

Master thesis

'Impact of climate risks on the agricultural land price in the Netherlands'



Master thesis of the Spatial Planning programme
Specialisation in Planning Land and Real Estate development
Nijmegen School of Management
Radboud University

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August 2024

Colophon

Radboud University Nijmegen
Nijmegen School of Management
master thesis for the Spatial Planning program
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Title: Impact of climate risks on the agricultural land price in the Netherlands

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Date: 7th of August, 2024

Words: 16.004

α.s.r. real estate

Abstract

Agriculture is one of the most important economic sectors, as it is expected to feed a global population projected to reach 10.4 billion by 2100. However, ongoing climate change is giving rise to various climate risks that will impact many economic sectors, particularly the Dutch agricultural sector. The Netherlands, a densely populated country, boasts one of the largest agricultural sectors in the world and some of the best soils for agricultural use. What is remarkable about the Dutch agricultural sector is the rising price of agricultural land, despite increasing climate risks. One would be expected these risks to lower land price, as shown by other international studies, especially considering the Netherlands' geographical position in a Delta of three rivers, with much of the country situated below sea level. To investigate the impact of climate risks on agricultural land prices in the Netherlands, a literature review was conducted and a hedonic price model was applied. This research identified six climate risks for the investigation: extreme heat, extreme precipitation, extreme drought, flood risks, surface water shortage and salinization. What could be concluded from this study is that at present and using this method climate risks have a minimal to no influence on agricultural land prices in the Netherlands.

Keywords: Agriculture land price, climate risks, hedonic price model

Acknowledgements

In front of you is my master's thesis on the impact of climate risks on agricultural land prices in the Netherlands. With this, I complete my Master's Degree in Spatial Planning at the Radboud University in Nijmegen.

The process of writing this master's thesis has been a joyful period and enriching experience. It has significantly expanded my knowledge of the agricultural land market, which I hope will be valuable in my future endeavors. I would like to express my sincere gratitude and appreciation to my supervisor Prof. Dr. E. van der Krabben (Erwin), for allowing me to explore my own topic of interest and for his invaluable guidance and feedback throughout this journey. I also want to extend my thanks to a.s.r. real estate for providing me with the opportunity to conduct a research internship with their rural real estate team. In particular, I am grateful to Sander Radix for his help in shaping the research idea. Additionally, I would like to thank all the people I met at a.s.r. and who helped and supported me during this research.

Finally, I would like to thank the readers of this master's thesis for taking the time to read this document. Your interest in this research is greatly appreciated.

(B.C.T.) Bram Sluijters

Utrecht, June 2024

Summary

Agriculture is one of the most important economic sectors, especially considering the global population is expected to reach 10.4 billion by 2100, with all these people needing to be fed. However, ongoing climate change is leading to increasing climate risks, which are expected to impact various economic sectors, particularly agricultural. The Netherlands, a densely populated country with one of the world's largest agricultural sectors and some of the best soils for agricultural use, presents a unique case. The Dutch agricultural land market is a somewhat remarkable market. Despite rising climate risks, agricultural land prices in the Netherlands have increased significantly over the past decades, which is somewhat surprising given the potential negative impacts of these risks.

Multiple international studies on agricultural land prices often account for climate risks, and many suggest a negative impact on land values. This would be especially expected in the Netherlands, given its geographic location in a delta formed by three rivers, with much of the country lying below sea level.

To investigate the impact of climate risks on agricultural land prices in the Netherlands, this research involved both a literature review and an application of a hedonic price model. The literature review examined what the Dutch agricultural land market defines, the variables that influence land prices, and the specific climate risks relevant to agricultural land in the Netherlands. Six key climate risks were identified as important for the Netherlands: extreme heat, extreme precipitation, extreme drought, flood risks, surface water shortage and salinization.

The hedonic pricing model was then used to assess the intensity and direction of the impact of the six climate risks and other variables on the agricultural land prices. The focus study laid on the six defined climate risks. The result of the statistical analysis showed that while these six climate risks could have both positive and negative significant effects on agricultural land price. However, the significant impacts were all so small that the impact was almost zero. Therefore, the conclusion from this study is that, at present and using this method, climate risks have a minimal to no significant influence on agricultural land prices in the Netherlands.

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1. Introduction

Land, labour and capital are the three main production factors that keep an economy going (Smith, 1776). Agriculture is one of the many economic sectors that is dependent on land. Often, the agricultural sector is seen as one of the most important economic sectors due to its production of food and feed for human and animal consumption (Beckman & Countryman, 2021). Resultingly, agriculture is also crucial for other markets, poverty reduction and economic development (Cervantes-Godoy & Dewbre, 2010; Slaboch & Čechura, 2020). Additionally, the urgency of food production is heightened by a growing world population, projected to reach 10.4 billion by 2100 (United Nations, n.d.).

However, the agricultural sector is undergoing a transition due to climate change. Climate change is causing rising temperatures, changing precipitations patterns, rising sea levels and more frequent extreme weather events (EEA, 2024; Furtak & Wolińska, 2023; Wen et al., 2022). These changes could negatively impact food security and other sectors which are dependent on the agricultural sector (Mirón et al., 2023). On the other hand, climate change could create opportunities in some regions around the world where different and more crops can be produced (Belyaeva & Bokusheva, 2018; Planbureau voor de Leefomgeving, 2012). However, this is only possible with investments in technological changes and seizing new opportunities.

Like other countries, the Netherlands is also facing climate change. The Netherlands is the second largest exporter of agricultural products in the world (Skryl & Gregoric, 2020). In 2021, 2,236,000 hectares of land in the Netherlands were used for agriculture, accounting for 54% of the total land and water surface (CBS, 2021). In the same year, the agrocomplex, which includes all direct and indirect activities related to agricultural, contributed 6,7 % to the total Gross Domestic Product (GDP) of the Netherlands (Verhoog, 2023). Due to the large surface of agricultural land and the geographical orientation of the Netherlands climate change is expected to have a significant impact on the country. Effects of climate change in the Netherlands includes changes in temperature, droughts, precipitation and sea level rise (KNMI, 2023; STOWA, 2021). These threats affect soil and water quality, indirectly impacting crop production (Jaramillo Roman et al., 2021). Changes in temperature, drought, precipitation, and sea level rise could influence crop and grass growth, potentially leading to yield and economic losses for the Dutch agricultural sector. However, there are also opportunities, such as the possibility of producing more and different crops due to rising temperatures (Planbureau voor de Leefomgeving, 2012).

Multiple studies have shown that climate change negatively impacts the agricultural land value (Bozzola et al., 2018; Hussain & Mustafa, 2016; Massetti et al., 2016; Mendelsohn et al., 1994). However, the specific climate risks and their impacts on land value vary by region. In case of the Netherlands, no research has been conducted on the impact of various climate risks on agricultural land value. A notable trend in the Netherlands that can be observed is the increasing price of agricultural land (Kuiper & Voskuilen, 2018; Luijt & Voskuilen, 2009; H. J. Silvis & Voskuilen, 2022). This trend contradicts findings on the negative impact of climate risks on agricultural land values globally (Bozzola et al., 2018; Hodge, 2021; Hussain & Mustafa, 2016; Massetti et al., 2016; Mendelsohn et al., 1994). However, agricultural land prices are not only determined by climate risks but also by a lot of other variables, such as physical characteristics, transaction characteristics, macroeconomic characteristics and government policy (Cotteleer et al., 2008; Cotteleer, Luijt, et al., 2007; Cotteleer, et al., 2007; Guiling et al., 2009; Woestenburg & Van Der Krabben, 2013). While the effects of many of these variables on agricultural land prices have been studied, the impact of climate risks on agricultural land prices in the Netherlands remains unknown.

Closely related to this issue are land valuations. In the Netherlands, valuations of agricultural land are based on comparable transactions in the same region. These valuations are important for buyers and sellers of agricultural land. Based on conversations with multiple Dutch agricultural valuers, it can be stated that, at present, climate risks are not considered in land valuations in the Netherlands. Valuation reports do not include a chapter on possible climate risks for the valued land. The question arises whether it is justified to ignore climate risks in agricultural land valuations and whether climate risks are already factored into transaction prices. To investigate the impact of climate risks on agricultural land prices in the Netherlands and determine if they should be considered in land evaluations, this study uses a hedonic pricing model. The data used includes a transaction dataset of agricultural land in the Netherlands. Transactions reflect the price paid for a piece of land. Additionally, data on other characteristics are used as control variables. For the climate risks researched in this study, open data from the *KlimaatEffectAtlas* has been utilized.

1.1 Research problem

The Netherlands is, as one of the most efficient agricultural countries, a leading power on the agricultural market (Skryl & Gregoric, 2020). However, its most important instrument in the agricultural sector, the soil, is in danger. Due to climate change, the Netherlands is experiencing changes in temperature, drought, precipitation and sea level rise (KNMI, 2023; Philip et al., 2020; STOWA, 2021; Ten Dam et al., 2023; van den Burg et al., 2024; Wen et al., 2022). Climate change could affect the agricultural soil by altering soil fertility (Mondal, 2021; Shourie & Singh, 2021; STOWA, 2021). For example, increasing temperatures can extend the growing season, while more frequent droughts due to insufficient water availability can slow down photosynthesis. Conversely, overly wet conditions can result in oxygen shortages. All these factors influence plant growth and, ultimately, yield and production. It is crucial for the agricultural sector and the economy of the Netherlands that the agricultural soils remain fertile and productive over the long term. The effects of climate change on the agricultural soil impact the value of agricultural land. Numerous studies have shown that climate risks affect agricultural land value (Bozzola et al., 2018; Hussain & Mustafa, 2016; Massetti et al., 2016; Mendelsohn et al., 1994).

Due to climate change, climate risks are occurring more frequently and becoming more severe. It would be expected that these climate risks impact agricultural land prices. In the case of the Netherlands, this impact could potentially be negative. Consequently, one would expect agricultural land prices to decrease over time. However, in the Netherlands, we observe the opposite trend: agricultural land prices are increasing (Kuiper & Voskuilen, 2018; Luijt & Voskuilen, 2009; H. J. Silvis & Voskuilen, 2022). This trend could be explained by other variables influencing the price of agricultural land. The question remains: what is the impact of climate risks on agricultural land prices in the Netherlands? This research will focus on the potential negative effects of climate risks in the Netherlands. This study does not consider future changes in crop varieties and animal breeds, technology, prices and investments. It is conceivable that by making such adjustment or changes, climate risks may not be reflected in transaction prices because people expect to solve the problem. Furthermore, questions remain regarding the valuation of agricultural land in the Netherlands because there is no scientific literature on this topic. This study will try to provide more insight into the impact of climate risks on agricultural land prices in the Netherlands and indirectly whether this could affect valuations.

1.2 Research objective and research questions

The main objective of this research is to investigate the impact of climate risks on agricultural land prices in the Netherlands. This is motivated by the observation that current valuations of agricultural land do not seem to include climate risks. To understand what the impact is on agricultural

land prices is and determine if it is needed to include climate risks in valuations, it is essential to gain knowledge about the following subjects: what the Dutch agricultural land market defines, which variables define agricultural land prices and which climate risks potentially influence the quality and use of agricultural land in the Netherlands. This research begins with a literature review. Using this theoretical framework, a hedonic pricing model will be used to investigate what impact of specific climate risks have on the agricultural land price in the Netherlands. Overall, this study aims to contribute to the scientific literature and existing knowledge about the impact of climate risks on agricultural land prices and pricing of climate risks in agricultural land valuation in the Netherlands. In relation to this, the following research question is formulated:

‘What is the impact of climate risks on the agricultural land prices in the Netherlands?’

In order to answer the research question, the following sub-questions are formulated:

‘What characterises the Dutch agricultural land market?’

‘Which variables define agricultural land prices?’

‘Which climate risks potentially influence the quality and use of agricultural land in the Netherlands?’

1.3 Relevance of the study

This research aims to identify the impact of climate risks on the agricultural land prices in the Netherlands. In doing so, this research seeks to make both a scientific and societal impact.

1.3.1 Scientific relevance

Numerous studies from the past decades have examined the impact of climate change and its risks on agriculture. However, when focusing on the economic influence of climate change on agriculture, the selection of scientific studies becomes narrower. Even fewer studies address the topic of climate change and agricultural land prices. Several of these studies have investigated the impact of climate change on land value, revealing that climate change does indeed affect land value. For example, Hossain et al., (2020) research the impact of climate change on farmland value in Bangladesh, finding that floods and temperature increase lead to decrease in agricultural land values. Another example is Van Passel et al., (2017), who studied the impact of climate change on agricultural land value in Europe. This study found that marginal temperature increases in spring and autumn would increase agricultural land value, while marginal temperature increase in summer and winter would decrease it. Precipitation increases in spring and autumn led to a decrease in agricultural land value, whereas increases in winter and summer led to an increase. However, this is with the notion that this is not uniform across different countries or regions in Europe. Most of these studies are from a few years ago, and with the increasing knowledge and awareness of climate change and climate risks, it is time for an update.

Furthermore, for the Netherlands, one of the leading agricultural countries in the world, the impact of climate risks on agricultural land prices has not been researched. Understanding this impact is particularly important due to the country's significant agricultural economy and unique geographical orientation. The Netherlands is situated in the delta of the Rhine, Meuse, and Scheldt rivers, with a large portion of the country lying below sea level. These circumstances necessitate the exploration of specific climate risks that could influence agricultural land prices.

Furthermore, this study indirectly seeks to determine if climate risks should be considered in land valuations. There is limited literature openly available on valuation, especially concerning the influence of climate risks within valuations. The organisation NVRT (Nederlands Register Vastgoed Taxateurs), the Dutch Register of Real Estate Appraisers, also provides little literature about valuation and certainly not

about climate risks in combination with valuation. Therefore, the questions remain: What are the impacts of climate risks on agricultural land prices in the Netherlands, and should climate risks be taken into account in the valuation of agricultural land?

1.3.2 Societal relevance

Land is a unique commodity with a special role in the economy (Buitelaar, 2021). It is attached to the earth's surface and there is a certain amount available. It is not possible to produce more or less land, except for land reclamation or erosion. However, this does not occur often. This means that only demand influences land price increases or decreases since supply remains constant. Besides being a special production factor, land is also an investment property due to its value retention. This is particularly important for densely populated countries like the Netherlands. Next to this agriculture is a crucial sector in the Netherlands, with more than half of the country's surface area used for agricultural purposes. So, agricultural land is an important production factor. It can be seen that there is an increasing demand for agricultural land due to extensification regulations and limited supply resulting in increasing land prices (Silvis & Voskuilen, 2021). Agricultural land prices are influenced by multiple factors like including: physical characteristics, transaction characteristics, macroeconomic variables and government policy.

However, the precise impact of climate risks on agricultural land prices in the Netherlands is not well understood. Climate risks such as flood risks, salinization, drought and changes in precipitation are physical changes which influence the physical characteristics. These climate risks can impact the agricultural land market in the form of differentiation soil fertility and crop yields. Indirectly, the agricultural land market is impacted by rules and regulation from governance to mitigate climate change and to reduce climate risks with these rules and regulations. Due to the direct and indirect impacts of climate change, the market for agricultural land is uncertain.

This study aims to contribute to a more transparent pricing structure for agricultural land in the Netherlands by researching the impact of climate risks on agricultural land prices in the Netherlands and quantifying this impact. Additionally, this research indirectly seeks to contribute to the discussion whether climate risks should be considered in agricultural land valuations. Currently, there are no rules mandating the inclusion of climate change in valuations. However, valuations are based on transactions using the so-called comparison method. If transaction prices change due to climate risks or other characteristics of the land, this will be reflected in valuations. If significant impacts of climate risks are found in this study, it becomes relevant to discuss changes in valuation rules. Including climate risks in valuations may be necessary to provide an accurate picture of land value. If climate risks are not adequately considered, valuations may present a misleading picture of land value.

1.4 Research strategy

The goal of this research is to understand what the impact of climate risks are on the agricultural land price in the Netherlands. To gain this knowledge there are multiple research strategies available. For this research a quantitative research approach has been chosen. This is chosen because most of the variables that impact land prices can be quantified in data. However, before utilizing quantitative data, a literature review was conducted. This review aimed to understand how the agricultural land market works in the Netherlands, which variables define agricultural land prices and which climate risks potentially influence the quality and use of agricultural land in the Netherlands. With the knowledge on which variables are needed to define the agricultural land price and the important climate risks for the Netherlands a hedonic pricing model can be employed. This is a statistical model displays the intensity and direction of the impact of each variable on the price of a plot of land. In other words, this model can reveal how strongly climate risks affect agricultural land prices in the Netherlands and

whether the impacts are positive or negative. Based on these results, conclusions can be drawn about whether climate risks have a significant impact on agricultural land prices.

1.5 Reading guide

Chapter 1 introduces this research, with section 1.2 describing the research problem. Furthermore, section 1.3 outlines the research objective and research questions of this study. Section 1.4 discusses both scientific and social relevance of this study. Finally, the research strategy is briefly discussed in section 1.5.

Chapter 2 provides an overview of the existing literature and the theoretical framework used in this study. Section 2.1 offers insight into the Dutch agricultural land market, section 2.2 formulates the variables that define agricultural land prices and section 2.3 focusses on which climate risks potentially influence the quality and use of agricultural land in the Netherlands. Section 2.4 presents the conceptual framework and the hypothesis used in this study.

Chapter 3 explains the research method which is used for this research. It shows the statistical model which is used, a hedonic pricing model, the study area and the data utilized in this study.

Chapter 4 presents and discussed the results. This includes descriptive results and the outcomes of the statistical tests conducted. This is followed by a discussion of the findings.

Chapter 5 draws conclusions based on the results and discussion. Section 5.1 provides answers to the research questions, section 5.2 highlights the scientific contribution. Furthermore, section 5.4 offers recommendations for practices. Finally, the limitations of this study are stated in section 5.4.

2. Literature review and theoretical framework

2.1 Dutch agricultural land market

The Dutch agricultural land market is a heterogeneous market characterised by continuous increase of the agricultural land price, see Figure 1 (Kuiper & Voskuilen, 2018; Luijt & Voskuilen, 2009; H. J. Silvis & Voskuilen, 2022; H. Silvis & Voskuilen, 2018). The agricultural land price is the price which is paid on the free market by farmers (Kuiper et al., 2022). The variation in agricultural land prices is largely determined by plot characteristics and soil quality. Land is site based, so farmers tend to value nearby land higher than land further away. Soil quality is crucial for farmers to efficiently grow their crops.

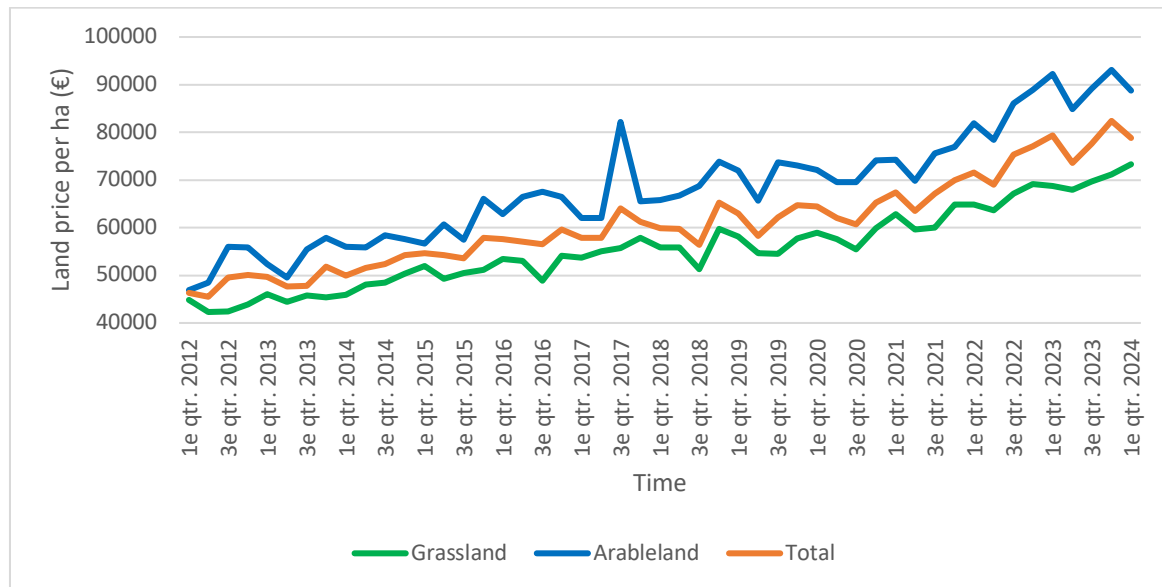


Figure 1: Price of unleased agricultural land in the Netherlands (Kadaster et al., 2022; Kadaster & Wageningen Economic Research, 2024)

The agricultural land market can be divided into grassland and arable land. Grassland constitutes the majority of agricultural land in the Netherlands, approximately 1.150.000 hectares, which is 57% of all agricultural land in 2023 (CBS, 2024a). The total area of arable land in the Netherlands is around 810.000 hectares. The prices of the two differ a lot from each other. Arable land is worth approximately €10.000 per hectare more than grassland, see Figure 1. This difference is due to the cultivation of more profitable crops.

In addition to the price difference between arable land and grassland there are also big variations in prices per region. Kadaster, the property register of the Netherlands, tracks transactions of agricultural land, as shown in Figure 2. There are substantial price differences between provinces, for example in the first quarterly of 2024 prices were ranging from €60.800 to €182.800 per hectare. These differences are explained by soil type and the forms of agriculture possible in each area.

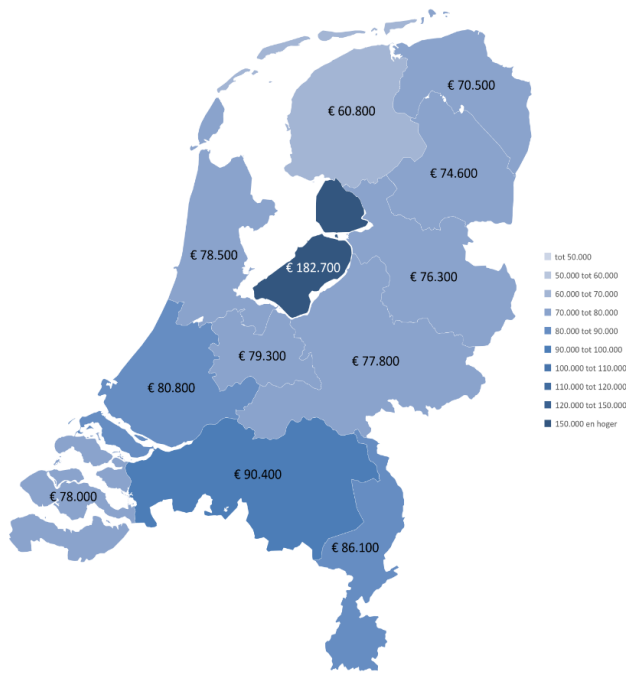


Figure 2: Agricultural land price per province, 1e quarterly 2024 (Kadaster & Wageningen Economic Research, 2024)

The increase in agricultural land prices in the Netherlands can be attributed to several variables. First, there is a limited supply of agricultural land and a high demand for it. This high demand, combined with the high yields of Dutch agricultural land, results in the second highest agricultural land price in the EU with €85.000 per hectare in 2022 (Eurostat, 2024). The demand for land comes mainly from farmers. However, this share is decreasing (Kuiper et al., 2023). Investors, nature organisations and governmental bodies are also buying land. Second, an increase in land area per farm can be observed (Silvis & Voskuilen, 2021). The number of farms in the Netherlands is decreasing, but the total area of agricultural land is not decreasing as rapidly (CBS, 2023a). Scaling is often necessary to meet new regulations and remain competitive (Silvis & Voskuilen, 2021). Third, decreasing interest rates contribute to rising agricultural land prices. Lower interest rates encourage farmers to take loans and invest in land, which could drive up land prices (Silvis & Voskuilen, 2018). Fourth, developers influence the increase in agricultural land prices near urban areas by speculating on agricultural land, hoping for changes in land use regulations that will allow for housing development (H. Silvis & Voskuilen, 2018). This speculation creates so called boom-bust cycles (Luijt & Voskuilen, 2009). Due to speculation the price is driven up and later followed by a price decrease. In the Netherlands this is clearly seen in the agricultural land market in the late 1970s and at the turn of the century. The most important indicator of boom-bust cycles is the trend in ground mobility. A sudden drop in ground mobility often precedes a bust, as seen in Figure 3. This could be seen in the late 1970s and at the turn of the century, see Figure 3 for the boom-bust cycle around the turn of the century. Fifth, rules and regulations have a great impact on the agricultural land market in the Netherlands. The Dutch government strictly regulates land use through zoning laws, designating specific areas for agriculture, urban development, nature reserves, and other uses. Furthermore, subsidies from the government such as the Common Agricultural Policy (CAP) of the European Union (EU), can increase the value of agricultural land by providing financial stability to farmers. Environmental and sustainability policies also influence the agricultural land market, such as voluntary purchase schemes. Finally, technological advances have increased the efficiency and productivity of Dutch agriculture over the last few decades (Sauer, 2017). Increased efficiency and productivity lead to higher revenue, making land more profitable and increasing its value.

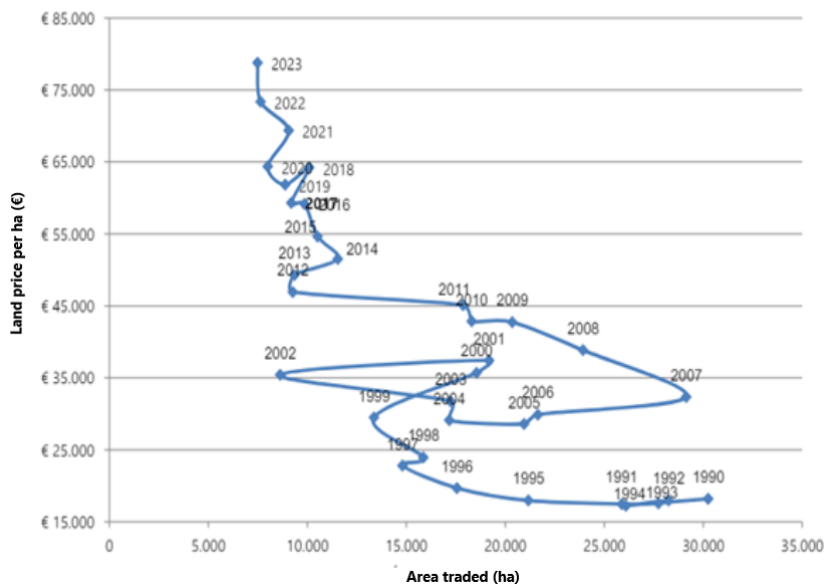


Figure 3: Land market cycles of clean up agricultural land in Netherlands 1990-2023 (Radix, 2023).

Price is not the only important factor of the Dutch agricultural land market. Ground mobility, which shows the traded land in hectares, is another explanatory factor. Figure 3 shows the traded area in hectares against the land price per hectare, using only clean up transactions. Transactions are cleaned up based on variables such as leased land, buy-sell relations and extreme outliers. This graph represents the changes over the last few decades, showing a strong decrease in ground mobility.

Recently, a change in the registration of agricultural land prices in the Netherlands occurred. The new registration method adjusted the capping method for calculating agricultural land prices (Kuiper et al., 2022). Previously, average land prices were calculated monthly at the national level. All transactions were gathered from the property register of the Kadaster and information on usage, buildings and topography was added (Kuiper et al., 2022; Michels et al., 2022). Transactions were then selected based on criteria such as: the buyer owning a farm, plots being grassland or arable land, the transaction being a buy and sell, full ownership rights, no buildings included in the transaction, no leasehold, no family relations, plots larger than 0.25 hectare and a price higher than one euro. Transactions with extreme low or high prices were excluded from the registration to avoid distorting the average land price. The sum of the price divided by the area gave the average agricultural land price. However, this method had a problem: it was done at the national level, so regional price differences were not considered, potentially leading to under- or overestimation at the regional level. To address this problem the adjusted capping method is now registered and calculated at the provincial level. Additionally, capping is now done on transactions over a time span of 12 months instead per month to ensure enough transactions per province. This change did not influence the national average agricultural land price much, which still shows an increasing trend of the land price. However, there were some changes on provincial level, with prices rising in some provinces and dropping in others.

2.2 Variables that define agricultural land prices

When investigating agricultural land prices, the hedonic pricing model is one of the most commonly used methods. Other methods employed in similar studies included the Difference-in-Differences (DiD) method and the Ricardian model. This study will use a hedonic pricing model to identify the impact of climate risks on agricultural land prices in the Netherlands. The hedonic pricing model tries to give non-market goods a value from goods that have a market price with some of the amenities of the non-

market goods (Rosen, 1974). In other words, an asset is broken down into the individual variables that make the price of an asset. For example, if two similar pieces of agricultural land differ only in their distance from a road, the price difference can be attributed to this distance. However, identifying the variable that influence the price can be challenging.

Therefore, it is crucial to identify the variables that could potentially influence agricultural land prices before applying the hedonic pricing model. Other studies using this model have shown that it is a widely adopted method for investigating the impact of various factors on agricultural land prices. Hedonic pricing models have been used to assess the impact on agricultural land prices by the distance to nature conservation areas, distance to urban areas, distance to roads, soil information, transaction characteristics, temperature and precipitation (Buurman, 2003; Cotteleer et al., 2008; Cotteleer, Luijt, et al., 2007; Cotteleer, Stobbe, et al., 2007; Hodge, 2021; Woestenburg & Van Der Krabben, 2013)

There are numerous variables that influence agricultural land prices, and a considerable body of research has explored these factors. Buurman (2003) provided an overview of factors affecting land prices found in empirical literature, see Appendix 1. He identified the following overarching themes: parcel characteristics, transaction characteristics, macroeconomic variables and government policy. This study will mainly focus on the parcel characteristics, as climate risks fall under this characteristic and their impact on land prices will be investigated. This research provides an enriched and updated version of the overview of factors impacting agricultural land prices found in the literature, see Appendix 2.

2.2.1 Parcel characteristics

Parcel characteristics address the spatial variables of a plot of land. Buurman (2003) subdivided these characteristics into three categories: location, physical properties and land use. Location factors include accessibility and distance to nearby areas. This can be expanded to include distance to nature conservation areas (Cotteleer, Luijt, et al., 2007), distance to N-2000 (Woltjer et al., 2023), distance to urban areas (Cotteleer, Stobbe, et al., 2007), distance to recreational areas (Guiling et al., 2009) and distance to roads (Cotteleer, Stobbe, et al., 2007). The influence of distance to wind turbines has not been extensively researched and could be an interesting addition. This study will focus only on undeveloped parcels, meaning there are no further improvements such as roads or buildings on the land.

The distance to nature conservation areas has a significant negative impact on the land price (Cotteleer, Luijt, et al., 2007). This is likely due to rules and regulations. Next to this it can be explained by the suitability of the land for agricultural use, maybe this land is more suitable for nature than for agriculture. The distance to Natura 2000 areas also affects agricultural land prices, with prices being 4-5% lower within a 2,500-meter radius compared to those outside this range (Woltjer et al., 2023). Land prices within Natura 2000 area almost 30% lower than those outside the N-2000 areas, likely due to restrictions by the extensivities, due to rules and regulations, that is taking place around these areas. This will pressure the land's yielding capacity.

The impact of the distance to urban areas has been extensively studied, and it is clear that closeness to urban areas and has a strong effect on agricultural land prices (Cotteleer, Stobbe, et al., 2007). Urbanization pressures from developers and speculators can lead to changes in zoning plans from agriculture to residential use. This increases the agricultural price in the Netherlands by a factor of 10.

The distance to recreational areas positively impacts agricultural land prices (Cotteleer, et al., 2007; Guiling et al., 2009). The presence of nearby recreational areas may create opportunities for farmers to generate additional income through a farm shop or campsite.

The distance to roads has a significant negative impact on the land price (Cotteleer, Luijt, et al., 2007; Khan et al., 2016). As the distance from the road increases, land price decreases, likely due to the accessibility for transportation of goods to markets and factories.

Lastly, the impact of the distance to wind turbines is worth investigating due to the high value of agricultural land for renewable energy development. Open GIS data on wind turbine locations is available, making it possible to include this variable in the study.

Physical properties within parcel characteristics defined by Buurman (2003) include slope, elevation, soil type, fertility, irrigation and parcel size. In addition to these, two other variables may influence land prices: plot shape and groundwater table. The shape of the plot is crucial because rectangular plots are easier to cultivate (Cid-Garcia et al., 2013). This may increase land value. Groundwater table, which indicates fluctuations in groundwater level, which impacts workability and crop health (Knotters et al., 2018). In the Netherlands is the fluctuation in groundwater level relatively big, it fluctuates between 0-200 cm below surface level. High water levels can prevent machinery use due to soil compaction. When the water level is lowered in the peatland areas in the Netherlands land subsidising will occur and the water costs will only become higher overtime. High water levels could also have another negative effect, plant roots will not root deep enough to extract water from the soil and will wither.

For land use Buurman (2003) distinguished between current and future land use due to relevance of conversion costs or potential value increases. For instance, zoning plan changes from agricultural to residential use can lead to a huge increase in land value, potentially by a factor 10. However, this study focuses solely on agricultural land zoned for agricultural use and does not consider other zoning plans.

2.2.2 Transaction characteristics

Transaction characteristics include the actors involved, the relationship between buyer and seller, and type of transaction (Buurman, 2003; Woestenburg & Van Der Krabben, 2013). The agricultural land market involves various actors, often categorized by legal entity or land use (Buurman, 2003). Buurman (2003) used categories such as municipalities, other governments, nature conservation organisations, relatives, lessors, tenants, natural persons and legal entities. This study will focus on farmer-to-farmer transactions to provide a transparent price indication. Next this is done because most of the time a farmer purchases a plot of land for agricultural use.

The relation between buyer and seller can significantly influence agricultural land prices (Woestenburg & Van Der Krabben, 2013). Land is often sold to relatives at lower prices typically from parents to a successor in the form of the children. However, this trend is declining due to the decreasing number of successors (Schnabel, 2001). Another form could be a tenant that becomes owner or vice versa an owner that sells the land and becomes tenant. Often there is then a contractual stipulation of how much must be paid for buying back land.

The type of transaction also affects land prices. Land exchanges, expropriations (which are also government policies), and other legal matters can either positively or negatively influences prices, depending on the nature of the transaction.

Market conditions play a role as well. The agricultural land market in the Netherlands is relatively transparent due to monitoring by the Kadaster (Schnabel, 2001). However, it tries to display a price development of clean up agricultural land. This means that only transactions with the following criteria are taken into account: buyer must have a farm, only grassland, arable land and silage corn, the transaction is buy-sell, only full ownership, no buildings, no regular lease or ground lease and no family relations between buyer and seller. In reality the agricultural land market is a complex market due to the multiple actors involved, multiple rules, regulation and subsidies. Market competition has

increased in recent decades due to growing interest in agricultural land from developers for housing and government for nature conservation and expansion (CBS, 2023c).

2.2.3 Macroeconomic variables

Supply and demand are the most important factors in explaining agricultural land prices in the Netherlands. With increasing demand for land for housing, nature, abrogation of derogation and the decrease in agricultural land availability, land prices in the Netherlands are rising (CBS, 2023c, 2023b). Another influential factor is the inflation rate. From 2015 till 2021 low inflation contributed to low interest rates and rising land prices (Woltjer & Voskuilen, 2022). However, since 2021, inflation has increased. Leading to higher interest rates, high interest rates increase financing costs for farmers, making land acquisition more challenging without bank loans. When interest rates are low, farmers are more inclined to take loans to finance land purchases (Jellema et al., 2023; H. J. Silvis & Voskuilen, 2022).

Gross Domestic Product (GDP) is another macroeconomic variable that could impact land prices. GDP reflects the value added through the production of goods and services in a country. When the GDP increases, people have more money to spend, boosting the economy. Other macroeconomic variables that could impact land prices include technological innovations, such as more productive crops, cost reduction methods, and climate risk mitigation strategies. Additionally, multifactor productivity growth, debt to asset ratio, credit availability, (rural) income, unemployment rate and economic expectations are variables to consider (Feichtinger & Salhofer, 2013).

2.2.4 Government policy

The Netherlands is a small, densely populated country which makes use of a lot of rules and regulations. One of the main regulations affecting the land market is zoning, where every piece of land is designated for a specific purpose, creating sub markets. These sub markets, such as housing, agriculture, or nature, can lead to scarcity within a specific sub market, driving up prices. The influence of zoning on agricultural land prices depends on government policy and can either increase or decrease prices. Land price will increase, by as much as tenfold, when zoning plans are changed from agricultural to residential use. Conversely, prices will decrease when agricultural land is rezoned for nature conservation. Other rules and regulations could also lower land prices due to reduced opportunities in land use. For example, designations like Natura 2000 areas or the phasing out of derogation can decrease land value (Bekamp & Smit, 2024; Woltjer et al., 2023). Additionally, a form of rules and regulations could play a role, taxation and subsidies. Taxation impose extra costs on farmers, reducing their likelihood of purchasing land. On the other hand, subsidies can add value or make land acquisition more feasible, thereby increasing land prices. These various rules and regulations create uncertainty in the agricultural sector, as their future impact and potential changes remain unclear.

In summary, several main characteristics influence agricultural land prices: parcel characteristics, transaction characteristics, macroeconomic characteristics and government policy. The specific variables that matter most depend on the focus of the study and the data available. Notably, while many studies consider factors like temperature and precipitation, they often do not explore the broader range of climate risks or the different ways these risks affect agricultural land prices. Only a few studies have tested or mentioned specific climate risks.

2.3 Climate risks and agricultural land in the Netherlands

Parcel characteristics, which partially determine agricultural land prices, are influenced by climate risks. There are two types of climate risks: physical risks and transition risks. Physical risks include short-term extreme weather events that damage crops and land, and long-term climate change effects such as

water shortages and sea level rise (Broeders et al., 2021; Jansen, 2019; PWC, 2021). Transition risks, on the other hand, stem from the shift toward a lower-carbon and more environmentally friendly economy to mitigate global warming. These risks may arise from policies, technological advances, or changes in market sentiment and preferences. This study focuses specifically on physical climate risks.

The Sixth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC) (2021) identifies seven Climate Impact-Drivers (CID's): Heat and Cold, Wet and Dry, Wind, Snow and Ice, Coastal, Oceanic and Other Climate Impact Drivers (Masson-Delmotte et al., 2021). The European Environmental Agency (EEA) condensed these into six hazard types relevant to Europe: Heat and Cold, Wet and Dry, Wind, Snow and Ice, Coastal and Open Ocean. Focusing on the Netherlands the Koninklijk Nederlands Meteorologisch Instituut (KNMI) utilized the report of the IPCC and their own data to create 'Klimaatsignaal'21'. This report identifies the most important climate risks for the Netherlands. A more recent report of the KNMI, 'Klimaatscenario's'23', highlights the following overarching climate risks for the Netherlands: temperature, precipitation, drought and sea level rise. Furthermore, research conducted by trade publication Nieuwe Oogst found that 61 percent of arable farmers experience yield losses due to increasing climate risks. The risks that had the largest impact were: extreme precipitation and extreme drought (Hiddink, 2024). Other climate risks that were mentioned were: shortage of surface water and salinization.

Before delving into the specific climate risks impacting agricultural land in the Netherlands, it is useful to review recent studies on the impact of climate risks on housing prices in the Netherlands. This comparison can provide insights into the important climate risks for the Netherlands. Recent studies on the impact of climate risks on housing prices in the Netherlands have focused on climate risks such as flood risk and land subsidence, which leads to foundation problems and damage (Bosker et al., 2019; Hans, 2024; Kadaster, 2024a; Mutlu et al., 2023; Willemsen et al., 2020). Some of these studies conclude that climate risks negatively impact housing prices (Bosker et al., 2019; Mutlu et al., 2023; Willemsen et al., 2020). However, Hans (2024) & Kadaster (2024) did not find a significant decrease in prices for houses with a high flood risk. Instead, they observe a significant price increase for houses with a medium or low probability of flooding. This could be possibly explained by the housing shortage in the Netherlands. While it is valuable to consider the climate risks affecting the housing market, agricultural land is influenced by different factors, so other climate risks may be more or less important. It is good to keep these conclusions in mind.

Climate risks are among the variables that shape the agricultural sector in the Netherlands (Schaap et al., 2011). These risks include changes in temperature, precipitation, drought, and sea level rise, which lead to more frequently extreme weather events (EWEs), salinization, water shortages and floods (KNMI, 2023; Van Tilburg & Hudson, 2022; Verstand et al., 2021; Wen et al., 2022). All these changes have direct and indirect effects on agriculture (STOWA, 2021). Direct impacts primarily involve crop damage and limited growth (Verstand et al., 2021). Indirect impacts affect infrastructure, soil and water resources (Escarcha et al., 2018; Nigussie et al., 2018; Talukder et al., 2021).

Temperature is the primary driver of climate change due to rise of greenhouse gases in the atmosphere. The temperature in the Netherlands has been increasing for more than a century, with this trend accelerating over the past 30 years and expected to continue (KNMI, 2023; Verstand et al., 2021). The temperature rise can have both positive and negative effects. Positive effects include increased crop growth, earlier harvesting, longer growing seasons, and the cultivation of different crops. Negative effects include heat stress for livestock, more diseases and pests, and frost damage to crops. The increase in temperature also drives other indirect climate risks including extreme's, also known as extreme weather events (EWE's). These effects are becoming more importance as they become more

frequent and extreme. For the Netherlands the EWE's include: extreme heat, extreme precipitation and extreme drought (KNMI, 2023).

Extreme heat occurs due to rising temperatures leads to more days with extreme heat (Visser, 2007). Visser (2007) found that the likelihood of extreme heat days has increased over the period of 1951-2006. This is a trend that is expected to continue. Extreme heat days, defined as days with a maximum temperature of 30 degrees Celsius or more, also known as a tropical day, can cause crop yield losses and heat stress for livestock (Geijzendorffer et al., 1994). Given the increasing probability of extreme heat days, this is an important climate risks to consider.

Rising temperatures have also led to an increase in precipitation over the past century, a trend that is expected to continue (KNMI, 2023; Verstand et al., 2021). Higher temperatures cause more water to evaporate, resulting in more water vapour in the air and, consequently, more precipitation. This increase in precipitation is not reflected so much in the number of days it rains but rather in the occurrence of EWE's, such as heavy rains. This means more and longer periods of heavy rains occur. While there is no uniform definition of extreme precipitation in the Netherlands, the KNMI considers a day with more than 50 millimetres of precipitation as a heavy precipitation day (de Keijzer & van Boxel, 2003; KNMI, n.d.). Such EWE's negatively affect land cultivation, crop quality, and cause direct crop damage. EWEs involving extreme precipitation can prevent farmers from working on their land or grazing their livestock, as overly wet conditions can lead to soil compaction, ultimately resulting in lower yields due to poorer crop growth (Herbert et al., 2023).

Drought is another result of rising temperatures and changes in precipitation (KNMI, 2023; Verstand et al., 2021). Higher temperatures lead to increased evaporation and a resulting shortage of surface water, known as a precipitation deficit (KNMI, 2023; Philip et al., 2020). Droughts are occurring more frequently and with greater severity, with extreme droughts becoming more common. One way to mitigate extreme droughts is through irrigation, provided that freshwater is abundant. However, freshwater is not available in all areas, particularly in the eastern and sandy soil regions of the Netherlands. Without sufficient water, crops can suffer extensive damage. Assessing the sensitivity of an area to drought requires examining the combination of soil type, location, crop type, and irrigation availability.

Sea level rise, driven by the expansion of water and melting ice due to increasing temperatures, is another important climate risk (Keizer et al., 2023). The sea level has been rising since 1890, with the pace accelerating over the past 50 years (Keizer et al., 2023; KNMI, 2023). The Netherlands is particularly vulnerable, with 26 percent of the country lying below sea level, as measured by the NAP (Nieuw Amsterdams Peil) (Atlas Leefomgeving, 2024). The NAP indicates the height of land relative to the average sea level of the North Sea (Dillingh et al., 2010). While the areas below sea level are protected by flood defences such as dikes and dunes, the flood risk is increasing due to the rising sea levels. However, flooding can have a positive aspects, as clay deposited on the land during a flood creates fertile soil. This clay creates a fertile soil. The key is finding a balance in the frequency of flooding. Soils remains fertile if flooding occurs only once every few hundred year.

Salinization is another risk associated with sea level rise (Eswar et al., 2021; Verstand et al., 2021). In addition to sea level rise, drought can also lead to salinization (Eswar et al., 2021; Kramer et al., 2019). Salinization is the increase and accumulation of salts in water and soil (van den Burg et al., 2024). In the Netherlands, salinization due to sea level rise occurs primarily in coastal regions (van den Burg et al., 2024). Higher sea levels will create pressure that allows more saltwater to flow underneath flood defences and enter the soil (Rijkswaterstaat, 2023). Salinization caused by droughts occurs when more water evaporates than precipitates, leaving salts behind in the soil (Eswar et al., 2021). With rising sea

levels and more frequent extreme droughts, salinization is becoming more widespread and severe (Hossain et al., 2020; Rozema & Flowers, 2008; Schwalm et al., 2017; Trenberth et al., 2014; van den Burg et al., 2024). The negative effects include reduced productivity of agricultural soils (van den Burg et al., 2024). Salinization can also occur at mouths of rivers like the Rhine, Meuse or Scheldt when river flows are low and sea levels rise, allowing saltwater to enter the rivers.

Higher temperatures lead to increased evaporation and more severe droughts, resulting in surface water shortages (KNMI, 2023; Verstand et al., 2021). During droughts, water is essential for irrigation, but when it is not available, plants may experience water stress. Plant roots primarily absorb water from the topsoil, and if water is scarce in this layer, crops cannot grow properly or may dry out. This has negative impacts on the agricultural sector. Additionally, human activities also contribute to surface water shortages. The Dutch water system was originally designed for drainage, but more recently, there has been a shift towards water retention strategies. The availability of surface water clearly affects soil quality and agricultural productivity.

Land subsidence in the Netherlands is largely driven by human interventions such as the drainage of polders, peatland and reclaimed land, construction on soft soils, and the extraction of salt, gas and freshwater (Stouthamer et al., 2020). Lower groundwater levels allow oxygen to penetrate the soil, enabling microorganisms to break down organic material (Verstand et al., 2023). This results to subsidence at an average rate of 0.5-1 cm per year on average in the Netherlands (Stouthamer et al., 2020). The process is accelerating due to rising temperatures and changes in precipitation patterns. Land subsidence also contributes to climate change through the emission of CO₂ during the oxidation of organic material (Verstand et al., 2023). Subsidence accounts for a quarter of the relative sea level rise in the Netherlands (KNMI, 2023). This increases the risks from both the sea and inland water. As mentioned earlier, rising sea levels, driven by temperature increases also salinization (Keizer et al., 2023). Flood risk in the Netherlands are further exacerbated by heavy rainfall, which is becoming more frequent due to climate change, leading to higher peak discharges from major rivers like the Rhine and the Meuse, and increasing the likelihood of flooding.

2.4 Conceptual framework and operationalisation

Based on the discussed agricultural land market, the characteristics that explain the agricultural land prices and the climate risks applicable to the Netherlands, as well as a brief explanation of the hedonic pricing method, a theoretical framework has been developed. This framework conceptualises the main theory of this research, see Figure 4 for the conceptual framework. The theoretical framework has indicated that the agricultural land price could be explained by four overarching characteristics: parcel characteristics, transaction characteristics, macroeconomic characteristics and governmental policies. In this study, the focus will be on climate risks, which have an indirect effect on the parcel characteristics. Therefore, these variables will be included under the parcel characteristics. To answer the research question: 'What is the impact of climate risks on the agricultural land prices in the Netherlands?', this theoretical framework will be tested by examining the six selected climate risks.

The following hypotheses are formulated:

- H₀ = Climate risks will have a significant impact on the agricultural land price in the Netherlands.
- H₁ = Climate risks will not have a significant impact on the agricultural land price in the Netherlands.
- H₀ = Climate risks will have a significant impact on the agricultural land price of arable land in the Netherlands.
- H₁ = Climate risks will not have a significant impact on the agricultural land price of arable land in the Netherlands.

- H_0 = Climate risks will have a significant different impact on the agricultural land price for different types of soil in the Netherlands?
- H_1 = Climate risks will not have a significant different impact on the agricultural land price in for different types of soil in the Netherlands?
- H_0 = Climate risks will have a significant different impact on the agricultural land price in different agricultural regions in the Netherlands?
- H_1 = Climate risks will not have a significant different impact on the agricultural land price in different agricultural regions in the Netherlands?

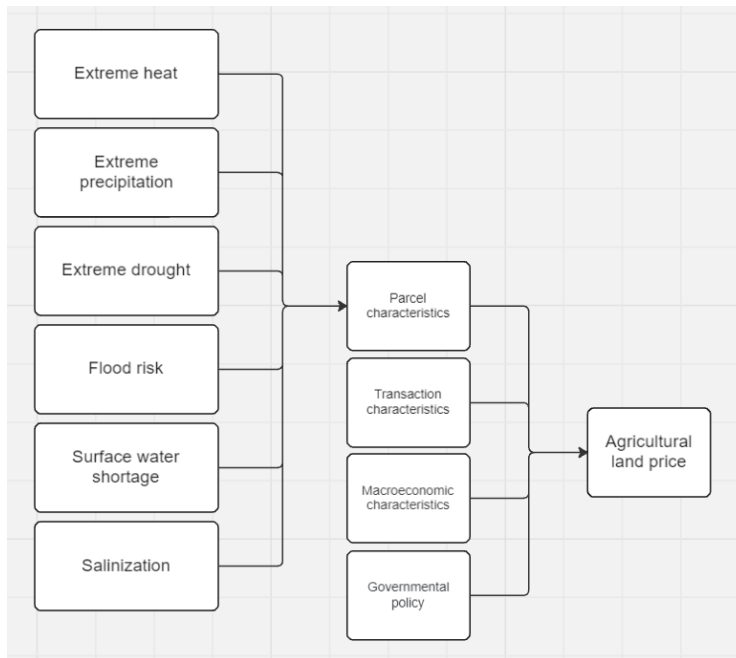


Figure 4: Conceptual framework (own work)

3. Methodology

This study employs a hedonic pricing model to identify the impacts of climate risks on the agricultural land prices in the Netherlands. The hedonic pricing model is used to regress the price of a product against a vector of characteristics, effectively displaying the intensity and direction of the impact each characteristic has on the price of an object. Given that real estate is a heterogeneous good composed of many characteristics, hedonic pricing is a valuable method for evaluating the influence of each characteristic on its value. This method is frequently used in housing real estate value research. The value of agricultural land, as described in Section 2.2, is influenced by multiple characteristics, including plot characteristics, transaction characteristics, macroeconomic characteristics and government policies. An underlying assumption that is made when using the hedonic pricing method is that buyers are perfectly informed of all characteristics. Therefore, farmers and appraisers would also consider environmental characteristics when purchasing or valuing a plot of land.

In this study, the environmental characteristics considered are six climate risks: extreme heat, extreme precipitation, extreme drought, flood risk, shortage of surface water, and salinization. These risks are quantified using the following indicators: for extreme heat, the number of days with a maximum temperature of 30 degrees Celsius or more; for extreme precipitation, the number of days with more than 25 millimetres of precipitation per day; for extreme drought, a combination of precipitation and evaporation resulting in a precipitation deficit, measured by the potential maximum precipitation deficit expected once every 10 years by 2050; for flood risk, the site-specific flood probability in 2050 with a flood depth of 0 cm; for shortage of surface water, the expected shortage in an extremely dry year in 2050; and for salinization, the salt influx expected with a 50 cm sea level rise.

To investigate whether climate risks are factored into the price of agricultural land, a hedonic price analysis is conducted using a transaction dataset. As previously mentioned, it is assumed that a buyers are perfectly informed and therefore consider climate risks when purchasing a plot of land. Based on the outcomes of this analysis, it is possible to predict the expected value for each agricultural plot of land.

3.1 Statistical model

In this study, a multitude of characteristics that could impact agricultural land prices are considered (Appendix 2). However, there may still be characteristics not included, leading to so called omitted variable bias (OVB). To address this problem, an ordinary least squares (OLS) statistical model is employed (Cropper et al., 1988; Zuehlke & Rasmussen, 1988). Control variables are included, but it is still possible that OVB may influence the model. To check for multicollinearity the variance inflation factor (VIF) is calculated, see equation 1, where R^2 represents the correlation between the two variables being tested for.

$$VIF = \frac{1}{1-R^2} \quad \text{equation 1}$$

Variables with a VIF of 10 and higher are removed from the corresponding dataset, unless there is no logical relation between the two variables, in which case they may be retained. For variables with a VIF between 5 and 10, a critical assessment is made to decide whether to delete or to keep them in the model. The remaining variables are used in the statistical test.

A log-linear model of OLS is chosen because it facilitates the interpretation of marginal impacts and allows for easier detection of these impacts even when misspecifications are present in the model (Cropper et al., 1988). The hedonic price analysis is conducted using a transaction dataset that includes

the six climate risks. The following equation is used to show the impact of all variables on agricultural land prices in the Netherlands, see equation 2.

$$\ln(P_i) = \alpha + \beta CRfr_i + \gamma CRssw_i + \delta CRs_i + \eta CReh_i + \iota CRep_i + \kappa CRed_i + \theta X_i \varepsilon_i \quad \text{equation 2}$$

In the equation, $\ln(P_i)$ is the natural logarithm of the transaction price per hectare, where i represents each transaction. α is the intercept term, representing the base price when all variables are set to zero. The climate risks variables include: flood risk ($CRfr_i$), shortage of surface water ($CRssw_i$), salination (CRs_i), extreme heat ($CReh_i$), extreme precipitation ($CRep_i$) and extreme drought ($CRed_i$). θX_i represents the vector of the control variables, and ε_i is the error term of the vector of the control variables.

Based on the output, the direction and strength of each variable's impact on agricultural land prices, including the climate risks variables, are evaluated. This analysis allows for conclusions to be drawn about the influence of climate risks on agricultural land prices in the Netherlands.

3.2 Study area

The Netherlands is selected as the overall study area due to substantial number of agricultural land transactions available for analysis. However, as highlighted in the literature review, there is a great disparity between arable land and grassland. Additionally, the location and soil type of arable and grassland often differ. To investigate the impact of climate risks on both arable land and grassland, and to explore the differences between them, the dataset is split accordingly.

Furthermore, to examine the influence of climate risks at a more localised level, the dataset is filtered by agricultural region. These regions comprise 14 areas covering the Netherlands, see Figure 5 (Kruijne, 2021). The 14 agricultural regions are used instead of the smaller agricultural areas because the number of transactions per agricultural region is large than the number of transactions per agricultural area, allowing for a more representative analysis. The following agricultural regions are used in the study:

1. Bouwhoek en Hogeland
2. Veenkolonien en Oldambt
3. Noordelijk Weidegebied
4. Oostelijk Veehouderijgebied
5. Centraal Veehouderijgebied
6. IJsselmeerpolders
7. Westelijk Holland
8. Waterland en Droogmakerijen
9. Hollands/Utrechts Weidegebied
10. Rivierengebied
11. Zuidwestelijk Akkerbouwgebied
12. Zuidwest-Brabant
13. Zuidelijk Veehouderijgebied
14. Zuid-Limburg



Finally, the dataset is divided in ground types, as different soils and land types exhibit varying levels of vulnerability to certain climate risks. The

Figure 5: 14 agricultural regions Netherlands(Kruijne, 2021)

8 main soil types and 2 other land types, which are water and buildings have been used, see Figure 6. The following 10 soil types and areas are being used:

- Buildings
- Heavy Clay
- Heavy Silt
- Light Clay
- Light Silt
- Loam
- Marshy on sand
- Peat
- Sand
- Water

3.3 Data

3.3.1. Transaction dataset

This study utilized a dataset containing transactions of agricultural land in the Netherlands. The data is provided by the Kadaster. The Kadaster is responsible for registering all real estate, land and buildings in the Netherlands on behalf of the government. This transaction dataset includes information on land transactions, transaction prices, locations and the legal rights attached to each sold parcel in the Netherlands. The dataset reflects the price paid for the plots as well as the price per hectare. To minimize the influence of extraneous variables, the dataset was clean up, based on the following criteria:

- Only farmer to farmer transaction were used
- Family transaction were excluded
- Leased land was removed
- Only arable land and grassland were used
- Extreme outliers in price were excluded

After cleaning up, 7921 transactions remained, see Figure 7. As shown in Figure 7, there is a good distribution of transactions across the Netherlands. The transactions used for this study took place between 2019 and 2023.

The dataset was enriched with data on physical, environmental and macroeconomic characteristics, see Appendix 3. Transaction characteristics were not included due to the large number of transactions, making it impractical to manually indicate these variables. Therefore, this study focuses on specific cases of transaction characteristics.

3.3.2. GIS

To enrich the transaction dataset, the program Feature Manipulation Engine (FME) was used. Open source GIS maps, including data from the KlimaatEffectAtlas (KEA), were utilized to add physical

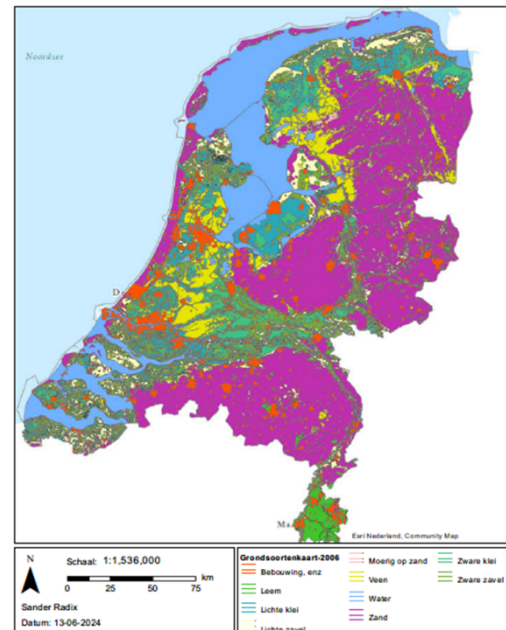


Figure 6: 10 different soil and areas types Netherlands (Radix, 2023)

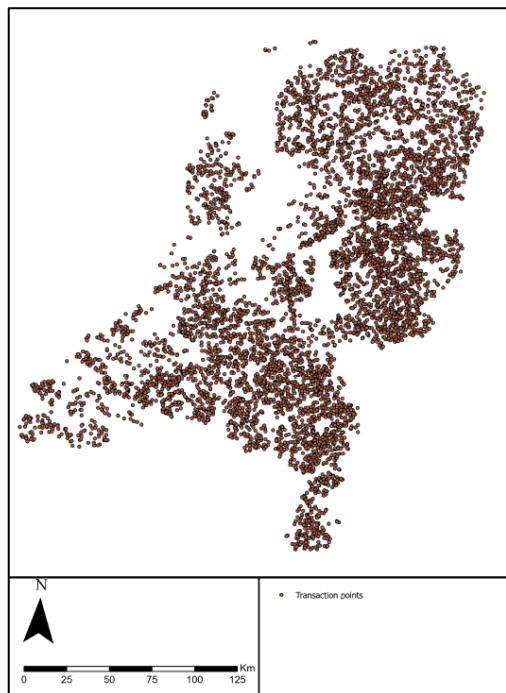


Figure 7: Map with all 7921 transaction. Map is own work. Data (Kadaster, 2023)

characteristics and indicate the six climate risks investigated in this study. This is open data is available upon request from KEA.

Six different map layers were used to indicate the climate risks investigated in this study, see Table 1. For flood risks the map layer “Site-specific flood probability > 0 cm in 2050”. The “> 0 cm” indicates the flood depth, meaning all floods are considered, as even minimal water depth can impact farming by saturating the soil and preventing farmers from accessing their land due to excessive moisture. Some assumptions and limitations apply to this data.

For salinization the map layer “Difference in salt influx at 0.5 m sea level rise” was used. Salinization occurs due to sea level rise and a precipitation deficit, and can be categorized into three types: groundwater, river mouth and locks. The chosen map layer identifies areas where salinization via groundwater is expected with 0.5 m sea level rise.

The map layer “Shortage surface water extreme dry year” was used to investigate two climate risks: salinization, which occurs due to precipitation deficits, and surface water shortage. In this study the map layer will only be used to indicate surface water shortage, as a different map layer will salinization. The map layer “Shortage surface water average year” was not used because climate change is expected to increase the frequency of extreme weather events, including extreme drought, making dry years more common in the future (KNMI, 2023).

For the three chosen extreme weather events (extreme heat, precipitation and drought) three corresponding maps were used. For extreme heat the map layer “number of tropical days (max ≥ 30 degrees)” was used. In the Netherlands, a tropical day is defined as a day with a maximum temperature of 30 degrees Celsius or more. No map layer was available for extreme heat days, defined as days with a maximum temperature of 35 degrees Celsius or more. For extreme precipitation the map layer “Days with ≥ 25 mm” was used. Although extreme precipitation days in the Netherlands are defined as days with 50 millimetre or more, only a map layer showing days with 25 millimetres or more was available (KNMI, n.d.). Finally, the map layer “Potential maximum precipitation deficit (once every 10 years)” was used to indicate extreme drought, as a precipitation deficit leads to drought.

Climate Risk	Map layer KEA
Extreme Heat	Number of tropical days (max ≥ 30 degrees Celsius) 2050
Extreme Precipitation	Days with ≥ 25 mm 2050
Extreme Drought	Potential maximum precipitation deficit (once every 10 years) 2050
Flood risk	Site-specific flood probability > 0 cm in 2050
Surface water shortage	Shortage surface water extreme dry year 2050
Salinization	Salt flux 0.5 m sea level rise sea level rise

Table 1: Climate risks and used data from KEA to display the climate risks (Own work)

3.3.3 Variables

In addition to the six climate risks, which are the primary focus of this study, other variables are also considered. This approach provides a more accurate overview of all the factors that influence agricultural land prices. Of the four main characteristics, physical characteristics, transaction characteristics, macroeconomic variables and government policy, three are included in this study. However, transaction characteristics are represented only by the timing of the transaction, specifically as a quarterly variable, see Table 2. The dataset has been cleaned based on certain transaction characteristics, as detailed in Section 3.3.1.. Government policy is left out of this study due to the challenges of quantifying policy measures and predicting future policies.

Furthermore, physical characteristics are represented by the following variables:

- Distance to boarder of the Netherlands
- Distance to N-2000 areas
- Distance to nature conservation areas
- Distance to urban areas
- Distance to road
- Distance to wind turbine
- Soil/Area type
- Total are of transaction
- Crop rotation
- Rectangularity
- Roundness
- Average height of plot
- Standard deviation height of plot
- Minimum height plot
- Maximum height plot
- Water stairs score of plot
- Arable land
- Grassland
- Agricultural region where plot was located

For macroeconomic variables, the following two variables are used:

- Transaction quarterly
- GDP

Variable	Indicator	Name indicator	Data source
Price	Price in euro's paid per hectare in transaction	Price per hectare	(Kadaster, 2024b)
Log(Price)	Log of price in euro's paid per hectare in transaction	Log(Price per hectare)	(Kadaster, 2024b)
Transaction quarterly	Transactions in certain quarterly (yes = 1, no = 0)	Transaction period ... (for example 01-2019)	(Kadaster, 2024b)
GDP	GDP year 2023 per province	GDP per province	(CBS, 2024b)
Inflation quarterly	Inflation Netherlands quarterly	Inflation	(CBS, 2024b)
Distance to boarder of the Netherlands	Distance to boarder of the Netherlands in meters	Distance_to_boarder_of_the_Netherlands	(a.s.r. real estate, 2024)
Distance to N-2000 areas	Distance to N-2000 areas in meters	Distance_to_N2000_area	(a.s.r. real estate, 2024)
Distance to nature conservation areas	Distance to nature conservation areas in meters	Distance_to_nature_conservation_area	(a.s.r. real estate, 2024)
Distance to urban areas	Distance to urban areas in meters	Distance_to_urban_areas	(a.s.r. real estate, 2024)
Distance to road	Distance to road in meters	Distance_to_road	(a.s.r. real estate, 2024)
Distance to wind turbine	Distance to wind turbine in meters	Distance_to_wind_turbine	(a.s.r. real estate, 2024)
Soil/Area type	Dominant Soil/Area type of the plot	Name of Soil/Area type (for example Buildings or Heavy Clay)	(a.s.r. real estate, 2024)
Total are of transaction	Total size of transaction in m ²	Total_area_of_Transaction	(Kadaster, 2024b)
Crop rotation	Score of the crop ration of last 10 year	Crop_rotation_score	(a.s.r. real estate, 2024)
Rectangularity	Shape	rectangularity	(a.s.r. real estate, 2024)
Roundness	Shape	roundness	(a.s.r. real estate, 2024)
Average height of plot	Average height of plot in meters	Average_height_plot	(a.s.r. real estate, 2024)
Standard deviation height of plot	Standard deviation height of plot in meters	Standard_deviation_height_plot	(a.s.r. real estate, 2024)
Minimum height plot	Minimum height plot in meters	Min_heigt_plot	(a.s.r. real estate, 2024)
Maximum height plot	Maximum height plot in meters	Max_heigt_plot	(a.s.r. real estate, 2024)
Water stairs score of plot	Water stairs score of plot	Water_stairs_score	(a.s.r. real estate, 2024)
Extreme heat	Amount of tropical days	Number of tropical days (max ≥ 30 degrees Celsius) 2050	(KlimaatEffectAtlas, 2024)

Extreme Precipitation	Amount of days with heavy precipitation	Days with ≥ 25 mm 2050	(KlimaatEffectAtlas, 2024)
Extreme Drought	Maximum precipitation deficit	Potential maximum precipitation deficit (once every 10 years) 2050	(KlimaatEffectAtlas, 2024)
Flood risk	Flood probability	Site-specific flood probability > 0 cm in 2050	(KlimaatEffectAtlas, 2024)
Surface water shortage	Shortage surface water	Shortage surface water extreme dry year 2050	(KlimaatEffectAtlas, 2024)
Salinization	Salinization	Salt flux 0.5 m sea level rise sea level rise	(KlimaatEffectAtlas, 2024)
Arable land	Arable land (yes = 1, 0 = no)	Arable land	(Kadaster, 2024b)
Grassland	Grassland (yes = 1, 0 = no)	Grassland	(Kadaster, 2024b)
Agricultural region where plot was located	Agricultural region	Name of Soil/Area type (for example Bouwhoek en Hogeland)	(Kadaster, 2024b)

Table 2: All variables used in this study

4. Results & Discussion

To determine the impact of climate risks on the agricultural land prices in the Netherlands, a hedonic pricing model was applied to the data.

4.1 Describing results

Using a hedonic pricing model, one dependent variable and multiple independent variables were analyzed. The dependent variable in this study was the logarithm of the price per hectare of a transaction. Figure 8 shows the price per hectare in different regions of the Netherlands. The average transaction price per hectare for the cleaned up dataset of agricultural land in the Netherlands was €66.480,77.

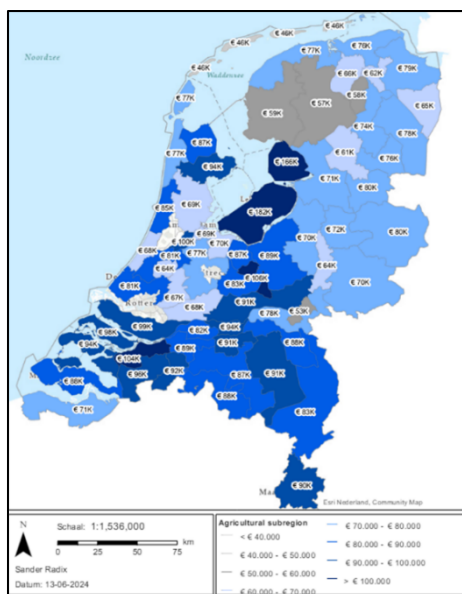


Figure 8: Map of depending variable (price per ha) in the Netherlands of Q4 2023, 12 month development (Radix, 2023)

This section focuses solely on the climate risks as independent variables since the research aims to assess their impact on agricultural land prices in the Netherlands. The climate risks variables were represented by specific maps:

- For extreme heat the map “Number of tropical days (max ≥ 30 degrees Celsius) 2050” was used, see Figure 9.
- For extreme precipitation the map “Days with ≥ 25 mm 2050” was used, see Figure 10.
- For extreme drought “Potential maximum precipitation deficit (once every 10 years) 2050” was used, see Figure 11.
- For floodrisk “Site-specific flood probability > 0 cm in 2050” was used, see Figure 12.
- For surface water shortage “Shortage surface water extreme dry year 2050” was used, see Figure 13.
- For salinization “Salt flux 0.5 m sea level rise sea level rise” was used, see Figure 14.

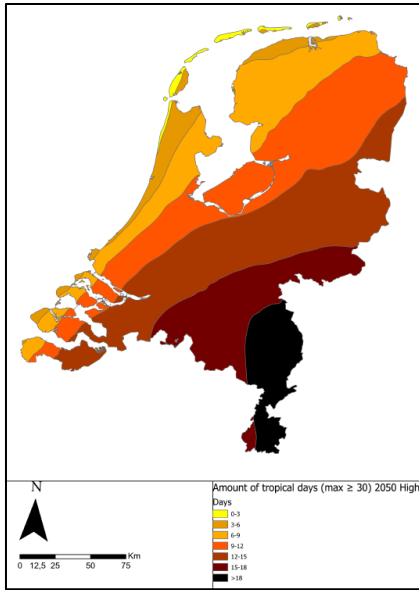


Figure 9: Map of independent variable (extreme heat). Map is own work. Data (KlimaatEffectAtlas, 2024)

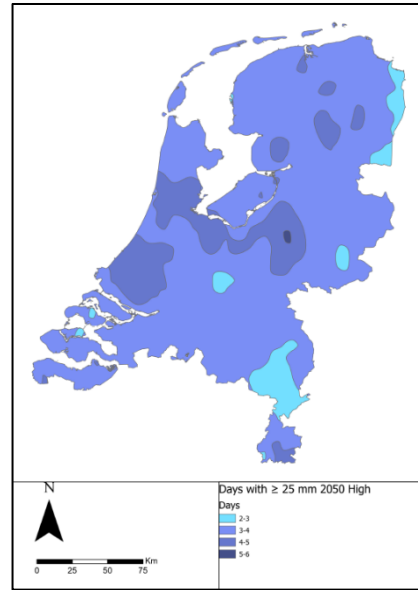


Figure 10: Map of independent variable (extreme precipitation). Map is own work. Data (KlimaatEffectAtlas, 2024)

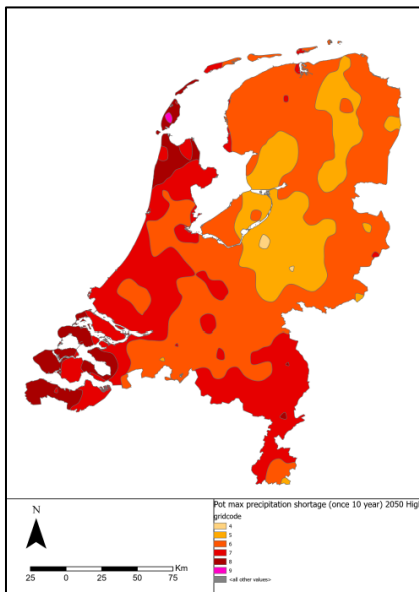


Figure 11: Map of independent variable (extreme drought). Map is own work. Data (KlimaatEffectAtlas, 2024)

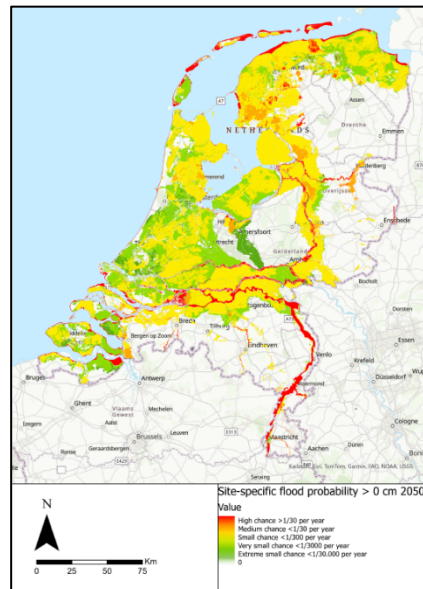


Figure 12: Map of independent variable (flood risk). Map is own work. Data (KlimaatEffectAtlas, 2024)

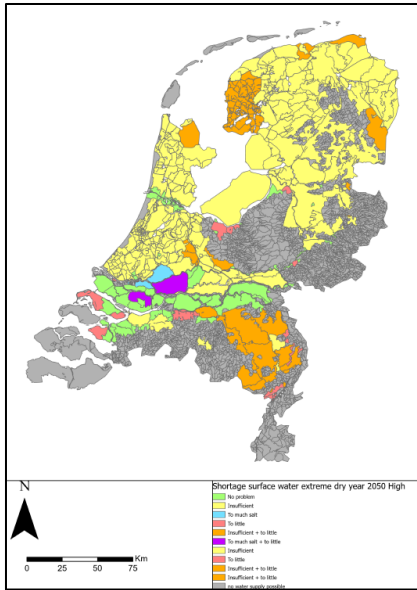


Figure 13: Map of independent variable (shortage surface water). Map is own work. Data (KlimaatEffectAtlas, 2024)

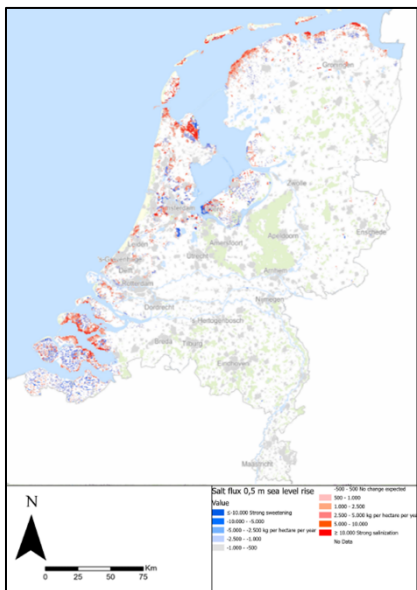


Figure 14: Map of independent variable (salinization). Map is own work. Data (KlimaatEffectAtlas, 2024)

4.2 Results statistical test

First, the Variance Inflation Factor (VIF) was calculated for all independent variables. For the complete VIF output tables see Metadata 1. Following this, an Ordinary Least Squares (OLS) regression was conducted with the remaining variables to assess their impact on the agricultural land prices in the Netherlands. Since this study focuses on climate risks, only the relevant results are presented in this section. The full output tables can be found in Metadata 2.

4.2.1 Netherlands

First there was tested for multicollinearity, see results in Metadata 1. For the Netherlands dataset the following variables did show multicollinearity with each other: minimum height, maximum height and average height. The VIF values of these variables were 500,250, 500,250 and 250,250 respectively. Given these high values and the logical correlation between these variables, they were removed from the analysis.

The analysis included 7,921 transaction, and the model yielded a R^2 of 0.358. Significant positive impacts from climate risks were found in (see Table 2): “Number of tropical days (max \geq 30) 2050 high” with a positive impact of 0.008 and “Shortage surface water extreme dry year 2050 high” with a positive impact of 0.003. Significant negative impacts from climate risks were found in “Site-specific flood probability $>$ 0 cm in 2050” with a negative impact of -0.003 and ‘Salt flux 0.5m’ with a value of -1.957E-40. Although these impacts are statistically significant, they are very small and close to zero. For the complete output, including other variables used in this study, see Metadata 2.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max \geq 30) 2050 High	0.008	0.002	0.080	3.941	<0.001***
Days with \geq 25 mm 2050 High	0.004	0.003	0.012	1.129	0.259
Pot max precipitation shortage (once 10 year) 2050 High	-0.002	0.003	-0.011	-0.707	0.480
Site-specific flood probability $>$ 0 cm in 2050	-0.003	0.001	-0.037	-2.708	0.007***
Shortage surface water extreme dry year 2050 High	0.003	0.001	0.063	5.298	<0.001***
Salt flux 0.5 m sea level rise	-1.957E-40	0.000	-0.034	-3.671	<0.001***
Significance level: ***0.99, **0.95, *0.90					

Table 3: Output Netherlands

4.2.2 Arable- and grassland

There was tested for multicollinearity, see results in Metadata 1. For the Arable land dataset, the following variables did show multicollinearity: GDP and crop rotation score, standard deviation of the height and rectangularity, minimum height and maximum height. The VIF values of these variables were 6,213, 500,250 and 55,807 respectively. The variables with VIF values above the threshold of 10, such as standard deviation and minimum and maximum height, were removed, while GDP and crop rotation score were retained in the model.

For this analysis 1,995 transaction were used, and the model yielded a R^2 of 0.346. Significant climate risk impact included: “Number of tropical days (max \geq 30) 2050 high”, -0.007 and “Flood risk 2050 $>$ 0

cm”, -0.005, see Table 3. Again, these impacts are very small and close to zero. See Metadata 2 for the full output dataset.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0.007	0.003	-0.080	-1.957	0.050*
Days with ≥ 25 mm 2050 High	0.004	0.006	0.013	0.589	0.556
Pot max precipitation shortage (once 10 year) 2050 High	-0.005	0.005	-0.033	-1.016	0.310
Site-specific flood probability > 0 cm in 2050	-0.005	0.002	-0.060	-2.323	0.020***
Shortage surface water extreme dry year 2050 High	0.000	0.001	0.007	0.301	0.763
Salt flux 0.5 m sea level rise	-4.500E-41	0.000	-0.009	-0.499	0.618
Significance level: ***0.99, **0.95, *0.90					

Table 4: Output Arable land

For the grassland dataset, multicollinearity was found in variables similar to the arable land dataset: GDP and crop rotation score, standard deviation of the height and rectangularity, minimum height with maximum height. The VIF values of these variables were 6,213, 500,250 and 55,807 respectively. Again, variables with VIF values above the threshold 10 were removed. There was no reason to deleted GDP or crop rotation score so this variable stayed in the model. The other variables had a VIF above the threshold of 10 so these variables were deleted.

This analysis also included 5,926 transaction with a R^2 of 0.325. Significant impact from the were found climate risks: “Number of tropical days (max ≥ 30) 2050 High”, 0.014 and ‘Shortage surface water extreme dry year 2050 High’, 0.004 and “Salt flux 0.5 m sea level rise”, -2.734E-40. All impacts are very small and close to zero. The full output dataset can be found in Metadata 2.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0.014	0.002	0.142	5.784	<0.001***
Days with ≥ 25 mm 2050 High	0.003	0.004	0.008	0.649	0.516
Pot max precipitation shortage (once 10 year) 2050 High	-0.001	0.003	-0.004	-0.224	0.823
Site-specific flood probability > 0 cm in 2050	-0.002	0.001	-0.025	-1.495	0.135
Shortage surface water extreme dry year 2050 High	0.004	0.001	0.081	5.792	<0.001***
Salt flux 0.5 m sea level rise	-2.734E-40	0.000	-0.045	-4.193	<0.001***
Significance level: ***0.99, **0.95, *0.90					

Table 5: Output Grassland

4.2.3 Ground types

For all ground type datasets, high multicollinearity was observed between minimum height, maximum height and average height. Consequently, the minimum height and maximum height were removed from all statistical tests for ground types.

For the analysis on the area type Buildings 77 transaction were used, the model yielded a R^2 of 0.788. Some multicollinearity was observed between average height and Zuid-Limburg, but these variables were retained due to the VIF value being just above 5. Significant impacts were found in (see Table 5): “Number of tropical days (max \geq 30) 2050 High”, 0.014, ‘Shortage surface water extreme dry year 2050 High’, 0.004 and ‘Salt flux 0.5 m sea level rise’, $-2.734E-40$.

For the analysis on the soil type Heavy Clay 531 transaction were used, the model yielded a R^2 of 0.436. Multicollinearity was found between average height and Zuid-Limburg, VIF value of 12.755, and standard deviation height and Zuid-Limburg, VIF value of 6.358, leading to the removal of average height. Two significant negative impacts were found (see Table 5): “Number of tropical days (max \geq 30) 2050 High”, -0.023, and “Salt flux 0.5 m sea level rise”, $-9.859E-40$.

For the analysis on soil type Heavy Silt 717 transaction were used, the model yielded a R^2 of 0.385. No multicollinearity was found, and one significant impact of climate risks was found: “Site-specific flood probability $>$ 0 cm in 2050”, -0.011 (see Table 5).

For the analysis on soil type Light Clay 484 transaction were used, the model yielded a R^2 of 0.549. No multicollinearity was found, and two significant negative impacts for the climate risks were found (see Table 5). “Number of tropical days (max \geq 30) 2050 High”, -0.034 and “Pot max precipitation shortage (once 10 year) 2050 High”, -0.023. One significant positive impact was found “Shortage surface water extreme dry year 2050 High”, 0.011.

For the analysis on soil type Light Silt 673 transaction were used, the model yielded a R^2 of 0.431. No multicollinearity or significant impacts from the climate risks were found.

For the analysis on soil type Loam 213 transaction were used, the model yielded a R^2 of 0.376. Some minor multicollinearity between water stairs score and Zuid-Limburg, VIF value of 5.118 was found. This is so little so not taken into account. One significant impact was found: “Shortage surface water extreme dry year 2050 High”, 0.031.

For the analysis on soil type Marshy on Sand 281 transaction were used, the model yielded a R^2 of 0.559. No multicollinearity was found, and only one significant impact was found. This was a positive impact of “Number of tropical days (max \geq 30) 2050 High”, 0.063.

For the analysis on soil type Peat 661 transaction were used, the model yielded a R^2 of 0.361. No multicollinearity was found, with only one significant positive impact: “Number of tropical days (max \geq 30) 2050 High”, 0.058.

For the analysis on soil type Sand 4229 transaction were used, the model yielded a R^2 of 0.322. No multicollinearity was found, and three significant impacts were found. These were all positive impacts: “Number of tropical days (max \geq 30) 2050 High”, 0.011, and “Days with \geq 25 mm 2050 High”, 0.010, and “Shortage surface water extreme dry year 2050 High”, 0.002.

For the analysis on area type 55 transaction were used, the model yielded a R^2 of 0,902. No multicollinearity or significant impacts were found.

	Buildings		Heavy Clay		Heavy Silt		Light Clay	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Number of tropical days (max ≥ 30) 2050 High	0.014	<0.001***	-0.023	0.036**	0.007	0.263	0.005	0.622
Days with ≥ 25 mm 2050 High	0.003	0.516	-0.016	0.338	0.001	0.960	-0.034	0.048**
Pot max precipitation shortage (once 10 year) 2050 High	-0.001	0.823	0.013	0.284	-0.010	0.197	-0.023	0.067*
Site-specific flood probability > 0 cm in 2050	-0.002	0.135	0.004	0.617	-0.011	0.006***	0.003	0.663
Shortage surface water extreme dry year 2050 High	0.004	<0.001***	0.002	0.427	0.002	0.342	0.011	<0.001***
Salt flux 0.5 m sea level rise	-2.734E-40	<0.001***	-9.859E-40	<0.001***	-4.134E-40	0.185	-2.546E-40	0.335
Significance level: ***0.99, **0.95, *0.90								

Table 6: Output Ground types

Light Silt		Loam		Marshy on Sand		Peat		Sand		Water	
B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
0.002	0.796	-0.035	0.190	0.063	<0.001***	0.058	<0.001***	0.011	0.001***	-0.086	0.463
0.016	0.326	0.014	0.567	0.028	0.190	0.016	0.249	0.010	0.012**	-0.075	0.637
-0.005	0.552	0.001	0.961	-0.003	0.849	0.004	0.681	0.000	0.964	0.065	0.582
-0.003	0.351	0.005	0.800	-0.003	0.577	0.001	0.821	-0.001	0.683	0.036	0.323
-0.001	0.682	0.020	0.031**	0.003	0.345	0.004	0.156	0.002	0.002***	0.029	0.259
-1.887E-06	0.252	-7.198E-42	0.972	-3.477E-40	0.232	-2.023E-40	0.435	-4.208E-41	0.510	-8.259E-40	0.401
Significance level: ***0.99, **0.95, *0.90											

4.2.4 Agricultural region

Most agricultural regions exhibited multicollinearity between minimum height, maximum height and average height. Consequently, the minimum height and maximum height were removed.

For the analysis on agricultural region Bouwhoek en Hogeland 187 transaction were used, the model yielded a R^2 of 0.608. No multicollinearity was found, only one positive significant impact of climate risks was found: "Pot max precipitation shortage (once 10 year) 2050 High", 0.142.

For the analysis on agricultural region Centraal Veehouderijgebied 428 transaction were used, the model yielded a R^2 of 0.390. No multicollinearity was found, and two positive significant impacts of climate risks were found: "Number of tropical days (max \geq 30) 2050 High", 0.037 and "Pot max precipitation shortage (once 10 year) 2050 High", 0.026. One negative significant impact was found "Site-specific flood probability > 0 cm in 2050", -0.013.

For the analysis on agricultural region Hollands-Utrechts Weidegebied 358 transaction were used, the model yielded a R^2 of 0.300. No multicollinearity was found, and one positive significant impact was observed: "Shortage of surface water in an extreme dry year 2050 high", 0.009.

For the analysis on agricultural region Ijsselmeerpolders 132 transaction were used, the model yielded a R^2 of 0.621. Multicollinearity was found between GDP and distance to the boarder, VIF value of 20.253 and, GDP with number of tropical days, VIF value of 6.213, GDP with pot max precipitation shortage VIF value of 7.834, distance to the boarder and pot max precipitation shortage, VIF value of 7.109. The correlation of GDP and distance to the boarder is unusual for Ijsselmeerpolders due to its central location in the Netherlands. One significant negative impact was found: "Number of tropical days (max \geq 30) 2050 High", -0.095.

For the analysis on agricultural region Noordelijk Weidegebied 1222 transaction were used, the model yielded a R^2 of 0.321. No multicollinearity was found between the variables. Five out of six climate risks had a significant impact. Only one was negative "Days with \geq 25 mm 2050 High", -0.047. The other four positive impacts were: "Number of tropical days (max \geq 30) 2050 High" 0.072. "Site-specific flood probability > 0 cm in 2050", 0.009. "Shortage surface water extreme dry year 2050 High", 0.004. "Salt flux 0.5 m sea level rise", 7.316E-06.

For the analysis on agricultural region Oosterlijk Veehouderijgebied 1757 transaction were used, the model yielded a R^2 of 0.242. No multicollinearity was found between the variables. Four out of six climate risks had a significant impact. Two were negative impacts: "Number of tropical days (max \geq 30) 2050 High", -0,023 and "Site-specific flood probability > 0 cm in 2050", -0.006. The other two positive climate risks were: "Days with \geq 25 mm 2050 High", 0.021 and "Shortage surface water extreme dry year 2050 High", 0.003.

For the analysis on agricultural region Rivierengebied 308 transaction were used, the model yielded a R^2 of 0,293. No multicollinearity was found between the variables. Only one climate risk had a significant impact. This was a positive impact; 'Days with \geq 25 mm 2050 High', 0,052.

For the test on agricultural region Veenkoloniën en Oldambt 619 transaction were used. The model had a R^2 of 0,376. No multicollinearity was found between the variables. Three climate risks had a significant impact. Two negative impacts of climate risks: "Shortage surface water extreme dry year 2050 High", -0.004, "Salt flux 0.5 m sea level rise", -6.038E-40. One positive impact from the climate risk: "Pot max precipitation shortage (once 10 year) 2050 High", 0.046.

For the analysis on agricultural region Waterland and Droogmakerijen 104 transaction were used, the model yielded a R^2 of 0.606. No multicollinearity or significant impacts were found for agricultural region Waterland and Droogmakerijen.

For the analysis on agricultural region Westelijk Holland 242 transaction were used, the model yielded a R^2 of 0.425. No multicollinearity was found, only one climate risks had a negative significant impact: "Shortage surface water extreme dry year 2050 High", -0.020.

For the analysis on agricultural region Zuidelijk Veehouderijgebied 1640 transaction were used, the model yielded a R^2 of 0.256. No multicollinearity was found. Only one climate risk had a negative significant impact which was: "Number of tropical days (max \geq 30) 2050 High", -0.028. One climate risk had a positive significant impact "Days with \geq 25 mm 2050 High", 0.018.

For the analysis on agricultural region Zuid-Limburg 189 transaction were used, the model yielded a R^2 of 0,373. For the agricultural region Zuid-Limburg Flood risks was multicollinearity with the water stairs score (16,383) and Loam had a very small multicollinearity with the water stairs score (5,417). The water stairs score was removed. No significant impacts were found.

For the test on agricultural region Zuidwest Brabant 195 transaction were used. The model had a R^2 of 0.313. No multicollinearity was found, only one climate risks had a negative significant impact which was "Site-specific flood probability $>$ 0 cm in 2050", -0.008.

For the analysis on agricultural region Zuidwestelijke Akkerbouwgebied 551 transaction were used, the model yielded a R^2 of 0.272. No multicollinearity was found. Two climate risks had a negative significant impact which were: "Pot max precipitation shortage (once 10 year) 2050 High", -0.028 and "Site-specific flood probability $>$ 0 cm in 2050", -0.009.

	Bouwhoek en Hogeland		Centraal Veehouderijgebied		Hollands-Utrechts Weidegebied		Ijsselmeerpolders		Noorderlijk Weidegebied		Oosterlijk Veehouderijgebied		Zuidwestelijke Akkerbouwgebied	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Number of tropical days (max ≥ 30) 2050 High	0.009	0.797	0.037	0.042**	0.017	0.285	-0.095	0.079*	0.072	<0.001***	-0.023	<0.001***	-0.010	0.109
Days with ≥ 25 mm 2050 High	-0.060	0.288	-0.002	0.897	-0.004	0.803	-0.046	0.422	-0.047	<0.001***	-0.011	0.140	-0.007	0.711
Pot max precipitation shortage (once 10 year) 2050 High	0.142	<0.001***	0.026	0.040**	0.002	0.905	0.039	0.385	0.008	0.239	0.021	<0.001***	-0.028	0.024**
Site-specific flood probability > 0 cm in 2050	0.025	0.123	-0.013	0.026**	0.000	0.981	-0.004	0.837	0.009	0.004***	-0.006	0.004***	-0.009	0.056*
Shortage surface water extreme dry year 2050 High	0.000	0.937	0.000	0.922	0.009	0.017**	0.011	0.727	0.004	0.008***	0.003	0.001***	0.000	0.900
Salt flux 0.5 m sea level rise	-3.026E-06	0.576	0.001	0.111	-7.755E-06	0.103	4.921E-06	0.329	7.316E-06	0.059**	-6.902E-41	0.491	0.000	0.973
Significance level: ***0.99, **0.95, *0.90														

Table 7: Output agricultural regions

Rivierengebied		Veenkoloniën en Oldambt		Waterland en Droogmakerijen		Westelijk Holland		Zuidelijke Veehouderijgebied		Zuid-Limburg		Zuidwest Brabant		Zuidwestelijke Akkebouwgebied	
B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
0.005	0.762	-0.004	0.808	0.026	0.784	0.016	0.576	-0.028	<0.001***	-0.033	0.354	0.057	0.113	-0.01	0.109
0.052	0.008***	0.010	0.403	0.029	0.664	0.022	0.494	0.018	0.018**	0.003	0.909	0.024	0.235	-0.007	0.711
-0.008	0.516	0.046	<0.001***	0.056	0.467	0.016	0.564	0.001	0.904	-0.012	0.668	0.007	0.497	-0.028	0.024**
0.001	0.940	0.006	0.357	0.069	0.194	-0.010	0.382	-0.003	0.233	-0.012	0.328	-0.008	0.065*	-0.009	0.056*
0.001	0.731	-0.004	0.043**	0.103	0.578	-0.020	0.049**	-0.002	0.172	-	-	1.93E-40	0.526	0.000	0.900
0.005	0.762	-6.038E-40	0.056*	6.477E-42	0.991	-5.87E-07	0.899	-7.92E41	0.206	-1.20E-40	0.593	0.057	0.113	-1.04E-41	0.973

4.3 Discussion

To answer the question, 'What is the impact of climate risks on the agricultural land prices in the Netherlands?', this study utilized a hedonic pricing model. In this model, six climate risks were examined as part of a range of variables to assess their impact on agricultural land prices: extreme heat, extreme precipitation, extreme drought, flood risk, surface water shortage and salinization. Furthermore, the study not only considered the Netherlands as a whole but also analyzed the country by subdividing it into arable and grassland, different agricultural regions, and soil types to investigate the influence of climate risks on a more regional level.

It was expected that the six climate risks would negatively influence agricultural land prices in the Netherlands due to their potential adverse effects on soil and crop growth. This could decrease land yield and workability, ultimately reducing the productivity and profitability of the land. For the subdivisions made within the Netherlands, it was also expected that climate risks would have a negative impact on the agricultural land price. The outcomes of this study did not meet the expected results. This study found several significant negative influences of climate risks on agricultural land prices. However, significant positive impacts were also identified. In both cases, the effects were relatively weak.

When compared to other studies on agricultural land prices that consider climate risk, this study presents differing results. For instance, Bozzala et al., (2018); Hodge (2021); Hussain & Mustafa (2016); Massetti et al., (2016) and Mendelsohn et al., (1994) found significant impacts of climate risks on agricultural land prices. In contrast, this study identified only minor to negligible impacts. Several factors could account for these differences. Firstly, the studies vary in their control variables and the specific climate risks they examine. Data consistency across these studies is lacking, as they were conducted in different countries and regions worldwide. Neither are climate variables globally standardized nor uniformly monitored. Secondly, many studies focus only on general climate risks such as temperature, precipitation, or sea level rise. In contrast, this study specifically examined six specific climate risks: extreme heat, extreme precipitation, extreme drought, flood risk, surface water shortage and salinization. These six climate risks were used because of the importance in special for the Dutch agricultural sector.

When comparing these findings to a related real estate market, such as the the housing market, noticeable differences emerge. While there are some overlapping variables and climate risks between the agricultural land market and the housing market, such as the risk flood risk, climate risks tend to have a more pronounced impact on housing prices than on agricultural land prices. For example, Bosker et al., (2019) researched the impact of flood risks on house prices in the Netherlands and found that house prices were, on average, 1% lower in flood-prone areas. Another study by Willemsen et al., (2020) found a significant negative impact of -6% on property values due to uniform land subsidence in two major cities in the Netherlands. These studies indicate that specific climate risks are taken into account in the Dutch housing market, unlike the agricultural land market in the Netherlands. Although it is not mandatory to disclose or consider climate risks, buyers in the housing market do take them into account. Additionally, some studies suggest no impact of climate risks on the housing market, which aligns more closely with the findings of this study (Hans, 2024; Kadaster, 2024a). The question that arises: why can impacts of climate risks be seen on the housing market but not in the agricultural land market? A possible explanation could be that actors in the agricultural land market trust in innovation and adaptive measures. This could be a reasonable assumption given the advances in agriculture over the last such as precision agriculture, computer-controlled horticulture in closed greenhouses, outdoor production with assistance from drones and vertical cultivation. However, it is also possible that actors in the agricultural land market are overlooking potential future.

Finally, this study did not take this possible explanation of trust in innovation and adaptive measures in the future into account. This omission was due to the uncertainty of outcomes and the difficulty in quantifying these factors into usable data for a hedonic pricing model. However, if a reliable method for quantifying these factors could be developed, it would be interesting to examine their impact on agricultural land prices. Such an investigation could reveal whether people believe that climate risks will be mitigated by future innovations or whether they expect technological advancements to enable adaptation to these risks.

5. Conclusion

5.1 Answers to the research questions

The importance of addressing climate change is increasing, as the impact of climate risks on agricultural land. This study aimed to provide insights into the impact of climate risks on agricultural land prices in the Netherlands. To explore this, the following main research question was posed:

'What is the impact of climate risks on the agricultural land prices in the Netherlands?'

In order to answer this main research question, three sub-questions were formulated. These three sub-questions will be answered, followed by an answer to the main research question.

'What characterises the Dutch agricultural land market?'

The literature review provided some general insights into the Dutch agricultural land market. The key points included: (1) increasing agricultural land prices, (2) price difference between arable and grassland, (3) regional price differences and (4) various economic influences on the market.

Firstly, the Dutch agricultural land market is characterised as a heterogeneous market which, meaning that the products, land in this case, have different attributes. Additionally, this market is characterised by a continuous increase in agricultural land prices. Secondly, there is a price difference based on land use. Specifically, arable land is more expensive than grassland, largely due to the profitability of crops grown on arable land. This price difference is approximately €10,000 per hectare. Thirdly, agricultural land prices vary by region, influenced by a combination of agricultural use and soil type. As of the first quarter of 2024, agricultural land prices in the Netherlands ranged from €60,800 and €182,800 per hectare. Lastly, the agricultural land market is influenced by several economic factors. The following influences are determined: (1) supply and demand, (2) increasing land area per farm, (3) interest rates, (4) developer influences and (5) rules and regulations.

Another important factor for the Dutch agricultural land market is ground mobility, which refers to the amount of land in hectares traded over a specific time period. What can be seen is a decrease in ground mobility in the Netherlands. Additionally, the method of registering agricultural land prices in the Netherlands recently changed. The new registration method involves adjustments to the capping method of price calculations and now operates at a regional level instead of national level due to regional price differences.

'Which variables define agricultural land prices?'

To answer the main research question, this study utilized a hedonic pricing model, which requires identifying the variables that define agricultural land prices.

From the literature, four main characteristics were identified as defining agricultural land prices: (1) parcel characteristics, (2) transaction characteristics, (3) macroeconomic variables and (4) government policy. These four main characteristics categorise the various variables that define agricultural land prices. Parcel characteristics address the spatial variables of a plot of land, including location, physical properties and land use. This is particularly relevant in this study as physical properties are closely related to climate risks. Transaction characteristics encompass variables related to transactions between actors, such as the parties involved in a transaction, the relationship between buyer and seller and type of transaction. Macroeconomic variables include indicators and statistics that describe geographic and demographic factors related to economics, such as supply and demand, inflation rate, interest rate, GDP and innovation. As last government policy refers to the rules and regulations imposed

and facilitated by the government, including zoning plans, Natura 2000 area regulations, derogation rules, and subsidies.

By understanding these four characteristics and reviewing previous studies, a clearer idea of the variables defining agricultural land prices is established, along with an understanding of which variables are available and relevant for this study.

'Which climate risks potentially influence the quality and use of agricultural land in the Netherlands?'

To identify the climate risks relevant to this study, a literature study was conducted on the most important climate risks in the Netherlands and their relation to agriculture. Four overarching climate risks were identified: temperature, precipitation, drought and sea level rise. For this study, six specific climate risks relevant to the Dutch agricultural sector were defined. Extreme heat, extreme precipitation and extreme drought were identified as key extreme weather events, which are expected to become more frequent and severe due to climate change. Additionally, flood risk, surface water shortage and salinization were considered due to the Netherlands' unique geographical positions and the importance of these factors to agriculture in the country.

'What is the impact of climate risks on the agricultural land prices in the Netherlands?'

With the information gathered from the three sub-questions and the results of the statistical test, the main question can be answered. It was initially expected that the climate risks would negatively impact agricultural land prices in the Netherlands. However, the hedonic pricing model revealed that climate risks have only minimal or no impact on agricultural land prices in the Netherlands. Some results indicated positive impacts, while others showed negative impacts. Even when analyzing specific soil and areas types or agricultural regions within the Netherlands, the influence of climate risks on agricultural land prices remained small to negligible. Therefore, the conclusion of this research is that, at present, climate change does not significantly impact agricultural land prices in the Netherlands.

5.2 Scientific contribution

This study on the impact of climate risks on agricultural land prices in the Netherlands contributes to the existing scientific literature by exploring the characteristics of the Dutch agricultural land market, identifying the variables that define agricultural land prices and assessing which climate risks affect agriculture in the Netherlands.

While the exploration of the agricultural land market has been extensively covered in previous studies, it was necessary to revisit this topic briefly to understand the key characteristics of this market. Additionally, this study reviews and expands upon the variables that define agricultural land prices. The overview of factors that define agricultural land prices by Buurman (2003) has been enriched with additional factors found in the literature. Moreover, a literature review has identified the most important climate risks related to agriculture in the Netherlands.

The most important contributions to the scientific literature is its answer to the main research question: there is no significant impact of climate risks on agricultural land prices in the Netherlands. Prior to this study, no research had been conducted on this specific impact. Furthermore, this research does not only look at the Netherlands but also zooms in on: arable or grassland use, different soil and area types and different agricultural regions. This study can also be seen as an update to existing research on the impact of climate risks on agricultural land prices. While earlier studies often found a negative impact of climate risks on agricultural land prices, this study shows no significant impact of climate risks on agricultural land prices in the context of the Netherlands.

While it is evident that climate change could influence land values, some knowledge gaps remain. First, most studies focus on the value of land, which may reflect transaction prices. However, often it indicates the production, yield or fertility. In this study, the price of agricultural land will be studied. It is important to distinguish between the two concepts 'value' and 'price'. Value refers to the worth of a good based on its utility or the satisfaction it provides, which is subjective (Leszinski & Marn, 1997). Price, on the other hand, is the amount of money actually paid in the market for a certain good, influenced by supply and demand (Fetter, 1912). Second, the impact of climate risks on agricultural land prices in the Netherlands, one of the world's leading countries, has not been previously researched. Understanding this impact is particularly important due to the Netherlands' significant agricultural economy and unique geographical location. Situated in the delta of the Rhine, Meuse and Scheldt rivers, large part of the Netherlands lies below sea level, potentially exposing it to unique climate risks. Exploring these risks could influence agricultural land prices in the Netherlands and contribute valuable insights to the scientific literature.

Furthermore, this study indirectly seeks to determine whether climate risks should be considered in agricultural property valuations. There is limited literature openly available on valuation, particularly regarding the influence of climate risks. The organisation NVRT (Nederlands Register Vastgoed Taxateurs), the Dutch Register of Real Estate Appraisers, provides little information and literature on valuation and even less on the impact of climate risks and valuation.

5.3 Recommendations for practice

Throughout this study, the relation between agricultural land transactions and valuations of has been highlighted. Valuations are often based on the so-called comparison method, which uses reference transactions to estimate the value or price of an asset. This study on the impact of climate risks on agricultural land prices in the Netherlands, which utilized a transaction dataset, raised the question of whether climate risks should be included in valuations. Based on the results of this study, several recommendations can be drawn up.

The findings of this study indicate that climate risks currently have little to no impact on agricultural land prices in the Netherlands. This suggest that other variables are more influential in determining price. As such, there is no immediate need to adjust the valuation guidelines in the Netherlands to account for climate risks. However, in the future, if climate risks begin to play a more significant role in agricultural land prices and people are no longer able to mitigate the effects of climate risks or make agricultural land profitable, there could be a decline in land values. When that time comes, it will be important to have already discussed which climate risks should be considered and how to measure their impact. This study could serve as a foundation for that discussion.

Additionally, investors in agricultural land typically have a long-term perspective. They should be aware of the potential for future changes in land prices due to increasing climate risks. While agricultural land prices in the Netherlands have been rising, this trend could halted or even reverse, leading to huge financial losses. Investors may want to consider selecting regions for investment based on future climate risk projections. However, this study also did not find region specific impacts of climate risks on agricultural land prices in the Netherlands. So, it remains crucial to monitor when and how these risks may begin to impact agricultural land values.

5.4 Limitations to this study

This study has several limitations. In the literature review on variables that influence agricultural land prices, four main characteristics with potential variables were described. Based on the international literature, numerous variables influence agricultural land prices, though their importance varies by

region. For example, the distance to Natura-2000 area, a variable used in this study, may not be relevant in other parts of the world. Conversely, variables that significantly impact agricultural land in other regions of the world, such as slope, are less relevant in the Netherlands, which is predominantly flat except for parts of Limburg. The same applies to the six chosen climate risks, which are most pertinent to the Netherlands but may not be as critical in other regions. It is important to consider which variables are applicable to the area that is being researched.

Further limitations are related to the method, the hedonic pricing model, and the variables and data used. The hedonic pricing model relies on the assumption that buyers are perfectly informed of all characteristics, which is rarely the case in practice. Even when actors are informed, another limitation arises: the future climate risk predications used in this study are not perfect and only provide estimates of potential future scenarios. Some variables were not included in this study due to a lack of data or time constraints in generating the data. Additionally, variables such as demand, rules, and regulations are difficult to quantify and were therefore excluded. Including these variables could enhance the study, especially by improving the explanation of Dutch agricultural land prices through macroeconomic characteristics. Quantifying supply and demand would be particularly beneficial. Moreover, understanding the influence of rules and regulations would be valuable, quantifying future rules and regulations is challenging due to the uncertainty of their impact.

Lastly, there are limitations related to the data used for the four of the six climate risks. For example, data on extreme heat used the number of tropical days, which are days with a maximum temperature of 30 °C. Ideally, data on the number of days with a maximum temperature of 35 °C, the threshold for extreme heat in the Netherlands, would have been used. Similarly, data on extreme precipitation used the number of days with ≥ 25 mm of precipitation, while the number of days with ≥ 50 mm would have been preferable. However, these two limitations are more about definitions, and the datasets still illustrate the increasing extremes. For flood risk, data on site-specific flood probability was used, based on the maximum permissible flood probability for primary flood defences as defined for 2050 in the Water Act of the Netherlands. In reality, many primary flood defences do not yet meet this future safety standard, meaning actual flood probabilities may be higher, except for coastal dunes where the is currently safe. For salinization, data on the silt flux with 0.5 m sea level rise was used, but there were issues with the model settings that inaccurately showed water sweetening in Zeeland. Additionally, salinization was calculated based solely on sea level rise, whereas other factors like precipitation and temperature also impact it. Using data that more accurately corresponds with the definitions could improve this study.

To assess the impact on agricultural land prices in the Netherlands 7,921 transaction between 2019 and 2023 were analysed. However, when dividing the Netherlands into different soil and area types and agricultural regions, some soil types and regions were underrepresented due to a low number of transactions. This could influence the outcome of associated hedonic pricing models. More transactions in these underrepresented soil types and regions which were underrepresented would result in stronger outcomes. However, most of the soil and area types and agricultural regions were adequately represented for reliable results.

Reference list

- a.s.r. real estate. (2024). *Data a.s.r. real estate*.
- Atlas Leefomgeving. (2024). *Houd jij dorge voeten? Bekijk het op onze nieuwe Overstromingskaart*.
- Beckman, J., & Countryman, A. M. (2021). The Importance of Agriculture in the Economy: Impacts from COVID-19. *American Journal of Agricultural Economics*, 103(5), 1595–1611. <https://doi.org/10.1111/ajae.12212>
- Bekamp, B., & Smit, H. (2024). *Agrarische grondprijzen: zet de stijging door?*
- Belyaeva, M., & Bokusheva, R. (2018). Will climate change benefit or hurt Russian grain production? A statistical evidence from a panel approach. *Climatic Change*, 149(2), 205–217. <https://doi.org/10.1007/s10584-018-2221-3>
- Bosker, M., Garretsen, H., Marlet, G., & Van Woerkens, C. (2019). Nether lands: Evidence on the price and perception of rare natural disasters. *Journal of the European Economic Association*, 17(2), 413–453. <https://doi.org/10.1093/jeea/jvy002>
- Bozzola, M., Massetti, ;, Mendelsohn, ;, Robert, Capitanio, & Fabian. (2018). *A Ricardian Analysis of the Impact of Climate Change on Italian Agriculture*.
- Broeders, D., van den End, J. W., & Rollingswier, R. (2021). *Europees monetair beleid wordt groener*.
- Buitelaar, E. (2021). *De werking van de grondmarkt en de rol van de overheid*.
- Buurman, J. J. G. (Jozef J. G. (2003). *Rural land markets: a spatial explanatory model*. s.n.].
- CBS. (2021). *Nederland in Cijfers*.
- CBS. (2023a). *CBS Statline*. <https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80785ned/table?dl=97499>
- CBS. (2023b). *Landbouw; gewassen, dieren en grondgebruik naar regio*. <https://opendata.cbs.nl/#/CBS/nl/dataset/80780ned/table>
- CBS. (2023c). *Minder natuur- en bosgebied in Nederland*. <https://www.cbs.nl/nl-nl/nieuws/2024/18/minder-natuur-en-bosgebied-in-nederland>
- CBS. (2024a). *Landbouw; gewassen, dieren en grondgebruik naar regio*.
- CBS. (2024b). *Regionale kerncijfers; nationale rekeningen*.
- Cervantes-Godoy, D., & Dewbre, J. (2010). *Economic Importance of Agriculture for Poverty Reduction*. <https://doi.org/10.1787/5kmmv9s20944-en>
- Ciaian, P., Baldoni, E., Kancs, A., & Drabik, D. (2021). *The Capitalization of Agricultural Subsidies into Land Prices*. <https://doi.org/10.1146/annurev-resource-102020>
- Cid-Garcia, N. M., Albornoz, V., Rios-Solis, Y. A., & Ortega, R. (2013). Rectangular shape management zone delineation using integer linear programming. *Computers and Electronics in Agriculture*, 93, 1–9. <https://doi.org/10.1016/j.compag.2013.01.009>
- Cottleer, G., Gardebroek, C., & Luijt, J. (2008). *Market Power in a GIS-Based Hedonic Price Model of Local Farmland Markets*.

- Cotteleer, G., Luijt, J., Kuhlman, J. W., & Gardebroek, K. G. (2007). *Oorzaken van verschillen in grondprijzen Een hedonische prijsanalyse van de agrarische grondmarkt*.
- Cotteleer, G., Stobbe, T., & Cornelis Van Kooten, G. (2007). *Farmland Conservation in The Netherlands and British Columbia, Canada: A Comparative Analysis Using GIS-based Hedonic Pricing Models*.
- Cropper, M. L., Deck, L. B., & McConnell, K. E. (1988). *On the Choice of Functional Form for Hedonic Price Functions* (Vol. 70, Issue 4). <https://about.jstor.org/terms>
- de Keijzer, S., & van Boxel, J. (2003). *De vernatting van Nederland Het gevolg van een toename van de extreme neerslag?* Stationery Office.
- Dillingh, D., Baart, F., & de Ronde, J. G. (2010). *Definitie zeespiegelstijging voor bepaling suppletiebehoefte*.
- EEA. (2024). *European climate risk assessment — Executive summary*. <https://doi.org/10.2800/204249>
- Escarcha, J. F., Lassa, J. A., & Zander, K. K. (2018). Livestock under climate change: A systematic review of impacts and adaptation. In *Climate* (Vol. 6, Issue 3). MDPI AG. <https://doi.org/10.3390/cli6030054>
- Eswar, D., Karuppusamy, R., & Chellamuthu, S. (2021). Drivers of soil salinity and their correlation with climate change. In *Current Opinion in Environmental Sustainability* (Vol. 50, pp. 310–318). Elsevier B.V. <https://doi.org/10.1016/j.cosust.2020.10.015>
- Eurostat. (2024). *Agricultural land prices by region*. https://doi.org/https://doi.org/10.2908/APRI_LPRC
- Feichtinger, P., & Salhofer, K. (2013). *What Do We Know about the Influence of Agricultural Support on Agricultural Land Prices?* <http://ageconsearch.umn.edu>
- Fetter, F. A. (1912). *The Definition of Price* (Vol. 2, Issue 4).
- Furtak, K., & Wolińska, A. (2023). The impact of extreme weather events as a consequence of climate change on the soil moisture and on the quality of the soil environment and agriculture – A review. In *Catena* (Vol. 231). Elsevier B.V. <https://doi.org/10.1016/j.catena.2023.107378>
- Geijzendorffer, I., Smidt, R., Engelbertink, R., Hermans, T., Schaap, B., Verhagen, J., & Blom-Zandstra, G. (1994). *Gevolgen van klimaatextremen voor de Nederlandse landbouw: noodzaak voor adaptatie?*
- Guiling, P., Doye, D., & Brorsen, B. W. (2009). Agricultural, recreational and urban influences on agricultural land prices. *Agricultural Finance Review*, 69(2), 196–205. <https://doi.org/10.1108/00021460910978689>
- Hans, L. (2024). *Prijseffecten overstromingsrisico's op de Nederlandse woningmarkt*.
- Herbert, Z., Van Der Kolk, J.-P., & Koopmans, C. (2023). *Incentives voor het voorkomen van bodemverdichting Een verkenning naar mogelijke oplossingsrichtingen*. www.louisbolk.nl/publicaties
- Hiddink, J. (2024). *Ruim helpt van akkerbouwers kampt met opbrengstderving door weerextremen*.
- Hodge, T. R. (2021). *Flooding and the Value of Agricultural Land*. <http://www.nws.noaa.gov/om/hazstats.shtml>.

- Hossain, M. S., Arshad, M., Qian, L., Kächele, H., Khan, I., Din Il Islam, M., & Golam Mahboob, M. (2020). Climate change impacts on farmland value in Bangladesh. *Ecological Indicators*, 112. <https://doi.org/10.1016/j.ecolind.2020.106181>
- Hussain, S. A., & Mustafa, U. (2016). *Impact of Climate Change on Agricultural Land Values: An Application of Ricardian Model in Punjab Pakistan*. <http://www.pide.org.pk>
- Jansen, L. (2019). *Klimaatverandering als financieel risico*.
- Jaramillo Roman, V., van de Zedde, R., Peller, J., Visser, R. G. F., van der Linden, C. G., & van Loo, E. N. (2021). High-Resolution Analysis of Growth and Transpiration of Quinoa Under Saline Conditions. *Frontiers in Plant Science*, 12. <https://doi.org/10.3389/fpls.2021.634311>
- Jellema, A., Beldman, A., & Woltjer, J. (2023). *Verkenning nieuwe eigendoms- en pachtvormen voor landbouwgrond*.
- Kadaster. (2024a). *Het risico op over-stroming van woningen*.
- Kadaster. (2024b). *Transacties 2019-2023*.
- Kadaster, RVO, & Wageningen Economic Research. (2022, January). *Agrarische grondprijs in vierde kwartaal naar 70.000 euro per ha*.
- Kadaster, & Wageningen Economic Research. (2024, April). *Kwartaalbericht agrarische grondmarkt 2024-1*.
- Keizer, I., Le Bars, D., De Valk, C., Jüling, A., Van De Wal, R., & Drijfhout, S. (2023). The acceleration of sea-level rise along the coast of the Netherlands started in the 1960s. *Ocean Science*, 19(4), 991–1007. <https://doi.org/10.5194/os-19-991-2023>
- Khan, S., Ali, G., Shah, S. A., Jan, A. U., Jan, D., & Fayaz, M. (2016). A hedonic analysis of agricultural land prices in Pakistan's Peshawar district. *Asian Journal of Agriculture and Rural Development*, 6(4), 59–67. <https://doi.org/10.18488/journal.1005/2016.6.4/1005.4.59.67>
- KlimaatEffectAtlas. (2024). *KlimaatEffectAtlas Data*.
- KNMI. (n.d.). *Extreme Neerslag*.
- KNMI. (2023). *KNMI'23 klimaat scenario's*.
- Knotters, M., Walvoort, D., Brouwer, F., Stuyt, L., & Okx, J. (2018). *Landsdekkende, actuele informatie over grondwatertrappen digitaal beschikbaar*.
- Kramer, N., Mens, M., Beersma, J., & Kielen, N. (2019). *Hoe extreem was de droogte van 2018?*
- Kruijne, R. (2021). *Verbetering van de Emmissieregistratie*.
- Kuiper, P. P., Prins, L., Hans, L., Silvis, H., & Voskuilen, M. (2022). *Aanpassing aftoppingsmethode agrarische grondprijsberekening*. <https://edepot.wur.nl/568427>
- Kuiper, P. P., Prins, L., Woltjer, J., & Voskuilen, M. (2023). *Agrariërs verwerven meeste landbouwgrond, maar hun aandeel daalt*.
- Kuiper, P. P., & Voskuilen, M. (2018). *Waardering verpachte landbouwgrond : Onderzoek op basis van kadastrale transactiegegevens en een enquête*. <https://doi.org/10.18174/443734>
- Leszinski, R., & Marn, M. V. (1997). *Setting value not price*.

- Luijt, J., & Voskuilen, M. (2009). *Langetermijnontwikkeling van de agrarische grondprijs*.
- Massetti, E., Mendelsohn, R., & Chonabayashi, S. (2016). How well do degree days over the growing season capture the effect of climate on farmland values? *Energy Economics*, 60, 144–150. <https://doi.org/10.1016/j.eneco.2016.09.004>
- Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Chen, Y., Goldfarb, L., Gomis, M. I., Matthews, J. B. R., Berger, S., Huang, M., Yelekçi, O., Yu, R., Zhou, B., Lonnoy, E., Maycock, T. K., Waterfield, T., Leitzell, K., & Caud, N. (2021). *Climate Change 2021: The Physical Science Basis*.
- Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). *The Impact of Global Warming on Agriculture: A Ricardian Analysis* (Vol. 84, Issue 4).
- Michels, R., Voskuilen, M. J., Hennen, W. H. G. J., & Roebeling, P. C. (2022). *Actualisatie normkosten natuur ten behoeve van kostenberekeningen*.
- Mirón, I. J., Linares, C., & Díaz, J. (2023). The influence of climate change on food production and food safety. *Environmental Research*, 216. <https://doi.org/10.1016/j.envres.2022.114674>
- Mondal, S. (2021). *Impact of Climate Change on Soil Fertility* (pp. 551–569). https://doi.org/10.1007/978-3-030-76863-8_28
- Mutlu, A., Roy, D., & Filatova, T. (2023). Capitalized value of evolving flood risks discount and nature-based solution premiums on property prices. *Ecological Economics*, 205. <https://doi.org/10.1016/j.ecolecon.2022.107682>
- Nickerson, C., Morehart, M., Kuethe, T., Beckman, J., Ifft, J., & Williams, R. (2012). *Trends in U.S. Farmland Values and Ownership*. www.ers.usda.gov
- Nigussie, Y., van der Werf, E., Zhu, X., Simane, B., & van Ierland, E. C. (2018). Evaluation of Climate Change Adaptation Alternatives for Smallholder Farmers in the Upper Blue-Nile Basin. *Ecological Economics*, 151, 142–150. <https://doi.org/10.1016/j.ecolecon.2018.05.006>
- Philip, S. Y., Kew, S. F., Van Der Wiel, K., Wanders, N., Jan Van Oldenborgh, G., & Philip, S. Y. (2020). Regional differentiation in climate change induced drought trends in the Netherlands. *Environmental Research Letters*, 15(9). <https://doi.org/10.1088/1748-9326/ab97ca>
- Planbureau voor de Leefomgeving. (2012). *Effecten van klimaatverandering in Nederland: 2012*. Planbureau voor de Leefomgeving (PBL).
- PWC. (2021). *Integrating climate risks in the risk management framework*.
- Radix, S. (2023). *a.s.r. Grondprijs monitor*.
- Rijkswaterstaat. (2023). *Handreiking Verzilting*.
- Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. In *Source: Journal of Political Economy* (Vol. 82, Issue 1).
- Rozema, J., & Flowers, T. (2008). Crops for a Salinized World. In *Science* (Vol. 322, Issue 5907, pp. 1477–1478). <https://doi.org/10.1126/science.1167219>
- Sauer, J. (2017). *Estimating the link between farm productivity and innovation in the Netherlands*. <https://doi.org/10.1787/2224dad0-en>

- Schaap, B. F., Blom-Zandstra, M., Hermans, C. M. L., Meerburg, B. G., & Verhagen, J. (2011). Impact changes of climatic extremes on arable farming in the north of the Netherlands. *Regional Environmental Change*, 11(3), 731–741. <https://doi.org/10.1007/s10113-011-0205-1>
- Schnabel. (2001). *Waarom blijven boeren?*
- Schwalm, C. R., Anderegg, W. R. L., Michalak, A. M., Fisher, J. B., Biondi, F., Koch, G., Litvak, M., Ogle, K., Shaw, J. D., Wolf, A., Huntzinger, D. N., Schaefer, K., Cook, R., Wei, Y., Fang, Y., Hayes, D., Huang, M., Jain, A., & Tian, H. (2017). Global patterns of drought recovery. *Nature*, 548(7666), 202–205. <https://doi.org/10.1038/nature23021>
- Shourie, A., & Singh, A. (2021). *Impact of Climate Change on Soil Fertility* (pp. 49–62). https://doi.org/10.1007/978-3-030-76863-8_4
- Silvis, H. J., & Voskuilen, M. J. (2022). *Rendement regulier verpachte landbouwgrond, 1990-2020*.
- Silvis, H., & Martien, V. (2021). *Verdiencapaciteit per hectare neemt toe met bedrijfsomvang*.
- Silvis, H., & Voskuilen, M. (2018). *Economie van de pacht*. <https://doi.org/10.18174/460704>
- Skryl, T., & Gregoric, M. (2020). Food commodity market under uncertainty: Regulation of access and influence on decision making. *E3S Web of Conferences*, 222. <https://doi.org/10.1051/e3sconf/202022206002>
- Slaboch, J., & Čechura, L. (2020). Land Pricing Model: Price Re-evaluation Due to the Erosion and Climate Change Effects. *Agris On-Line Papers in Economics and Informatics*, 12(4), 111–121. <https://doi.org/10.7160/AOL.2020.120408>
- Smith, A. (1776). *The Wealth of Nations*.
- Stouthamer, E., Erkens, G., Cohen, K., Hegger, D., Driessen, P., PeterWeikard, H., Hefting, M., Hanssen, R., Fokker, P., Van Den Akker, J., Groothuijse, F., & Van Rijswijk, M. (2020). Dutch national scientific research program on land subsidence: Living on soft soils subsidence and society. *Proceedings of the International Association of Hydrological Sciences*, 382, 815–819. <https://doi.org/10.5194/piahs-382-815-2020>
- STOWA. (2021). *Effecten klimaatverandering op landbouw*.
- Svenungsson, G. (2019). *Capitalising of Agricultural Support in Higher Land Price. A study on how CAP affects agricultural land price in Sweden*. <http://stud.epsilon.slu.se>
- Talukder, B., van Loon, G. W., Hipel, K. W., Chiotha, S., & Orbinski, J. (2021). Health impacts of climate change on smallholder farmers. In *One Health* (Vol. 13). Elsevier B.V. <https://doi.org/10.1016/j.onehlt.2021.100258>
- Ten Dam, R., Vellinga, P., & Negacz, K. (2023). From experiment to market development: A case study of prospects and value chain of saline agriculture in Terschelling, the Netherlands. *NJAS: Impact in Agricultural and Life Sciences*, 95(1). <https://doi.org/10.1080/27685241.2023.2211541>
- Trenberth, K. E., Dai, A., Van Der Schrier, G., Jones, P. D., Barichivich, J., Briffa, K. R., & Sheffield, J. (2014). Global warming and changes in drought. In *Nature Climate Change* (Vol. 4, Issue 1, pp. 17–22). <https://doi.org/10.1038/nclimate2067>
- United Nations. (n.d.). *Population*. Retrieved January 26, 2024, from <https://www.un.org/en/global-issues/population>

- van den Burg, S., Deolu-Ajayi, A. O., Nauta, R., Cervi, W. R., van der Werf, A., Poelman, M., Wilbers, G. J., Snethlage, J., van Alphen, M., & van der Meer, I. M. (2024). Knowledge gaps on how to adapt crop production under changing saline circumstances in the Netherlands. In *Science of the Total Environment* (Vol. 915). Elsevier B.V. <https://doi.org/10.1016/j.scitotenv.2024.170118>
- Van Passel, S., Massetti, E., & Mendelsohn, R. (2017). A Ricardian Analysis of the Impact of Climate Change on European Agriculture. *Environmental and Resource Economics*, 67(4), 725–760. <https://doi.org/10.1007/s10640-016-0001-y>
- Van Tilburg, A. J., & Hudson, P. F. (2022). Extreme weather events and farmer adaptation in Zeeland, the Netherlands: A European climate change case study from the Rhine delta. *Science of the Total Environment*, 844. <https://doi.org/10.1016/j.scitotenv.2022.157212>
- Verhoog, D. (2023). *Aandeel agrocomplex in Nederlandse economie in 2021 gedaald*.
- Verstand, D., Bijker, W., & Simonse, D. (2021). *Klimaatrisico's en kansen in de open teelten*. <https://doi.org/10.18174/555534>
- Verstand, D., van Alphen, M., Bakema, G., van Aalderen, N., & Hendriks, D. (2023). *Laag NL in 2050: Langetermijnperspectief en kortetermijn tegenstellingen in Laag Nederland*.
- Visser, H. (2007). *Kans op extreem warme dagen in Nederland*. www.mnp.nl
- Wen, W., Timmermans, J., Chen, Q., & Van Bodegom, P. M. (2022). Monitoring the combined effects of drought and salinity stress on crops using remote sensing in the Netherlands. *Hydrology and Earth System Sciences*, 26(17), 4537–4552. <https://doi.org/10.5194/hess-26-4537-2022>
- Willemsen, W., Kok, S., & Kuik, O. (2020). The effect of land subsidence on real estate values. *Proceedings of the International Association of Hydrological Sciences*, 382, 703–707. <https://doi.org/10.5194/piahs-382-703-2020>
- Woestenburg, A., & Van Der Krabben, E. (2013). *Een institutionele analyse van agrarische grondprijzen*.
- Woltjer, J., & Voskuilen, M. (2022). *Hoge inflatie zet druk op de agrarische grondprijzen*.
- Woltjer, J., Voskuilen, M., Kuiper, P. P., & Prins, L. (2023). *Afstand tot Natura 2000-gebieden heeft weinig invloed op prijs landbouwgrond* *Afstand tot Natura 2000-gebieden heeft weinig invloed op prijs landbouwgrond*.
- Zuehlke, & Rasmussen. (1988). *A search model of housing market transaction*.

Appendices

Appendix 1 Overview of factors that define agricultural land prices literature by Buurman (2003)

Overview of the factors that affect land prices found in the empirical literature		
<i>Parcel characteristics</i>		
Location	Accessibility Distance from/to 'Neighbourhood'	A better accessibility leads to a higher land price; the effect of the distance to and from features depends on the actor and the feature; a small <i>distance to an urban area</i> is often mentioned as an important factor that leads to a higher land price
Physical properties	Slope Elevation Soil type Fertility Irrigation Parcel size	The physical properties are valued by the actors according to the advantage or disadvantage a property gives.
Land use	Current Future	Current and future land use may be relevant as conversion costs from one type of land use to another can be high in some cases. Current land use can also include buildings, transport infrastructure, cables, etc.
<i>Transaction characteristics</i>		
Actors involved		Different actors make different bids.
Relation of buyer and seller		Relatives may get more advantageous conditions, such as a lower price.
Type of transaction		Land exchange, expropriation (which are also government policies), and other legal matters affect the price.
Market conditions		Transparency, market competition, information on land prices, etc. are all factors that affect prices according to economic theory (market conditions are also related to macroeconomic variables and government policy).
<i>Macroeconomic variables</i>		
Supply and demand of land		Supply and demand can be viewed in many ways: total, by

	market segments, etc. Supply and demand conditions affect the price.
Interest rates	Higher interest rates make borrowing more expensive and decrease the demand for land; or opportunity costs rise and land is sold; both cause a decrease in land price.
Technological innovation (in agriculture)	Land prices rise due to increased demand in order to apply innovation efficiently.
(Rural) income	If income rises a higher budget is available and more can be spent on land.
Expectations	Expectations are from different actors about the factors and relate to general economic conditions.
<i>Government policy</i>	
Zoning	Can have a negative or positive effect on land prices.
Taxation & subsidies	Many direct and indirect effects on land prices are the result of taxation and subsidies at all government levels.

Appendix 2 Enriched overview of factors that define agricultural land prices found in the literature

Overview of the factors that affect land prices found in the empirical literature		
<i>Parcel characteristics</i>		
Location	Distance to 'nature conservation areas' Distance to N-2000 Distance to 'urban areas' Distance to 'roads' Distance to 'wind turbines'	A better accessibility leads to a higher land price; the effect of the distance to and from features depends on the actor and the feature; a small <i>distance to an urban area</i> is often mentioned as an important factor that leads to a higher land price` (Cotteleer, Stobbe, et al., 2007; Guiling et al., 2009) (Woltjer et al., 2023)
Physical properties	Soil type Fertility Irrigation Parcel size	The physical properties are valued by the actors according to the advantage or disadvantage a property gives.

	Slope Elevation Shape of plot Groundwater table	(Cotteleer et al., 2008; Cotteleer, Luijt, et al., 2007) (Nickerson et al., 2012).
Land use	Current Future	Current and future land use may be relevant as conversion costs from one type of land use to another can be high in some cases. Current land use can also include buildings, transport infrastructure, cables, etc.
Climate risks	Temperature Precipitation Flood risk Salinization	(Bozzola et al., 2018; Hodge, 2021; Hussain & Mustafa, 2016; Massetti et al., 2016; Mendelsohn et al., 1994; Van Passel et al., 2017)
Transaction characteristics (Woestenburg & Van Der Krabben, 2013)		
Actors involved		Different actors make different bids.
Relation of buyer and seller		Relatives may get more advantageous conditions, such as a lower price.
Type of transaction		Land exchange, expropriation (which are also government policies), and other legal matters affect the price.
Market conditions		Transparency, market competition, information on land prices, etc. are all factors that affect prices according to economic theory (market conditions are also related to macroeconomic variables and government policy).
Macroeconomic variables		
Supply and demand of land		Supply and demand can be viewed in many ways: total, by market segments, etc. Supply and demand conditions affect the price.
Interest rates		Higher interest rates make borrowing more expensive and decrease the demand for land; or opportunity costs rise and land is sold; both cause a decrease in land price.
Technological innovation (in agriculture)		Land prices rise due to increased demand in order to apply innovation efficiently.

(Rural) income	If income rises a higher budget is available and more can be spent on land.
Expectations	Expectations are from different actors about the factors and relate to general economic conditions.
Leased and unleased agricultural land	(Kuiper & Voskuilen, 2018; H. J. Silvis & Voskuilen, 2022)
Government policy	
Zoning	Can have a negative or positive effect on land prices.
Taxation & subsidies	Many direct and indirect effects on land prices are the result of taxation and subsidies at all government levels. (Ciaian et al., 2021; Svenungsson, 2019)

Appendix 3 Variables used transaction dataset

Variable	<i>sub indicator</i>
Price per hectare (€)	
Log(price per hectare) (€)	
Transaction period (quarterly) → (Reference = 01-2019)	01-2019
	02-2019
	03-2019
	04-2019
	01-2020
	02-2020
	03-2020
	04-2020
	01-2021
	02-2021
	03-2021
	04-2021
	01-2022
	02-2022
	03-2022
04-2022	
01-2023	
02-2023	
03-2023	
GDP (€)	
Inflation (%)	

Distance to boarder of the Netherlands (m)	
Distance to N2000 area (m)	
Distance to nature conservation area (m)	
Distance to urban area (m)	
Distance to road (m)	
Distance to wind turbine (m)	
Soil or area type (m²) → (Reference = Buildings)	<i>Heavy clay</i>
	<i>Sand</i>
	<i>Heavy silt</i>
	<i>Peat</i>
	<i>Water</i>
	<i>Marshy on sand</i>
	<i>Light silt</i>
	<i>Light clay</i>
	<i>Buildings</i>
<i>Loam</i>	
Parcel size / total transaction or taxation size	
Crop rotation last 10 year	
Shape	<i>rectangularity</i>
	<i>roundness</i>
Topography	<i>Average height plot</i>
	<i>Standard deviation height plot</i>
	<i>Minimum height plot</i>
	<i>Maximum height plot</i>
Groundwater table score	
Grass land or arable land (Reference = Arable)	<i>Grass</i>
	<i>Arable</i>
Climate risks	<i>Extreme heat</i>
	<i>Extreme precipitation</i>
	<i>Extreme drought</i>
	<i>Flood risk</i>
	<i>Surface water shortage</i>
	<i>Salinization</i>

Appendix 4 Output Area and Soil

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,009	0,034	0,028	0,258	0,797
Days with ≥ 25 mm 2050 High	-0,060	0,057	-0,092	-1,066	0,288
Pot max precipitation shortage (once 10 year) 2050 High	0,142	0,037	0,304	3,875	<0,001***
Site-specific flood probability > 0 cm in 2050	0,025	0,016	0,123	1,552	0,123
Shortage surface water extreme dry year 2050 High	0,000	0,006	0,007	0,079	0,937
Salt flux 0.5 m sea level rise	-3,026E-06	0,000	-0,037	-0,561	0,576
Significance level: ***0,99, **0,95, *0,90					

Table 8: Output Bouwhoek en Hogeland

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,014	0,002	0,142	5,784	<0,001***
Days with ≥ 25 mm 2050 High	0,003	0,004	0,008	0,649	0,516
Pot max precipitation shortage (once 10 year) 2050 High	-0,001	0,003	-0,004	-0,224	0,823
Site-specific flood probability > 0 cm in 2050	-0,002	0,001	-0,025	-1,495	0,135
Shortage surface water extreme dry year 2050 High	0,004	0,001	0,081	5,792	<0,001***
Salt flux 0.5 m sea level rise	-2,734E-40	0,000	-0,045	-4,193	<0,001***
Significance level: ***0,99, **0,95, *0,90					

Table 9: Output Buildings

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,023	0,011	-0,188	-2,105	0,036**
Days with ≥ 25 mm 2050 High	-0,016	0,017	-0,043	-0,960	0,338
Pot max precipitation shortage (once 10 year) 2050 High	0,013	0,012	0,065	1,072	0,284
Site-specific flood probability > 0 cm in 2050	0,004	0,009	0,021	0,501	0,617
Shortage surface water extreme dry year 2050 High	0,002	0,003	0,043	0,794	0,427

Salt flux 0.5 m sea level rise	-9,859E-40	0,000	-0,146	-3,868	<0,001***
Significance level: ***0,99, **0,95, *0,90					

Table 10: Output Heavy Clay

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,007	0,006	0,080	1,120	0,263
Days with ≥ 25 mm 2050 High	0,001	0,013	0,002	0,050	0,960
Pot max precipitation shortage (once 10 year) 2050 High	-0,010	0,008	-0,071	-1,290	0,197
Site-specific flood probability > 0 cm in 2050	-0,011	0,004	-0,113	-2,768	0,006***
Shortage surface water extreme dry year 2050 High	0,002	0,002	0,040	0,950	0,342
Salt flux 0.5 m sea level rise	-4,134E-40	0,000	-0,043	-1,328	0,185
Significance level: ***0,99, **0,95, *0,90					

Table 11: Output Heavy Silt

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,005	0,011	0,039	0,494	0,622
Days with ≥ 25 mm 2050 High	-0,034	0,017	-0,082	-1,981	0,048**
Pot max precipitation shortage (once 10 year) 2050 High	-0,023	0,013	-0,123	-1,835	0,067*
Site-specific flood probability > 0 cm in 2050	0,003	0,006	0,017	0,436	0,663
Shortage surface water extreme dry year 2050 High	0,011	0,003	0,181	3,944	<0,001***
Salt flux 0.5 m sea level rise	-2,546E-40	0,000	-0,036	-0,965	0,335
Significance level: ***0,99, **0,95, *0,90					

Table 12: Output Light Clay

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,002	0,007	0,021	0,259	0,796
Days with ≥ 25 mm 2050 High	0,016	0,016	0,036	0,982	0,326
Pot max precipitation shortage (once 10 year) 2050 High	-0,005	0,009	-0,039	-0,595	0,552
Site-specific flood probability > 0 cm in 2050	-0,003	0,003	-0,034	-0,933	0,351

Shortage surface water extreme dry year 2050 High	-0,001	0,002	-0,018	-0,409	0,682
Salt flux 0.5 m sea level rise	-1,887E-06	0,000	-0,038	-1,147	0,252
Significance level: ***0,99, **0,95, *0,90					

Table 13: Output Light Silt

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,035	0,026	-0,217	-1,316	0,190
Days with ≥ 25 mm 2050 High	0,014	0,024	0,061	0,574	0,567
Pot max precipitation shortage (once 10 year) 2050 High	0,001	0,024	0,006	0,048	0,961
Site-specific flood probability > 0 cm in 2050	0,005	0,022	0,023	0,254	0,800
Shortage surface water extreme dry year 2050 High	0,020	0,009	0,239	2,172	0,031**
Salt flux 0.5 m sea level rise	-7,198E-42	0,000	-0,003	-0,035	0,972
Significance level: ***0,99, **0,95, *0,90					

Table 14: Output Loam

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,063	0,015	0,597	4,325	<0,001***
Days with ≥ 25 mm 2050 High	0,028	0,022	0,085	1,313	0,190
Pot max precipitation shortage (once 10 year) 2050 High	-0,003	0,016	-0,014	-0,190	0,849
Site-specific flood probability > 0 cm in 2050	-0,003	0,005	-0,032	-0,558	0,577
Shortage surface water extreme dry year 2050 High	0,003	0,003	0,061	0,947	0,345
Salt flux 0.5 m sea level rise	-3,477E-40	0,000	-0,061	-1,199	0,232
Significance level: ***0,99, **0,95, *0,90					

Table 15: Output Marshy on Sand

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,058	0,010	0,380	5,601	<0,001***
Days with ≥ 25 mm 2050 High	0,016	0,014	0,053	1,154	0,249
Pot max precipitation shortage (once 10 year) 2050 High	0,004	0,011	0,023	0,412	0,681

Site-specific flood probability > 0 cm in 2050	0,001	0,006	0,012	0,226	0,821
Shortage surface water extreme dry year 2050 High	0,004	0,003	0,059	1,419	0,156
Salt flux 0.5 m sea level rise	-2,023E-40	0,000	-0,029	-0,781	0,435
Significance level: ***0,99, **0,95, *0,90					

Table 16: Output Peat

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,011	0,003	0,106	3,414	0,001***
Days with ≥ 25 mm 2050 High	0,010	0,004	0,039	2,511	0,012**
Pot max precipitation shortage (once 10 year) 2050 High	0,000	0,003	-0,001	-0,045	0,964
Site-specific flood probability > 0 cm in 2050	-0,001	0,002	-0,006	-0,409	0,683
Shortage surface water extreme dry year 2050 High	0,002	0,001	0,052	3,105	0,002***
Salt flux 0.5 m sea level rise	-4,208E-41	0,000	-0,009	-0,659	0,510
Significance level: ***0,99, **0,95, *0,90					

Table 17: Output Sand

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,086	0,111	-0,594	-0,776	0,463
Days with ≥ 25 mm 2050 High	-0,075	0,151	-0,192	-0,493	0,637
Pot max precipitation shortage (once 10 year) 2050 High	0,065	0,113	0,211	0,577	0,582
Site-specific flood probability > 0 cm in 2050	0,036	0,034	0,423	1,063	0,323
Shortage surface water extreme dry year 2050 High	0,029	0,024	0,510	1,230	0,259
Salt flux 0.5 m sea level rise	-8,259E-40	0,000	-0,241	-0,894	0,401
Significance level: ***0,99, **0,95, *0,90					

Table 18: Output Water

Appendix 5 Output Agricultural Regions

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,009	0,034	0,028	0,258	0,797

Days with ≥ 25 mm 2050 High	-0,060	0,057	-0,092	-1,066	0,288
Pot max precipitation shortage (once 10 year) 2050 High	0,142	0,037	0,304	3,875	<0,001***
Site-specific flood probability > 0 cm in 2050	0,025	0,016	0,123	1,552	0,123
Shortage surface water extreme dry year 2050 High	0,000	0,006	0,007	0,079	0,937
Salt flux 0.5 m sea level rise	-3,026E-06	0,000	-0,037	-0,561	0,576
Significance level: ***0,99, **0,95, *0,90					

Table 19: Output Bouwhoek en Hogeland

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,037	0,018	0,174	2,038	0,042**
Days with ≥ 25 mm 2050 High	-0,002	0,014	-0,009	-0,130	0,897
Pot max precipitation shortage (once 10 year) 2050 High	0,026	0,013	0,123	2,061	0,040**
Site-specific flood probability > 0 cm in 2050	-0,013	0,006	-0,172	-2,235	0,026**
Shortage surface water extreme dry year 2050 High	0,000	0,003	-0,007	-0,099	0,922
Salt flux 0.5 m sea level rise	0,001	0,001	0,073	1,599	0,111
Significance level: ***0,99, **0,95, *0,90					

Table 20: Output Centraal Veehouderijgebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,017	0,016	0,078	1,070	0,285
Days with ≥ 25 mm 2050 High	-0,004	0,015	-0,015	-0,249	0,803
Pot max precipitation shortage (once 10 year) 2050 High	0,002	0,016	0,009	0,119	0,905
Site-specific flood probability > 0 cm in 2050	0,000	0,011	-0,002	-0,024	0,981
Shortage surface water extreme dry year 2050 High	0,009	0,004	0,160	2,405	0,017**
Salt flux 0.5 m sea level rise	-7,755E-06	0,000	-0,087	-1,635	0,103
Significance level: ***0,99, **0,95, *0,90					

Table 21: Output Hollands-Utrechts Weidegebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

Number of tropical days (max ≥ 30) 2050 High	-0,095	0,053	-0,485	-1,781	0,079*
Days with ≥ 25 mm 2050 High	-0,046	0,057	-0,079	-0,807	0,422
Pot max precipitation shortage (once 10 year) 2050 High	0,039	0,045	0,275	0,873	0,385
Site-specific flood probability > 0 cm in 2050	-0,004	0,020	-0,022	-0,207	0,837
Shortage surface water extreme dry year 2050 High	0,011	0,032	0,056	0,350	0,727
Salt flux 0.5 m sea level rise	4,921E-06	0,000	0,110	0,981	0,329
Significance level: ***0,99, **0,95, *0,90					

Table 22: Output IJsselmeerpolders

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,072	0,006	0,400	12,183	<0,001***
Days with ≥ 25 mm 2050 High	-0,047	0,012	-0,103	-3,819	<0,001***
Pot max precipitation shortage (once 10 year) 2050 High	0,008	0,007	0,032	1,179	0,239
Site-specific flood probability > 0 cm in 2050	0,009	0,003	0,120	2,888	0,004***
Shortage surface water extreme dry year 2050 High	0,004	0,002	0,075	2,669	0,008***
Salt flux 0.5 m sea level rise	7,316E-06	0,000	0,051	1,889	0,059**
Significance level: ***0,99, **0,95, *0,90					

Table 23: Output Noordelijk Weidegebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,023	0,005	-0,163	-5,124	<0,001***
Days with ≥ 25 mm 2050 High	-0,011	0,007	-0,034	-1,477	0,140
Pot max precipitation shortage (once 10 year) 2050 High	0,021	0,005	0,115	4,053	<0,001***
Site-specific flood probability > 0 cm in 2050	-0,006	0,002	-0,091	-2,913	0,004***
Shortage surface water extreme dry year 2050 High	0,003	0,001	0,096	3,360	0,001***
Salt flux 0.5 m sea level rise	-6,902E-41	0,000	-0,015	-0,689	0,491
Significance level: ***0,99, **0,95, *0,90					

Table 24: Output Oosterlijk Veehouderijgebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,005	0,018	0,027	0,303	0,762
Days with ≥ 25 mm 2050 High	0,052	0,019	0,193	2,683	0,008***
Pot max precipitation shortage (once 10 year) 2050 High	-0,008	0,013	-0,043	-0,650	0,516
Site-specific flood probability > 0 cm in 2050	0,001	0,010	0,006	0,075	0,940
Shortage surface water extreme dry year 2050 High	0,001	0,004	0,027	0,345	0,731
Salt flux 0.5 m sea level rise	0,005	0,018	0,027	0,303	0,762
Significance level: ***0,99, **0,95, *0,90					

Table 25: Output Rivierengebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,004	0,016	-0,016	-0,243	0,808
Days with ≥ 25 mm 2050 High	0,010	0,012	0,041	0,837	0,403
Pot max precipitation shortage (once 10 year) 2050 High	0,046	0,013	0,173	3,619	<0,001***
Site-specific flood probability > 0 cm in 2050	0,006	0,006	0,056	0,922	0,357
Shortage surface water extreme dry year 2050 High	-0,004	0,002	-0,085	-2,026	0,043**
Salt flux 0.5 m sea level rise	-6,038E-40	0,000	-0,067	-1,914	0,056*
Significance level: ***0,99, **0,95, *0,90					

Table 26: Output Veenkoloniën en Oldambt

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,026	0,093	0,050	0,276	0,784
Days with ≥ 25 mm 2050 High	0,029	0,067	0,064	0,437	0,664
Pot max precipitation shortage (once 10 year) 2050 High	0,056	0,076	0,127	0,733	0,467
Site-specific flood probability > 0 cm in 2050	0,069	0,053	0,180	1,315	0,194
Shortage surface water extreme dry year 2050 High	0,103	0,184	0,064	0,559	0,578
Salt flux 0.5 m sea level rise	6,477E-42	0,000	0,002	0,012	0,991

Significance level: ***0,99, **0,95, *0,90

Table 27: Output Waterland en Droogmakerijen

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,016	0,028	0,099	0,560	0,576
Days with ≥ 25 mm 2050 High	0,022	0,032	0,066	0,686	0,494
Pot max precipitation shortage (once 10 year) 2050 High	0,016	0,028	0,063	0,579	0,564
Site-specific flood probability > 0 cm in 2050	-0,010	0,011	-0,063	-0,876	0,382
Shortage surface water extreme dry year 2050 High	-0,020	0,010	-0,228	-1,978	0,049**
Salt flux 0.5 m sea level rise	-5,869E-07	0,000	-0,009	-0,127	0,899
Significance level: ***0,99, **0,95, *0,90					

Table 28: Output Westelijk Holland

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,028	0,006	-0,154	-4,595	<0,001***
Days with ≥ 25 mm 2050 High	0,018	0,008	0,078	2,371	0,018**
Pot max precipitation shortage (once 10 year) 2050 High	0,001	0,007	0,004	0,120	0,904
Site-specific flood probability > 0 cm in 2050	-0,003	0,002	-0,037	-1,193	0,233
Shortage surface water extreme dry year 2050 High	-0,002	0,001	-0,037	-1,365	0,172
Salt flux 0.5 m sea level rise	-7,915E-41	0,000	-0,029	-1,266	0,206
Significance level: ***0,99, **0,95, *0,90					

Table 29: Output Zuidelijk Veehouderijgebied

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,033	0,035	-0,132	-0,930	0,354
Days with ≥ 25 mm 2050 High	0,003	0,023	0,011	0,115	0,909
Pot max precipitation shortage (once 10 year) 2050 High	-0,012	0,027	-0,060	-0,430	0,668
Site-specific flood probability > 0 cm in 2050	-0,012	0,012	-0,162	-0,981	0,328
Salt flux 0.5 m sea level rise	-1,200E-40	0,000	-0,039	-0,535	0,593

Significance level: ***0,99, **0,95, *0,90

Table 30: Output Zuid-Limburg

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	0,057	0,036	0,148	1,593	0,113
Days with ≥ 25 mm 2050 High	0,024	0,020	0,144	1,191	0,235
Pot max precipitation shortage (once 10 year) 2050 High	0,007	0,010	0,099	0,681	0,497
Site-specific flood probability > 0 cm in 2050	-0,008	0,005	-0,243	-1,860	0,065*
Shortage surface water extreme dry year 2050 High	1,925E-40	0,000	0,047	0,635	0,526
Salt flux 0.5 m sea level rise	0,057	0,036	0,148	1,593	0,113
Significance level: ***0,99, **0,95, *0,90					

Table 31: Output Zuidwest Brabant

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of tropical days (max ≥ 30) 2050 High	-0,010	0,006	-0,092	-1,604	0,109
Days with ≥ 25 mm 2050 High	-0,007	0,019	-0,017	-0,371	0,711
Pot max precipitation shortage (once 10 year) 2050 High	-0,028	0,012	-0,186	-2,259	0,024**
Site-specific flood probability > 0 cm in 2050	-0,009	0,005	-0,100	-1,914	0,056*
Shortage surface water extreme dry year 2050 High	0,000	0,003	0,010	0,126	0,900
Salt flux 0.5 m sea level rise	-1,042E-41	0,000	-0,001	-0,034	0,973
Significance level: ***0,99, **0,95, *0,90					

Table 32: Output Zuidwestelijke Akkerbouwgebied