# Climate, Irrigation, and GHGs: A Regional Analysis of EU Arable Land Values

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# Abstract

This master's thesis explores the influence of climate conditions on EU arable land values, pioneering a novel approach that blends the Ricardian Approach models within an Ordinary Least Squares (OLS) framework. By employing this methodology at the regional level of NUTS2, the study offers insights into the interplay between climate and land value. The analysis incorporates the share of irrigated land and greenhouse gas (GHG) emissions as crucial factors, establishing a more comprehensive understanding of their influence and contributions. Key findings reveal that EU arable land values are sensitive to temperature extremes, with irrigation as an effective countermeasure. GHG emissions exhibit a positive, unexpected relationship with land value, suggesting further investigation into this association is needed.

Keywords: *air pollution, climate change, EU, global warming, irrigation, land value*

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My journey through this research would not have been possible without the unwavering support of my supervisors, Shon Ferguson and Adan Martinez Cruz. Their expertise, guidance, and encouragement steered me through multiple projects at SLU in Sweden, and their belief in my potential fuelled my resolve. My deepest gratitude to my parents, Ivana and Zoran, for their unwavering support and understanding. They have always embraced my life goals, even when they seemed distant or daunting, and their love has been a constant source of strength. Special mention must go to my friends Vladislav and Aleksa, who patiently endured my daily complaints about statistical significance and econometric modelling. Their unfaltering friendship provided a much-needed dose of levity and reminded me of the human connections that make this work meaningful.

This thesis isn't just an academic exercise; it's a dedication. It's dedicated to the dreamers, changemakers, and everyday heroes fighting for dignity and a better world. It's a call to action, a trigger to think bigger about climate change and its consequences, to move beyond despair and embrace the hope of a brighter future. It's for all those who dare to dream of a world where sustainability reigns, and justice prevails. It's for those who are ready to roll up their sleeves and work, not just for their own tomorrow but for the collective promise of a better tomorrow for all.

This research is, however, just the first step. It's a launchpad, a springboard for further exploration, deeper understanding, and bolder action. The journey continues. Also, I invite you to join me as we strive to make that dream of a better world a reality.

"If you can dream, you can do it" - Enzo Ferrari.

Filip Marković
Uppsala 2024

# Popular science summary

Imagine you want to invest in agricultural land in the European Union. How much is it worth? The answer depends on the soil quality and location and the weather.

This master's thesis investigated the complex relationship between climate change and the value of arable land in the European Union. It looked at how things like extreme heat, irrigation, and even air pollution can affect how much farmland is worth.

Namely, Extreme heat is terrible for land value: Hotter temperatures, especially prolonged heatwaves, can make farmland less valuable. This is because crops struggle to grow in such conditions, leading to lower yields and profits for farmers. Also, irrigation can be a lifesaver: The good news is that irrigating your land can help counteract the adverse effects of heat waves. The study found that irrigated land tends to be more valuable, even in areas with hot summers. However, air pollution has a surprising effect: While greenhouse gases (in terms of air pollution) are generally seen as harmful to the environment, the study found that they can increase land value in some cases. This is likely because higher $CO_2$ levels can act as a fertilizer for some crops, boosting yields and making the land more profitable. However, it is essential to note that more research will be needed to examine the whole relationship between GHGs and land value.

Overall, this study shows that climate change is already impacting the value of farmland in Europe. Nevertheless, it also suggests that there are ways to adapt, such as using irrigation more effectively. By understanding the complex relationship between climate and land value, we can make better decisions about managing our land in the face of a changing climate.

# Table of contents

# List of tables

# List of figures

# Abbreviations

| Term | Description |
|---|---|
| $CO_2$ | Carbon dioxide |
| EDD | Extreme Degree-Days |
| EDD1 | Days of extreme heat stress (UTCI > 46°C) |
| EDD2 | Days of strong heat stress (UTCI > 32°C) |
| EU | European Union |
| GDD | Growing Degree-Days |
| GDP | Gross domestic product per capita |
| GHG | Greenhouse gases |
| IPCC | Intergovernmental Panel on Climate Change |
| USA | United States of America |
| VOC | Volatile organic compounds |
| $NO_x$ | Oxides of nitrogen |

# 1. Introduction

This master's thesis intends to explore a possible causal connection between climate change and the European Union's arable land values. Therefore, the research question is: *What is the impact of climate conditions on arable land values of the EU in terms of global warming, and does irrigation and air pollution affect the relationship between climatic conditions and land values?* The panel fixed effect regression is implemented based on the Ricardian Approach to establish this connection. Also, this section introduces the background of this master's thesis, followed by its motivation and methodology, aim and main research question, and a summary of structure.

## 1.1 Background

The International Panel on Climate Change (IPCC, 2018) asserts immense risks associated with exceeding a 1.5°C increase in global temperatures compared to pre-industrial levels. These risks include rising sea levels, ecosystem collapse, and severe consequences for human health and well-being. The report emphasized the crucial need to reduce CO2 emissions by 45% (relative to 2010 levels) by 2030 to limit warming within this critical threshold. Moreover, the 2023 IPCC report (IPCC, 2023) estimates a 50% chance that an increase of 1.5°C will be reached between the years 2030 and 2052, emphasizing the urgency of net-zero greenhouse gas emissions due to their detrimental impact on all sectors, especially agriculture and health.

However, in recent decades, the global community has witnessed climate change first-hand every day. Despite this, society continues to endure and adapt to the evolving circumstances daily. According to research by Hristov *et al*. (2020) and Bowen and Dietz (2016), there is a potential for a rise in temperatures until 2050, creating permanent changes in the agricultural sector. This anticipated temperature increase could have varying economic implications for European countries.

Negative influences of air pollution on agriculture are multifaceted and well documented. Local air pollutants, particularly oxides of nitrogen ($NO_x$), are detrimental to plant production. According to Metaxoglou and Smith (2020), high concentration of $NO_x$ pollution from burning coal and other fossil fuels leads to reduced corn yields.

Moreover, the effect of climate change on agriculture is reflected in changes in arable land value, as examined by Mendelsohn *et al.* (1994), Mendelsohn and Dinar (2003) and Ortiz-Bobea (2020). According to these authors, land value is a key variable, as it reflects the influences of climate change on agriculture. Additionally, Sajid *et al.* (2023) showed that global warming decreases farm profitability and its primary value, land value. However, this topic is often studied in the context of the USA, with less research focusing on the EU. To mitigate this problem, farmers develop irrigation systems, which are considered as an effective adaptation strategy to the impact of climate change on agriculture (Babel *et al.* 2014). Namely, through the combined mechanisms of mechanical action and water provision, irrigation acts as a potent agricultural tool for mitigating limitations and promoting improved productivity. Moreover, Mendelsohn and Dinar (2003) show that irrigated crops have higher resistance to climate change than non-irrigated crops.

## 1.2 Motivation, Aim and Research Question

This section briefly represents the paper's motivation, the research question and the methodology.

This thesis aims to analyse climate change's impact on agriculture, specifically focusing on the impact on arable land value within the European Union. The motivation of this thesis is built on the challenge to go one step further and incorporates ideas by Mendelsohn *et al*. (1994), Mendelsohn and Dinar (2003), Ortiz-Bobea (2020), Sajid *et al*. (2023), and Van Passel (2017). Namely, the thesis observes the change in the arable land value of the EU by establishing a connection between land value and climatic conditions, and also to incorporate the crucial element of greenhouse gas (GHG) emissions and irrigation share as interaction terms. To answer the chosen aim, this thesis should answer the following research question:

***What is the impact of climate conditions on arable land values of the EU in terms of global warming, and does irrigation and air pollution affect the relationship between climatic conditions and land values?***

To answer this question a regression model is used, which is explained in more detail in the next section following principles from the connected literature such as Sajid *et al.* (2023), Mendelsohn *et al*. (1994) and Mendelsohn and Dinar (2003).

## 1.3 Methodology

Firstly, to answer the research question a dataset has been constructed. Namely, the historical data have been used from the period 2011-2020. The data is based on several secondary data sources, which is discussed in the later section. In order to answer the research question, this study employs a panel fixed-effect regression model, similar to the approach used by Sajid et al. (2023), where key variables are used such as Extreme Degree-Days (EDD) and Growing Degree-Days (GDD), crop output per hectare, GDP per capita, change in soil moisture and the interaction terms based on the GHG emissions and irrigation share in utilised agricultural area by NUTS 2 regions. The panel fixed effect regression for this thesis is adapted to the Ricardian approach, the same as Mendelsohn *et al.* (1994) and Mendelsohn and Dinar (2003).

## 1.4 Outline

The thesis structure is constructed as follows: the second section presents a literature review. The third Section presents the theoretical framework. The fourth section represents detailed methodology and the fifth data description. In section six, analyses and results are presented. The section seven is a discussion, where results and theory are be compared with current literature and observation of limitation and future improvements is made, and the final section eight presents the conclusion.

# 2. Literature review

This section presents a literature review, and it gives more insight into the literature gap and inter-literature connections, which is organized into four parts. The first part presents the thesis foundation, the second part represents literature for understanding the problem and further extension of the Ricardian Approach, the third provides literature about the impact of climate change and the fourth represents a contribution to the literature.

## 2.1 The Ricardian Approach

The beginnings of land value analysis can be found in Mendelsohn et al.'s (1994) paper, which establishes the connection between land value and climate change. Mendelsohn et al.'s (1994) main contribution is introducing a new approach, called the Ricardian approach. In contrast, previous research was done by using production-function approaches to estimate impacts of climatic conditions. The production function approach directly models the relationship between climate variables (e.g., temperature, precipitation) and crop yields. It requires detailed data on specific crops and agricultural practices, which can be challenging to obtain and can limit the analysis to specific regions.

The Ricardian approach uses farmland prices as a proxy for agricultural productivity. The assumption is that farmland prices reflect the expected profitability of agriculture in a given location, which is influenced by climate. This approach eliminates the need for detailed crop data and allows for analysis across diverse regions. Economic substitution, such as switching crops, is neglected in the production-function approach, leading to biased estimates. Modelling these relationships accurately can be difficult due to the fact that the switch is based on the non-linear relationship between observed factors, leading to uncertainties in predictions. In the Mendelsohn et al. (1994) paper, the analysis was mainly based on temperature change, and the conclusion was that warmer weather leads to higher crop yields. Also, different plants have different responses to global warming, which triggers farmers to switch from one crop to another when temperature changes reach the level when activity drops down. However, this paper left a question – what about the impact of irrigation? In Mendelsohn and Dinar (2003), this gap is filled in terms of irrigation, and the conclusion is based on the fact that irrigation effectively mitigates the effects of climate change. Since Mendelsohn *et al.* (1994) set a strong foundation, many future authors, including this thesis, are based on the seminal paper.

## 2.2 Further extensions of the Ricardian Approach

Concepts used in the thesis are also coming from Ortiz Bobea (2020) and Sajid *et al.* (2023), who include other important factors that affect land values. Ortiz-Bobea (2020) showed that it is important to control for non-farm factors when estimating the impact of climatic conditions on land values. According to Ortiz-Bobea (2020) non-farm factors refer to any factors outside the agricultural sector that can influence farmland prices and, consequently, estimates of climate change impacts derived from Ricardian models. Furthermore, in terms of non-farm factors, Ortiz-Bobea (2020) highlights the importance of incorporating socioeconomic factors as a part of non-farm factors, indicating that Ricardian models can better capture the complex interactions between climate change, agriculture, and the broader economy. This may lead to more accurate estimates of climate change impacts, which is essential for informing policy decisions.

Moreover, Sajid *et al.* (2023) went one step further and proved that the situation in the 21st century is different than at the end of the 20th century since the paper shows that a difference of 1ºC hotter leads just to a land value decrease but also to a net profit decrease. Sajid *et al.* (2023) showed that an increase of 1 °C Celsius leads to a 51% net income loss. Also, the mentioned study reveals that a 1°C warming results in a 7% decrease in gross income and a substantial 66% decrease in net farm income, which finally reflects as the land value decreases.

## 2.3 Impacts of climate change on EU agriculture

Another important set of literature supports the understanding of climate change and its influence on the EU. Namely, Lobell *et al*. (2008) led to a discussion of the potential negative effects of climate change on agriculture and delivered possible ways for mitigation. The leading papers on understanding the potential dangers of climate change are by Jacobs (2019) and Hristov (2020). According to these papers, the European continent will face an agricultural shift in favour of Northern Europe due to temperature increases in the South. Differences in plant activity explain the shift due to temperature change and a deeper picture of what climate change brings with it, including possible plant infections and diseases, not only droughts and floods. The understanding of Kanae (2009) and Shrestha *et al*. (2013) is based on the water elements and their potential to bring negative or positive effects to agriculture.  Also, IPCC reports (2018, 2023) direct to the problem of global warming and greenhouse gases emissions. The reports highlight the connections between climate, ecosystems, biodiversity, and human societies. According to the latest IPCC (2023), stopping global warming to 1.5°C requires cuts in GHG emissions. Delaying action increases the cost and difficulty of achieving net zero and worsens climate impacts. Every change of a degree of warming matters, according to the report. Each additional emissions unit leads to further sea level rise, extreme weather events, and ecological damage, which, in the case of the thesis, leads to a decrease in arable land value.

## 2.4 Contribution to the literature

This thesis builds upon existing literature by focusing on the EU and by including the impact of local GHGs emissions. Namely, Ortiz-Bobea (2020), Sajid *et al.* (2023), Mendelsohn *et al*. (1994), and Mendelsohn and Dinar (2003) all focus on the USA. Van Passel *et al*. (2017) establish the Ricardian analysis of climate change on European land values, concluding that the North and South will feel the impact of global warming differently. However, Van Passel (2017) did not include mitigation in the form of irrigation. Since the EU and USA have different agricultural technologies and habits, the assumption is set that not adding irrigation is not enough to create a complete picture of the climate influence of EU Land Values.

Furthermore, another important difference compared to previous work is that in this thesis the impact of air pollution is analysed. Blande (2010) establishes their potential negative influence on plants, namely harm to vital functions and compromised between-plant communication, which Blande (2010) attributes to high volatile organic compounds (VOCs) and oxides of nitrogen ($NO_x$) concentrations.  Between-plant communication, sometimes called "plant talk," refers to the ways plants can send and receive signals to each other, influencing each other's growth, defence, and resource sharing. Similarly, Metaxoglou and Smith (2020) provide evidence that increased $NO_x$ emissions from fossil fuels lead to reduced corn yields. This decrease is driven by ground-level ozone caused by $NO_x$ reacting with VOCs (Metaxoglou and Smith, 2020), directly affecting plant biological processes. However, Warwick (1988) and Taylor and Schlenker (2021) offer a counterpoint, arguing that elevated $CO_2$, a key GHG component, can also boost productivity. The reason is that plants consume $CO_2$ during photosynthesis, and more $CO_2$ enhances photosynthesis and reduces transpiration. Lin *et al.* (2023) confirmed correlation between emissions of between GHGs and $NO_x$ in China.

Namely, according to Lin *et al.* (2023) high levels of GHGs emissions is positively correlated with high levels of $NO_x$ emissions.

# 3. Theoretical framework

This section outlines theorya behind this thesis. In the beginning, this section starts by describing the theory in previous literature; then, assumptions are presented about how climate change influences land value according to the literature. Also, GHG influence is shortly analysed, and its influence to global warming.

## 3.1 Climatic conditions, land values, and the impact of irrigation

The great number of authors research and write about climate change effects, attempting to connect it with agriculture, the most valuable sector for food production for human and animal use. Namely, according to Jacobs (2019) and Hristov (2020), temperature changes will lead to agriculture shifts of EU. Moreover, Hristov (2020) uses the concept of the 2°C scenario, considering a scenario where the global temperature change on a yearly level exceeds 2°C, pointing us toward global warming. According to the mentioned authors, EU will experience agriculture shift across its regions. What does that mean? Shrestha *et al*. (2013) claim that Northern regions will be able to have a higher yield, more harvests, and a greater variety of agricultural products than before due to the higher temperature. On the other side, a negative impact will be observed in Southern regions, where the yield will drop, as explained by Mendelsohn *et al.* (1994) in terms of lower plant activity due to higher temperatures. However, story does not stop here, namely Metaxoglou and Smith (2020) claim that increased emissions of greenhouse gases ($CO_2$ equivalent) lead to decreased plant productivity. Also, greenhouse gases are considered as one of key factor of climate change and as global warming accelerators, but on the other side Taylor and Schlenker (2021) claim that certain amount of $CO_2$ can increase productivity. However, Mendelsohn and Dinar (2003), which is built on Mendelsohn *et al.* (1994), highlights the influence of irrigation as mitigation measure for climate change, which is represented in the *Figure 1*.

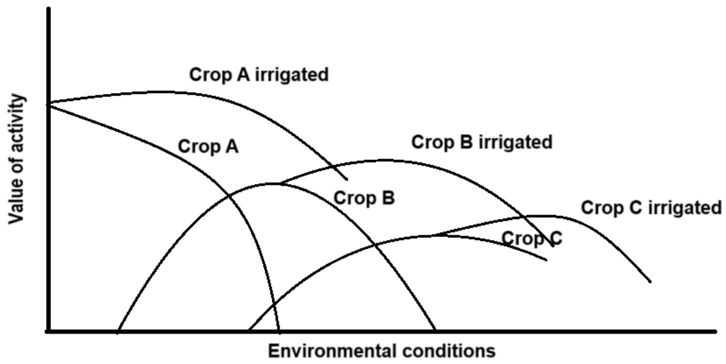


*Figure 1 Bias in Production Studies and influence of irrigation (Mendelsohn and Dinar, 2003).*

*Figure 1* above represents the value of activity corresponding with Environmental conditions, which can be recognised as temperature change. Namely, Crops A, B and C have different potentials in different environmental conditions. As it goes from left to right, the plant activity potential of Crop A decreases, but Crop B increases until reaches its peak, and the same is true for Crop C, where moving from left to right represents temperature change. In theory (Mendelsohn *et al.*, 1994), farmers will switch from Crop A to B at the moment when environmental conditions reach a place of intercept of the function of Crop A and B. Interestingly, including irrigation appears to mitigate the negative effects of the environmental conditions. This is evidenced by increased plant activity across a wider range of conditions.

How do all these connections relate to arable land value? Namely, if the point of view is set from the market of arable land, there are two main sides: Supply and Demand. Since the supply of arable land is mostly constant (*Figure 2*), its impact can be assumed as zero in this research, so the supply side is set as fixed. In this case, agriculture producers are direct consumers of arable land. So, if yields (plant activity) decrease or increase demand for land will follow because higher yield leads to higher profit, which can be consider as the main factor of any firm – profit maximization. Moreover, Sajid *et al.* (2023) establish that profit decreasing relates to arable land value decreasing. Higher profit leads to higher demand. Since supply is fixed, the value of land is determined by demand. Namely, the hypothesis is set that irrigation will have a positive effect on the land value.

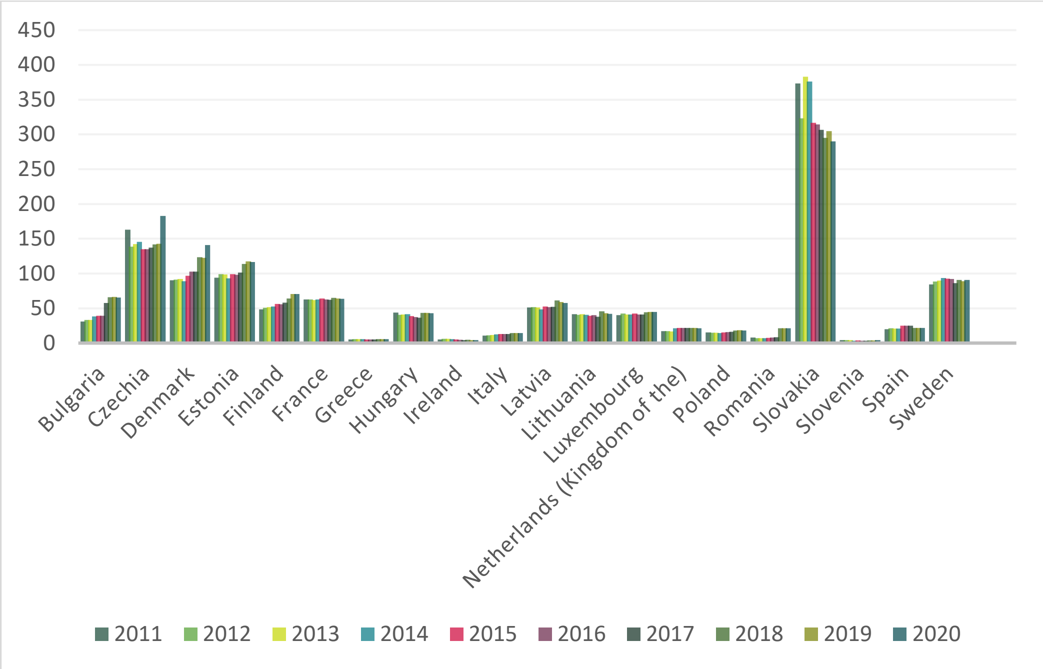


*Figure 2 Value of arable land across European Union (Source. EUROSTAT).*

Figure 2 presents arable land availability in thousands of hectares in time frame from 2011 to 2020.

However, according to Kanae (2009), more than the impact of additional irrigation is needed to understand the change in arable land value. Specifically, the percentage change in cropland soil moisture anomaly, which will be introduced as one of the independent variables in the next section, is another key factor. Kanae (2009) claims that too much or too little water can also positively or negatively influence productivity, directly affecting the observed variable. For example, in cases where there is too much water, the negative impact can be observed as floods or damage due to ice forming in the surface land area. In the other scenario, with too little water, damage is reflected as drought. However, the story does not end here.

## 3.2 Climatic conditions, land values, and air pollution

Another key factor is air pollution, which will be expressed in this thesis as GHGs through $CO_2$ equivalent. Air pollution has two ways to influence agriculture. Firstly, according to Warrick (1988), $CO_2$ fertilisation increases plant productivity, which is shown empirically by Taylor and Schlenker (2021). The assumption is based on Hristov (2020), where greenhouse gases are represented as already being on a high level, which endangers agriculture production. Blande (2010) showed a negative connection between plant activity and air pollution. Namely, plants communicate via volatile organic compounds and putting one of vital function as this in danger leads to decreasing of activity. The study by Blande (2010) demonstrates that air pollution, particularly ozone, can negatively impact plant-to-plant communication through volatile organic compounds. This has implications for the effectiveness of indirect plant defences against herbivores and the overall health of plant communities. Moreover, Metaxoglou and Smith (2020) establish connection that nitrogen oxides as part of air pollution directly influence ozone, which again directly affect plant productivity.

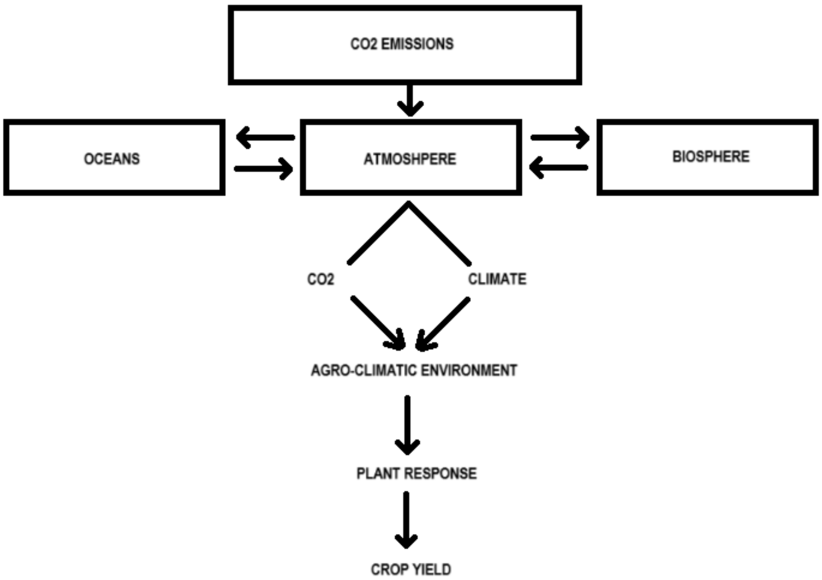


*Figure 3 CO2 influence to crop yield (Warrick, 1988).*

According to Warrick (1988), the Figure 3 presents the diagram of $CO_2$ influences on crop yield (agriculture). Firstly, emissions are partially neutralized by the ocean and biosphere; the rest can be recognized as reflecting its influence through climate change and $CO_2$ particles in the air, which interact in the agro-climatic environment in which plants respond and respond is reflected in crop yield. If the influence is positive, the yield increases, and if it is negative, the yield decreases.

Mendelsohn's method is explained as the hedonic pricing model built on the Ricardian approach, followed by Van Passel *et al*. (2017) in the following section. The methodology for that will be presented in the next section. Namely, the second hypothesis is set here and that is assumption that air pollution in terms of GHG emissions and global warming will negatively affect land values.

# 4. Method

In the light of development, this section presents an overview of the methodologies employed in previous studies and outlines the methodology adopted to address the research question set in this thesis.

Specifically, to answer previously research question and understand changes this thesis will employ the panel fixed effect regression. In panel data analysis involving multiple observations of the same entity over time, panel fixed effects are a statistical technique used to control for unobserved time-invariant individual effects. These effects are characteristics of the entity that do not change over time but might influence the dependent variable, potentially biasing the analysis. In the panel fixed effects regression, the independent variables explain the variation over time within each NUTS2 region. Expanding on the Ricardian Approach, this study delves into irrigation's and GHG’s impact on land value through an Ordinary Least Squares (OLS) as estimator for regression. OLS models linear relationships between variables by finding the best-fitting straight line to the data, minimizing squared residuals, and providing interpretable coefficients that shows the influence of each independent variable to the variation in the dependent variable into a quantifiable language of coefficients. Despite the fact that Ortiz-Bobea (2020) utilized the Generalized Method of Moments (GMM) for solving a problem, this thesis will use simple estimators to avoid misunderstandings. GMM is a statistical estimation technique that matches population moments to sample moments and is particularly valuable in econometrics for handling complex models while addressing issues like endogeneity and measurement errors (Hansen & Singleton, 1982). Notably, all mentioned methodologies can be recognized as variations of the Hedonic price model (Brown *et al.*, 1982), where non-price elements are employed to explain changes in the value of arable land.

A slight terminological difference is observed between this thesis and the previously mentioned authors. In this study, the term "arable land value" is used to specifically denote land suitable for commercial agriculture to prevent any ambiguities. Another important note, this thesis is focused exclusively on the land values, since the rental rates are not available.

To investigate the causal relationships between arable land value and climate parameters, this thesis employs a set of four main regressions, presented below. These regressions aim to elucidate the connections between arable land value and parameters. The first variables are based on the pre-GHG and pre-irrigation levels similar to those of Mendelsohn *et al*. (1994). The second, third, and fourth regression are based on Mendelsohn and Dinar (2003) and Sajid *et al.* (2023) where irrigation share and GHGs emissions are employed as interaction terms. In the second only the irrigation is employed and only GHGs emissions in the third, but in the fourth, both of them.

Based on Mendelsohn and Dinar (2003), The Ricardian model for this thesis relies on the next formulation of a linear regression model:

$$V_{it} = \alpha + \beta_1 F_{it} + \beta_2 Z_{it} + \beta_3 F_{it} * irrigation_i + \beta_4 F_{it} * GHG_{it} + u_{it}$$

Where, V is arable land value, $\beta_n$ is coefficients, F comprises vector of climate variables, Z constitutes vector of soil variables, and G represents vector of economic variables, including market access, $\alpha$ is intercept and *u* represent error term. The variables operate within the framework of time (t), as detailed in Mendelsohn *et al.* (1994). However, this thesis contains data split according to Ortiz-Bobea (2020) on Climate (Environmental), what is *F* according to Ricardian approach and Socioeconomic, what is Z and G. Mendelsohn and Dinar (2003) contains multiple different climate variables, marked with F in the equation above. Also, in the regression are included two interaction variables GHG for greenhouse gas emissions and irrigation for irrigation share, which interact with climate factors. Subscripts *i* and *t* mark respectively region and year.

This thesis employs a stepwise approach to model estimation. Model 1 is estimated without including irrigation or greenhouse gas (GHG) emissions as explanatory variables based on Mendelsohn *et al*. (1994).. Subsequently, Model 2 inspired by Mendelsohn (2003) introduce irrigation as an interaction term with temperature variables. In Model 3, the interaction term is replaced with GHG emissions. Finally, Model 4 combines irrigation and GHG emissions as explanatory variables with temperature interactions.

Robustness check is also conducted with two additional analyses The first robustness check incorporates a dummy variable for geographical position as an additional factor, while the second introduces GDP per capita interaction with irrigation and GHGs.

# 5. Data description

The panel dataset is constructed based on the following two public datasets: EUROSTAT and OECD Public database. The panel dataset contains data for all variables by EU countries on the NUTS2 level and by timeframe from 2011 to 2020.

For the dependent variable, data is taken from EUROSTAT, already known as arable land value per hectare, the same as Van Passel (2017). Also, EUROSTAT provides annual GDP per capita on regional NUTS2 level and 2010 irrigation data. The irrigation data from the year 2010, which is the year before the observed period, is included to avoid endogeneity problems. The socio-economic data, which include variables of GDP per capita and Crop output, are from the OECD database, the same as the environmental data, which include extreme degree days, growing degree days (Sajid *et al.*,2023) and percentage of moisture change. *Table 1* below represents data descriptions.

This thesis focuses on air pollutants but necessitates using a proxy. Due to data limitations, **total greenhouse gas (GHG) emissions** (source: OECD database) are employed as the proxy. While imperfect, GHGs offer several advantages; Lin et al. (2023) showed a correlation between GHGs and other air pollutants, including NOx. GHG data are readily available at the NUTS2 level compared to individual air pollutants, which is crucial for analysis in this thesis. However, GHGs also have limitations as the proxy: carbon dioxide (CO2), the primary GHG, primarily affects climate change and has minimal direct impact on local plant health.

The identified importance of differentiated GHG concentrations in their impact on plant activity is a crucial factor influencing land value, according to Mendelsohn (1994). Notably, utilizing the NUTS2 level of aggregation for both air pollution (establish in total GHG emissions) and the dependent variable ensures consistency in scale and facilitates a more meaningful analysis of their relationship. Recognizing the localized variability of GHG emissions is crucial, as NUTS2-level data may only partially capture the potential impact of industrial areas, regional concentration gradients, and GHG fluxes across border regions. Moreover, it is worth considering that some GHGs, such as carbon dioxide, have transboundary effects, and this research does not consider such effects.

*Table 1 Data description*

| ***Label in regressions*** | ***Explanation*** |
|---|---|
| *Dependent variable of Arable Land Value* | Value of Arable Land per hectare in EUR |
| *EDD1* | Days of extreme heat stress (temperature > 46°C) |
| *EDD2* | Days of strong heat stress (temperature> 32°C) |
| *GDD* | Temperature growing degree days |
| *Crop output* | Value of crop output per hectare in EUR |
| *GDP* | Gross domestic product per capita |
| *Percentage soil moisture change* | Percentage change Cropland soil moisture anomaly |
| *Irrigation* | Share of irrigable and irrigated areas in the utilised agricultural area from 2010 |
| *GHG emissions* | Total greenhouse gas emissions (in Mt of $CO_2$ equivalent) |

The Table 1 above represents summary of meanings all used labels in the analysis. Important note is that every variable is based on the NUTS2 level. Namely, EDD and GDD variables are included in the same regression following Sajid *et al.* (2023), which will be presented in the next section.

The dataset includes data for 81 regions of the EU (Appendix 1) and it is balanced. For each region dataset contains data for whole observed period 2011-2020, except the irrigation data, which is based on 2010, as it is said before. The number of regions is lowered to 81 due lacks continues data for the rest of the regions. Namely, the limitations were found in EUROSTAT, where there are missing arable land values for the year 2010, what caused shorted time-period from 2011 to 2020. Also, not all countries had available data for dependent variable and for irrigation.

*Table 2 Data summary*

| | | **MEAN** | **MEDIAN** | **MIN** | **MAX** |
|---|---|---|---|---|---|
| **Dependent variable** | Arable land value | 18938.81 | 8388.5 | 997 | 133863 |
| **Independent variables** | DDD | 64.39 | 11.70 | 0 | 617.86 |
| | EDD1 | 0.018 | 0 | 0 | 1.74 |
| | EDD2 | 29.69 | 18.8805 | 0 | 128.55 |
| | GDD | 1942.25 | 2196.605 | 0 | 6583.46 |
| | GHG emissions | 13.01 | 9.2105 | 0 | 81.15 |
| | Crop output | 871.43 | 544.625 | 51.91 | 12038.61 |
| | GDP | 24305.19 | 24200 | 7400 | 53200 |
| | Percentage soil moisture change | -0.97 | -0.73 | -19.42 | 23.29 |

Table 2 above presents the datasets mean, median, minimum and maximum of all included variables.

Moreover, none of the variables are highly correlated, which means that collinearity is not a problem for the analysis. (see Appendix 2). However, for the analyses process dataset is demeaned. Demeaning data means subtracting the sample mean from each observation so that they are mean zero.

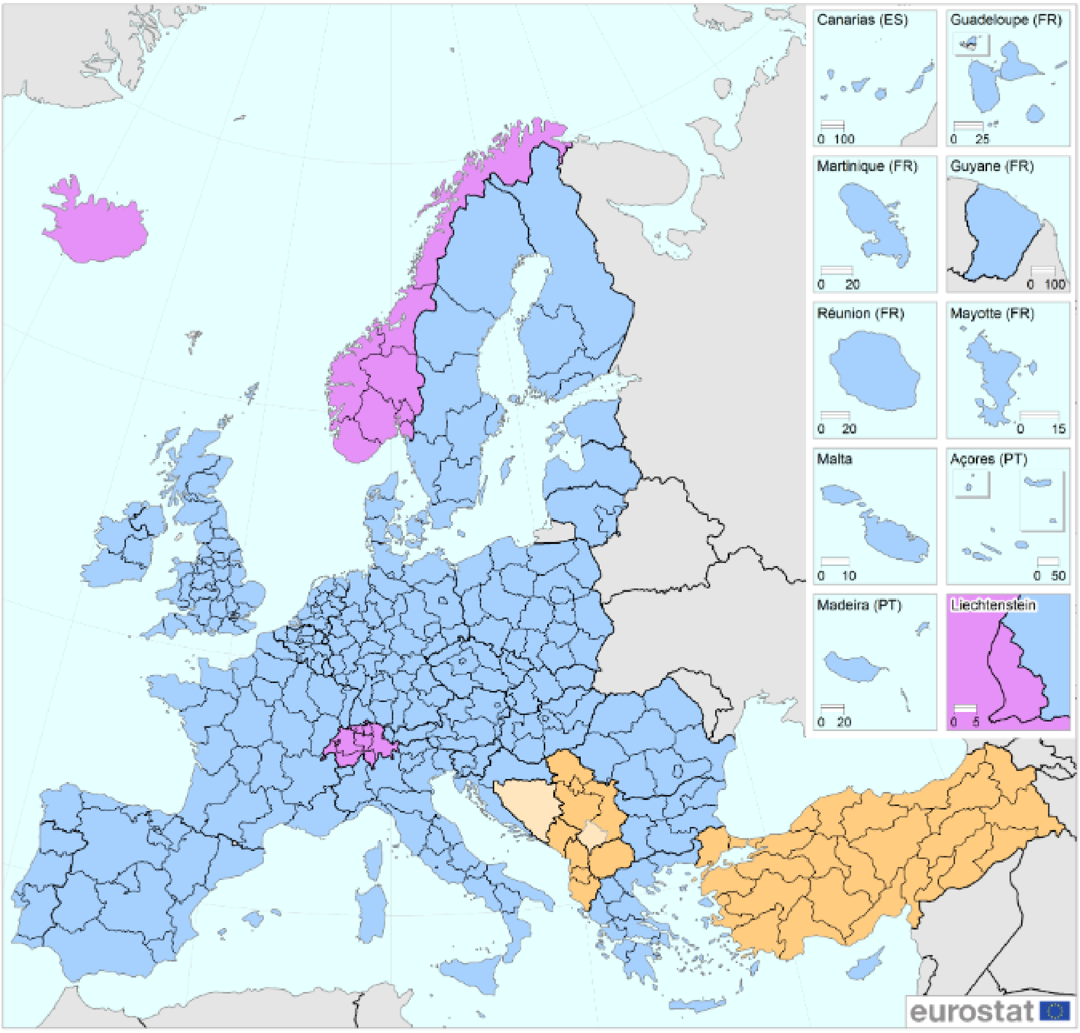


*Figure 4 Map of NUTS2 regions (source: EUROSTAT 2023).*

Previously mentioned NUTS2 regions are presented on the *Figure 4.* Only the regions from EU (coloured blue) are included, the non-EU are not part of this research.

# 6. Analyses and Results

This section presents results of regression analyses.

As it is previously stated, four regression analyses are performed, and they are presented in the *Table 3.* The regression performed in column 1 does not include the effect of irrigation and GHG emissions. The regression in the second column is with included effect of irrigation. The regression in the third column is with included effect of GHG emissions, but no irrigation. The final regression in the fourth column is with included effect of both irrigation and GHG emissions.

*Table 3 Main regression analyses results*

| | Column 1 Arable Land Value (without irrigation and GHG interaction) | | Column 2 Arable Land Value (with irrigation interaction) | | Column 3 Arable Land Value (with GHG interaction) | | Column 4 Arable Land Value (with irrigation and GHG interaction) | |
|---|---|---|---|---|---|---|---|---|
| | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* |
| Intercept | 0.38 | 2.07 | 1.13 | 6.47 | 0.44 | 2.30 | 1.18 | 6.50 |
| EDD1 | 0.01 | 0.08 | - 0.19 | - 1.03 | 0.16 | 1.39 | - 0.21 | - 1.09 |
| EDD2 | - 0.18 | - 2.65 | - 0.30 | - 3.64 | - 0.27 | - 3.31 | - 0.33 | - 3.66 |
| GDD | - 0.14 | - 1.89 | - 0.48 | - 6.91 | - 0.19 | - 2.28 | - 0.46 | - 5.95 |
| EDD1 X irrigation | / | / | 0.01 | 1.66 | / | / | 0.01 | 1.65 |
| EDD2 x irrigation | / | / | - 0.002 | - 0.65 | / | / | - 0.002 | - 0.53 |
| GDD X irrigation | / | / | 0.04 | 13.65 | / | / | 0.04 | 13.47 |
| EDD1 X GHG | / | / | / | / | - 0.13 | - 1.88 | 0.02 | 0.27 |
| EDD2 x GHG | / | / | / | / | 0.05 | 1.44 | 0.03 | 0.76 |
| GDD X GHG | / | / | / | / | 0.01 | 0.28 | - 0.03 | - 0.79 |
| Crop output per hectare | 0.19 | 4.73 | 0.06 | 1.58 | 0.19 | 4.57 | 0.05 | 1.25 |
| GDP per capita | 0.91 | 6.78 | 0.24 | 1.86 | 0.91 | 6.71 | 0.22 | 1.70 |
| Percentage soil moisture change | - 0.60 | - 0.65 | - 1.48 | - 1.84 | - 0.52 | - 0.57 | - 1.50 | - 1.86 |
| *Regression Statistics* | | | | | | | | |
| Multiple R | | 0.29 | | 0.55 | | 0.55 | | 0.55 |
| R Square | | 0.09 | | 0.30 | | 0.30 | | 0.30 |
| Adjusted R Square | | 0.08 | | 0.29 | | 0.29 | | 0.29 |
| Standard Error | | 1.42 | | 1.25 | | 1.25 | | 1.25 |
| Observations | | 810 | | 810 | | 810 | | 810 |

*Note: Coefficients accompanied by robust standard errors reflect the inclusion of panel fixed effects, effectively controlling for unobserved group-specific heterogeneity.*

The first column presents a regression model capturing influences on arable land value per hectare. Building on the framework of Mendelsohn et al. (1994), this model highlights the connection between climate factors and land value. Notably, only the extreme degree-day variable (EDD2) exhibits a statistically significant effect, with each additional degree-day above 32°C decreasing land value by €0.18. This suggests that a higher number of days with extreme temperatures negatively impacts land values. EDD1 and GDD did not show significant results. Conversely, both crop output and GDP per capita display significant positive influences. Specifically, each additional unit of crop output increases land value by €0.19, while an additional unit of GDP per capita leads to a €0.91 increase in land value.

The second column introduces a regression analysis incorporating an interaction term for irrigation. This analysis reveals that extreme degree-days (EDD2) and growing degree-days (GDD) negatively impact arable land value, with each additional degree-day decreasing the value by €0.30 and €0.48, respectively. However, the interaction terms involving irrigation suggest a mitigating effect of irrigation on GDD, contributing a €0.04 increase in value per day. This finding suggests that irrigation might act as a potential buffer against the negative impacts of extended heating periods. Notably, when accounting for these interaction terms, the influence of crop output, GDP, and soil moisture change becomes statistically insignificant in this model.

The third column presents a regression analysis with interaction term for greenhouse gas (GHG) emissions, exploring their impact on land value alongside temperature variables. This analysis reveals that EDD2 and GDD exhibit negative and statistically significant impacts, decreasing the land value by €0.27 and €0.19 per day, respectively. Interestingly, the interaction terms between temperature variables and GHG emissions reveal a contrasting pattern. EDD2 and GDD exhibit positive effect, but with no significance. GDP per capita and crop output maintain the same significant relationships observed in the first column, suggesting that wealthier regions are willing to pay similar prices for land regardless of GHG considerations. However, soil moisture change remains negative, but statistically non-significant.

The fourth column (Table 3) presents the combined effects of previously included factors, GHG and irrigation share. As expected, all three climate variables negatively influence land value. However, only EDD2 can be considered significant, and with every additional day of EDD2, the land value will decrease by

€0.33. Also, GDD reveals significant and negative influence, which will increase land value by €0.46 for an extra day of heating period. This aligns with the findings from the second column. However, the interaction between GDD and GHG reveals a nuanced effect. In this case, none of the interactions with GHG have significant influence. In the case of interactions with irrigation, only GDD has significant influence, which leads to increased land value by €0.04 per additional day of interaction. The influence of GDP per capita and crop output remains consistent with the second column and non-significant.

Overall, the inclusion of irrigation and GHG emissions in the regression analyses significantly improves the level of explanation of the model. The R-squared of the model increases from 0.09 to 0.30 when irrigation and GHG emissions are included. This suggests that these factors are important for explaining the variation in arable land value. The impact of the number of days with extreme and strong temperatures, (EDD1 and EDD2 respectively) on arable land value presents a complex picture in these regression analyses. However, the EDD2 has significant influence in all four regressions, which is not case in of EDD1. On the other side, the lack of statistically significant of interaction terms of GHG and irrigation suggests a limited independent effect, also the lack of significant interactions doesn't fully preclude a nuanced interplay between these factors. Regarding GDD, which has mainly significant results, long heating periods due to climate change threaten agricultural land values. However, irrigation can significantly mitigate this threat, highlighting the importance of proactive water management and sustainable practices for long-term economic viability.

Looking beyond environmental factors, the analysis confirms expected relationships. Higher crop output and regional wealth (GDP per capita) contribute positively to land value, showcasing the crucial role of resource availability and economic infrastructure in determining land profitability.

These regression analyses offer valuable insights into the multifaceted factors influencing arable land value. While the analyses explain a limited portion of the variance, it highlights the complex interplay between temperature extremes, irrigation, GHG emissions, and other climate and economic factors. Further exploration, potentially incorporating non-linear relationships or missing variables, could enhance model fit and provide a deeper understanding of the intricate dynamics shaping land value in the face of a changing climate, the impact of the factors is summarised in the Table 4 below.

*Table 4 Representation of factors influence on arable land value.*

| Factor | Influence |
|---|---|
| *Days of extreme heat stress (UTCI > 46°C) – EDD1* | Weakly negative |
| *Days of strong heat stress (UTCI > 32°C) – EDD2* | Negative |
| *Temperature growing degree days - GDD* | Negatively affected by warmer temperatures, but mitigated by irrigation |
| *Value of crop output per hectare in EUR* | Positive |
| *Gross domestic product per capita* | Positive |
| *Percentage change Cropland soil moisture anomaly* | Negative |
| *Interaction between climate factors (EDD1, EDD2, GDD) and Irrigation* | Positive |
| *Interaction between climate factors (EDD1, EDD2, GDD) and GHGs* | Positive |

Irrigation has a positive effect on arable land value. This suggests that irrigation increases the value of arable land in regions with higher temperatures and longer growing seasons. Despite the hypothesis, GHG emissions positively affect arable land value. Crop output per hectare and GDP per capita have a positive influence, which amount differs if the land is irrigated or not, and percentage change in cropland soil moisture anomaly according to analyses have a negative effect, especially in cases with a high percentage of change. The analyses suggest that this factor is less crucial for explaining the variation in arable land value than irrigation, GHG emissions, and GDP per capita.

In conclusion, irrigation and GHG emissions both have positive influence on the arable land value, but irrigation showed higher level of significant, and it can be considered as the key element. Regions with more intensive irrigation tend to have higher arable land value. While crop output per hectare and GDP per capita also play a significant role.

## 6.1 Robustness check analyses

This section represents additional analyses, which go along with Hristov (2020) and Jacobs (2019) findings about agriculture shift from South to North of Europe and examine the influence of economic parameter of GDP per capita interacting with irrigation and GHG emissions.

In the Table 5 below is represented results of four regressions, but a dummy variable is included. The dummy variable marks the geographic position of the country. Namely, value of 1 it takes for the Southern Europe countries and 0 for Northern Europe.

*Table 5 Regression results with included regional dummy variable.*

| | Column 1 Arable Land Value (without irrigation and GHG interaction) | | Column 2 Arable Land Value (with irrigation interaction) | | Column 3 Arable Land Value (with GHG interaction) | | Column 4 Arable Land Value (with irrigation and GHG interaction) | |
|---|---|---|---|---|---|---|---|---|
| | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* | *Coefficients* | *t Stat* |
| Intercept | 0.30 | 1.52 | 1.09 | 5.98 | 0.36 | 1.78 | 1.13 | 6.02 |
| Dummy south | 0.21 | 1.57 | 0.11 | 0.90 | 0.19 | 1.44 | 0.11 | 0.91 |
| EDD1 | 0.03 | 0.32 | -0.18 | -1.00 | 0.17 | 1.47 | -0.21 | -1.09 |
| EDD2 | -0.25 | -3.08 | -0.34 | -3.62 | -0.33 | -3.60 | -0.37 | -3.69 |
| GDD | -0.13 | -1.70 | -0.47 | -6.70 | / | / | -0.45 | -5.80 |
| EDD1 X irrigation | / | / | 0.01 | 1.69 | / | / | 0.01 | 1.67 |
| EDD2 x irrigation | / | / | 0.00 | -0.57 | / | / | 0.00 | -0.44 |
| GDD X irrigation | / | / | 0.04 | 13.49 | -0.18 | -2.14 | 0.04 | 13.32 |
| EDD1 X GHG | / | / | / | / | -0.12 | -1.76 | 0.02 | 0.34 |
| EDD2 x GHG | / | / | / | / | 0.05 | 1.36 | 0.02 | 0.72 |
| GDD X GHG | / | / | / | / | 0.02 | 0.33 | -0.03 | -0.76 |
| Crop output per hectare | 0.18 | 4.46 | 0.05 | 1.44 | 0.18 | 4.31 | 0.04 | 1.09 |
| GDP per capita | 0.95 | 6.96 | 0.26 | 1.98 | 0.95 | 6.87 | 0.24 | 1.83 |
| Soil moisture change | -0.73 | -0.80 | -1.55 | -1.91 | -0.65 | -0.71 | -1.57 | -1.94 |
| *Regression Statistics* | | | | | | | | |
| Multiple R | | 0.30 | | 0.55 | | 0.31 | | 0.55 |
| R Square | | 0.09 | | 0.30 | | 0.10 | | 0.30 |
| Adjusted R Square | | 0.08 | | 0.29 | | 0.09 | | 0.29 |
| Standard Error | | 1.42 | | 1.25 | | 1.42 | | 1.25 |
| Observations | | 810 | | 810 | | 810 | | 810 |

According to Table 5, Column 1 presents that this regression analyses the relationship between arable land value climate conditions and GDP without irrigation and GHG interaction. The coefficient for the Dummy variable is 0.21, which means that being in the South is associated with a 0.21EUR increase in land value, holding all other factors constant. Including this dummy variable showed that regions located on the south of EU have a starting larger land value compared with Northern regions. The value of the coefficient for dummy variable differs in all four regressions, but delivers the same positive results.

However, in case of the column 1, the coefficient for EDD1 is 0.03, which means that a one-unit increase in EDD1 is associated with a 0.03EUR increase in income, holding all other factors constant. The coefficient for EDD2 is -0.25, which means that a one-day longer in EDD2 is associated with a 0.25EUR decrease in land value, holding all other factors constant. The coefficient for GDD is -0.13, which means that a one-unit increase in GDD is associated with a 0.13EUR decrease in land value, holding all other factors constant.

In the case of Column 2, this regression analyses the relationship between climate conditions and GDP with irrigation interaction. The coefficients for the interaction terms are small and not statistically significant, meaning that irrigation does not significantly impact the relationship between income and the other independent variables.

Column 3 presents the causal relationship between the factors mentioned in Column 1, including GHG interaction. The coefficients for the interaction terms are also small and not statistically significant, which means that GHG does not significantly impact the relationship between income and the other independent variables.

Column 4 presents the final regression including both interactions with GHG and irrigation. The coefficients for the interaction terms are small and not statistically significant. While the overarching trends in land value remain complex, a regional analysis using a dummy variable in this regression sheds light on a significant factor. Notably, southern locations exhibit a positive effect on land value, counterintuitively deviating from expectations. Existing research, such as Hristov (2020), posits that Southern European farms should see profitability decline due to global warming, potentially reflected in land value depreciation as hinted by Sajid *et al*. (2023). Surprisingly, this analysis suggests that Southern European farms, despite the established global warming effects documented by Hristov (2020) and Jacobs (2019), appear resilient in terms of land value, at least based on this specific regional analysis. This opens intriguing avenues for further investigation to understand the underlying mechanisms driving this divergence from expected trends.

Table 6 presents change of arable land value based on geographical position excluding climate variables and including interactions between geographical position (dummy variable - 0 value for North and 1 for South) and irrigation and GHGs.

*Table 6 Regression results based only on the geographical position.*

| Arable Land Value (based on interaction of geographical position) | | |
|---|---|---|
| | *Coefficients* | *t Stat* |
| Intercept | 0.52 | 3.06 |
| Dummy south | - 0.65 | - 4.84 |
| dummy x irrigation | 0.04 | 7.90 |
| dummy x GHG | 0.05 | 1.18 |
| Crop output per hectare | 0.04 | 0.91 |
| GDP per capita | 0.58 | 4.18 |
| Percentage change Cropland soil moisture anomaly (%) | - 0.90 | - 1.02 |
| *Regression Statistics* | | |
| Multiple R | | 0.38 |
| R Square | | 0.15 |
| Adjusted R Square | | 0.14 |
| Standard Error | | 1.38 |
| Observations | | 810 |

The regression analysis from Table 6 confirms the predictions of Hristov (2020) and Jacobs (2019) regarding the negative effects of their geographical location on land values in Southern European regions, as evidenced by the negative coefficient of the dummy variable representing geographical position. The statistically significant interaction between irrigation and the geographical dummy variable suggests that irrigation is an effective mitigation measure in these regions. However, it is essential to note that this analysis follows previous one from the Table 5, but excludes climate variables such as EDD1, EDD2, and GDD. Consequently, it only captures a partial picture of the influence of geographical position and overlooks the potential interactions with climate factors.

The Table 7 presents regression results between dependent variable of arable land value and climate conditions and GDP per capita, with a goal to test connection between wealth of regions and possibility to mitigate climate change effect.

*Table 7 Regression results with included GDP interaction with GHG emissions and irrigation*

| Arable Land Value (with irrigation and GHG interaction with GDP) | | |
|---|---|---|
| | *Coefficients* | *t Stat* |
| Intercept | 1.25 | 7.34 |
| EDD1 | 0.12 | 1.65 |
| EDD2 | -0.44 | -7.06 |
| GDD | -0.21 | -2.85 |
| Crop output per hectare | 0.01 | 0.20 |
| GDP per capita | -0.34 | -2.41 |
| GDP x GHG | 0.04 | 14.24 |
| GDP x irrigation | 0.21 | 4.20 |
| Soil moisture change | -1.12 | -1.41 |
| *Regression Statistics* | | |
| Multiple R | | 0.56 |
| R Square | | 0.31 |
| Adjusted R Square | | 0.31 |
| Standard Error | | 1.23 |
| Observations | | 810 |

Comparing to Table 5, regions with higher GDP per capita will have lower land values in this scenario. However, on the other hand, this additional finding tells us that the amount of irrigation and GHG emissions will increase land value in interaction with GDP per capita. In this case, factors like EDD2, prolonged warm periods (GDD), and regional wealth (GDP per capita) tend to decrease land values, as evidenced by their negative coefficients. However, a surprising twist comes with greenhouse gas emissions (GHG). Combined with wealth (GDP x GHG), they can increase land value, suggesting a complex interplay between environmental and economic factors. Similarly, irrigation (GDP x irrigation) also increases land value, mitigating the negative impact of these factors on land value.

# 7. Discussion

This section discusses the findings of this thesis in terms of current literature including IPCC reports (2018, 2023). Also, this section goes across limitations of this paper and potential steps in the future research.

## 7.1 Empirical Findings and Hypothesis Testing discussion

The key findings of this thesis confirm the anticipated negative impact of extreme temperatures and extended heating periods on agricultural productivity, reflected in a demonstrably decreasing arable land value with each additional day of extreme temperatures. This directly addresses the first research question and aligns with established literature. Regarding the second question, irrigation emerges as a potent mitigation strategy against extreme temperatures and prolonged heating periods, demonstrably contributing to land value appreciation. Notably, however, air pollution, while exhibiting a statistically significant but moderate influence, surprisingly demonstrate a predominantly positive association with land value. This finding aligns with Taylor and Schlenker (2021) but challenges initial expectations of a negative relationship. This basically tells that land ends to be more valuable close to urban industrial centres, which is not surprising since Shi *et al.* (1997) already established positive influence of urbanisation on increasing of land value.

Both hypotheses formulated in the theoretical section require refinement in the future work. While the expected positive interaction between GDP and irrigation materialized, a positive interaction between GDP and GHGs was also observed, contradicting the hypothesized negative relationship. Similarly, the robustness check analyses reveal an unexpected positive influence of southern European geographical location on land value, contrary to the negative effects posited by Hristov (2020) and Jacobs (2019).

Due to limited $NO_x$ data on the NUTS2 level, air pollution analyses relied on GHGs as a proxy. This substitution leverages the established correlation between $NO_x$ and GHGs reported by Lin (2023). Obtaining $NO_x$ data at NUTS2 or finer detail level in the future could enable researchers to refine their analyses for greater accuracy.

## 7.2 Limitations and Future Research Directions

This thesis acknowledges several potential limitations that may have influenced the identification of causal relationships. Firstly, the diverse nature of growing seasons across the EU regarding the number of harvests, lengths, and crop types remains an unaccounted-for factor. Additionally, as Mendelsohn (1994) highlighted, focusing solely on annual temperature changes might mask crucial variations within crucial agricultural months, potentially introducing spurious correlations in the EU context. Furthermore, the exogenous nature of climate conditions must be considered, as neighbouring regions may share similar climatic conditions despite having disparate irrigation levels and GDP per capita. This principle also applies to GHGs, which often travel beyond their point of origin. Furthermore, climate change and global warming could trigger a dramatic scenario, resulting in reduced irrigation share due to reduced water availability. Another limitation is the current absence of water availability data at the NUTS2 level.

The current methodology employed by EUROSTAT for collecting irrigation data, relying on observations every 3-4 years, presents another limitation. This approach fails to capture temporal changes in irrigation practices and only reflects static levels from 2010. However, using 2010 as the base period is a limitation, since 2010 irrigation are likely driven by earlier factors, such as geography and level of technological development. Since time-varying irrigation would be exogenous.

Future research endeavours could improve upon this study by adopting alternative estimators and explicitly focusing on different types of GHG emissions. While this thesis observed GHGs through an aggregated $CO_2$ equivalent measure, incorporating individual gases with their varied impacts on specific crops would offer valuable insights. Also, one of the potential sources of bias in this research can be attributed to the variation in GHG concentrations across the observed regions. Concentrations are associated with urban centres and industrial areas. A higher density of cities and industries in a region could lead to a higher influence of GHGs, which is reflected in higher land values. Additionally, including data on specific crop outputs and differentiating temperature variables across diverse seasons (as suggested by Mendelsohn, 1994) would further enrich the analysis. Acknowledging the potential endogeneity of greenhouse gases (GHGs) in these analyses is also essential. This arises from the inherent feedback loop between GHG emissions and global warming. Increased GHG emissions contribute to the greenhouse effect, leading to higher temperatures reflected in the core variables of EDD1, EDD2, and GDD. However, the current dataset does not reveal strong correlations between GHGs and these temperature variables (Appendix 2), necessitating further investigation into the nature of this potential endogeneity.

## 7.3 Policy implications

Both reports of IPCC (2018, 2023) note problems with global warming. Namely, this thesis brings additional support for warning about climate change. Namely, according to IPCC (2018), irreparable damage will be done if humanity does not stop the temperature increase of 1.5ºC. Until 2050. The regression analyses showed that extreme degree days negatively influence arable land values, which implies negative effects of climate change on agriculture. This fact is consistent with the IPCC prediction and suggestions. Also, both reports recommend mitigation measures, which is, in this case, irrigation, and it is shown that it has a positive influence. Moreover, irrigation can be considered an effective response to global warming within the borders of the EU. However, the latest IPCC report acknowledges that climate change will impact water resources and availability, potentially impacting agricultural practices like irrigation. Furthermore, according to IPCC (2023) irrigation is one of the methods for increasing food safety. In terms of this thesis results, if the irrigation is put in the question and share of it decreases, that will mean that observed land value will also decrease and result in profit loss. While irrigation implementation incurs costs for farmers, it also provides mitigating effects for global warming. Policymakers can implement one of several possible strategies: the first is to implement measures to reduce global warming; the second is to provide subsidies for irrigation and other mitigation systems; and the third is to combine the two previous approaches.

Also, IPCC (2023) implies that GHGs must be minimized on the net-zero effect. The theory part of this thesis aligned with this accretion. According to the findings of this thesis, policymakers should put a significant focus on the mitigation of climate change because progress to carbon net zero emissions is questionable according to IPCC (2023). According to the findings, extreme temperatures are one of the most harmful elements to agriculture, which leads to decrease of the profitability in this sector and putting in danger decent life of citizens from rural areas. In this case policy maker can implement also few possible strategies: the first is to implement measures to reduce GHGs production; the second is to provide subsidies for implementing and developing clean technologies with lower carbon footprint and lower GHG emissions; and the third is to combine previous two.

# 8. Conclusions

In conclusion, this thesis delves into the intricate relationship between arable land value and climatic conditions, with a specific focus on the interaction between greenhouse gas emissions (GHGs) and irrigation with climate conditions. The results suggest that extreme weather events, such as prolonged heating seasons and excessive hot days, tend to depreciate arable land value. Importantly, the findings highlight the potential of irrigation as a valuable tool to mitigate the negative impacts of extreme temperatures and heatwaves on land value, offering an alternative perspective to the views expressed by Warrick (1988) and Blande (2010).

This thesis also makes a significant contribution to the existing literature by addressing a critical gap identified by Van Passel (2017) – the previous exclusion of irrigation in such analyses. Furthermore, it builds upon the groundwork laid by Mendelsohn *et al.* (1994), Mendelsohn and Dinar (2003), Ortiz-Bobea (2020) and Sajid *et al*. (2023) by applying their findings to the European context, moving beyond the prior focus on the United States.

Ultimately, the research presented here underscores the profound impact of climate change on everyday lives, particularly in the sensitive domain of land usage and value. This thesis, despite the contributions and analysis, should be, in the first place, a trigger to “think bigger” and raise awareness about climate change and its influence on our future.

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# Appendix 1

*Table Appendix 1 List of NUTS2 regions*

| NUTS2 Regions | Country |
|---|---|
| **Severozapaden** | Romania |
| **Severen tsentralen** | Bulgaria |
| **Severoiztochen** | Romania |
| **Yugoiztochen** | Bulgaria |
| **Yugozapaden** | Bulgaria |
| **Strední Cechy** | Czech Republic |
| **Severozápad** | Czech Republic |
| **Severovýchod** | Czech Republic |
| **Jihovýchod** | Czech Republic |
| **Strední Morava** | Czech Republic |
| **Sjælland** | Denmark |
| **Syddanmark** | Denmark |
| **Midtjylland** | Denmark |
| **Nordjylland** | Denmark |
| **Attiki** | Greece |
| **Voreio Aigaio** | Greece |
| **Notio Aigaio** | Greece |
| **Kriti** | Greece |
| **Galicia** | Spain |
| **Principado de Asturias** | Spain |
| **Cantabria** | Spain |
| **Comunidad Foral de Navarra** | Spain |
| **La Rioja** | Spain |
| **Aragón** | Spain |
| **Comunidad de Madrid** | Spain |
| **Castilla y León** | Spain |
| **Extremadura** | Spain |
| **Cataluña** | Spain |
| **Comunitat Valenciana** | Spain |
| **Illes Balears** | Spain |

| | |
|---|---|
| **Andalucía** | Spain |
| **Región de Murcia** | Spain |
| **Canarias** | Spain |
| **Jadranska Hrvatska** | Spain |
| **Kontinentalna Hrvatska (NUTS 2016)** | Croatia |
| **Piemonte** | Croatia |
| **Liguria** | Italy |
| **Lombardia** | Italy |
| **Veneto** | Italy |
| **Toscana** | Italy |
| **Umbria** | Italy |
| **Marche** | Italy |
| **Lazio** | Italy |
| **Abruzzo** | Italy |
| **Molise** | Italy |
| **Campania** | Italy |
| **Basilicata** | Italy |
| **Calabria** | Italy |
| **Sicilia** | Italy |
| **Sardegna** | Latvia |
| **Latvija** | Malta |
| **Malta** | Netherlands |
| **Groningen** | Netherlands |
| **Friesland (NL)** | Netherlands |
| **Drenthe** | Netherlands |
| **Overijssel** | Netherlands |
| **Gelderland** | Netherlands |
| **Flevoland** | Netherlands |
| **Utrecht** | Netherlands |
| **Zeeland** | Netherlands |
| **Limburg (NL)** | Poland |
| **Mazowieckie (NUTS 2013)** | Poland |
| **Slaskie** | Poland |
| **Zachodniopomorskie** | Poland |
| **Lubuskie** | Poland |
| **Pomorskie** | Romania |
| **Centru** | Romania |
| **Vest** | Slovakia |
| **Bratislavský kraj** | Slovakia |
| **Západné Slovensko** | Slovakia |
| **Stredné Slovensko** | Slovakia |

| | |
|---|---|
| **Východné Slovensko** | Finland |
| **Åland** | Sweden |
| **Stockholm** | Sweden |
| **Östra Mellansverige** | Sweden |
| **Småland med öarna** | Sweden |
| **Sydsverige** | Sweden |
| **Västsverige** | Sweden |
| **Norra Mellansverige** | Sweden |
| **Mellersta Norrland** | Sweden |
| **Övre Norrland** | Sweden |

# Appendix 2

*Table Appendix 2 Dataset correlations*

| | *Dependent variable Arable land value* | *EDD1 Days of extreme heat stress (UTCI > 46°C)* | *EDD2 Days of strong heat stress (UTCI > 32°C)* | *GDD Heating degree days* | *Crop output per hectare* | *GDP per capita* | *Percentage change Cropland soil moisture anomaly (%)* | *Irrigation* | *Total greenhouse gas emissions (in Mt of CO2 equivalent)* |
|---|---|---|---|---|---|---|---|---|---|
| *Dependent variable Arable land value* | 1.00 | | | | | | | | |
| *EDD1 Days of extreme heat stress (UTCI > 46°C)* | 0.01 | 1.00 | | | | | | | |
| *EDD2 Days of strong heat stress (UTCI > 32°C)* | -0.04 | 0.30 | 1.00 | | | | | | |
| *GDD Heating degree days* | -0.06 | -0.08 | -0.29 | 1.00 | | | | | |
| *Crop output per hectare* | 0.13 | 0.23 | 0.41 | -0.15 | 1.00 | | | | |
| *GDP per capita* | 0.23 | -0.03 | -0.14 | 0.04 | -0.05 | 1.00 | | | |
| *Percentage change Cropland soil moisture anomaly (%)* | -0.01 | -0.06 | -0.04 | 0.05 | 0.02 | 0.04 | 1.00 | | |
| *Irrigation* | 0.54 | 0.06 | 0.30 | -0.18 | 0.35 | 0.34 | 0.07 | 1.00 | |
| *Total greenhouse gas emissions (in Mt of CO2 equivalent)* | 0.10 | 0.07 | 0.19 | 0.29 | 0.27 | -0.10 | -0.01 | 0.11 | 1.00 |

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