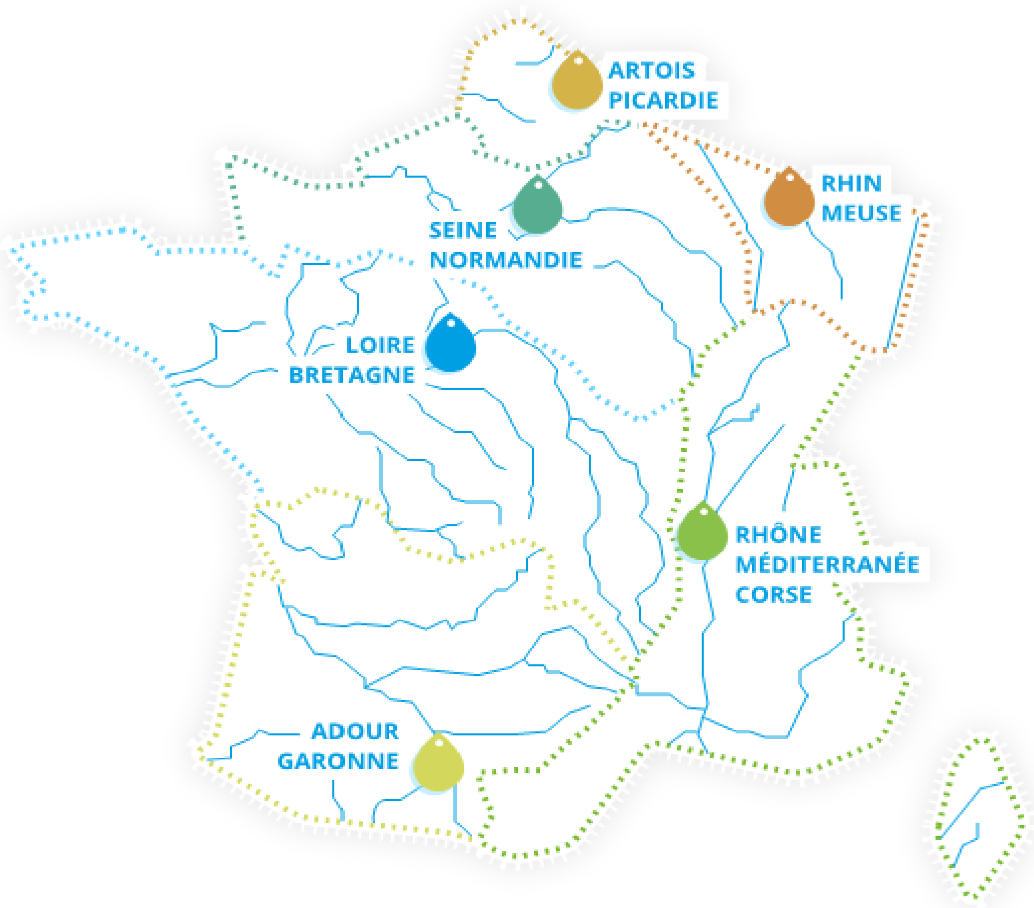


Image 1 Map of "Agence de l'eau" perimeter Source: Agences de l'eau, 2024

At the department (more than a municipality less that an administrative region) level the prefect will also play the role of coordinating the action of the state. They will be the authority in charge of the “Arreté restriction temporaire des usages de l'eau”, or temporary restriction of water use these are local decrees to stop activities related to water in scarce time.

Provided for under article “R211-66 du code de l’environement” they allow to temporary restriction on the use and stock of water. A recent decree (Ministry of Ecological Transition and Territorial Cohesion, 2023) from the ministry of ecological transition, added a scale on which added alert threshold and appropriate actions (see box). This the main tool to take proper action when facing droughts in France.

At the under-basin level the “Commission locale de l’eau” or Local water commission will draft a “Schéma d’Aménagement et de Gestion de l’Eau” SAGE or water development and management plan. This plan will give the guidelines for the quantity and quality of water. However, not every under-basin has signed a SAGE, in 2021 it covers only 53% of the territory (Cours des comptes, 2023, p. 147)

Level of warning *(Ministry of Ecological Transition and Territorial Cohesion, 2023)*

vigilance:

heightened staff awareness of the rules of proper use and water conservation, according to a written procedure posted on site.

alert:

reduce water consumption by 5%.

reinforced alert:

water consumption reduced by 10%.

Since the 2006 law, in certain area farmers willing to irrigate need to request to a "organismes uniques de gestion collective" (OUGC) or unique collective management organization. These OUGC ought to draft a "Plan annuel de repartition" or annual repartition plan, which needs to be approved by the department prefecture. They are the administrative body that will do the repartition of water and the collection of taxes. It is often the "chambre d'agriculture" or chamber of agriculture, that oversee this responsibility. However, this collective management is criticized due to the lack of transparency as the chamber of agriculture are not able to give a detailed survey of the irrigation use, at a local level. (Cours des comptes, 2023, p. 104).

The Figure 2 provides a mapping to better identify the complexity of water management in France. Detailing at each level gives the actors and tool we mentioned above.

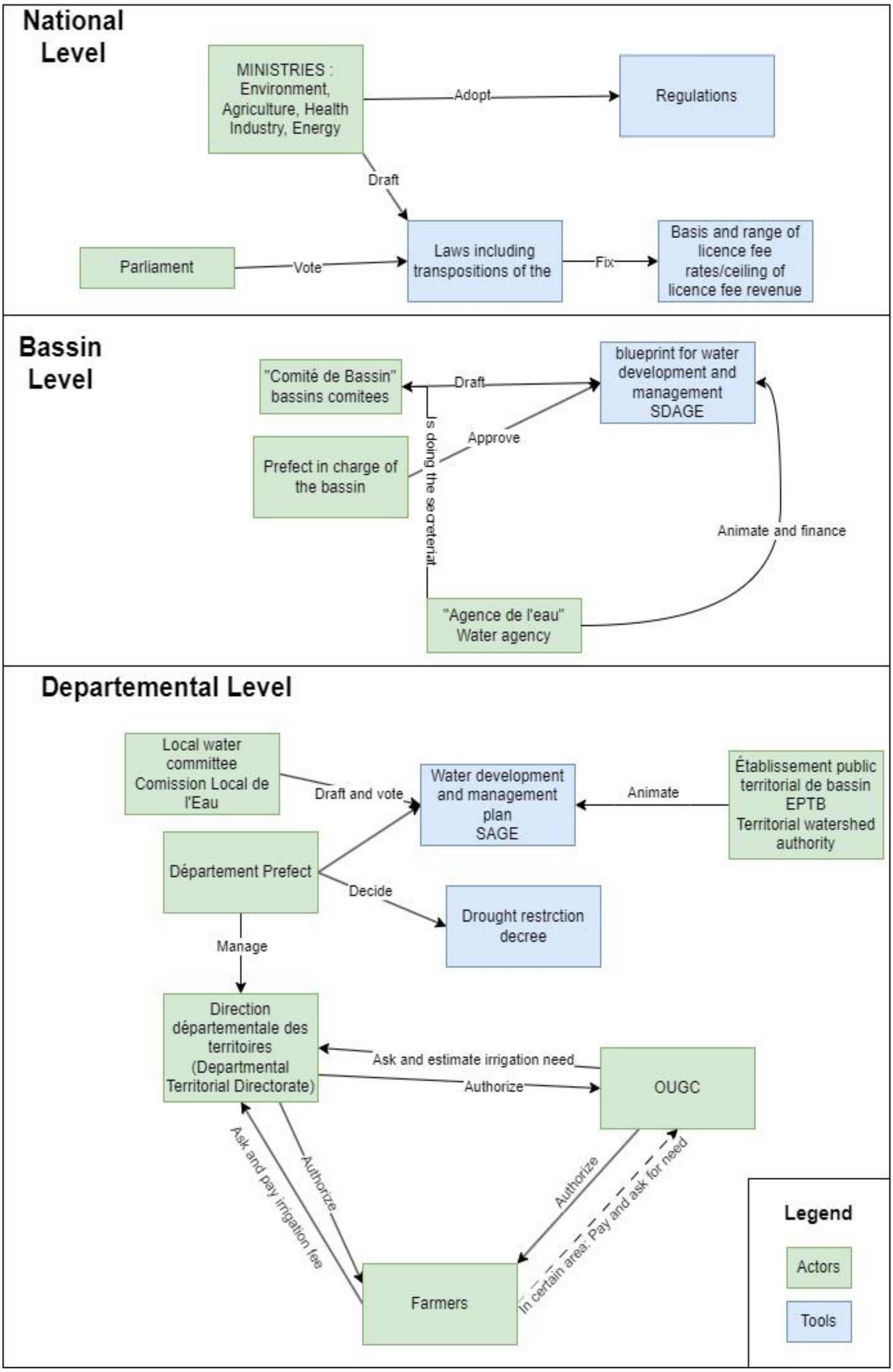


Figure 2 Functioning of the water management in France Source: (Cours des Comptes 2023) and own additions.

3.3 France agriculture and the rise in drought.

In this section we will research the different effects global warming has in France and on the prevalence of droughts, and what scheme farmers adopt to cope with such difficulties.

3.3.1 French agriculture

Before diving more into the question, we are going to do a panorama of what agriculture in France is. According to the last census done in 2020, France has a total of 269000km² in used agricultural area (UAA), which is 49% of the territory used for agriculture. Most of the farmers own less than 20 hectares. The part of the area used for crops is equivalent to the one used for cattle, about a third of the total land use. France is cultivating less and less cereals and more fibre plants (linen notably) and pasture. The north of France uses more of the land for agriculture. And the biggest exploitations are located more in the east, like in champagne or near Paris in Iles de France.

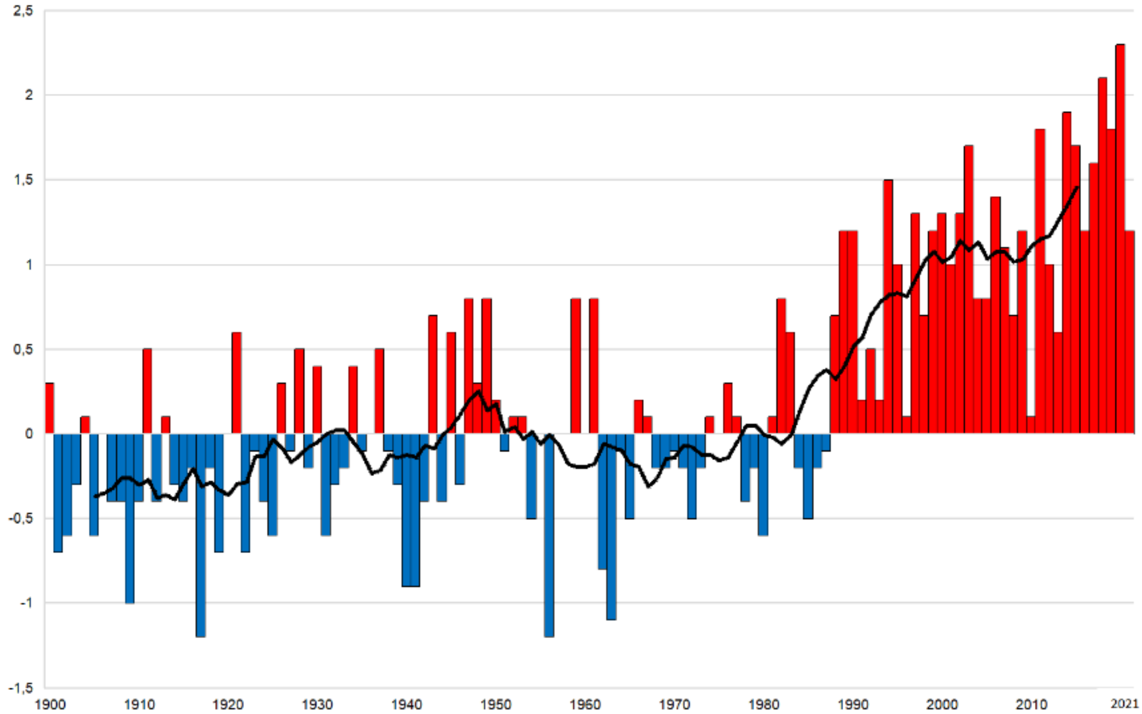
Today a bit more that 813000 people work in agriculture, falling drastically since the 1970s, back then it was more that 2 million people. Most of the farm workers are working for themselves. It is a small part of the work force that is seasonal or outside of the family. More than 50% is individual companies and less than 40% is limited responsibilities or cooperatives companies. The age structure of the profession is centred around 50 to 60 y.o.

Crop wise, France cultivates mostly wheat with 33 684 056 tonnes produced which is one percent of the total export done by France, then barley at 11 374 843 tones and finally maize at 10 842 633 tones. All agricultural products combined, France has a global trade share of 4%, exporting to Europe and Asia (Source). France produces a lot of bovines which is the main component of the livestock produce followed by pork.

3.3.2 Global warming in France

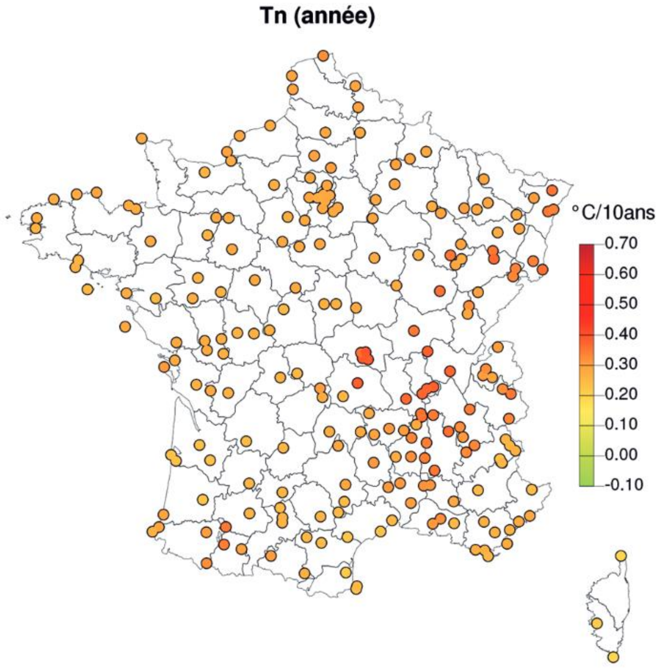
France is highly threatened by global climate change. In this part we will make a summarization of the main indicators of climate change and asses its importance.

The first effect we can see in France is the rise of temperature. Graph 1 gives us a fair idea of this overall rise in temperature on the last three decades. In France temperature has been above the normal temperature from the period 1961-1990. This count for a gap of 2.7 °C compared to the same period. (Ministère de la Transition Écologique et de la Cohésion des Territoires, 2023) Recent projection using new projection models find that rise of temperature will be at 3.8 °C on average (Ribes *et al.*, 2022, p. 1405).



Graph 1 Normal deviation of mean temperatures since 1900 (1961-1990 normal) Source: Météo France

There is regional disparities on the impact of climate change in France if we take Image 2 we can see that the southeast quadrant of the map is more touched. The minimal and maximal averages are both impacted but we find more extreme maximal again in the southeast.



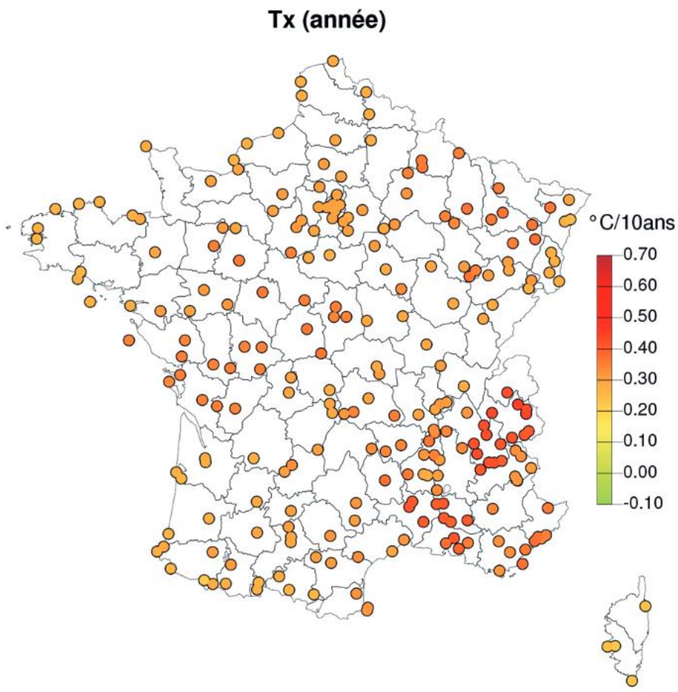
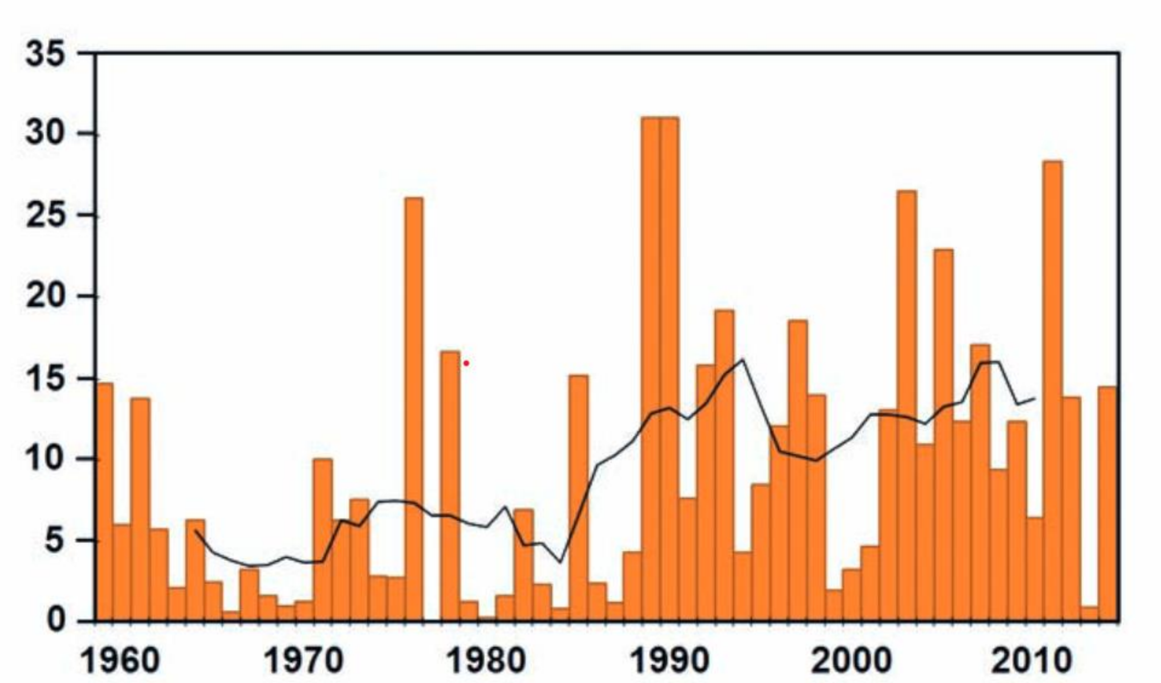


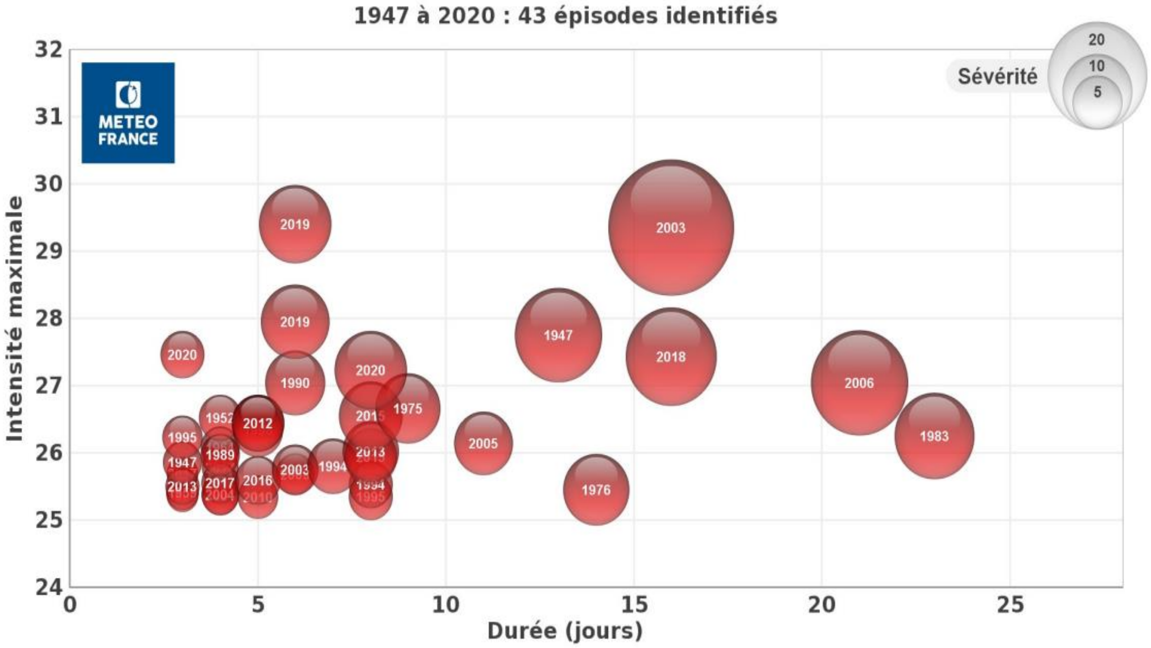
Image 2 Tn (yearly) Average minimal temperature, Tx (yearly) average maximum temperature in C°

Another important consequence of global warming is the precipitation changes. The north of France have seen an augmentation in precipitation when the south have seen less rain. (Dubuisson and Moisselin, 2006, p. 9) Something concurred in multiple projections. (DRIAS, 2020) The south of France will be more impacted by climate change as we just saw through multiple studies. The practical part will go deeper into the subject. Also, agricultural lands are affected, "Météo France" did a calculation of the impacted land until 2015, we can see in Graph 2. Averages growing constantly since the mid eighties.



Graph 2 Evolution of the average annual index of the surface area of metropolitan France affected by agricultural drought over the period 1959-2014. Source: Météo France

We see different consequences among the years, as the lowering of the low flow particularly in the Garonne and Seine, less snow and underground water reducing. Moreover, the ET is increasing, as proven by the Climfourel30 study, which shows a significant increase in ET around the Mediterranean during May to August (from 40 to 60 mm, i.e. an increase of 4 to 6% per decade depending on the region). This climatic variable stands for the most significant change affecting agricultural production and groundwater recharge. This leads to an additional water deficit in summer, while a possible increase in winter precipitation could lead to excess water, generating constraints just as damaging as summer droughts.(AYPHASSORHO *et al.*, 2020, p. 15). Moreover, the size and frequency of the events are expanding. With more drought since the 2010, which we can see in Graph 3.



Graph 3 Heat Wave observed in France and their severity, days on the x axis, maximal intensity on the y axis, size of the bulble is the severity Source: Soubeyroux et al., 2022

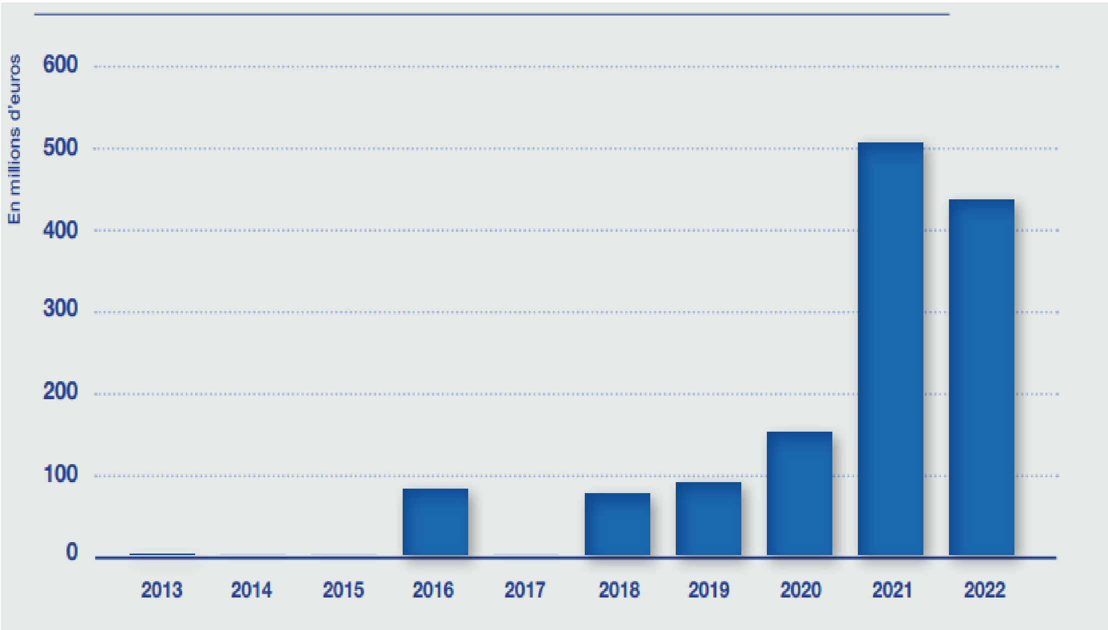
Additionally, we can see several other types of consequences in France due to the global climate change. Not all regions are touched the same way, number of different consequences outside of drought can be seen. We will see more flooding, submersion, cyclones. All these consequences will influence agriculture and farmers.

To conclude this part, we can add that there are growing political conflict around the question of repartition of water usage. Today the main use is for agriculture, but the more pressure there is on water supply the more the way to use water is contested. France has seen last year a conflict around the creation of substitution storage for water supply. This so called “basin” are made by farmer in agreement with the state to puncture water form under and overground sources, during the winter for summer times. These basins are of a major scale and with winter-time scarcity increasing the tension on the resources start to grow. The tension was so high that protestor tried to stop the project in a clash with the police as the government defends harshly the project. However, critics are coming also from institution, arguing that this kind of reserve might not be the most efficient due to the rise of evapotranspiration and the proliferation of bacteria. (Cours des comptes, 2023, p. 84) Today in France the subject as taken such a scale that the media call it the “water war”. (*Le Monde.fr*, 2023)

3.3.3 Risk management and remediation.

After drought events there is several remediation schemes put in place to avoid economic damages and food security jeopardy. Even though part of this remediation is made through specialised insurance scheme, France as development a mechanism of compensation called the “Fonds national de garantie des calamités agricoles” (Notional guarantee fond of agricultural calamities, FNGCA). Such calamities are larger than just the question of drought, but drought is a significant part of the schemes. It is a complementary part of their insurance coverage. It covers for around 30% of the damages. The calamities regime is triggered by a 30 % fall in yield.

When a drought leads to an "agricultural disaster", farmers can be compensated by a special fund: the FNGCA, financed by the State and farmers (additional contribution to the insurance premiums on their insurance contracts). The recognition is done at the prefecture level, which draft the file and lead an investigation. The Ministry of Agriculture then confirm afterward the demand, it is then that the individual demand can be done. Graph 4 shows the consequent rise in demand of coverage which corroborate the rise of temperature and the fall of precipitation in the south of France. It should be noted that this crisis are not only drought but are connected to global warming.



Graph 4 Expenses for compensation and management of agricultural crises linked to climatic hazards (million euros) Source: I4CE, 2022

The rise in covered events is also a growing charge on the state fund. It is estimated that damage of to avoid physical consequences rose from fifty-five million in 2013 to 71 million in seventy-one million in 2022. As well as the economic compensation, today 286 million are given to that matter.

This part was beneficial to understand better the complexity around drought management. We have seen the different way to qualify and quantify drought. The diversity of indexes and mythologies around multiple research field make the subject a symbol of the need for transdisciplinary approaches.

Soon after we analysed the law and legal framework of water management to better understand the question of allocation of water. Then we have studied the different tool for crisis management such as the decrees and state insurance policies.

4 Comparison of the state decrees, the FADN and the meteorological data

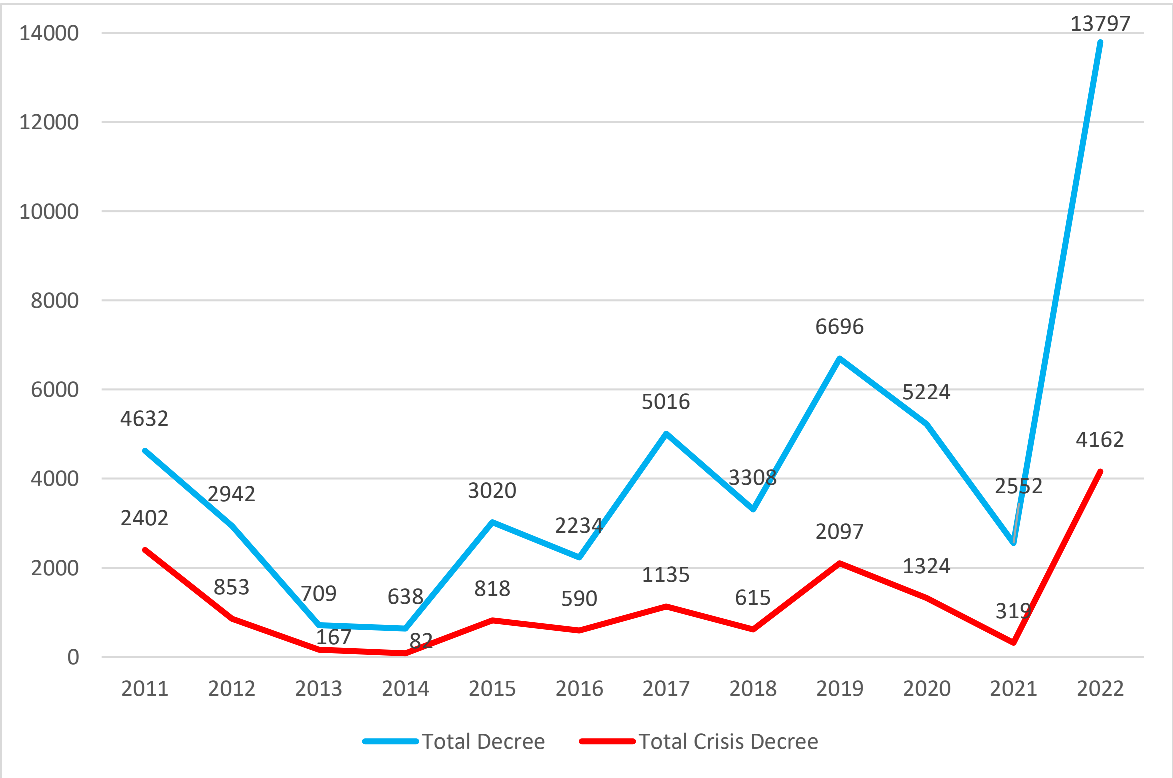
This section will be divided in two parts, the first will make a portrayal of the data extracted during the processing and their key insight on the three aspects of the databases that were created. The second part will be about modelling and testing those models using OLS, LSDV and other types of methodologies.

4.1 Response of the French State to droughts

In the theoretical part, the French states means of action to reduce water consumption through the prefectures decrees was explained. As, how water scarcity can affect agricultural land. In this part the number, size, and duration of the restriction will be shown. This will allow for a more thorough analysis of the state action about drought, and it will help to demonstrate the impacted areas of France a regional level. As restriction might foster the effect of drought on agricultural output.

These decrees are of four different categories. The guide for restriction gives details about it. Level 1 is called Vigilance; it will mean that the public will be informed and sensibilized about the usage of water. The same goes for the famers, and local authorities. They will also start to draft anticipation measure with the OUGC. The second level is called “Alerte”, this time restrictions are in order. Among which we cannot irrigate private garden between 11h00 to 18h00. For the famers, they cannot use sprinkler irrigation between 11h00 and 18h00. There is no limitation for water destinated to farm animals. Collectively the OUGC needs to provide specific modalities. The third level is the “Alerte Renforcé”. It will extend the hours of irrigation restriction between 9h00 to 20h00. Like on the previous level the OUGC needs to draft proposition of specific management. Last level, the “Crise” or crisis level, this time all sprinkler irrigation must stop, and drip irrigation is restricted for new seeding. For animals prefectures can choose whether they allow it or not. The OUGC cannot allow for more irrigation to go ahead. This corroborates what we have seen in the legal part with the graduation. However, in the dataset there is seven levels, without going into the details, they are the old different levels with the last one being the full stop off unnecessary withdrawal.

To be able to properly assess the crisis level in the dataset, a function was coded to take only into account the level above five, which are the crisis level. This to consider only the tougher times, where water irrigations are on a full stop. Thus, showing where the farmers are the most affected due to irrigation abstraction ban.



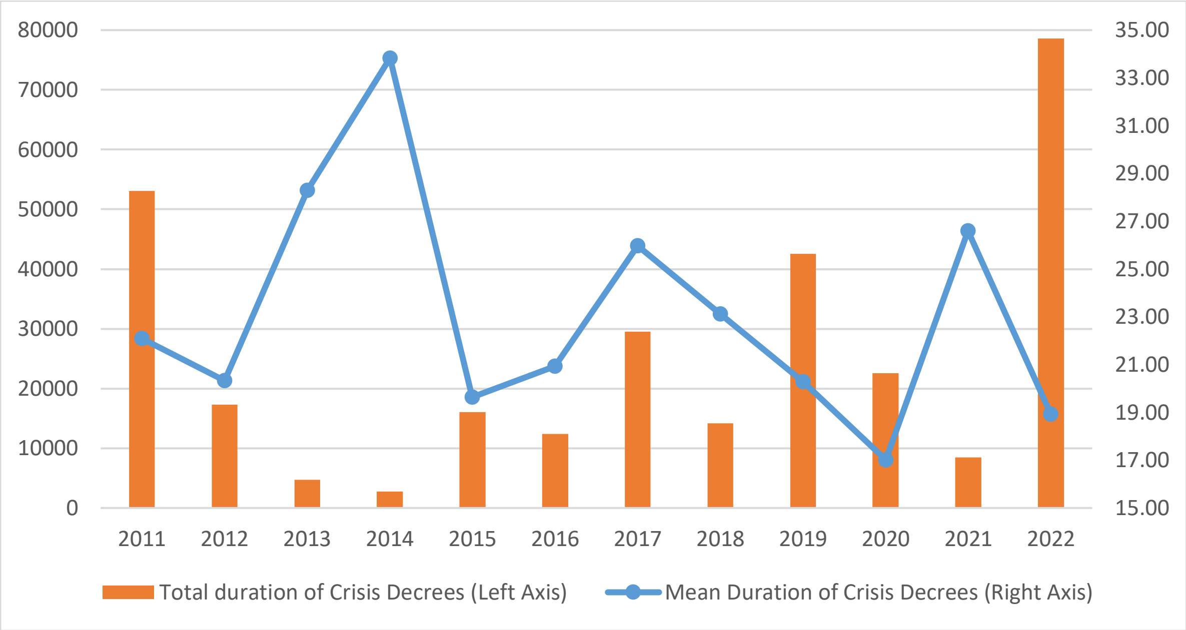
Graph 5 Number of Decrees in France from 2011 to 2022 Source: Own Calculation

According to calculation, in France in 2022 a total of 13797 decree were taken by the different prefectures, among them 4162 were crisis decrees. Graph 5 show that the period of 2012 to 2019, was on a bandwidth of a thousand in 2017 to a lowest of 82 in 2014. 2019 is an exception being need the record of 2011. However, the last year of the sample has seen decrees skyrocketing going up to 4162.

This constat cannot be taken alone as we miss a dimension of the problem. Analysing the decree by itself would not show the real strength of crisis. To better assess the impact of a crisis we need to study the duration of a crisis and its surface. The first one will give an idea of the length in time of the crisis knowing that the damage can be more important over time. With the second one we will get insights about the area touched.

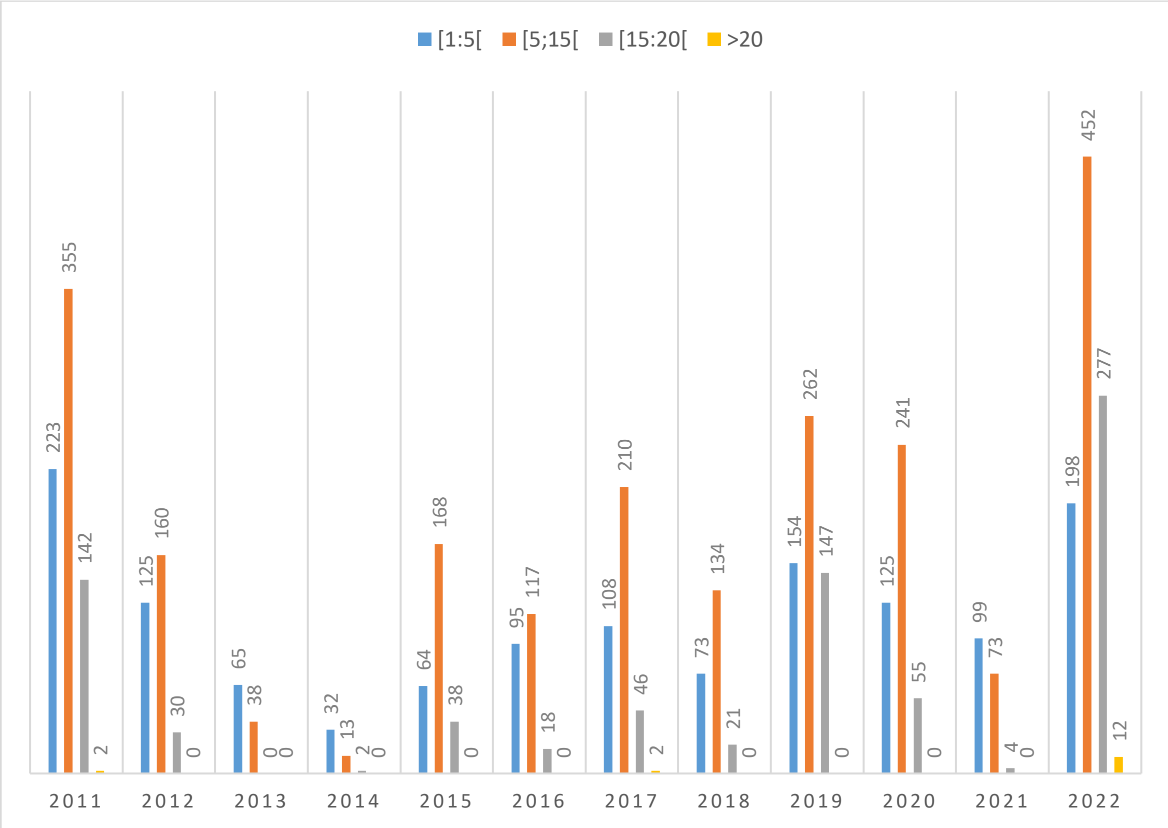
The duration of the crisis was compute using the mean and the sum to make a comparison of both in Graph 6. Of course, due to the mathematical relations of the mean and the sum, the mean is high when the sum is very low. Also, the sum in day, is for all the decrees and might concern multiple time the same zone. Nevertheless, we can see some interesting key points. Like the year 2019, 2097 crisis decree were signed, for a total of 42551 days averaging of 23.11 days per decrees. This year was among the strongest on all indicators, high in volume, mean, and quantity of decrees. Again, we find coherent results with the surge in decree in 2022, which will be analyse later. Moreover, the year 2011 was also an important year, with a total of 53044 days of crisis.

We will make a focus on the year 2019 and 2022 to analyse the form of the distribution. For 2019 we have a median of 13 days against 10 days in 2022. Despite 2022 being the most impressive year, fifty percent of the distribution is under 10 days, there is a stronger place of shorter decrees. However, the longest duration happened in 2022 when compared to 2019, with a decree that lasted for 153 days.



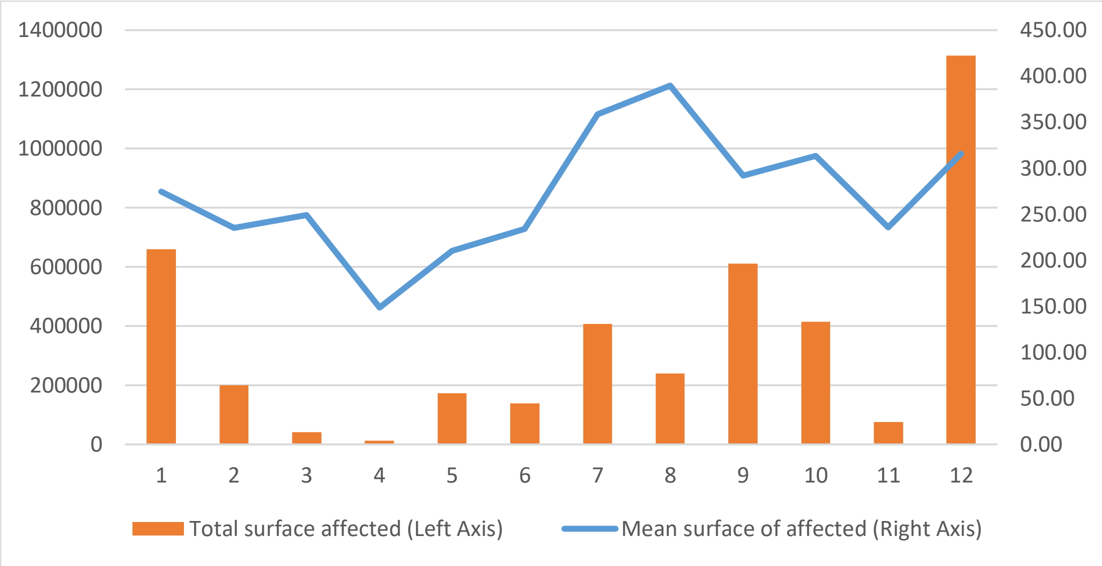
Graph 6 Total and mean duration of crisis decree in France Source: Own Calculation

About the same analysis was conducted on the surface indicator in Graph 8. It is important to note that again the total area is more than the total area of France due to place being affected multiple times by drought. This time again we find the strong years, 2011, with 660 000km² affected by crisis decrees, 2019 with 611 000 km2. With this last graph we can prove that the year 2022 was highest in every mater since the last 11 years with 1 300 000 km² touched. Yet, on average its lower that the rest of the time, this is because of the rise in the number of decrees as a lot of them were signed on the same period.



Graph 7 Number of times a same place was impacted by a crisis Source: Own Calculation

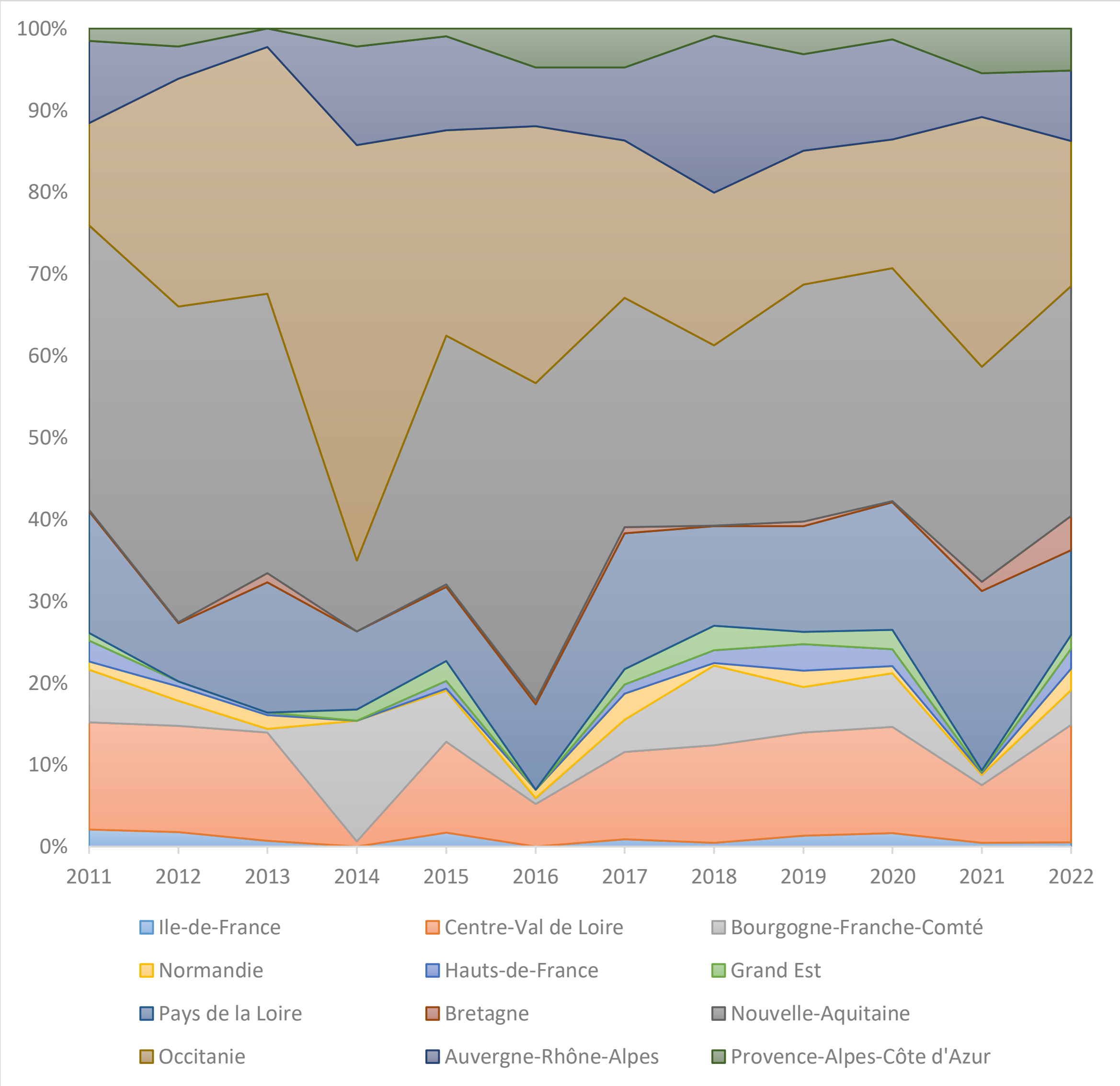
Once more, when comparing 2019 against 2022, the number of times a same place was affected was plotted in Graph 7. We perceive that the crisis in 2022 as seen more places changed overall, which is expected due to the size of the crisis. Though, 2022 has seen two areas being affected up to nineteen times, when the maximum time a same place was impacted in 2019 was six places twelve times. Only 2017 and 2011 has seen places begin affected more than twenty times.



Graph 8 Surface affected by crisis decrees Source: Own Calculation

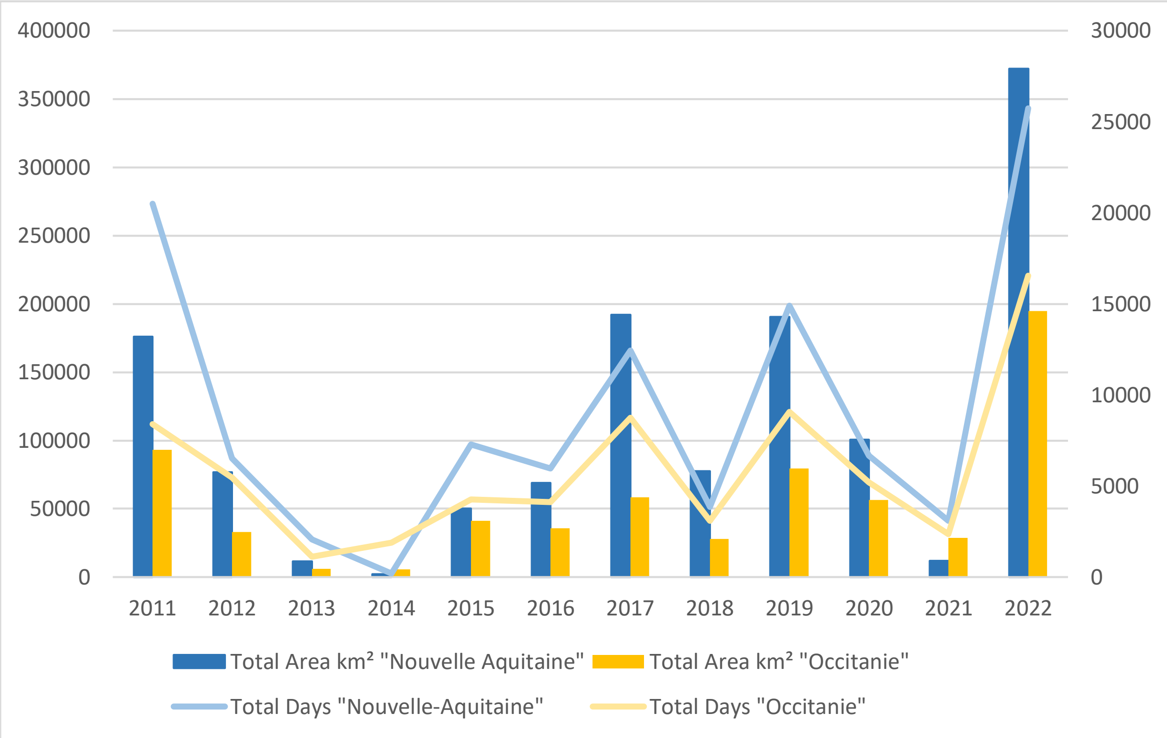
Figure 3 Map of France with surface area

Now that we described the most impacted years and the size and area of the impact, we can compute the same but including regional disparities. All regions have different structure in size, type of production, population, etc. The main influence factor for our analysis is the size of the regions we can find in Figure 3. If we compare the region size to the number of decrees, we can see that the bigger one get the most decrees. However, there is some exception to that, the "Auvergne-Rhône-Alpes" get less twice decrees that the slightly bigger "Occitanie". This can be explained by first region being more mountainous than the second one. In Graph 9 we can observe stronger years, which will account for time a region was getting more decree that another. The "Occitanie" in 2014 was the most touched by restrictions when the "Auvergne-Rhône-Alpes" got a strong 2021. The "Grand-Est" region is the outlier here; it is a big region but rarely hit by drought decrees. This, and the fact that "Normandie", "Bretagne", are also on the lower side is explained by the climate and geographical position of the regions. They are all in the most northern part of France and in more rainy regions.



Graph 9 Share of the total number of decrees per Regions Source: Own Calculation

To better grasp the decrees locally we will run the same indicators as before, for the most hit region, “Occitanie” and “Nouvelle-Aquitaine”. Graph 10 shows the relation between duration in days and the km² impacted. There is a relationship between both, when there is a great number of decrees, the duration and size also follow. Only in 2014 the “Occitanie” had more impacted days, but it was a less impacted year overall. The analysis of the frequencies gives us results similar of wat we saw earlier, places are in general touched one time, but a bit less than half are touched multiple times. “Nouvelle-Aquitaine” is always above “Occitanie”, to the exception of 2017 where more places has been affected two times.



Graph 10 Duration and surface of crisis decrees Source: Own Calculation

This analysis was the opportunity to see what is the extend of the state restrictions in France. Giving interesting insights about the different aspect of the question. Still, we are missing a step in analysing the relationship between farms revenue, drought, and state actions.

4.2 Weather data and the state action.

One question is remaining from the previous analysis, what happened in 2022? To have a rough idea of the question weather data should be analysed. To this extent and as described in the methodology part data from "Météo France" was used. Compiling data from 2011 to 2022. The main indicators used are the yearly average of maximum daily temperatures (maximum temperature), the yearly maximum temperature, and yearly total precipitation. They were compiled this way to allow for a comparison with the other data, especially allowing for linear regression with the FADN. Though monthly data show a better picture of weather variation.

Still, weather data bear it shares of acumens. Firstly, when compiling the maximum temperatures and the absolute maximum temperature we have more insight. We find that 2011, like shown previously is a hot year with a maximum of 42.8°C degrees which is only beaten by 2017 and 2022. As for the average maximum temperature 2011, 2018, 2019 and

Table 4 Temperature maximums, average and absolute

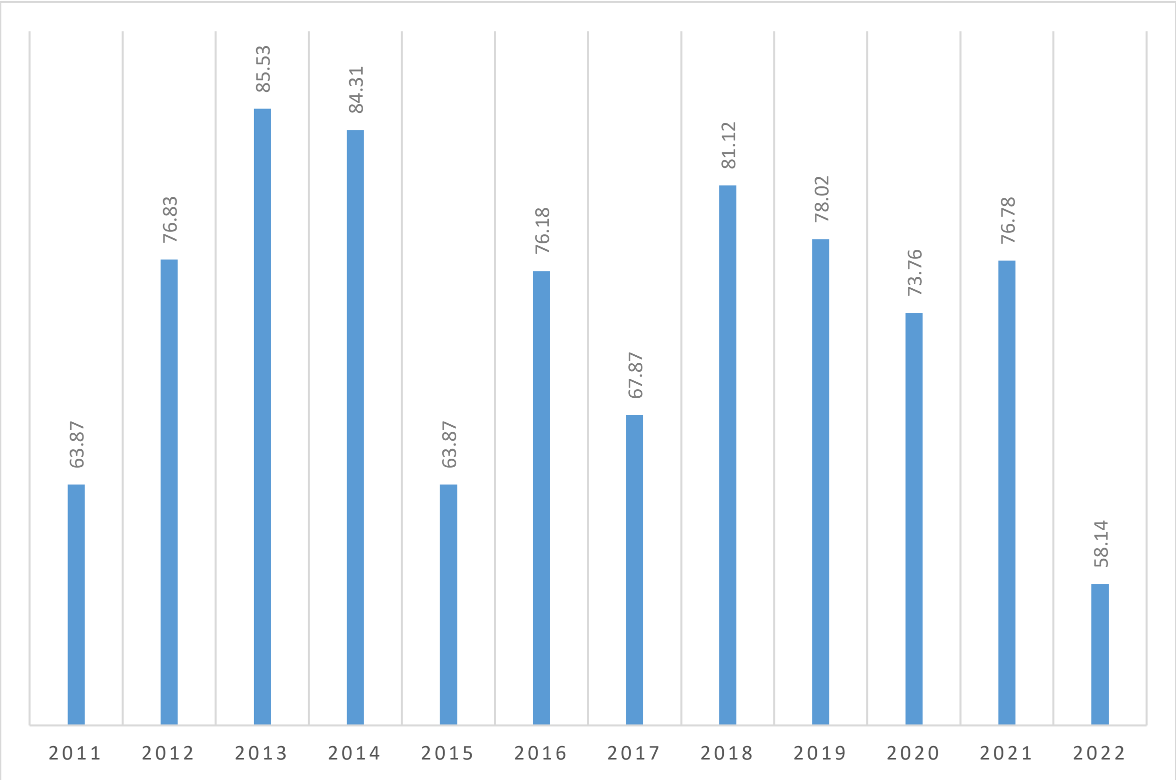
YEARS	YEARLY MEAN OF MONTHLY MAXIMUM TEMPERATURE	YEARLY MAXIMUM TEMPERATURE
2011	17.26	42.8
2012	16.07	42.3
2013	15.30	41.5
2014	16.98	40.3
2015	16.99	42.7
2016	16.35	41.5
2017	16.80	43.1
2018	17.19	42.5
2019	17.12	46
2020	17.67	42.7
2021	16.22	41.2
2022	18.23	43.6

Source: Own Calculation

2022 are the only one above 17°C. These averages are very sensitive to the variation in temperature occurring along the year, thus the apparition of the maximum yearly temperature. We have an explanation factor for the high level of decrees in 2022 in this

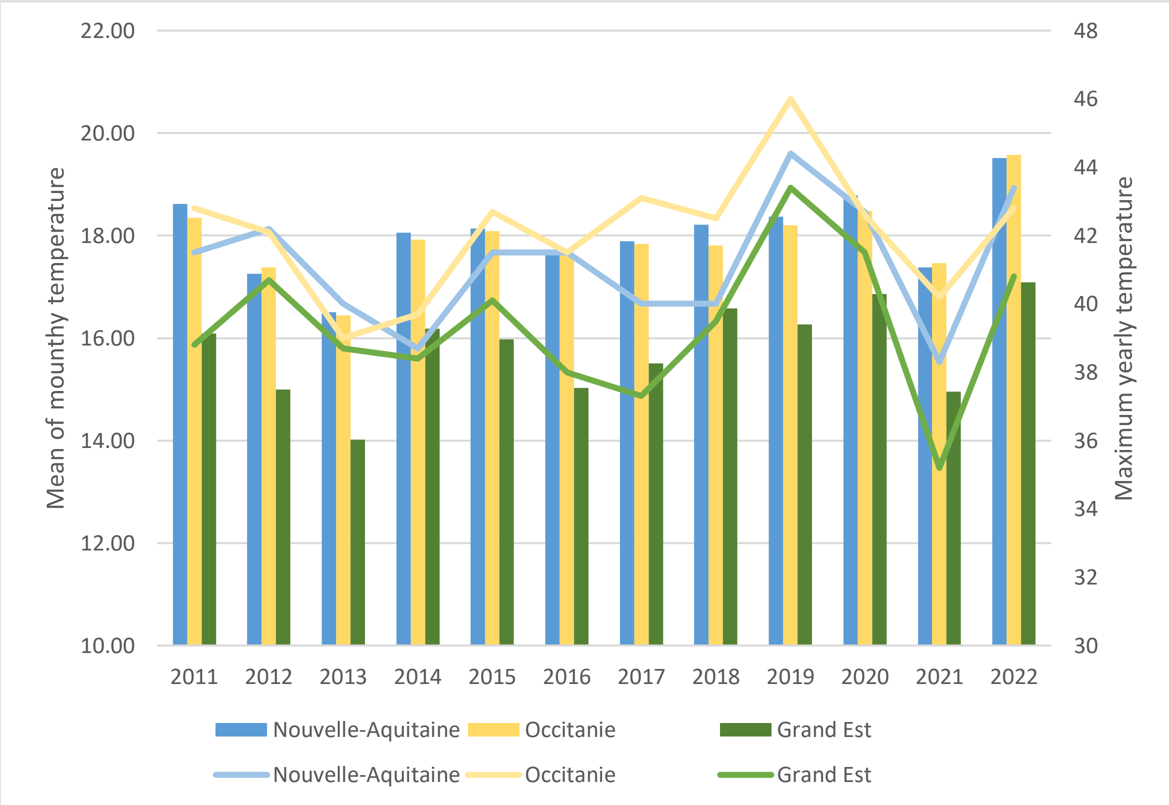
data, as it was a particularly hot year. Indeed, 2022, as high mean temperature, and high absolute temperature and the average being at 18.23, more than 0.5 from the earlier record. The year 2019 is also important here with an all-time high of forty-six degrees Celsius.

To further our comprehension of the problem precipitation data where added. It is a simple tool to comprehend the dryness of territory, even though it does not account for the humidity or absorption of the soil. Graph 11 show the evolution of the average of total precipitation in millimetres along the years. This corroborate what we find earlier for 2011 and 2022 as being dry years. However, 2019 received quite high compared to other hot year. This can be explained by a more wet year the rest of the time.



Graph 11 Average of total precipitation in mm Source: Own Calculation

Again, this analysis lacks a regional setting to access which region were the most affected by the weather disparities. Using the same three indicators. Comparing the three regions we already mentioned (Graph 12), we can notice a similar trend to the trend as mentioned in the previous part. Although comparable in size we see the effect of meteorological particularities. The “Grand-Est” is on average and on absolute less hot than the two others, therefore being less affected by droughts decrees. And the results are also in coherence with the hot years we already pointed out. With 2019, again being the hottest of all, and 2022 experiencing a rise. However, the average temperature is higher in 2022 due to more hot temperatures in general.



Graph 12 Absolute maximum and maximum monthly mean temperature Source: Own Calculation

Precipitation wise, the trends are similar for all the three regions, to the exception of 2018 in “Occitanie” were we observe a pick in precipitation. “Occitanie” is exposed to a meteorological event called the “Cevenols”, which cause high precipitation on a short time, therefore flooding. For the two other regions, there is a fall in precipitation in 2022.

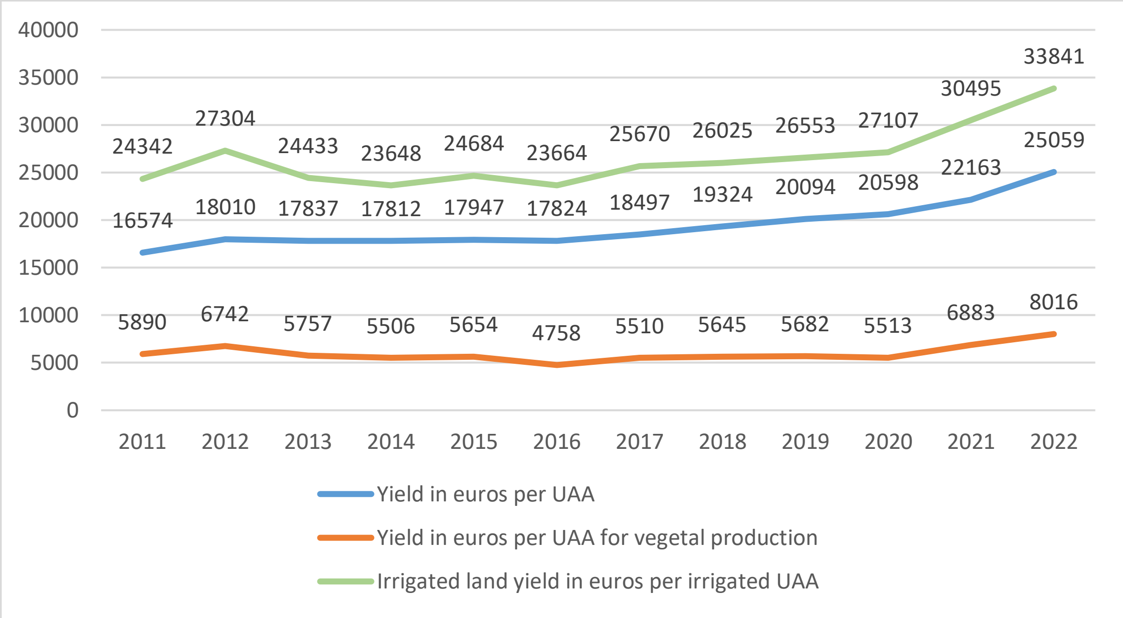
This part showed the link between temperature, precipitation, and the rise in the number of decrees. It is worth noting that during the analysis the use of CDI was attempted, unfortunately there is a technical complexity in extracting country specific CDI from Copernicus unified NETCDF files. It needed a level of coding and times hardly achievable for this piece.

4.3 Farm revenue and droughts

Before linking our three types of data an analysis of the FADN data is needed. To this extent, France is producing every year detailed accounting data on a representative sample of around seven thousand farms per year. There are numerous indicators in the database that we can use for our analysis. The first step was to select to one related to our topic. Due to the lack of access for departmental data, the regional echelon was selected. Indeed, there is a 6-month procedure to access departmental data as they are under the seal of secrecy.

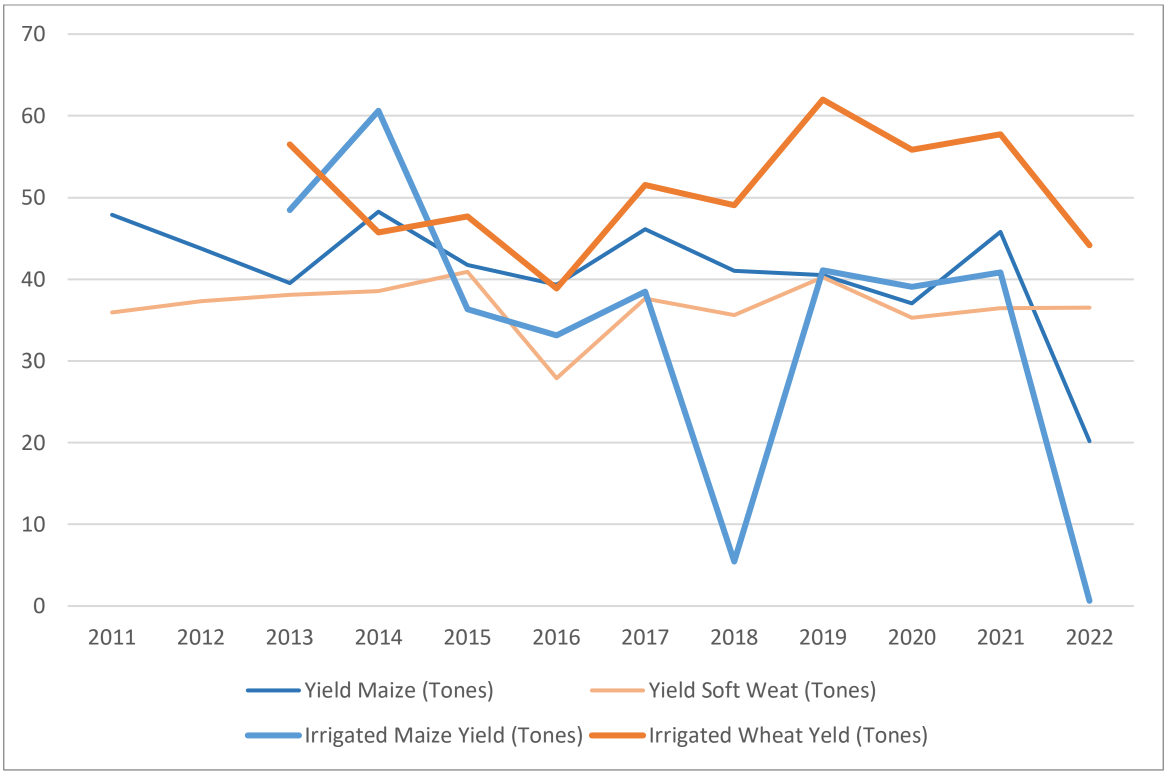
The variable picked for this analysis are of three nature, revenue, cost, and production. For the revenue, the mean total revenue per year was calculated for every region. For the costs, we used the mean yearly irrigation and public waters cost. Finaly for the production, the total, overall, vegetal and animal, in euros and particularly maize and wheat production in tones or in euros. When it was possible, yield indicators and cost intensity were computed.

To begin with Graph 13 shows the evolution of yields on our sample for all the agricultural production as well as only for vegetal production. The evolution of this monetary yield was steady until the last two years where we have seen better yield. To further our understanding of the question irrigated land yield was added. This yield only considers farm that use irrigation. We can see in Graph 13, that the growth is a steady as the other yields, but the overall return is way better per irrigated land use. This data shows no fall into overall yields during hotter years pointed earlier on.



Graph 13 Agricultural Yield in France Source: Own Calculation

To be able to see the effect of drought on production wheat and maize are going to be compared. These two types of crops are being selected because they are having different sensitivity to weather changes. Maize is very sensitive to the lack of water when wheat is less. Graph 14 show the evolution of yields in our data set, soft wheat yields are stable over time when maize is experiencing a fall over time. Although higher at many points, the years 2022 makes a compelling example of the fall the yield are falling to fifteen tonnes per UAA. At the same time, the total maize UAA felt of 12 % against 42% in the same period for wheat. Making the fall of maize productivity more important. To explain this fall and in the context of our analysis we can start to see the link with the rise of temperature, the fall of precipitation and the rise of decree made by the state. But the decrees are more a consequence of the weather as well as the fall in yield. In Fig .. we can see evidence of this phenomenon, when irrigated land both wheat and maize has seen the yield fall, when the non-irrigated wheat stayed stable.



Graph 14: Irrigated and no irrigated yield for wheat and maize per UAA Source: Own Calculations

On the comparison of regions, "Nouvelle-Aquitaine" happened to be the biggest maize producer followed shortly after by the "Grand-Est". The "Grand-Est" in our sample always has been more productive that the "Nouvelle-Aquitaine". Yet all the region has seen a fall in productivity, but the "Grand-Est" stays on top. Regarding the wheat production, the yields were stable all-around France being less affected than maize by the climatic condition.

Yet the question of the farm revenue is still a stone unturned, overall farm revenue of our sample grew since the last twelve years although they were a fall of one point of revenue in 2013 and 2016, the 2022 as seen an increase of twelve point of revenue. Unfortunately, this matter needs a thesis by itself, and no Gini-coefficient or Lorenz curve where computed.

For our subject, the structure of water cost as well as the evolution of revenue for maize famers as well as the cost structure of water are going to be scrutinized. The maize famers revenue underwent in 2013, 2016, 2019, the biggest fall was in 2016 when the revenue suffered a of minus 14% compared to the previous year. 2022 as seen a minus 10% from the previous year. For the wheat farm, the variations are less important with a pick in 2020 at minus 8%, the years 2021 and 2022 are years of growth of 17%. Overall, the revenue of maize farmer as grew more than the one of wheat farmer. If 2011 is a base one hundred, wheat farmers are at 138 points when maize farm at 145 points.

It is complicated to assess for any conclusion form this data. The cost structure might give better results, for that matter the costs insensitivity of water was calculate. This is a ratio between the total costs and the irrigation water cost, the same was done for public water cost. From 2011 to 2021 the share of irrigation costs were stable at around 0.26%, though in the year 2022 this cost doubled. Among the region that pays the most in irrigation we find the "Occitanie" with up to 3 percent of the cost being irrigation cost, with the cost having tripled in the past year. "Occitanie" was one of the most hit by drought and we can explain this rise by the plants need becoming higher. Globally we find results that corroborate the fact that southern region pays more in irrigation water. Yet "Nouvelle-Aquitaine" is not one of them, with only 0.39 percents of their cost in irrigation water. On public water cost we also see the recent rise, notably in "Occitanie" too, but some region of the north part appears to be more presents.

5 Econometric models of the relations between revenue, weather, and state actions.

The earlier parts were an opportunity to build a good set of knowledge about the three aspects of our analysis. We have shown the rise in decrees due to scarce weather condition and displayed the regional disparities. The third part developed on yields aspects and revenue stream disparities. Unfortunately, the last part was not enough to make the link between water restrictions and the losses in revenue.

The economic field provides many tools to assess for this kind of relation between variables. For this purpose, multiple econometric models were designed to assess for a linear relationship between our variables.

The first one to tested is the relation between revenue, and weather data of our panel data. After checking for collinearity, model (1) was designed.

$$Revenue_{mean} = \beta_{i0} + \beta_{i1} Max\_Temp + \beta_{i2} Max\_Temp\_Absolute + \beta_{i3} Max\_Temp + \beta_{i4} Dummy\_Duration + \beta_{i5} Dummy\_Surface \quad (1)$$

Where, the revenue is the mean revenue in a year in euro, Max_Temp is the average maximum temperature in degree Celsius, Max_Temp_Absolute is the maximum temperature recorded in a year in degree Celsius, Dummy_Duration is a dummy when 1 is a duration above the mean duration in the region, Dummy_Surface is one when the surface is above the mean of the region.

Since we are working on panel data there is a need to identify if we can use a unique fixed effect model or a multiple fixed effect model. One of the ways to have within fixed models is call Least Square Dummy Square (LSDV) variable, it uses dummies to assess for the particular effect of classes in panel data, in our case to assess the regional effects. Then it is computed in an OLS model. Using Gretl, we get this result for testing for differing group intercepts - Null hypothesis: The groups have a common intercept

Test statistic: $F(11, 127) = 24.1604$

with p-value = $P(F(11, 127) > 24.1604) = 3.9038e-26$

We can therefore reject the null and move to use a LSDV to assess for a difference in intercepts. To do so dummy were created with Gretl, to assess for each region in our panel.

Table 5 Pooled OLS on Revenue_mean

Included 12 cross-sectional units
Time-series length = 12
Dependent variable: Revenue_mean

	coefficient	std. error	t-ratio	p-value	
const	−136136	127378	−1.069	0.2872	
du_1	37551.4	19704.7	1.906	0.0589	*
du_2	1491.96	18345.1	0.08133	0.9353	
du_3	13174.9	19729.1	0.6678	0.5055	
du_4	72220.0	18335.6	3.939	0.0001	***
du_5	51262.3	21282.9	2.409	0.0174	**
du_6	30860.9	20040.2	1.540	0.1261	
du_7	98060.8	18790.2	5.219	7.13e-07	***
du_8	187175	18914.2	9.896	1.83e-017	***
du_9	−46052.5	18380.2	−2.506	0.0135	**
du_10	−83454.6	18097.5	−4.611	9.62e-06	***
du_11	−52267.1	21627.0	−2.417	0.0171	**
Max_Temp	17149.4	6150.37	2.788	0.0061	***
Max_Temp_Abs	2762.00	2044.78	1.351	0.1792	
Mean_Precipitati~	−66.3999	434.130	−0.1529	0.8787	
Mean_Crisis_Dura~	−145.873	186.810	−0.7809	0.4363	
Mean_Crisis_Surf~	8.53216	16.5030	0.5170	0.6061	

R-squared	0.734062	Adjusted R-squared	0.700557
F(16, 127)	21.90963	P-value(F)	4.49e-29
rho	0.663745	Durbin-Watson	0.670033

In Table 5, Mean_Temps, Mean_Temps_absolute have a positive effect with the temperature effect being the strongest. In economic term it would mean that the more the temperature is the more the revenue is which is counterintuitive. This is the same kind of counterintuitive relations from the Crisis area also have a positive effect. This could be explained by the winner looser relation. Fall of revenue in certain area making the revenue in other.

The results we are getting are not satisfactory due the high pvalue of the distribution on many of our regressor. In matter-of-fact maximum temperature is the only one with a low enough p value to conclude for a significant relationship. Also, the Durbin Watson test is at 0.67, telling for an autocorrelation of the error term, meaning the OLS assumption were not meet.

To correct the homoscedastic nature of our regressed data, a weighted linear regression was done to incorporate the error term in the regression giving a weight factor for our regressors. Before using this solutions, multiple technique had been tested notably Newey-West and Cochrane-Orcutt method, however they gave mixed results with a Durbin-Watson still too low.

Using Gretl again we obtain:

Table 6 WLS on Revenue_mean

Included 12 cross-sectional units					
Dependent variable: Revenue_mean					
Weights based on per-unit error variances					
	coefficient	std. error	t-ratio	p-value	
--					
const	490264	87388.1	5.610	1.07e-07	***
Max_Temp	6148.15	4253.44	1.445	0.1506	

Max_Temp_Abs	**−5823.76**	**2084.04**	**−2.794**	**0.0059**	*******
Mean_Precipitati~	**−1244.77**	**309.344**	**−4.024**	**9.39e-05**	*******
Mean_Crisis_Dura~	**−317.862**	**177.913**	**−1.787**	**0.0762**	*****
Mean_Crisis_Surf~	**22.0006**	**12.8082**	**1.718**	**0.0881**	*****

Statistics based on the weighted data:

Sum squared resid	**129.5852**	**S.E. of regression**	**0.969032**
R-squared	**0.185651**	**Adjusted R-squared**	**0.156145**
F(5, 138)	**6.292089**	**P-value(F)**	**0.000027**
Log-likelihood	**−196.7330**	**Akaike criterion**	**405.4660**
Schwarz criterion	**423.2849**	**Hannan-Quinn**	**412.7066**

Table 6, gives the results of this regression and they are more satisfactory, the p-values are higher to the exception of the maximum average temperature. We have a negative relationship with the maximum temperature, the precipitation the duration. And a positive relation with surface although quite low. The highest fall in revenue in the model is attributed to the absolute temperature. Showing that a rise of 1 degree, make the revenue fall of 5823 euros of revenue. Precipitation seems counter intuitive as normally less rain will create a fall in revenue. In this model, less rain would mean a rise in revenue.

This model as a strong F test, with a lower p-value, which means it statistically significant. However, the R2 of the regression is quite low, with 18 percent of the data variation explained by the model.

To see a bit more through the question of the relation between revenue and the climatic condition and the governmental actions. To better understand the subject, we will use the same regressor but with yield using the UAA and the production in euros, as the endogenous variable.

$$YieldineurosperUAA = \beta_{i0} + \beta_{i1} Max\_Temp + \beta_{i2} Max\_Temp\_Absolute + \beta_{i3} Max\_Temp + \beta_{i4} Dummy\_Duration + \beta_{i5} Dummy\_Surface \quad (2)$$

As done previously, we are using the weighted OLS, on the panel data.

Table 7 WLS on Yield in euros per UAA

Included 12 cross-sectional units				
Dependent variable: YieldineurosperUAA				
Weights based on per-unit error variances				
	coefficient	**std. error**	**t-ratio**	**p-value**
const	**12235.1**	**8243.86**	**1.484**	**0.1401**
Max_Temp	**1787.52**	**368.692**	**4.848**	**3.31e-06 *****
Max_Temp_Abs	**−485.955**	**191.658**	**−2.536**	**0.0123 ****
Mean_Precipitati~	**−51.5849**	**30.3432**	**−1.700**	**0.0914 ***
Dummy_Duration	**−53.5827**	**821.499**	**−0.06523**	**0.9481**
DummySurface	**−761.290**	**926.902**	**−0.8213**	**0.4129**
Statistics based on the weighted data:				
Sum squared resid	**102.8128**	**S.E. of regression**	**0.863146**	
R-squared	**0.231840**	**Adjusted R-squared**	**0.204008**	
F(5, 138)	**8.330022**	**P-value(F)**	**6.62e-07**	

In Table 7, we see that the p-values of this model are less interesting than the previous ones, but we get a significant one for the maximum temperature. The R2 is better also being at 0.20 for the adjusted R2, the R2 ponderated by the degree of liberty.

On the results side, we find the same weight of the absolute temperatures that in the earlier regression. As well as a similar sense of variation for the precipitation. The average maximum temperature is having a positive effect on yield.

Comparing both regressions, we see similar results, to the exception of the surface dummy, which have a bigger impact.

The next model computes the same regressor but for maize yield to assess again the relation with our variable. Maize yields this one calculated by tones per hectares. Maize being one of the most sensitive crops to weather changes.

$$Yield\text{maizetones} = \beta_{i0} + \beta_{i1} Max\_Temp + \beta_{i2} Max\_Temp\_Absolute + \beta_{i3} Max\_Temp + \beta_{i4} Dummy\_Duration + \beta_{i5} Dummy\_Surface \quad (3)$$

Table 8 WLS on Yield Maize Tones

Included 12 cross-sectional units					
Dependent variable: YieldMaizeTones					
Weights based on per-unit error variances					
	coefficient	**std. error**	**t-ratio**	**p-value**	
---					
const	**55.2523**	**15.6082**	**3.540**	**0.0005**	*******
Mean_Precipitati~	**0.126171**	**0.0544032**	**2.319**	**0.0219**	******

Max_Temp	**−0.852121**	**0.754827**	**−1.129**	**0.2609**
Max_Temp_Abs	**−0.267516**	**0.346226**	**−0.7727**	**0.4410**
Dummy_Duration	**−0.745959**	**1.56077**	**−0.4779**	**0.6334**
DummySurface	**−0.409624**	**1.62934**	**−0.2514**	**0.8019**
Statistics based on the weighted data:				
Sum squared resid	**143.5158**	**S.E. of regression**	**1.019789**	
R-squared	**0.096450**	**Adjusted R-squared**	**0.063712**	
F(5, 138)	**2.946173**	**P-value(F)**	**0.014704**	

The model (3) in Table 8 is inconclusive as the R2 is too low to draft anything from the relationship. Another variant of the model was tested using the production, it gave comparable results.

The last model computed used the production of the production of irrigated land as the endogenous variable.

$$\text{IrrigatedLandYield} = \beta_{i0} + \beta_{i1} Max\_Temp + \beta_{i2} Max\_Temp\_Absolute + \beta_{i3} Max\_Temp + \beta_{i4} Dummy\_Duration + \beta_{i5} Dummy\_Surface \quad (4)$$

Table 9 WLS on IrrigatedLandYield

Included 12 cross-sectional units
Dependent variable: IrrigatedLandYield
Weights based on per-unit error variances

	coefficient	**std. error**	**t-ratio**	**p-value**

--

const	72410.6	15374.7	4.710	5.98e-06	***
Mean_Precipitati~	−323.285	54.8522	−5.894	2.76e-08	***
Max_Temp	−2635.49	628.474	−4.193	4.88e-05	***
Max_Temp_Abs	563.984	335.790	1.680	0.0953	*
Dummy_Duration	1856.35	1464.31	1.268	0.2070	
DummySurface	−2993.37	1500.02	−1.996	0.0480	**

Statistics based on the weighted data:

Sum squared resid	113.7206	S.E. of regression	0.907779
R-squared	0.237886	Adjusted R-squared	0.210273
F(5, 138)	8.615064	P-value(F)	3.98e-07
Log-likelihood	−187.3302	Akaike criterion	386.6604
Schwarz criterion	404.4792	Hannan-Quinn	393.9009

Statistics based on the original data:

Mean dependent var	29722.92	S.D. dependent var	14249.83
Sum squared resid	2.42e+10	S.E. of regression	13253.41

This model (4) however promising is also lacking a R2, the model explaining only 0.23 of the variations as show in Table 9

Multiple ways were tested to assess the relationship between revenue weather and the government decrees. Some giving better results than others. The commentary of the results and comparison with the results will be done in the following part.

6 Results and Discussion

The practical part of this thesis was the opportunity to discuss in detail the relationship between three sets of variables. The prefectural decrees, the revenue of farmers and the weather. To investigate this relation attempt was made to cross three databases very different in nature.

The first part showed a compelling rise in the number of decrees made by prefecture. Indeed, the number of decrees taken by local authorities doubled in the last year of 2022. It also rose in length and duration. Places where affected, multiple times, 12 area experienced more than 20 times restriction decrees. The year 2022 was a lesson for the French government. More and more pressure from the “Cours des Comptes” (Cours des comptes, 2023) and other institution led them to adopt a new decree for the whole territory in June 2023, clarifying the rules for prefecture to manage water scarcity.

Even when compared to a hot year that was 2019, the year 2022 is exceptional on many sides. The fall of average precipitations is also quite compelling, being divided by two. The average maximum temperature is also experiencing a significant rise, from one point in average going to 18.2. It is important to mention that is it an average that can be driven by low and high temperatures, this one point is therefore a big leap from the average temperature. For this matter an extensive work was done by many different institutions to show the extent of the global warming in France. “Metéo France” showed that France is already affected, and studies are multiplying on the question. Forecasting temperatures rise, drought rise, etc. (Mittelberger, Soubeyroux and Batté, 2024)

The analysis done is this thesis would have benefited from the diversity of indicators existing on the question of droughts. A comparison between the CDI index, or the SWI index would have shown when and where the state decides to take actions. There is database existing on the question, but they need a level of technical competences in using software like ArcGIS. Attempt where made during this research to use those files but extracting them for only France took more time and technical resources than available.

Moreover, the “calimité” Agricole regime database could have shown the difference between the recognition of droughts decrees and the decrees we analysed. It would have given a good idea of the gaps between insurance and real restrictions actions. Also it could have been interesting to analyse the hydrological modelling behind the decision making and making a comparison with more complete models like the one provided by (2023).

The literature is however not very extensive on the state effect on drought management. In terms of efficiency, assessing if the French states action does influence the water supply overall. And in term of weighting the effects, the “Cours des comptes” was the main source of information on the subject. However, data is available to make such an analysis.

In our analysis, an endeavour was made to investigate the link between climatic conditions and the revenues of famers. Expending from the FADN data, we were able to prove that 2022 is an exceptional year. At first glance, the yields in euros are growing but when we look in details, we see the yield for weather sensitive crops falling drastically in 2022 to the lowest in 10 years. The difficulty faced during the analysis was to reconstruct seasonal effect, weather event being restricted in time it could be interesting to try to reconstruct seasonal variation. This study did that using seasonal crops, but statistical model might show better results.

Analysis of the FADN database through the lens of drought has been done in the literature by Kapsambelis (2022) by computing a loss function from the FADN database using Olympic mean of yields. Showing the growing losses of famers. The analysis made in this thesis was more done at the surface level due to the attempt of crossing three different databases. It would have been interesting to consider only the FADN database and try to expend from Kapsambelis’ work.

To understand better farmer revenue the FADN is the most useful database, but outside of it, the literature is quite productive also. Few indicator were created to assess the resilience of farm like the Multivariate Standardized Reliability and Resilience Index (Mehran, Mazdiyasni and AghaKouchak, 2015; Guo *et al.*, 2019). Other exist and merit to analyse the problem through the crossing of multiple indicators. Which is important due to multifactorial nature of the problem. Indicators like Risk of Drought Impact for Agriculture (RDrI-Agri; only on Global Drought Observatory) do such things.

Numerous methodologies exist to assess the economic impacts, but there is no unified framework to do so. A list of the different method was made by Logar and van den Bergh (2013), as they surveyed the diverse tentative to do so. But there is no framework that do the analysis like this study's atempt to link the threes aspects. And particularly involve governmental actions into the scope. There is a need for simpler and global model for public authorities to assess the trade-off existing between saving water, preserving food security. The literature also points out that we need to change model specifically around the question of irrigation. The sprinkler irrigation being pointed out as less effective that the drip one. (Mantovani *et al.*, 1995). The type of irrigation playing a key role into the severity of drought. Irrigation being a solution and part of the problem.

In the final part of this diploma thesis, the creation of an econometric model was done on the database created. The linear relationship between weather and revenue was assessed through different lens. Due to the nature of the panel data, some special techniques needed to be used like the LSDV. Unfortunately, the results were disappointing due to a high correlation of the error term. To avoid this problem multiple technics were tested, the most promising was using Weighted Least Square.

It gave interesting results when tested on revenue, with statistically significant coefficients. The absolute maximum temperature showed a huge negative impact on the revenue. And the crisis duration dummies also having a negative impact. However, the precipitations were more interesting as more precipitation mean less revenue. This relation should investigate more to see what the underlining effects are. We were able to corroborate these relations using the Yield this time. Both models gave a R2 around 0.20 and small p value. Other attempts to dig the subject with the same method failed as the R2 was too low.

To further the subject, it would have been interesting to dig the question of drought impact on livestock. Some regions of France, like Bretagne growing pork, can see the rise of temperatures as a problem on cost and liveability of the livestock. A more thorough analysis of the decrees would have allowed to see the exact decision concerning water for livestock.

It is possible to find in the literature few tries of assessing the same relationship however never on panel data. Panel data allows to compute the differences between region, especially LSDV. The autocorrelation problem of the panel data is known and there are methods to avoid the problem. A recently developed method uses support vector machines, which are machine learning algorithms, to make linear regression on panel data more robust (Ji, Wei and Xu, 2023). It uses a bandwidth and minimizing the error term from this bandwidth. It is an interesting method to fight outliers. These outliers where a problem for our regression and is the reasons we used dummies.

Other types of regression where tried tying weather results and the links with revenue or yield. (Salami, Shahnooshi and Thomson, 2009; Lopez-Nicolas, Pulido-Velazquez and Macian-Sorribes, 2017). A new model making the link between hydrological data and economic output is also interesting. (Englezos *et al.*, 2023)

Globally, the results of this paper give an interesting entry point into the questions. The difficulties of panel data analysis and geographical analysis limited the analysis. It would be an interesting contribution to the literature to extend the analysis of the FADN through the lens of drought to provide better analytics tool for policy making. To avoid social costs of farm loss in revue and economical cost of insurance on crop losses.

Conclusion

The rise in drought is a key question for every country around the world. And global warming as put more a more pressure to act and prepare ourselves to face such problems, France is no exception. The French agriculture is under more and more pressure, the rise in temperature, the fall of precipitation creates tensions between the different usages. Agriculture needing a lot of this resource is the leading demand force. To avoid ruptures in the continuum of water supply and loss in quality the state used different tools, such as recognising drought affected area for insurance purposes. But the main emergency tool is the water restriction decree. This thesis proved that there is a rise of this kind of decree especially in the year 2022. This rise was in duration, in length, and in the number of impacted territories.

The main reason for that are droughts, the meteorological induced droughts are growingly frequent. A demonstration was made to show that the rise of temperature and the ratification of precipitation are at the forefront of this mater. Yet, many indicators exist to assess the diversity of drought. It will depend on the nature of the drought; this is why a clarification of the different definitions was necessary.

Among the effects of drought, we find the affliction that farmers face when the resource in water is being less available. Famers are the first affected by this matter. This is why this study had for ambition to assess the effects of weather and restrictions on farmers. To these extents an analysis of the FADN database showed a fall in the yield of maize in the affected regions but not a fall of the revenue overall.

The relations between these three variables were analysed using a weighted least square method, giving mixed results. However, what came out of this analysis is the existence of a negative relation between, the rise in high temperature and revenue. Other relation like a negative relation with the duration of the decree was shown.

With the global warming being a key subject of our societies a needed for tools to analyse the diversity of effects. The international community, the government and the local authority should put double the effort to assess properly the different effect through simple indicators easily accessible to the public. It is a collective problem, and collective solutions should be developed.

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6.1 List of figures

6.2 List of tables

6.3 List of graphs

6.4 List of abbreviations

ADI	Aggregate Dryness Index
CB	Comité de Bassin
CLE	Communauté Local de l'Eau/ Local Water Community
CNE	Comission Nationale de l'Eau/ National Water Commission
ET	Evapotranspiration
FADN	Farm Accountancy Data Network

FAO	Food and Agriculture Organisation
FNGCA	Fonds National De Garantie Des Calamités Agricoles
IPCC	Intergovernmental Panel on Climate Change
LSDV	Least Squares Dummy Variables
NDVI	Normalized Difference Vegetation Index
OECD	Organisation for Economic Co-operation and Development
OFB	Office Français de la Biodiversité
OLS	Ordinary Least Squares
OUGC	Organismes Uniques De Gestion Collective
PDSI	Palmer Drought Severity Index
RICA	Réseau d'information comptable Agricole (FADN)
SDAGE	Schémas Directeurs D'aménagement Et De Gestion Des Eaux/Water Development And Management Master Plans
SPI	Standardized Precipitation Index
UAA	Used Agricultural Area
WFD	Water Framework Dicrective
WLS	Weighted Least Squares
WP	Water Productivity
WUE	Water Use Efficiency