Mediterranean Agronomic Institute of Montpellier

CIHEAM
MAI MONTPELLIER

Montpellier University

Institut Agro

l'institut Agro
agriculture • alimentation • environnement

Montpellier SupAgro

MASTER 2

ECONOMICS

"MEDITERRANEAN FARMING SYSTEM DESIGN
FOR A SUSTAINABLE FOOD-SYSTEM"

Thesis submitted by: **MORINA Anxhela**

Evaluating the impact of climate change on agriculture and farmer's decision-making using bioeconomic models in Luxor, Egypt

MIDAS

Supervised by **Belhouchette Hatem**

September 2022

Mediterranean Agronomic Institute of Montpellier

Montpellier University

Institut Agro

MASTER 2

ECONOMICS

"MEDITERRANEAN FARMING SYSTEM DESIGN FOR A SUSTAINABLE FOOD-SYSTEM"

Thesis submitted by: **MORINA Anxhela**

Evaluating the impact of climate change on agriculture and farmer's decision-making using bioeconomic models in Luxor, Egypt

Supervised by **Belhouchette Hatem**

September 2022

“The Mediterranean Agronomic Institute of Montpellier neither approves nor disapproves the opinions expressed in this thesis. The opinions herein are solely those of the author.

Title: Evaluating the impact of climate change on agriculture and farmer’s decision-making using bioeconomic models in Luxor, Egypt.

Abstract

Climate change is one of the world's most critical issues, particularly in areas with dry and hot climates, where even minor changes can cause major problems. Developing countries, such as Egypt, are having a difficult time adapting to climate change mitigation practices. Agriculture is the most vulnerable sector, as low precipitation and high temperatures have a significant impact on production. The primary goal of this study was to test this impact for the next 20 years by using bioeconomic models. We conducted some tests using rainfall and temperature data from the previous 20 years and discovered that the level of production was highly limited by these two factors, particularly high temperatures. Moreover, we tested a scenario involving the addition of a new variety that is heat resistant and requires less water than other crops and found out that it slightly increases revenues while offering a low level of production.

Author keywords

Keywords: bio-economic models, climate change, water scarcity, heat resistant varieties, agriculture, typology.

Title: Évaluation de l'impact du changement climatique sur l'agriculture et la prise de décision des agriculteurs à l'aide de modèles bioéconomiques à Louxor, en Égypte.

Abstract

Le changement climatique est l'un des problèmes mondiaux les plus critiques, en particulier dans les régions au climat sec et chaud, où même des changements mineurs peuvent causer des problèmes majeurs. Les pays en développement, comme l'Égypte, ont du mal à s'adapter aux pratiques d'atténuation du changement climatique. L'agriculture est le secteur le plus vulnérable, car les faibles précipitations et les températures élevées ont un impact significatif sur la production. L'objectif principal de cette étude était de tester cet impact pour les 20 prochaines années en utilisant des modèles bioéconomiques. Nous avons effectué des tests à partir des données de précipitations et de températures des 20 dernières années et avons découvert que le niveau de production était fortement limité par ces deux facteurs, notamment les températures élevées. De plus, nous avons testé un scénario impliquant l'ajout d'une nouvelle variété qui résiste à la chaleur et nécessite moins d'eau que d'autres cultures et avons découvert qu'elle augmente légèrement les revenus tout en offrant un faible niveau de production.

Mots-clés de l'auteur

Mots-clés: modèles bio-économiques, changement climatique, rareté de l'eau, variétés résistantes à la chaleur, agriculture, typologie.

Acknowledgments

It’s a pleasure for me to express my appreciation and gratitude to my supervisor, Dr. Belhouchette, for his consistent support and guidance, without which I would not have been able to complete this research.

I want to express my gratitude to Dr. Kleftodimos for always being willing to help me.

I appreciate Dr. Elshaikh's assistance in providing data and information as well as his willingness to address all of my questions.

I would like to thank Dr. Chenoune as well for her availability and for clarifying my doubts.

I want to thank my colleagues and friends for supporting me when I most needed their encouragement.

A special thanks to my family, who helped and inspired me to keep going even when I thought I wouldn't succeed.

Contents

Table of Tables (optional)

Table of Figures (optional)

Introduction

Egypt is a country in Africa with a semi-arid climate that is regarded as "one of the hot spots for worsening extreme heat, drought, and aridity conditions under climate change" (Waha et al., 2017). It is already dealing with a variety of issues as a result of climate change, including water and land scarcity, droughts, and sea-level rise. All these components will be analysed in greater detail below, with a particular emphasis on water scarcity as the key issue. Among the factors that cause water scarcity in the region are: population growth, urbanization, poverty, inefficient irrigation systems, and political instability (Swain, 2011). Climate change is expected to aggravate scarce resources, impacting especially agriculture which is very sensitive to this climate variability, but still remains the most important industry that fulfills human needs for food. (Verner, 2012) Even though it only occupies 3% of Egypt's total land area, it still contributes to the majority of GDP because farmers rely on it for their existence. (Dimov et al., 2016)

Therefore, it is essential to adapt to climate change in order to try and mitigate or avoid the negative effects of climate change, meet the needs of an expanding population in the future, and maintain stable livelihoods for farmers. In order to adapt to climate change, they must first be made aware of the threats that the changes will bring in the future. (Omar, 2021).

To achieve adaptation, we must make a future prediction and determine what is anticipated to show up as a result of this climate change. We can test scenarios or potential policies by using bioeconomic models to see how the lack of resources and climate change will affect agricultural production and farmers behaviour for different farm types. (Janssen and van Ittersum, 2007) These models are useful methods that can help the policymakers to make decisions about future policies and give them the ability to protect natural resources while also raising farmer productivity and income. (Kruseman and Bade, 1998)

Using these models, we will try to attain our main goals, which are:

1. To evaluate the impact of low precipitation and high temperatures on agriculture at the farm level for various farm types by using bioeconomic models.
2. To analyse how the farmer's decision-making regarding their crop production will be impacted by climate change and its effects.
3. To simulate scenarios and to see how potential future changes may affect both the production process itself and the farmer's behaviour toward those changes.
4. To assess the efficacy of potential policy scenarios that could assist farmers in making decisions that would preserve the limited natural resources while guiding them toward more profitable practices.

To achieve these goals, we addressed the following research question: In the next 20 years, how will water scarcity and high temperatures affect yield and farmer decision-making in Luxor area?

1. We anticipate that with a 2 degree increase in temperature and a lack of precipitation, production will decrease by 7% for wheat and 11% for other crops for the next 20 years.

2. We expect that the introduction of new heat-resistant varieties in the next 20 years will reduce irrigation requirements while increasing farmer productivity and pushing them toward these new alternatives.

This study is divided into 4 main parts:

The first section is a review of the literature which is going to be divided in two main chapters: impact of climate change on agriculture and the second one the bioeconomic model. We will also see the effects of climate change in the rise of sea levels, drought, lack of land, and, most importantly, lack of water. Furthermore, we will explain what bioeconomic models are, why they are important, and how we will use them to test the impact of climate change on the farming system.

The second section addresses the methodology that we have used, briefly explaining farm typology and specifying a little more about the bioeconomic models. In this part, we will highlight the equations used in the model and explain them in detail to better understand why we used them. We will also describe the scenarios we aim to test and why these scenarios were chosen.

The third section presents the results of using this model as well as the outcomes of the scenarios that we tested. Also, shows a comparison of the effectiveness of the tested scenario to eight different types of farms in Egypt.

Finally, in the discussion section, we will share the project's limitations, the benefits of using the bioeconomic model and whether or not our hypothesis were proven.

Part I

Literature review

I - Climate change

1. Agriculture in Egypt

In Egypt, there are two types of agriculture: rain-fed agriculture which is based on rainfall and irrigated agriculture which is based on the irrigation system and is responsible for the production of the majority of food to satisfy the consumer's needs. Due to the climate conditions and droughts, it's difficult to produce under rain-fed agriculture. (Ouda and Zohry, 2016)

The majority of the agricultural land, around 80% is located in the Nile Delta Valley. Agriculture is the most important sector in terms of GDP, although it doesn't provide high revenues due to the poor soil quality which is determined by the salinity and groundwater level. (Frihy and El-Sayed, 2013) Agriculture has low productivity, lack of employment, scarce natural resources, low incomes, poverty, water scarcity, land fertility. (Tellioglu and Konandreas, 2017)

According to a USAID study, agriculture is one of the main sectors that employs the majority of the population, 55% of them. It employs 32% of the workforce. As a result, agriculture is important to the GDP, accounting for 11.3% of total GDP.

Egypt is capable of producing fruit, vegetables, and livestock to meet its own needs, but this is not the Egyptian diet. It is made up of cereals, sugar, and vegetable oil, none of which they produce. Under these circumstances they must import. Egypt is known as the largest wheat importer in the world. (Power, 2014)

2. Climate change impact on agriculture

Climate change can directly impact agriculture through its own components: rainfall and temperature. Since rainfall is rare in Egypt because is a very dry country, this will cause a decrease of available water that can be used also for irrigation. From the other hand, urbanization and growing population, will increase this demand for water, leading to even less available water per person. Apart from rainfall, an increase of temperature, can cause heat waves and at the same time, it will increase the evapotranspiration and droughts. (Ouda et al., 2007) Like this Egypt will face a soil salinity that will affect land productivity, farmer's income and health and also an increase of sea level rise will be noticeable, which will oblige people to migrate. (El Raey, 2010)

Climate change is accompanied by several impacts. A change in rainfall pattern, an increase in temperature, an increase in humidity, an increase of heat waves and droughts will directly affect livestock and crop production. Dry areas will get even more dry, because it is projected that climate change will reduce the available groundwater resources and renewable surface water. Day by day coastal and low-lying areas are risking to be submerged due to sea level rise. Coastal floods and erosions are expected due to population growth, urbanization and economic development. The life of inhabitants will be in danger and there will be less available land for inhabitants, which means lack of natural resources causing conflicts between countries since these resources are indispensable to fulfill human needs. (Dokken, 2014) At the same time there will be less available water since the population is growing and the demand for this resource is growing along with it. (Omar et al., 2015)

3. Climate change impact on food production and trade

Many years back, Egypt was export-oriented mostly in dairy-products, but recently it is not very important in the trade field and at the same time has become a larger importer particularly of wheat. The production of food even if it's only for self-consumption is starting to get difficult in Egypt due to the negative impact of climate change on agriculture and the population growth that is increasing the demand. Since the country is unable to fulfil the society's needs for food, they're obliged to increase the imports. At the same time, the exports have started to decrease due to the limited arable land availability and water availability that doesn't allow to produce more, at least for those crops that Egypt is specialized. The government decided to increase the price of products, causing a price inflation that led to an increase of the poverty rate. A trade gap between the imports and exports it's noticeable and this gap might come because the agriculture in Egypt is characterized by lack of infrastructure, of specific policies related to agricultural production, weak institutions. From the other side, the farmer's products don't meet some certain criteria to be exported, such as: the excessive use of pesticides, the control and safety quality requirements, they don't have very developed agricultural practices, different issues that they face during the storage of the products. (Tellioglu and Konandreas, 2017)

4. The effects of climate change on:

A. *Land scarcity*

In Egypt the land is fragmented into small plots and sometimes it is difficult in financial terms to introduce a new technology. Besides, the agricultural land was not enough to satisfy the demand for food, the arable land is scarce. A lot of effort was done to create more land for agricultural production by making the desert areas functional through irrigation. This irrigation was even more costly for the rest of the region, because it enhanced the water scarcity. At the same time, it was very difficult to use the desert areas as land for agricultural production, because the soil's texture is not the same and adoptable for production. (Tellioglu and Konandreas, 2017)

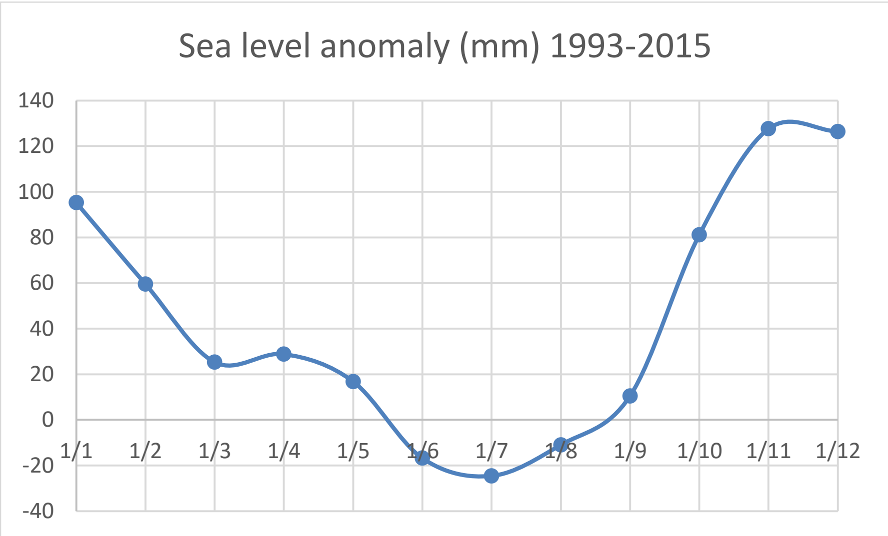
Right now they stopped making efforts in reclaiming dessert areas because they started to lose a lot of water. (Power, 2014) Soil salinity, pollution, urbanization and seawater intrusion have caused land degradation, due to which, Egypt's already limited agricultural lands are becoming contaminated and desertified. (Power, 2014)

B. *Sea level rise in Egypt*

Climate change will cause a sea level rise which will have disastrous effects in the region. One-meter sea level rise will inundate the agricultural land by 13% and a large proportion of population around 10% will be displaced, causing a decrease on GDP by around 7%. (Dasgupta et al., 2009) Since the economy is heavily reliant on agriculture, as it's the sector that employs the most, it will directly impact the employment rate. (Gouda, 2020)

Additionally, the low-lying Nile Delta regions could be affected by rising sea levels as increased saltwater intrusion threatens freshwater supplies and crop yields. (Elshinnawy and Almaliki, 2021; McCarl et al., 2015).

Figure 1: Historic Sea level rise for coastal Egypt



Source: Worldometer

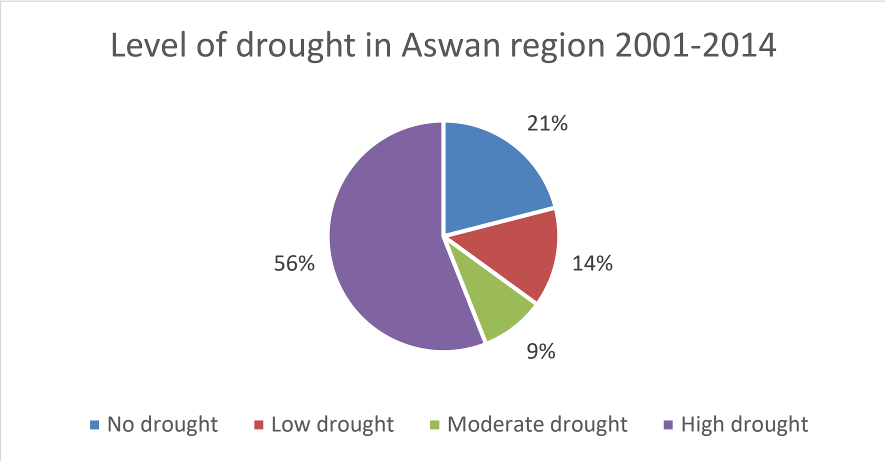
According to this graph, there was a sea level anomaly from 1993 to 2015, which is indicated in millimetres. It is obvious that the summer months of June, July, and August will be less affected by the impact of climate change, because there will be no increase in sea level rise due to high temperatures. In comparison to other months, there is a significant increase in sea level rise, particularly during the winter months of November and December, when the sea level arrives at respectively 127.54 and 126.39 mm.

C. *Droughts*

Droughts have always caused crop failure and depletion of water supplies. Egypt will always be tied to the other countries by the Nile River, and climate change will always have an impact on it. An increase of temperature and heat waves will impact more and more the situation of Egypt regarding droughts. (FAO, droughts) The land in Egypt is separated into new and old lands. The most irrigated lands are the old ones, irrigated by traditional surface irrigation systems with very low field water application efficiency. The new ones are mainly those that have just been reclaimed. The fundamental issue with old lands is that soil fertility is deteriorating in many agricultural areas, and they are being transformed into non-agricultural land. Meanwhile, the new lands are less productive, but their output could rise with proper agricultural management practices. In these conditions, the effects of climate change, such as a lack of water and an increase in temperature, will exacerbate the area's drought difficulties and will increase the water demand.

The Aswan region is characterized by 56% severe drought and 9% moderate drought. Only 21% of the area is not affected by drought at all and 14% has low drought, as shown in the graph below:

Figure 2: Droughts in Aswan region from 2001-2014



Source: Hesham and Khalil, 2015

D. ***Water scarcity***

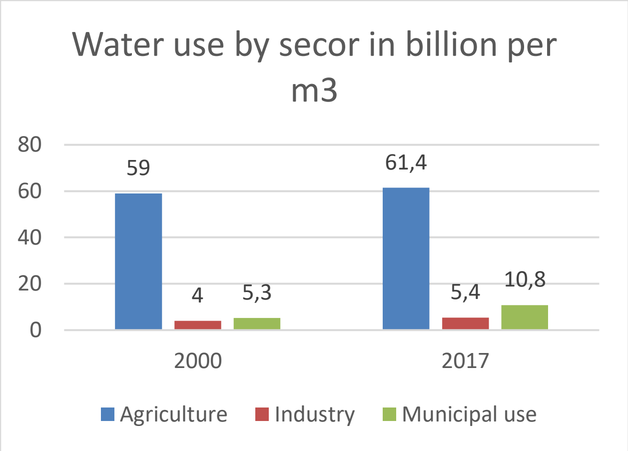
Climate change impact increases the level of water scarcity in an area. According to Abrams (2009), water scarcity can be explained though the strong link that exists between water demand and its availability. The lack of sufficient available water resources to meet the demand for water usage within a region is known as water scarcity. Based on the region, on sectoral water use and climate situation, the demand for water might be different. Being that the poverty is one of the main issues of Egypt, one way to reduce it is by enhancing the water situation in the region though water management and conservation. Egypt is suffering from economic water scarcity, which means that there are not enough water investments done and the water distribution is not equal. (2012) The scarcity of resources, combined with the effects of climate change, makes rainfed agriculture production difficult, particularly in areas where crop production is dependent on seasonal rain fall. (Pereira, 2005).

5. Water resources and water use

The Nile River is Egypt's primary source of water, providing 85% of the country's agricultural water. (Gad, 2017). It is the world's longest river, running through Tanzania, Burundi, Rwanda, the Democratic Republic of the Congo, Kenya, Uganda, South Sudan, Ethiopia, Sudan, and the cultivated part of Egypt, covering a distance of around 4,132 miles. (2022a) The second source of water is ground water followed by rainfall that is very inconsiderable. (Power, 2014) Furthermore, in 1970 the Aswan High Dam was built with the main purpose to provide water for irrigation, protect the place from annual flow variability and generate hydroelectricity. As shown in the graph number 4, the main source of water is the Nile River (55.5 million per m3), groundwater (8.4 billion per m3), and drainage water (7.4 billion per m3). Rainfall is clearly insignificant, with only 1.3 billion per m3 per year.

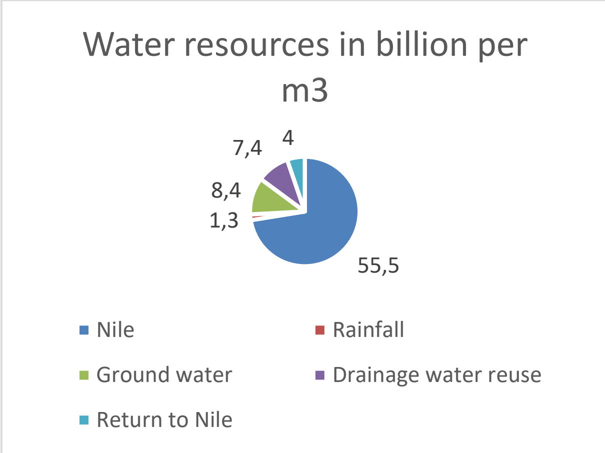
Water use sectors are conventionally organized into agricultural, industrial (including evaporated cooling water) and municipal (including domestic). According to the graph below, agriculture was the largest consumer of water in 2017, accounting for 61.4 billion per m3, followed by municipalities at 10.8 billion per m3 and industry at 5.4 billion per m3. Furthermore, there is a noticeable increase in water use when compared to 7 years ago. To increase the efficiency in agricultural water usage, the government encouraged the farmers to cultivate crops that require less water by eliminating government procurement at rates that differ from those on the global market. (Tellioglu and Konandreas, 2017)

Figure 3: Water use by sector in billion per m3



Source: Worldbank

Figure 4: Water resources in billion per m3



Source: Hesham Y., Khalil A. (2015)

Egypt is reliant on "external" water sources. (Hoekstra and Chapagain, 2007) It has a high water dependency rate, 98,3% in 2018 because is almost totally dependent on Nile River for consumption and irrigation. (Worldbank)

6. Irrigation systems

Irrigation systems are composed of 3 main elements: the hydropower Aswan High Dam, delivery networks and on farm irrigation. The main problems of on farm irrigation is inefficient water use, inadequate quality of irrigation, high cost of irrigation, high salinity. (Molden et al., 1998) There are various irrigation systems in Egypt, but not all of them are used:

1. Flood irrigation is the most dominant one, the water consumption for which represents 61% of the total water resources and is mostly used in the old cultivated lands. It causes soil damage and raises groundwater levels due to evaporative loss and over irrigation. (Molden et al., 1998)
2. Sprinkler irrigation is a technique used to distribute water by spraying it into the air via pumping, similar to rainfall. It is mostly used on traditional crops like wheat, maize, alfalfa and vegetables. (FAO)
3. Pressure irrigation is the most effective technique, because it has a better field water application efficiency than the others and it has been required by law to irrigate newly reclaimed lands. (ICARDA)

By using new efficient technologic irrigation systems, we can improve the water use and have better management practices, which will have a positive impact not only on water but also on soil.

7. Factors that lead to water scarcity in Egypt

Water resources in Egypt are an important factor in determining productivity, services, and long-term growth. (Swain, 2011) There are numerous reasons that have contributed to this scarcity. Among them are:

1. A fixed water supply and a population that is growing rapidly. Under these conditions, the demand for food and water rises and so does the need for production, leading to higher water and land necessities. (El Raey, 2010)
2. Urbanization and pollution are putting unprecedented pressure on renewable water resources, particularly in semi-arid or desert regions. As per the World Bank Group classification based on

workforce and the contribution of agriculture in GDP, Egypt seems to be classified as an urbanized country, since it employs 23.3% of the workforce and the agriculture contributes with 11.05% in the GDP. (Omar, 2021b)
3. Political instabilities. Egypt has frequent disagreements with riparian countries over the sharing of the Nile.
4. Poor infrastructure and management. Egypt is a country with 100% irrigation that is not rain fed and use traditional irrigation methods. Because the irrigation is poor, the water is not being used as efficiently as it should be.
5. Insufficient financial resources. Egypt is known as a poor country that struggles to meet its demands in terms of food and resources.
6. An extremely unpredictable climate change. (Swain, 2011), (Power, 2014).

Water scarcity is also slightly impacted by land fragmentation. The farm size is mostly small and this is very convenient for the farmers, since the ones that owe less than 2 feddans of land are discharged from paying taxes. So, there is no incentive for farmers to cooperate, to apply efficient production practices in order to ameliorate the production, to produce crops that are more profitable and require less water. Through this way they can also increase the exports and have a direct impact on the poverty rate and the trade gap. At the same time, they can overcome the water scarcity in the region and also increase their own revenues. (Tellioglu and Konandreas, 2017)

8. Water situation in Egypt, the conflict with riparian countries

Water is a renewable resource, but its distribution varies through time and space. All land area that is located on a river basin is connected by water, meaning that a change of activity outside the borders of Egypt may impact the whole country. (2012)

Egypt is the largest consumer of Nile River, even though the water comes from outside the Egypt's borders. Egypt and Sudan, as well as Egypt and the United Kingdom, inked a number of agreements. Egypt uses three-quarters of the Nile River, while Sudan uses the rest, indicating that water distribution is inefficient. At the time, the Nile River's bordering countries were not independent to make choices about the river. However, nowadays, water scarcity affects them as well, therefore this separation of Nile River rights is considered as unfair. Under the Entebbe Agreement, riparian countries were granted the right to use the Nile River to construct dams and other infrastructure. Egypt strongly disagreed with this decision, because these measures entail less water for Egypt, which is already experiencing water shortages due to the factors outlined above. Right now, the construction of the Grand Ethiopian Renaissance Dam is the greatest concern of Egypt, because it will inevitably reduce its share of the Nile's flow, aggravating the region's water deficit. (Power, 2014) Many protests and revolutions have been held to stop the dam's construction, but none have succeeded and the situation has led to political instability. (Omar, 2021b)

9. Some solutions that can be provided: Improve management practices on farm scale

1. Growing crops in raised beds – through this method they can save up to 20% of the water used for surface irrigation. (Karrou, 2012)
2. Shifting the crop sequence from 2 to 3 crops per year - Farmers can cultivate 3 cultures per year instead of 2 and through this way they can use the preserved water from the previous practice more efficiently to irrigate the third crop. (Sheha, 2014)
3. The introduction of heat-resistant varieties that will save water and be more resilient to high temperatures.
4. Adopting diverse intercropping techniques, which means that 2 or more crops can be cultivated simultaneously on the same field. (Eskandari et al. 2009) The benefit from this technique is that it can improve soil fertility and increase land productivity as well as farmer's income. (Kamel et al., 2010)

10. Adaptation to climate change

Human adaptation to climate change is defined as "the process of adjustment to actual or expected climate and its effects by seeking to moderate or avoid harm or exploit beneficial opportunities" (Dokken, 2014)

Based on a study made by (Khan et al., 2021) the farmer's capacity to adjust to climate change adaptation strategies depends on several factors such as: farmers age and their adoption to new technologies, farmers education, farm size, active farm labour, livestock holding, off-farm income, access to information, market and credit.

Developing countries like Egypt have a higher probability to get more affected by climate change than developed countries and this risk comes as a result of socio-economic indicators, a high poverty rate, low income, political instability, unfair distribution of resources. Agriculture seems to be more sensitive than the other sectors, especially in developing countries just because the farmer's income are heavily dependent on production. These factors make these countries less capable to adapt to climate changes. (Dokken, 2014)

The farmers perception of climate change was mostly related to the change of temperature and rainfall pattern which led them to a change of sowing date and frequency of irrigation. The risk of the impacts of this climate change is mostly distinguished by the level of farmer's education. (Omar et al., 2015) Climate change is a global issue, but its impact is not the same for every country because the climatic conditions are not the same.

II - Bio-economic models

1. Bioeconomic models

It is very difficult to explain the relationship between natural resources and agriculture and for this reason we need a lot of knowledge and different types of models. Based on spatial and time scale, bio economic models are classified in: farm models, landscape models, regional and national models. (Flichman and Allen, 2013) Since we're in the context of agriculture, we will focus on explaining farm models.

Models from several fields are combined in bioeconomic models. A combination of several agronomic and economic elements must be developed in order to construct a farm bioeconomic model. The integration of these two fields is the primary goal of this model, which is mainly focused on economic optimization but always works in conjunction with agronomic models. (Castro et al., 2018) However, it is crucial to understand all the objectives and how they are related to one another to obtain many trade-offs. In these situations, we move away from the specific objective function of profit maximization and toward a broader concept of sustainability, which also considers economic, social, and environmental factors. (Castro et al., 2018)

These farm bioeconomic models should include the following three elements. They must have an objective function, usually a single one that seeks to increase the farmer's profit. (Voinov et al., n.d.) The operations of every farmer should be described in detail, and the limitations on each activity should be shown. (ten Berge et al., 2000)

There are three levels of bioeconomic models: farm, regional and national scale. Farm level is increasingly prevalent and more beneficial, especially when it comes to evaluating various environmental regulations. This level examines all farms, making it simpler for farmers to understand and manage their production systems. It also helps policymakers make decisions and formulate policies. (Flichman and Allen, 2013)

2. Types of bioeconomic models based on time factor

There are two types of bioeconomic models: static and dynamic. (Flichman and Allen, 2013) The way in which the time factor is integrated and taken into account in these models has a significant impact on the outcomes and decision-making for policy makers. The key distinction between these two types of models is that while static models predict future events, they do not take time into account. (Bertsimas et al., 2011). This is a disadvantage for static models since it prohibits the decision-making process from being adjusted and does not account for changes that occur later in time. (Delmotte et al., 2013) Dynamic models can accommodate changes since time is incorporated into them. As a result, the model is flexible enough to consider things like changes in input prices or climate and it also takes into account the decisions impacted by these changes. (Castro et al., 2018)

3. Classification of bioeconomic models

We can divide bioeconomic models of agricultural systems into three categories: regression, accounting and mathematical programming. (Weersink et al., 2003)

The first category of regression examines the link between prices, inputs, and various policies that have been implemented primarily using statistical data. (Weersink et al., 2003) One of the biggest issues that these types of models face is the difficulty in gathering all of the necessary data. Furthermore, they are based on limited statistical data, making future predictions challenging. Furthermore, they do not account for changes in external environmental circumstances or production. (Janssen and van Ittersum, 2007)

As per the second classification, agricultural production systems can use models that calculate simple profits such as accounting ones which are mostly descriptive since they have difficulties in reflecting many dynamics of environmental systems. (Bouman et al., 1999)

The third group is the linear programming of agro-economic models. The primary goal of these models is to maximize profit or decrease costs while accounting for changes caused by external sources. (Kopke et al., 2008) Compared to the other classifications, their difference is that they are based on economic optimization, which allows for profit maximization by accounting for price, input, labor, capital, and environmental variations. (Norton and Hazell, 1986)

4. **Why we need bioeconomic models?**

Bioeconomic models are used to evaluate the impact of a policy on agriculture by combining socioeconomic and agroecological data, it might be at farm, regional or national scale. These bioeconomic models have been used by politicians because they have helped them during the policy making processes and also have served as support systems for decision-making. Since these models can make several simulations based on specific data that they enter into it, policy-makers can also check if a policy is effective or not in order to lead the farmers towards sustainability. (Kruseman and Bade, 1998) (Deybe, 1998) Also, a grown interest has been shown for bioeconomic models because they assist policymakers in making better management decisions. (Brouwer and Ittersum, 2010)

According to (Janssen and van Ittersum, 2007) "Bio-economic farm models (BEFMs) are developed to enable assessment of policy changes and technological innovations, for specific categories of farming systems."

These bioeconomic models are critical because they enable for the trade-off of socioeconomic and biophysical processes associated to nature. This allows for the evaluation of the influence of managerial decisions on the various policy objectives. (van den Bergh et al., 2001)

Bioeconomic models have also been used to examine the multiple welfare effects of environmental quality and have mainly been developed to assist in environmental management by combining biophysics and economics. (Knowler, 2002)

Another reason we need bioeconomic models is that they are now essential instruments for predicting the outcomes of a policy or technological implementation in the future. These models are extremely complex and thorough since they account for risk, multiple objective functions, and the time factor. (Castro et al., 2018)

III - Study area

Luxor is one of 5th governorates of Upper Egypt with 52% or population living in rural areas. Out of its total surface area of 2424.82 km^2, 241.42 km^2 is occupied by desert, which is inhabitable. The total area is divided in 3 parts: 73.8% represented by agricultural land, 19.4% stands for urban area and only 6.8% is barren lands on both sides of the Nile Valley (Baines and Malek 2000). Luxor's climate is identified as hyper desert and arid. The majority water hydrology source is coming from the Nile River, irrigation canals and groundwater. (Molden et al., n.d.) Rainfall is very low, variable and sporadic in Egypt. The annual rainfall is between 0.0 to 0.03 mm and it has 99% dry days during the whole year. (Patrick J. Tyson, 2014, n.d.)

The main contributors to Luxor's GDP are tourism and agriculture, a sector that employs about 61% of the nation. Sugar cane, winter wheat, grain and fodder corn, alfalfa, berseem and tomatoes are Egypt's primary agricultural products. The summer crop growing season begins in May-June and the winter one in October-November (Rosenzweig & Hillel,1994). Before the construction of Aswan High Dam, the farmers were producing only one crop per year by practicing flood irrigation, which derives in evaporative loss and over-irrigation, and consequently damaging the soil and increasing the groundwater tables. (Swain, 2011).Through this method they wasted a lot of water and due to water scarcity, following the completion of the High Dam, they switched the production to perennial irrigation. Additionally, crops from one season may be harvested before those from the previous season and as a result, they could make crop rotations and produce 2 to 3 crops per year. (Abu-Zeid and El-Shibini, 1997) Perennial irrigation following the dam construction resulted in maximum water consumption for the summer season (Ahmed et al., 2014)

One of the challenges that Luxor is facing right now is the salinity due to fertilization, domestic wastes, and meteoric recharge, which mixed with each other are affecting the groundwater, which are part of water sources. (Ahmed et al., 2014)

Due to the geographic position of Luxor, it is predicted to be more affected by climate change than the other regions in Egypt. The lack of water will impact the cultivated areas and they won't have enough water to irrigate and continue producing the crops for the whole surface. For example, sugarcane is a crop that requires a lot of water, thus the surface for the production of this crop will decrease. (Zohry and Ouda, 2016)

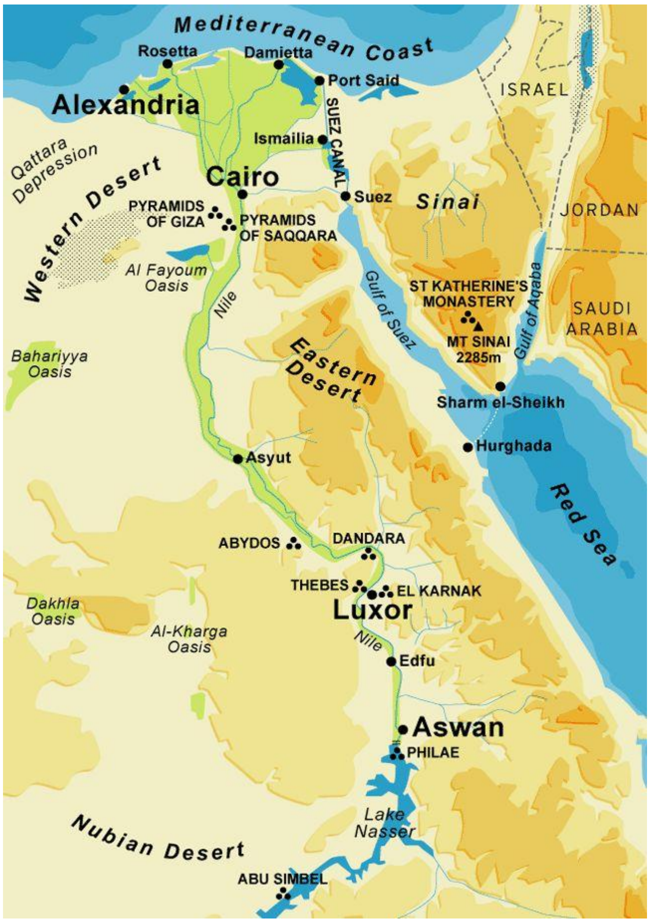
Egypt is characterized by small farms and fragmented lands. The table number 1 shows the percentage distribution of farms based on farm size. As our study area is Luxor, we will concentrate on the region of Upper Egypt, where we can see that half of the farms (50.2%) are extremely small, with less than one feddan. Only 32.82% of farms have one to three feddans, whereas medium and big farms are insignificant.

Table 1: Farm size in Egypt for all regions in feddan

Regions	Extra small (less than 1 feddan)	Small (1 to 3 feddan)	Medium (3 to 5 feddan)	Large (more than 5 feddan)
Metropolitan	7.3	22.63	18.97	51.10
Lower Egypt	36.1	37.49	11.01	14.89
Middle Egypt	40.14	41.54	10.63	7.69
Upper Egypt	50.20	32.82	8.59	8.39
Border	8.48	18.94	15.91	56.67

Source: (Abou-Ali and Kheir-El-Din, 2010)

Figure 5: Map of Egypt, Luxor area



Source: Biger, 1982

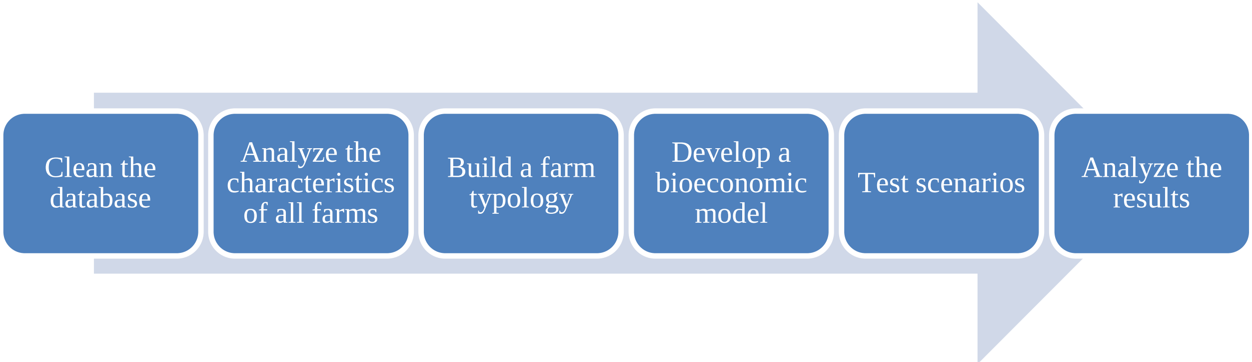
Part II

Methodology

For this thesis report, we worked as part of SupMed project to obtain and analyse data collected from farmers in Luxor, Egypt. This project aims to assist farmers in developing climate change adaptation strategies. They are carrying out this project in two areas: Beqaa in Lebanon and Luxor in Egypt, both of which have high levels of poverty and overuse of natural resources, mainly water and land. For the purposes of this thesis, we will focus only on the area of Luxor in Egypt.

1. **Outline of the methodology**

Figure 6: Outline of the methodology



To build a complete bio-economic model, lots of data are needed. We got a database from the data collectors of the project SupMed. This database was coming from some surveys that they conducted with the farmers in the Luxor area, focused mostly on their crop production and livestock. Based on that data we could calculate the costs and revenues of each farmer and make comparisons between them and their crop profitability. We got a farm typology based on expertise and each type of farm is briefly described below along with its key components.

2. **Farm typology**

Figure 7: Age of landholders

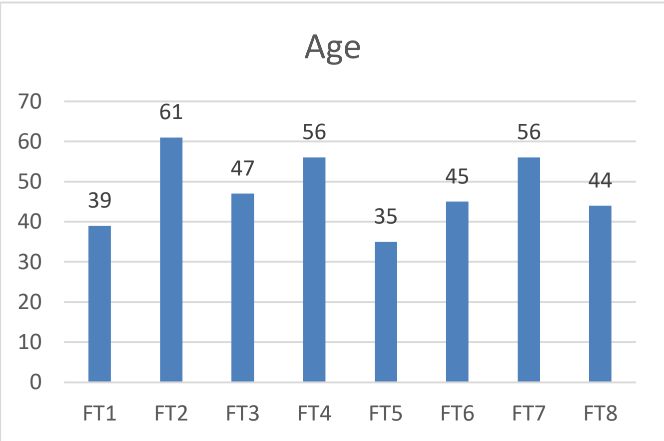


Figure 8: Number of family members per each farm type

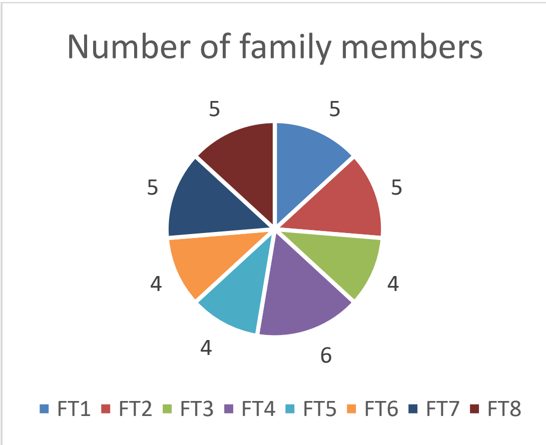
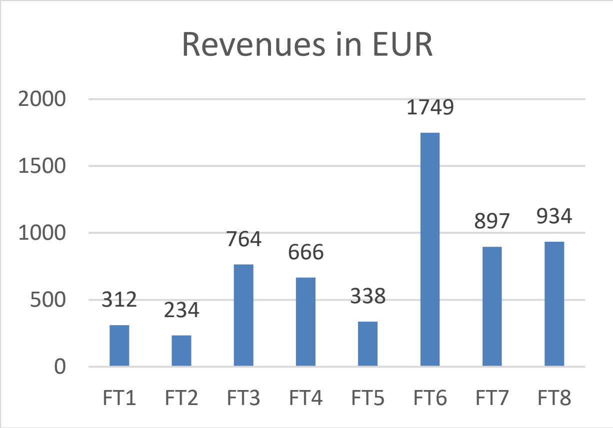
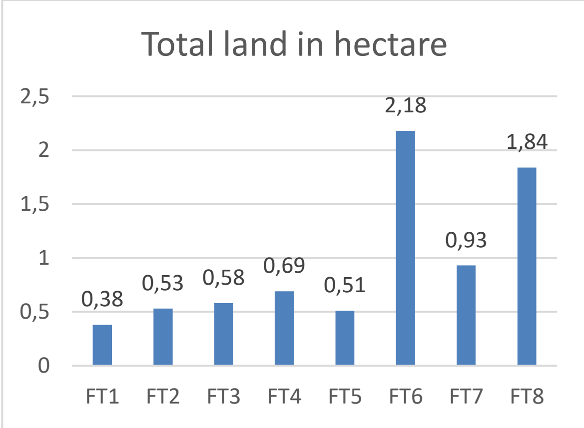


Figure 9: Total revenues per year in EUR

Figure 10: Total land in hectare per each farm type





Farm type 1

Farmers in this farm type are considered young head householders, with an average age of 39 and households of 5 people. They farm, although their formal jobs are in government offices. The majority of family heads are men. They own a small plot of land, approximately 0.38 hectares, and their annual earnings is relatively low, approximately 312 euros. They primarily produce sugarcane and clover, but they also cultivate maize, sorghum, and clover. Sugarcane is a profitable crop. The majority of it is sold, while clover is offered to the animals. Furthermore, farmers in this typology elect to sell a portion of their maize production. Some farmers in this typology take out loans to acquire animals for fattening as well as agricultural supplies.

Farm type 2

Farmers of this type rely mostly on agriculture and don't work in the public sector because the head of the household is primarily an elderly man of 61 years of age. They normally have 5 family members. The land is small, but not insignificant when compared to other farm kinds. As shown in figure 10, they typically own 0.53 hectares and have the lowest annual revenue of 234 euros when compared to the other farm types. The farmers grow clover, a crop that is never sold and is always utilized to feed the animals because these farmers also have livestock. This farm type is distinguished by the fact that it doesn't grow sugarcane at all, and its principal crops are wheat and maize, both of which are grown solely for self-consumption. These farmers have the lowest revenues because they sell only a small portion of their sorghum production.

Farm type 3

The owner of the household is a 47-year-old male who works primarily in agriculture. Some of this group's farmers obtain loans to purchase agricultural goods. They have four family members, less than the preceding farm types. They have 0.58 hectares of land. Apart from agriculture, they have other sources of income, such as remittances from those who live abroad, and their earnings are quite high in comparison to others, reaching 764 euros per year. The farmers only cultivate sugarcane, a cash crop that is entirely sold.

Farm type 4

This farm type has the largest family members, six, and is usually led by a 56-year-old man. Their primary source of income is agriculture, and they don't have any other side jobs. Even though their land size is larger than that of other farm types, their revenues are not. The farm is 0.69 hectares and generates 666 euros per year. The farmers grow a lot of clover that is just used to feed the cattle, and only a little amount of the wheat, maize, and sorghum that is harvested is sold because most of it is consumed by the family.

Farm type 5

The head of the household is generally a 35-year-old young male. They are classified as tiny families since they have four members. Farmers frequently take out loans to purchase animals for fattening as well as agricultural supplies. Their primary source of income is not agricultural farming because they also work as government officials. The land area is 0.51 hectares, and its annual revenue is only 338 euros. Farmers grow massive amounts of sugarcane that is only sold. The clover produced is entirely for animal feed, whereas the majority of wheat and sorghum are grown for human use. These farmers do not grow maize.

Farm type 6

Farmers of farm type 6 are those whose primary occupation is that of a government official; the average age of the head of the family is 47 years old, and he is usually a male. The average family has 4 members. They also borrow money to buy animals for fattening and agricultural supplies. A part of their revenue is also derived from agricultural producion. They grow massive amounts of sugarcane purely for sale. Clover, like the other farm types, is only used to feed the animals. They also grow wheat, maize, and sorghum for personal consumption, with just a small portion of wheat production sold. They have the largest land area compared to any other farm type, 2.18 hectares, and the highest revenue, 1749 euros per year.

Farm type 7

The family's head is mostly a 56-year-old male. Because they don't have any other side employment, their income is entirely dependent on agricultural production. Their families have 5 members. Their land is large, 0.93 hectares, and their revenue is relatively significant, 897 euros per year. Sugarcane production is very high for these farmers, and because it is a cash crop, it enhances the farmers' profits. They also produce wheat, maize, and sorghum for their own subsistence, with just a small portion of wheat production sold. Clover production, like that of other agricultural farm types, is used only to feed cattle.

Farm type 8

This farm type's farmers are also among the wealthiest in terms of revenue and land area. Their major activity is agriculture, and their annual income is 934 euros. Their average land size is 1.84 hectares. Their families are typically made of 5 people, with the head of the family being a man with an average age of 44. Some farmers take out loans to acquire animals for fattening as well as agricultural goods. They mostly cultivate sugarcane for sale. Only a small amount of wheat and sorghum output is sold, while the rest and maize production is used only for self-consumption. Clover is an important crop to feed livestock.

3. Bioeconomic model

Since environmental issues are included in the model, the timeframe is very important, because the production and the prices of inputs might change due to climate conditions and every other external factor. (Belhouchette et al., 2012) To address dynamic relationships between ecological and socio-economic systems, it is needed an integration of multiple disciplines. (Flichman and Allen, 2013) The model that we need to use is dynamic rather than static because time factor is a crucial consideration given that climate change is the primary concern. In Luxor, there are eight different types of farms, and we will run the model for each one at farm scale and make simulations for the next 20 years. The tool that we are going to use to test the baseline and the scenario is GAMS.

Since agriculture in Egypt is highly affected by the climatic conditions, especially the rainfall pattern which is very insignificant and high temperatures, we created a baseline scenario where we tested the impact of these two components in the model for all farm types.

4. Rainfall pattern

The level of precipitation is very low, almost 0 in Egypt and from this component alone we don't anticipate a significant change in the yield. For this reason, in this model we calculated the real yield by taking into consideration the impact of rainfall pattern for the last 20 years and also the evapotranspiration over the crop cycle. In Egypt, estimating Actual Evapotranspiration (ETa) is crucial for managing and planning water supplies. To calculate this actual evapotranspiration, we needed some parameters that we took from literature as well as expert knowledge. According to the table below, the source of data we obtained is divided into two sections:

Table 2: Division of sources of data

Literature review	Expert knowledge
Crop coefficient	Field capacity
Yield sensitivity to water stress	Initial soil water content
Cumulative reference evapotranspiration	Wilting point

Irrigation efficiency	Calendar of land use per crop

Based on all the information we had, we used the following equation according to De Azevedo et al., 2012, to determine the real yield over a 20-year period for every type of farm:

$$Yr = Ymax - Ymax * ky * \frac{1 - ETC}{(ETmax * occupation)}$$

Where:
• Ymax – maximum yield
• Ky – crop coefficient
• ETC – actual evapotranspiration over the crop cycle
• ETmax – maximum evapotranspiration
• Occupation – land use per crop in months

Through this equation we can determine the level of production under various climatic conditions as well as how actual evapotranspiration and rainfall will impact the yield.

5. Temperature variability

Egypt for the next 20 years due to climate change is expected to go through an increase in temperature by 2 degrees Celsius. This will increase the mean temperature in Luxor to 24.9 degrees. (Mimura, 2021) There is a linear relationship between the temperature and crop water requirements, meaning that the increase in temperature will also increase the needs of crops for water. This 2-degree Celsius rise in temperature will result in a decrease in production by 9% for wheat and 11% for maize, sorghum, sugarcane, and clover. (El-Bahrawy, 2014)

To calculate the impact of temperature variability on yield, we needed some temperature data per month that we took from FAO for the last 20 years (2000-2020). Later on, we calculated a standard average temperature for the first 3 years that served as a reference temperature. To determine this new yield, which takes into account the rainfall pattern and temperature, we used the following equation:

$$Yrt = Yr - Yr(a * \Delta T)$$

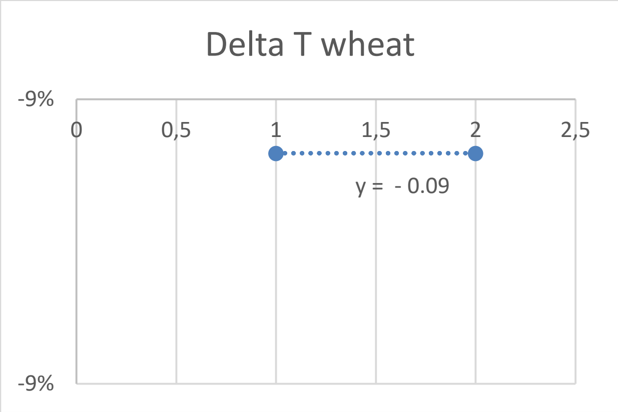
Where:

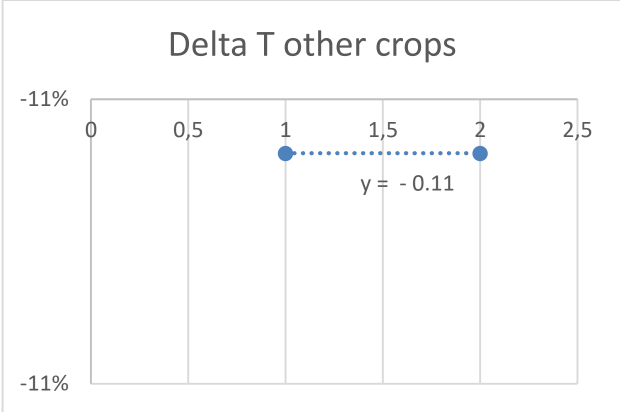
- Yrt – Real yield including the impact of temperature and rainfall
- Yr –Real yield that considers only the impact of rainfall
- A – The slope representing the reduction of yield for all the crops
- ΔT – Delta T represents the difference in temperature (T_i-T_{av})

Based on the reduction of yield in percentage for all the crops we calculated the slope for wheat and for the rest of the crops, considering them as linear, as shown in the next graphs:

Figure 11: Slope of wheat

Figure 12: Slope of other crops





For this equation, we set a condition, assuming that if the average temperature of the year would be higher than this average temperature, the yield that includes the impact of temperature and rainfall would be calculated as follows: $Yrt = Yr - Yr(a * \Delta T)$. So, we can say that the temperature will have an impact on yield and we will get a specific value of this impact.

If the temperature would be lower than the average temperature, then the yield impacted by temperature and rainfall would be the same as the yield impacted by rainfall, meaning that for that specific year, the temperature wouldn't have an impact on yield: $Yrt = Yr$

Since heat waves and high temperatures in Egypt are among the climate features that have a significant impact on the yield, but still, we don't anticipate a significant variation from year to year because monthly temperature variations are often low.

6. Risk part

Furthermore, we made some simulations to see what will happen in the next 20 years with farmer's behaviour and the production in general, by taking into account also a variability of selling prices for the last 4 years. This price variability has consequences because is one of the factors that impacts directly the market and gross margin and for this reason is fundamental for farmers to take into account the risk. Farmers are usually risk averse; they tend to avoid taking risks. To consider it, we took a coefficient of risk aversion (PHI) that usually ranges between 1 and 3. The higher the risk aversion coefficient, the higher is the risk that the farmer will take and vice versa. (Gandelman N., Hernández-Murillo R, 2015). In our case, we decided to have a coefficient of 1.2 because the farmers aren't risk takers, they prefer guaranteed profit and little to no risk.

7. Equation interpretations

Some of the most important equations that we used in our model are represented in the following table:

Table 3: Equations 1

	Equations	Initials
Objective function	$u = z - \sum_{t} PHI * \sigma$	PHI - Risk aversion coefficient z - Gross margin σ - standard deviation
Gross margin	$z = \sum_{c,p,irrig\_system,t} (X * Y * P) - TC$	
Real gross margin	$real\_z = \sum_{c,p,irrig\_system,t} (X * Y * P) - (CP * P) - TC$	

We are working on these equations to reach our major objective, to see how the gross margin and the production quantity will be affected by climate change. These are simple equations taken from literature, some of which we were obliged to adapt according to our needs. The reason why we calculated the revenues in this way, was because the production quantity for all farm types was used for sale but also for self-consumption. In the model, the yield represents the total quantity of production, without making a division per sale or per consumption. For this reason, since the farmers aren't getting a monetary profit from their own consumption, we decided to exclude the quantity of consumption from the total revenues. Through these equations, we will see how much will the farmers benefit from selling their productions, which part of their production will go for sale, and which part will go for self-consumption. We can make comparisons between farm types and see which one has the highest profit.

The constraints in our model were the ones of land, labor, and irrigation. We will present them in the table below:

Table 4: Equations 2

Constraints	Equations	Initials
Land	$\sum_{c,p,irrig\_system,t} X \leq land$	X – crop surface FL – family labor RL – rented labor nb_irrig – number of irrigations dose_irrig – dose of irrigation
Labor	$\sum_{c,p,irrig\_system,t} * \sum_{tasks,tasks\_irrig} labor\_needs + (labor\_irrig * nb\_irrig) \leq FL + RL$	
Irrigation	$\sum_{c,p,irrig\_system,t} X * dose\_irrig \leq water\_availability$	

With the sea level rise that Egypt is expected to suffer, the land will be even more scarce. The land is a constraint in our case because farmers can produce the type of crops that they want but they can't overpass the total available land. In the model, labor is expressed per task and per crop and is a limitation because it can't be higher than the total available family labor and rented labor, by which we mean temporary workers that are hired during specific periods such as planting, weed controlling, pest controlling, irrigating and harvesting. As per water constraints, farmers can't irrigate more than the available water coming from the previous resources mentioned above. This availability is limited because there is a scarcity of water and the climate is exceedingly arid and unfavourable to it.

Another equation of high importance was the one of own consumption:

$$consumption\_part \geq self\_consumption$$

where the consumption part is the variable that represents the value of own consumption for which the model will decide and the consumption quantity is the real consumption of farmers based on answers coming from the surveys. To calculate the self-consumption, we added a coefficient that we adjusted selon different farm types with the goal of being as close to reality as possible, and for that, we focused on the surveys and the real quantity of self-consumption for each farm type. We decided to develop this equation and to see how will the quantity of consumption be affected by climate change and water scarcity, since Egypt is suffering from poverty, and the majority of production goes for self-consumption.

To take into consideration the risk coming from the price variability, we recalculated the gross margin through the next equation:

$$GM = (Y * P * P_{var}) - C$$

• where P_var is price variability expressed per each crop calculated for the last 4 years.

8. Scenario

The baseline describes the situation as it currently stands and is used as a point of reference when comparing the scenario with the actual situation. To assess the impact of specific policies, we will test a scenario for all farm types. The scenario that will be evaluated is the one of improved seeds where we will observe how these new alternative seeds affect production, farmer revenues, and already scarce natural resources such as water. The improved seeds are seeds that are used by farmers to preserve the yield in less favourable areas, under specific conditions. The main goal is to provide good quality of seeds that will improve crop productivity and production. These improved varieties of seeds that are actually on the market can offer a higher yield, a more stable production with better quality.

Since the main problem that is being faced is climate change, we're always trying to find a solution to reduce the impact that it will have on agriculture. Based on the problem of the region, with the heat waves that Egypt is facing and the lack of rainfall and water availability, the introduction of improved seeds that are heat resistant in the agricultural systems is seen as a quick solution. Like this, we expect that the production will not decrease, so the revenues will continue increasing, and the farmers will have more water available that maybe can use to cultivate other crops that seek more water and that are economically more profitable.

The scenario that we tested in the model represents the current situation, but also incorporates a few of our minor changes. We included these additional alternative crops in the model: wheat alternative, maize alternative, sugarcane alternative, and sorghum alternative. In order to determine the amount of gross margin that the farmers will receive from these crops as well as the level of production, we added costs and revenues for each.

Part III

Results

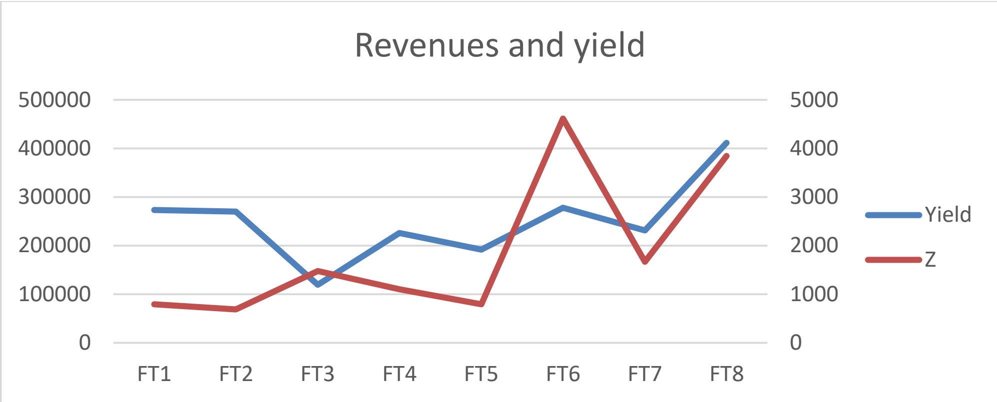
1. Calibration

Many different types of data were used to develop these bio-economic models, and it is obviously difficult to determine whether or not the models are calibrated. After testing the model for eight different farm types, we found that the outcomes were somehow consistent with reality and that the general trends persisted. Nevertheless, just as it was stated in the database, farm type 2 was the least profitable and farm type 6 was the most profitable even in the model. A model, as we mentioned above, is a representation of reality, but we shouldn't expect to obtain values that are exactly the same as those from the farmer's surveys. Farmers of all farm types continue to cultivate the crops that they declared they would cultivate. Furthermore, the model predicts that farmers will produce roughly the same yield per crop. Since the trends are consistent, we can say that the model is calibrated, taking into account that a percentage of error is always expected.

2. Results baseline

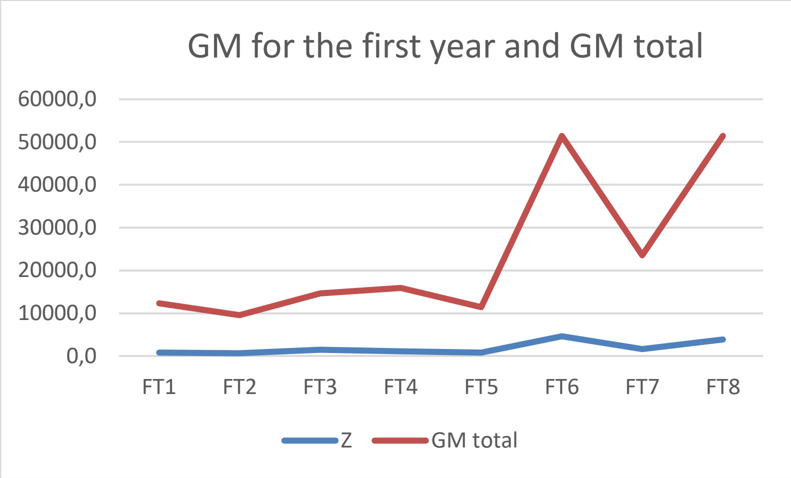
Our analysis will be primarily focused on our main goal of determining how farmers would react to climate change and how crop production would change.

Figure 13: Revenues and yield for all farm typologies



The most important thing for any farmer is to end the month with a high profit. After running the model, we found that farm type 6 is the most representative in terms of revenues, but despite having the highest revenues, this farm type does not have a high yield, as shown by the graph 13. The typology demonstrates that the farmers of this farm type were not solely focused on agriculture, indicating that agriculture was not their main source of income. Farm type 2 is the poorest because its primary activity is agriculture and it produces primarily for its own consumption rather than for sale, indicating that it has no other external resources. The remaining farms fall somewhere in the middle, with lower or average earnings. Because of its large land size, type 8 is the most representative farm in terms of yield. Despite the fact that the model was run for eight farm types, we will only present the most representative ones in this section of results, based on income: the farm with the highest income and the farm with the lowest. As a result, farm types 6 and 2 will be our primary focus.

Figure 14: Comparison of gross margin for the first year and in total



Climate change, specifically rainfall and temperature variability, is considered while calculating the gross margin. The blue line represents the gross margin in the first year for all farm types. The orange line represents the total gross margin, which is calculated by adding the gross margins from all 20 simulated years. The graph above shows that the trend will continue for all farm types, implying that the same farms will be the richest and poorest in terms of revenue after 20 years under these climate conditions.

Figure 15: Total revenues in EUR

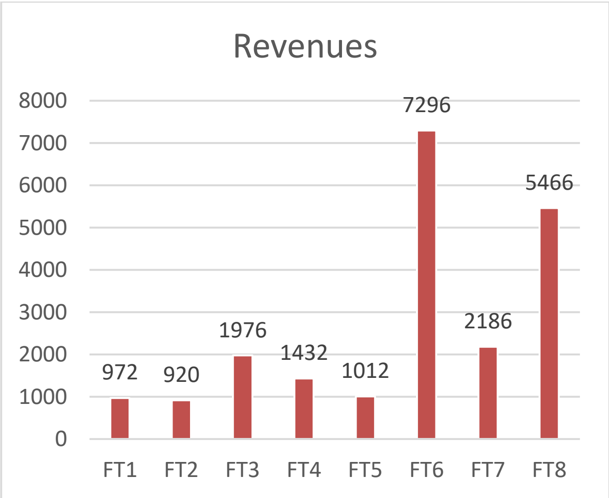
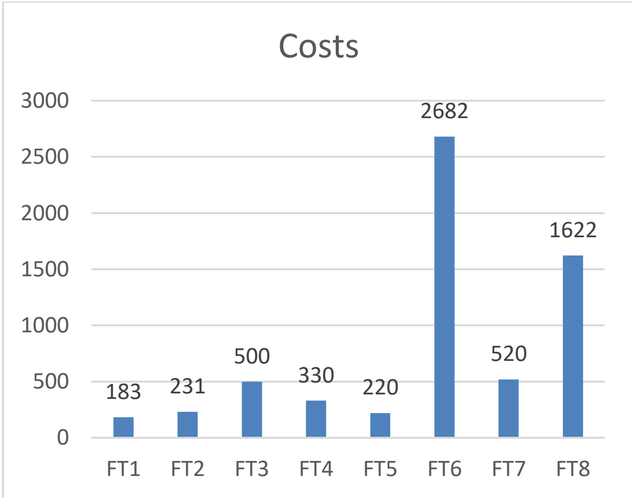
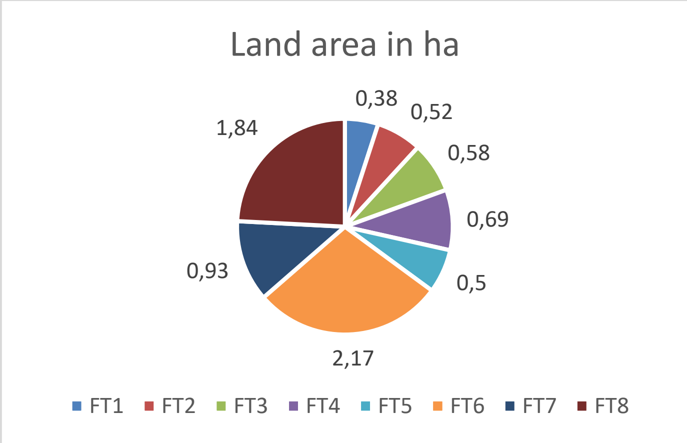


Figure 16: Total costs in EUR



The graphs above show total revenues and total costs in EUR for each farm type. The farms with the highest costs have the most available land, which allows them to produce more than the other farms. Farm type 2 has the lowest revenue, only 920 EUR per year, because most of its production is for its own consumption, while farm type 8 has the highest revenue, 7296 EUR per year, because it produces a large amount of sugarcane for sale as well as other profitable crops. It is reasonable to expect a low annual gross margin because Egypt is a poor country with very low incomes, as evidenced by the relatively small revenues and

Figure 17: Total land area in ha



This graph shows the total area of all farm types in hectares. We can see that farm type 6 has the biggest land (2.17 hectares), followed by farm type 8 (1.84 hectares). These two are the types that can be considered as big farms. Farm type 1 has the smallest land, measuring only 0.38 hectares. The remaining farms are roughly the same size, ranging from 0.50 to 0.70 hectares.

Figure 18: Own consumption per farm type

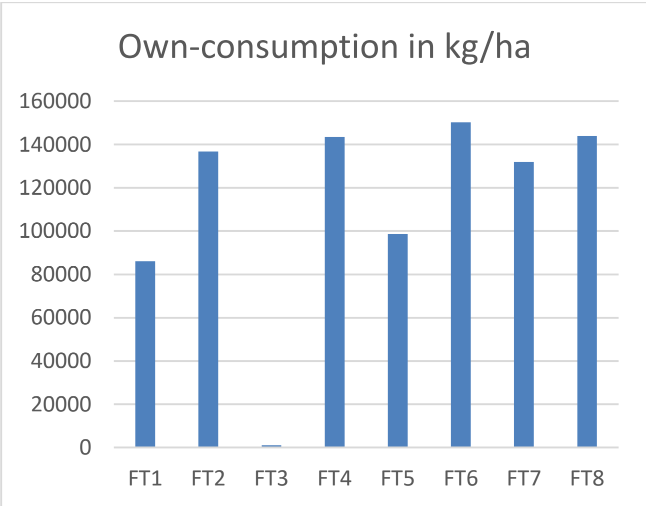
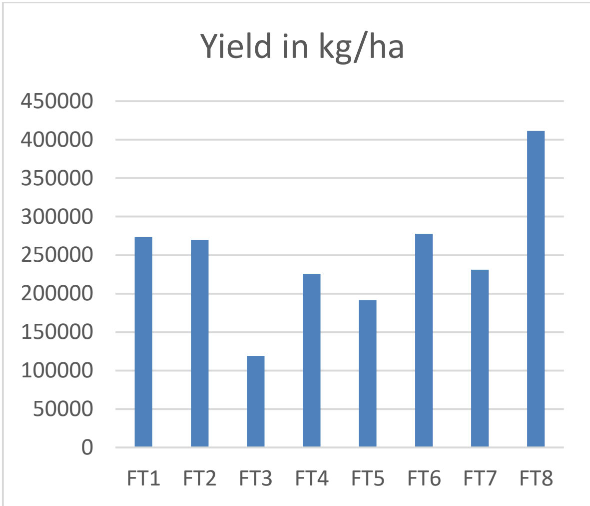


Figure 19: Yield per farm type



One of the reasons Egypt is considered a poor country is that the majority of its production is for its own consumption, reducing sales. Farmers rely on agriculture as their primary source of income in these circumstances. According to the previous graphs, farm type 8 has the highest production of all farm types. In terms of farm types, 2 and 6 have very high yields. It is normal for these farms to consume a lot of food under these conditions. A significant difference is observed for farm type 3, which consumes only a small portion of its own production because the majority of it goes for sale.

Figure 20: Average area per crop in ha type 2

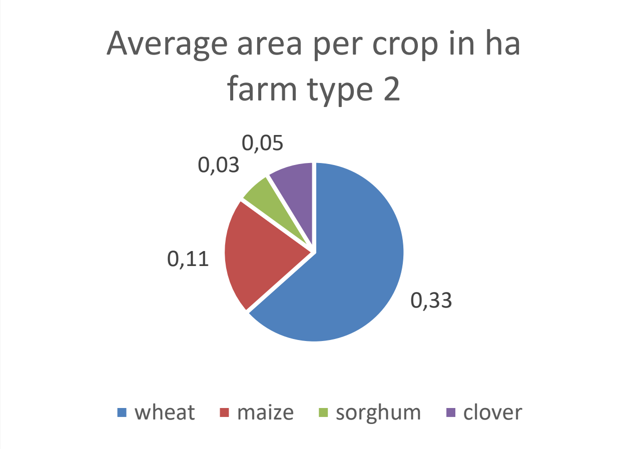
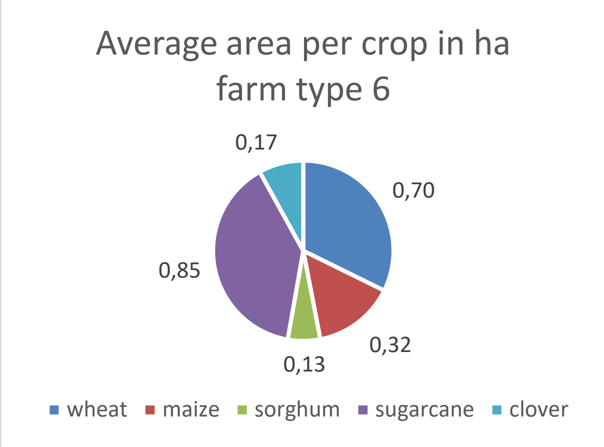


Figure 21: Average area per crop in ha type 6



Wheat and maize appear to be the main crops for farm type 2 because they occupy a large area in comparison to other crops, 0.33 and 0.11 hectares, respectively. Furthermore, they only produce a trace amount of sorghum and clover. All of these crops are for their own consumption. Farm type 6 places a high value on the crop that is sold, which explains why this type generates a lot of money. They grow a lot of sugarcane (0.85 ha), but they also grow a lot of wheat (0.7 ha) and maize (0.32 ha).

Figure 22: Yield in kg/ha type 2

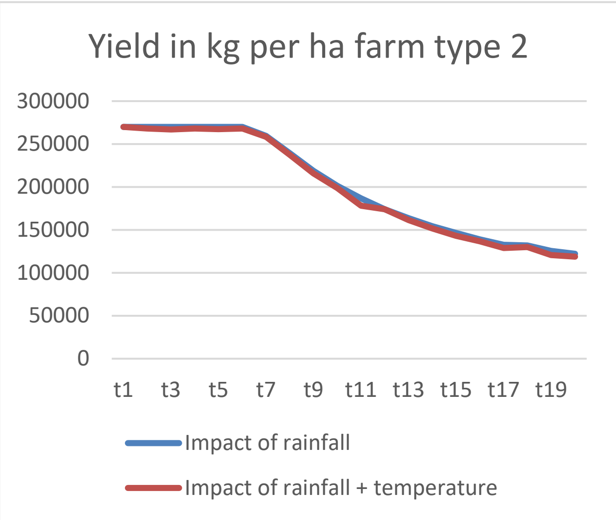
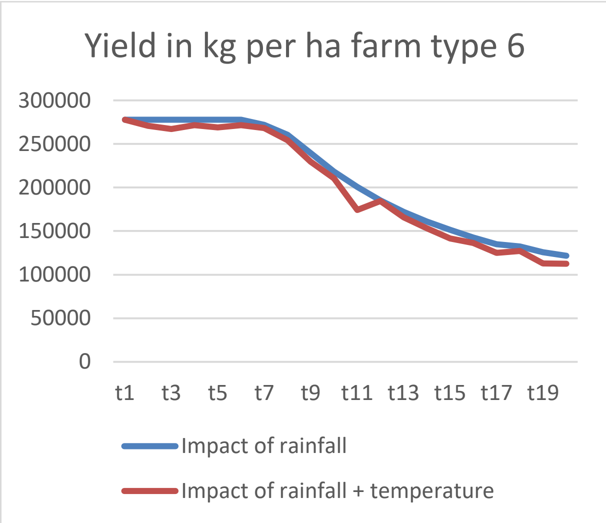


Figure 23: Yield in kg/ha type 6



The amount of rain and the temperature will have a significant impact on future yield. Farmers' yield is most affected by the combination of rainfall and high temperatures. These two graphs show this relationship and predict that the conditions of both types of farms will remain essentially stable over the next ten years, but that a yield decline will eventually become apparent. These farm types have very different revenue streams, but in terms of productivity, they are nearly identical. The impact of rainfall and temperature is greater in the year T11, which has a higher temperature than the others, an average of 23.38 degrees. It is truly remarkable because it shows that temperature has a greater impact on yield reduction than rainfall for both farm types.

Table 5: Constraints 1

Land constraint farm type 2	**Level of land used in ha**	**Upper value**	**Marginal value**
P1	0.2	0.2	1608
P2	0.1	0.1	2064

We expressed the land in three periods in the model. Winter crops such as wheat and clover represent the first period, summer crops such as maize and sorghum represent the second one, and perennial crops such as sugarcane the third one. Farm type 2 does not produce sugarcane at all, so there is no period 3 for this farm type. Meanwhile, the land is being used to its full potential for the remaining crops. If the farmer added an extra hectare of land for winter crops, he would have made an extra profit of 1608 euros, and if he did the same for summer crops, he would have made an extra profit of 2064 euros. In this case, we can confirm that land is a constraint for this type of farm.

Table 6: Constraints 2

Labor constraint farm type 2	**Level of labor used**	**Upper value**	**Marginal value**
Wheat	2.88	2.88	0.67
Maize	2.88	2.88	0.33
Sorghum	0.015	2.88	-
Sugarcane	2.88	2.88	0.27
Clover	0.005	2.88	-

According to the table below, labor is a limiting factor for some crops, such as wheat, maize, and sugarcane. If the farmer had invested more in labor, he would have received 0.67 euro for wheat, 0.33 euro for maize, and 0.27 euro for sugarcane for each unit of additional labor. Also, he is not using all of the available labor for sorghum and clover; we can see that he chose to use only 0.015 of the 2.88 available labor for sorghum and 0.005 for clover.

Table 7: Constraints 3

Land constraint farm type 6	**Level of land used in ha**	**Upper value**	**Marginal value**
P1	0.7	0.7	1234.9
P2	0.62	0.62	1968.8
P3	0.85	0.85	-

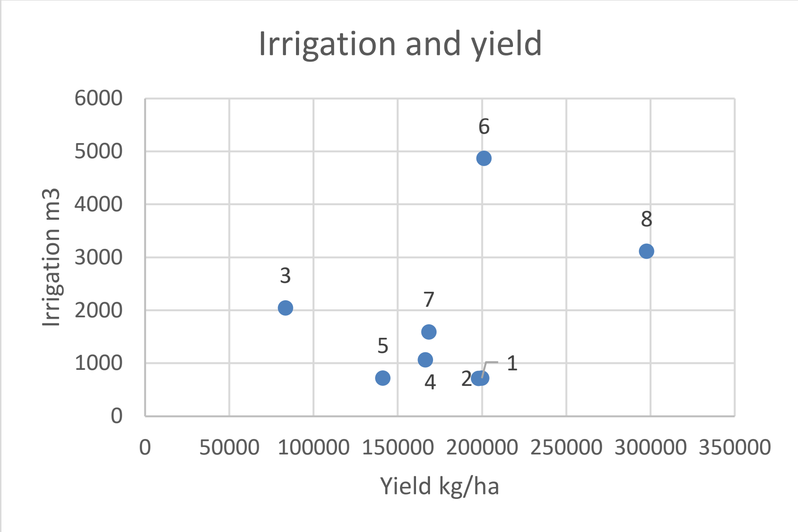
Farmers use all of their available land for this farm type, which has the highest revenue. If the farmer had added one more unit of land to his winter crop, he would have received 1234.9 euros, whereas the profit for summer crops is higher, 1968.8 euros. Even if he added one more unit of land to the perennial crop of sugarcane, he would not profit. Even for this type of farm, land is a constraint, at least for winter and summer crops.

Table 8: Constraints 4

Labor constraint farm type 6	**Level of labor used**	**Upper value**	**Marginal value**
Wheat	3.44	3.44	2.47
Maize	3.44	3.44	1.13
Sorghum	3.44	3.44	0.45
Sugarcane	3.44	3.44	3
Clover	3.44	3.44	0.62

Farm type 6 is using all available labor for all crops, and if he added one more unit of labor, he would profit more from each crop. Wheat profit would be 2.47 euros, maize profit would be 1.13 euros, sorghum profit would be 0.45 euros, sugarcane profit would be 3 euros, and clover profit would be 0.62 euros. Even for this type of farm, labor is a constraint.

Figure 24: Level of irrigation and yield for all farm types



Since Egypt is experiencing water scarcity, this graph shows how much each farm type produces and how much irrigation is used. The farm type with the highest production is 8, which is to be expected given that farm type 8 has the largest area per crop compared to other farms. Farm types 6 and 8 use more water than the others, which can be explained by farm type 8's production, but this is not the case for farm type 6, whose production is nearly equal to farm types 1 and 2. The main reason these two farms irrigate more is that their land is larger than the other farm types. Meanwhile, farm types 1, 2, 4, 5, and 7 have a high yield but a low level of irrigation, which is determined by the size of their land and the crops they cultivate. Farm type 3 produces less, but its irrigation level is high because it is solely dedicated to the production of sugarcane, a crop that requires more water than the others.

Figure 25: Level of gross margin and yield for all farm types

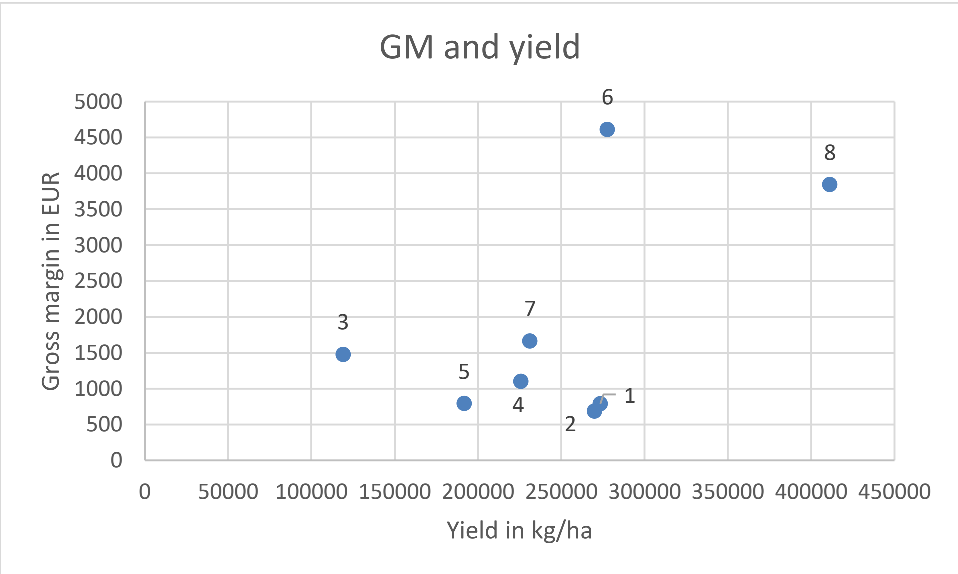


Figure 25 can be used as a reference to compare farmer profit and production. We will divide these farm types into three major categories based on their level of profitability. According to the graph, farm type 2 has the lowest income, followed by farm types 1, 5, and 4. These are considered to be those with a low level of income but acceptable output. They have a low income because agriculture is their main source of income and the majority of their output is consumed by themselves. Farm types 3, 4, and 7 are considered to have normal incomes because a significant portion of their output is sold. The third group consists of high-income farms (types 6 and 8). Farm type 8 makes the most money because its land area is larger than the others, allowing it to produce more and sell a larger portion of its output. While farm type 6 has the most land compared to the others and almost the same level of production as farm types 1 and 2, its profitability is much higher because agriculture is not their primary source of income.

Figure 26: Trend of irrigation and yield type 2

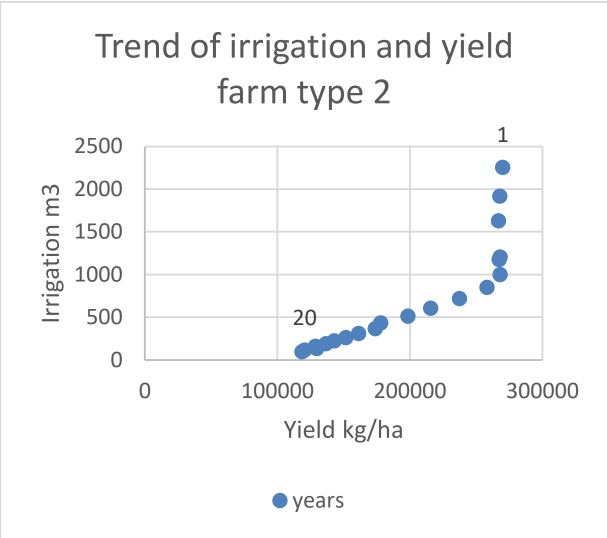
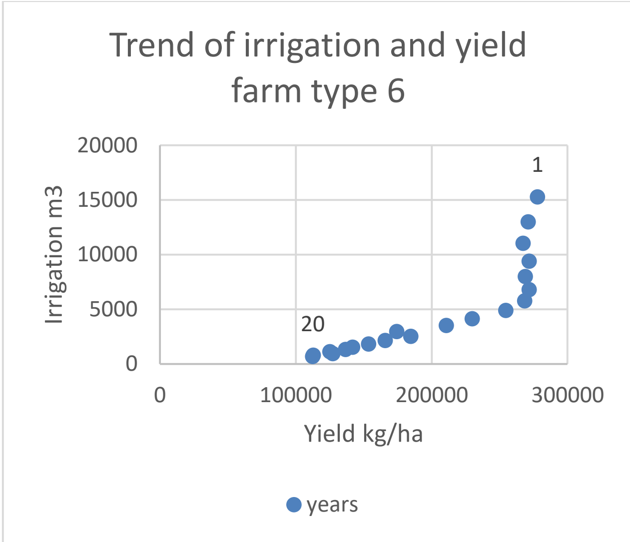


Figure 27: Trend of irrigation and yield type 6



Variability in rainfall and temperature will have a significant impact on farmer output. According to the figures above, even though these two farm types are revenue extremes, their climate impact can be similar. It is noticeable that in the first year of simulation, their level of production and irrigation is relatively high, but from one year to the next, it creates an exponential decrease by reducing the quantity of irrigation and production.

Figure 28: Irrigation per m3 per crop type 2

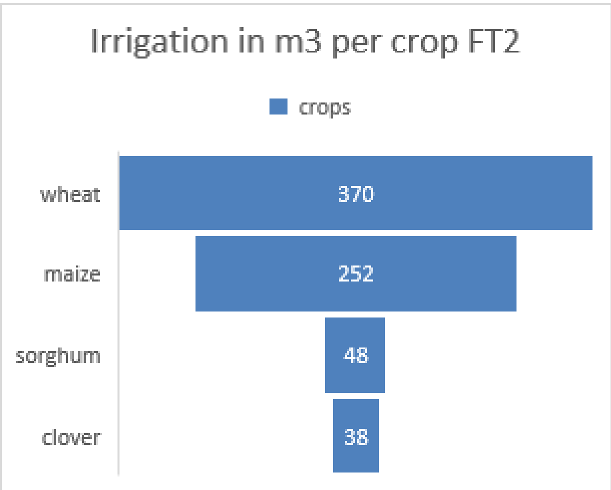
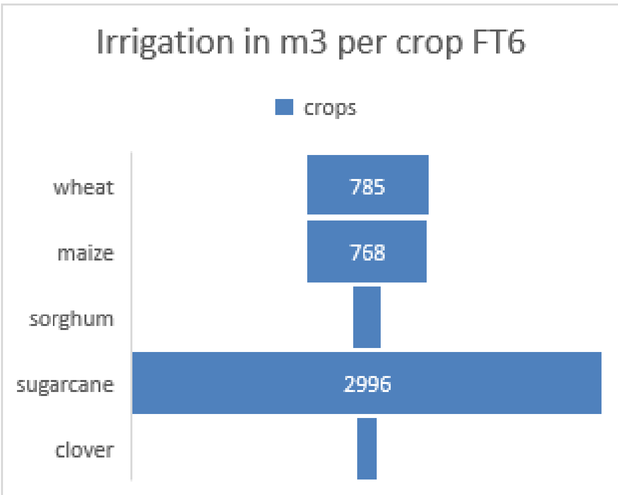


Figure 29: Irrigation per m3 per crop type 6

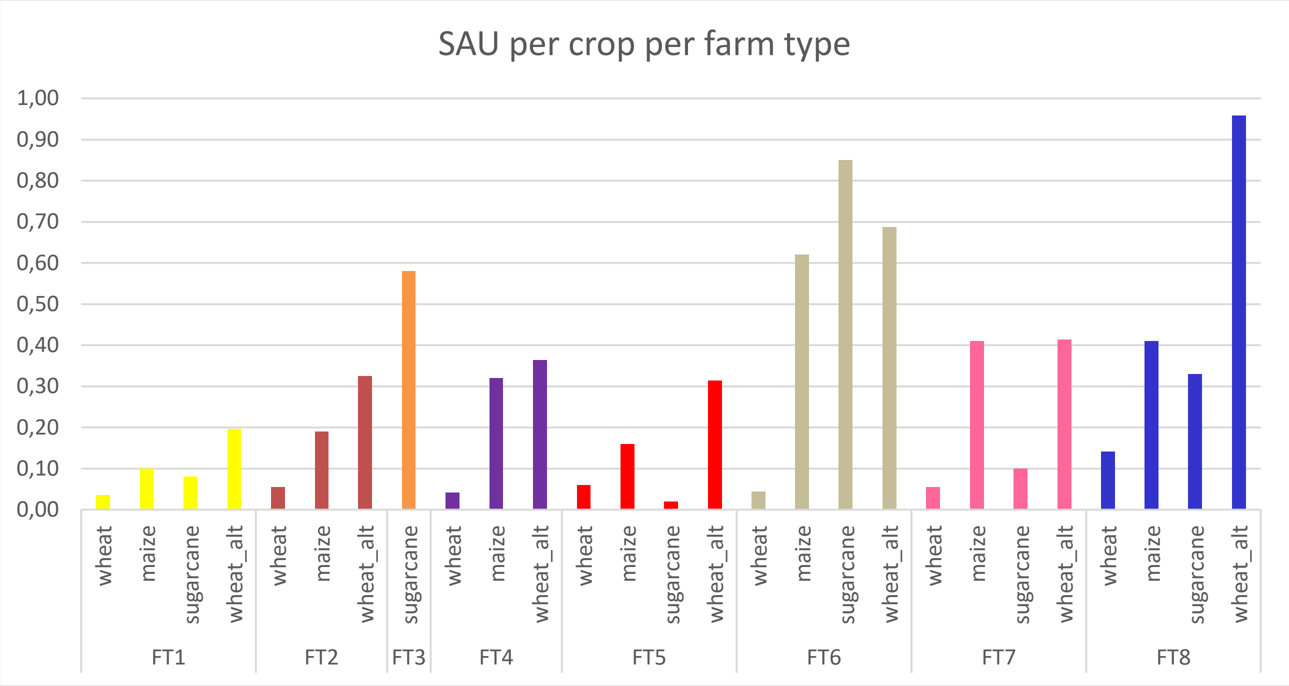


These two graphs illustrate the irrigation levels per crop for our two main farm types. Farm type 6 requires more irrigation water because it produces a large amount of sugarcane, which requires 2996 m3 of water, as well as wheat and maize, which require 785 and 768 m3 of water, respectively. While farm type 2 has only two major crops that require a lot of water: wheat and maize, sorghum and clover, as shown in the graph above, require only 48 and 38 m3. Irrigation is also related to land size, with a difference of 1.65 hectares.

3. **Results of improved seeds scenario**

We will use the same analysis to introduce the scenario into the model as we did for the baseline. We will compare only two farm types in depth: the poorest one and the richest one.

Figure 30: Area per crop for all farm types



This graph represents the available crop area per farm type. Farmers appear to be cultivating nearly the same crops: wheat, maize, sugarcane, and wheat with improved seeds. We can see from the graph that only farm type 3 is not producing wheat alternative; before implementing this scenario, this farm type was using the entirety of their available land for this crop and apparently, it is profitable for the farmer, and he has no interest in producing other crops. The rest of the farm types are all dedicating the majority of their land to alternative wheat. This means that the new crop we want to introduce is economically viable. After incorporating this scenario into the model, we discovered that sorghum and clover are no longer cropping priorities. Evidently, they are not profitable for farmers when compared to wheat, maize, and sugarcane, which are still grown.

Figure 31: Comparison of gross margin in EUR

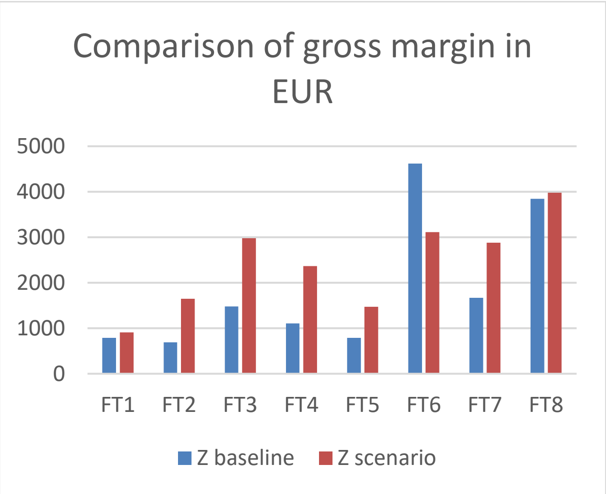
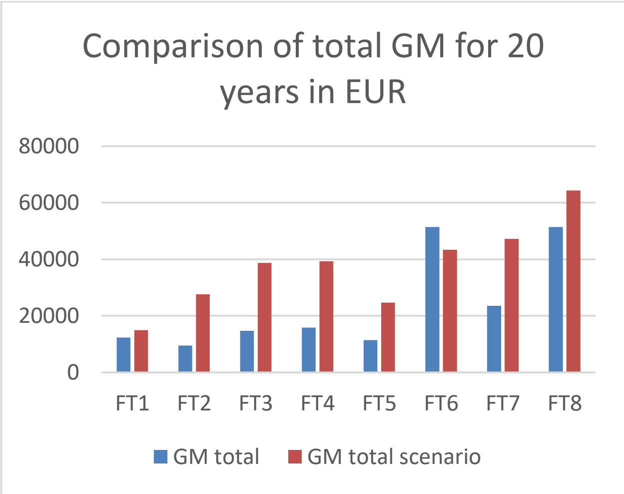


Figure 32: Comparison of total gross margin for 20 years

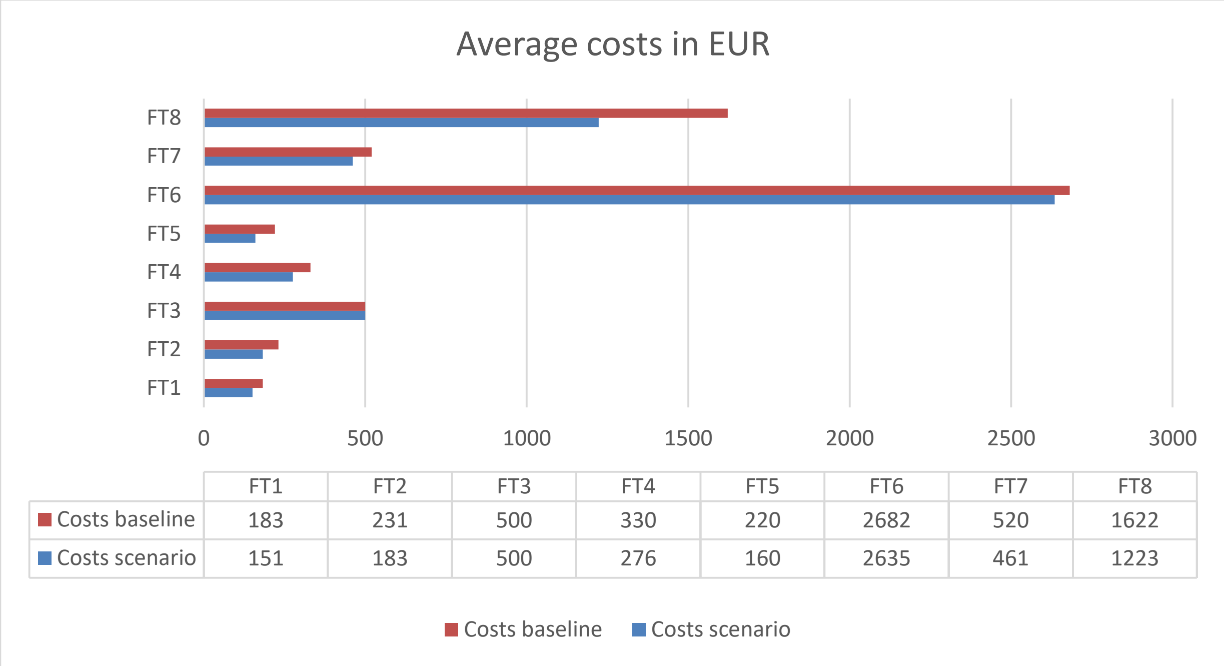


Farmers' profitability began to change after new seeds were introduced into the model, and overall farmer income increased. The ranking of farmers shifted due to economic factors. Farm type 2, which was the poorest during the baseline, is now competing with farm type 1, which has the lowest revenues of all farms.

Farm type 8 appears to be the most profitable, with the highest incomes, rather than farm type 6, which existed prior to the introduction of the new seeds.

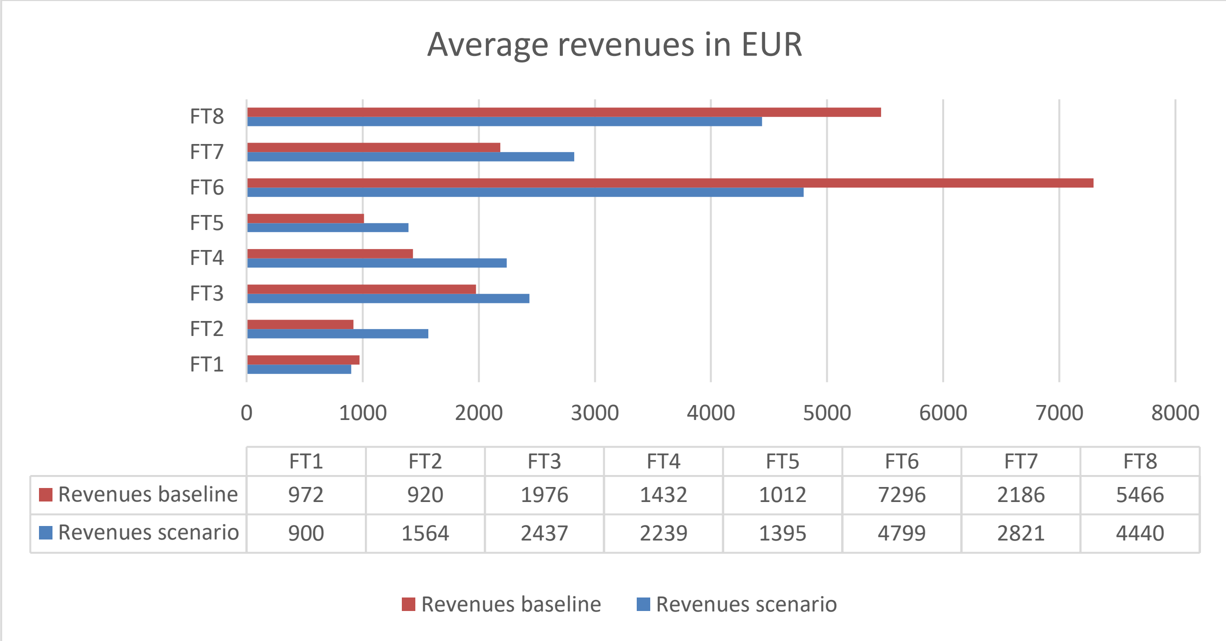
To compare and see if this scenario was useful, we can start by looking at the farmer's profit. Figure 32 shows that farmer incomes increased for all farm types except type 6, which was the richest at the start. Apparently, the introduction of new heat-resistant varieties was not profitable for this farm type. Long term, after 20 years of simulation, farm types 2, 3, 4, and 7 are more resistant to these changes, climate impact, and the implementation of new varieties in terms of economics.

Figure 33: Average cost in EUR



This graph indicates the average annual costs of farmers in EUR for the baseline and scenario. After testing the scenario, we discovered a reduction in farmer costs compared to the baseline for all farm types, particularly farm type 8. This farm type decided to dedicate a large area to a new variety of alternative wheat, which is less expensive economically than the other crops. While all farm types have had their costs reduced, farm type 3 has maintained the same level of costs because farmers did not incorporate the new crop into their production and continue to produce only sugarcane.

Figure 34: Average revenues in EUR



Through this graph will show the average revenues in euros for all farm types before and after implementing the scenario in the model. Revenues for farm types 6 and 8 have decreased significantly when compared to the baseline. This scenario appears to be profitable only for farms with a low level of income because the rich farms saw their income decrease. Farm type 6 has a significant decrease in revenues when compared to the database, whereas farm type 8 has a significant decrease in costs and thus a high profit despite having fewer revenues than the baseline. Apart from farm types 6 and 8, farmers of type 1 saw their revenues fall by 72 euros per year compared to the baseline, but their costs were low.

Figure 35: Yield in kg/ha type 1

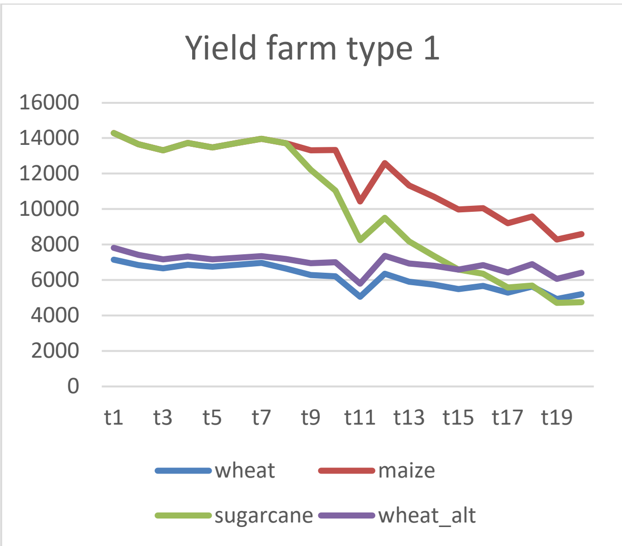
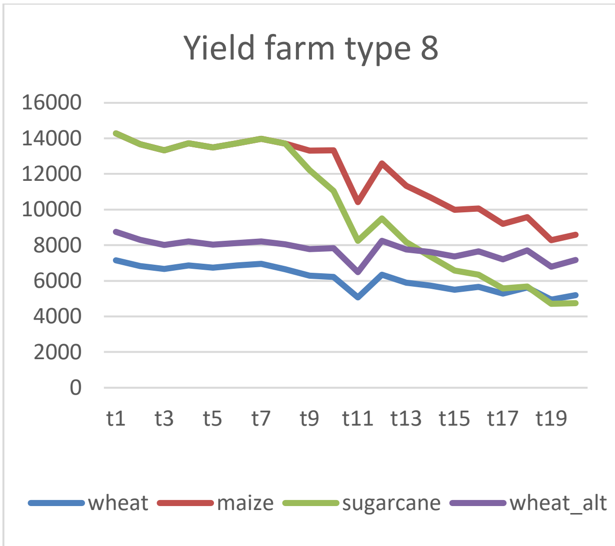
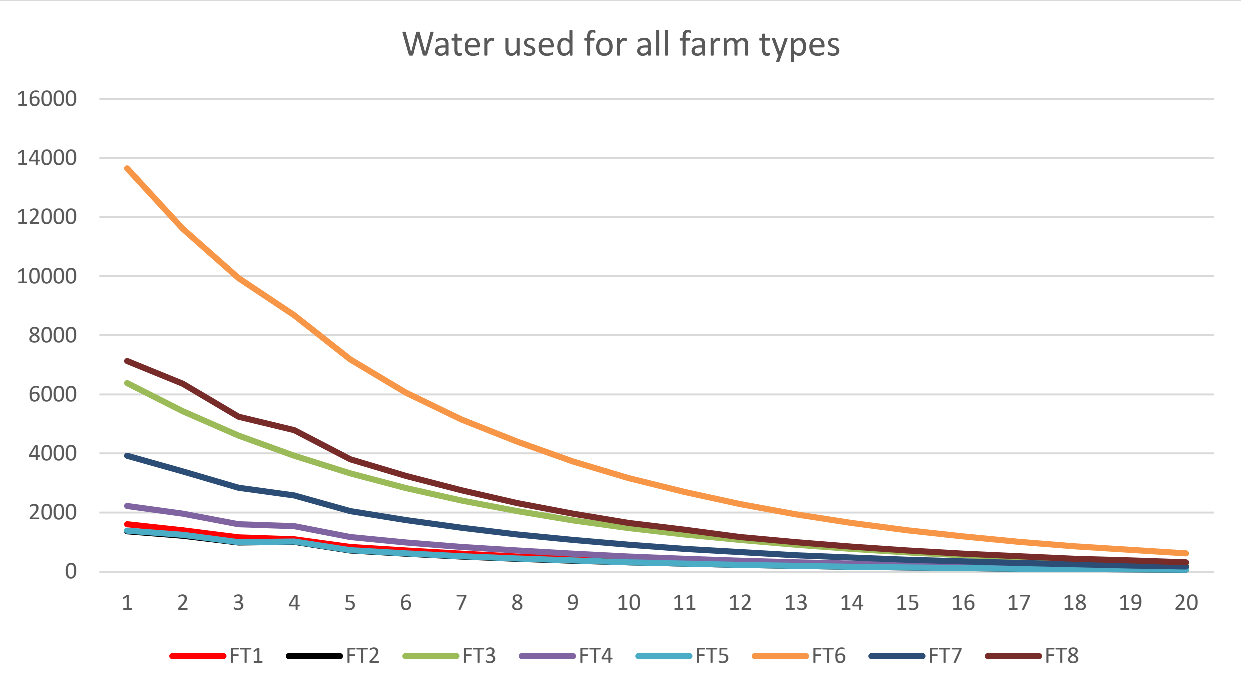


Figure 36: Yield in kg/ha type 8



In terms of production, the new varieties generate income but are not the most profitable for the farmer. If we look at their trend, we can see that they are more stable and resistant than other crops, but in the long run, alternative wheat will produce more than wheat and sugarcane, but not maize. According to the graph, sugarcane is a crop that is extremely vulnerable to a lack of rain and high temperatures, as there is a drastic decrease in production from a high level. The same applies for maize, but it is more productive than the new variety. Alternative wheat provides more stability in production but not the highest level of output, so we cannot push farmers to adopt these varieties.

Figure 37: Water used for all farm types



Water is used by all farmers to irrigate their crops. The graph above shows that farm type 6 uses more water than the others in the first year of the simulation, as do farms of type 8 and 3, because they cultivate a large amount of sugarcane, a crop that requires a lot of water. Long term, we observed an exponential decrease in the level of irrigation for all types of farms, bringing irrigation to tens or hundreds of cubic meters in the simulation's final year. This reduction arises from a lower level of production in the future as a result of climate change, which means that farmers will not require more irrigation in the future because production will not be able to meet society's food needs.

Figure 38: Water used per crop type 1

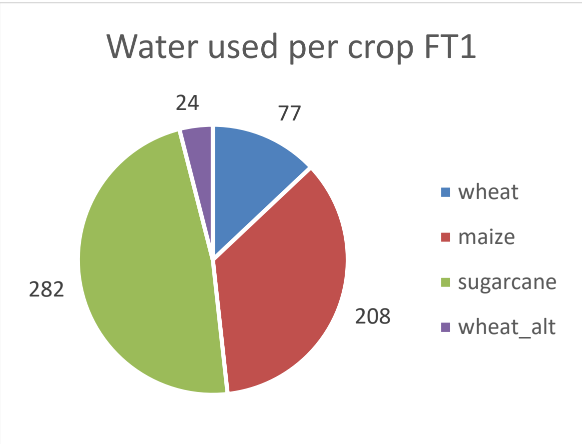
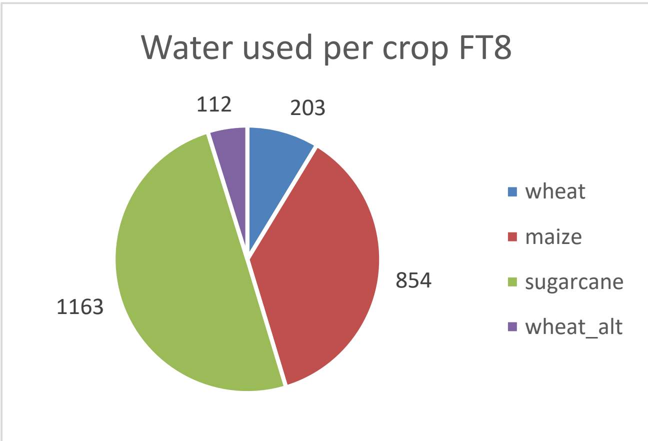


Figure 39: Water used per crop type 8



Because farm type 8 produces a large amount of sugarcane, it is normal for it to use more water than the other farm types. According to the graphs above, after sugarcane maize is the crop that requires more water, followed by wheat. The new introduced crop, alternative wheat, even though it occupies the majority of the farm sizes, still seeks less water for production.

Table 9: Constraints 5

Farm type	**Constraints**	**Level**	**Upper value**	**Marginal value**
Farm type 1	Land	0.13	0.13	2920
	Labor	2.88	2.88	0.42

	Irrigation	15262	62054	-
Farm type 8	Land	0.61	0.61	2002
	Labor	2.94	2.94	1.67
	Irrigation	12877	62054	-

This table shows the amount of land, labor, and irrigation used by farmers of farm types 1 and 8. Land and labor are both limiting factors for both farm types. If both farmers added one more unit of these constraints, their profit would increase. When we compare farm types 1 and 8, we see that land is more of a limiting factor for farm type 1 than for farm type 8 because its profitability is higher, 2920 euros. Labor is still a constraint, but it is not as significant as land. While irrigation, as it was in the baseline, is still available, farmers are not using it to its full potential.

Figure 40: Irrigation and yield type 1

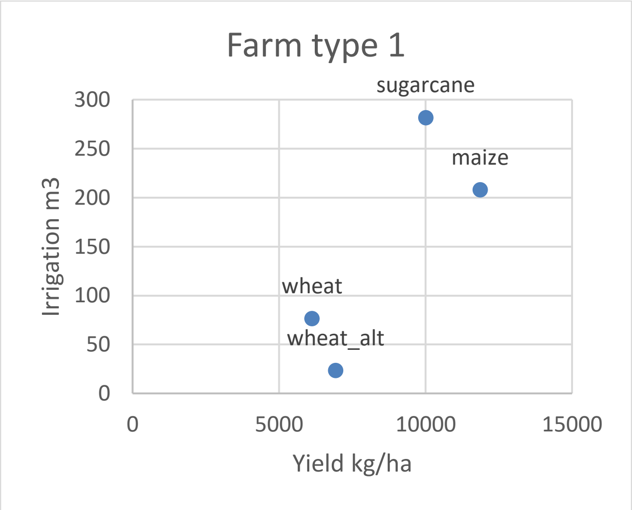
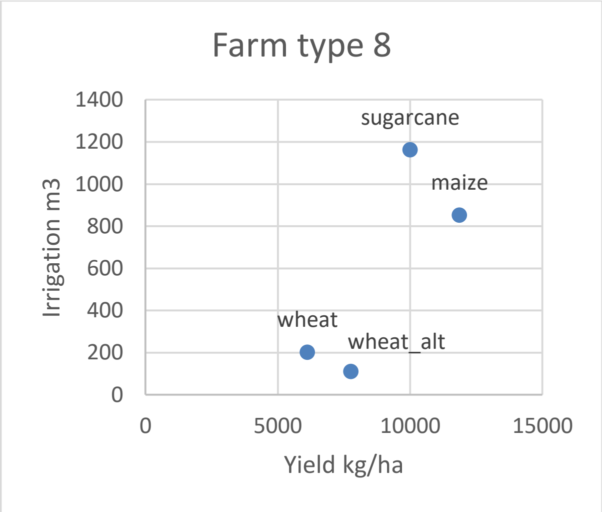


Figure 41: Irrigation and yield type 8



This graph indicates the amount of irrigation in m3 on the y-axis and the amount of production in kg/ha on the x-axis for each crop cultivated by farmers. Maize and sugarcane are more productive for both farm types, but they require more water than the other crops. Alternative wheat is a crop that requires little to no irrigation, but its yield is low in comparison to the previous two crops. As a result, farmers should avoid cultivating this crop due to its low level of production.

Figure 42: Labor and yield type 1

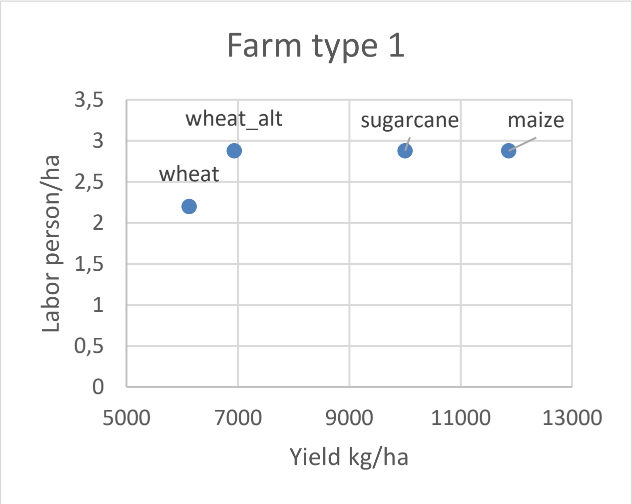
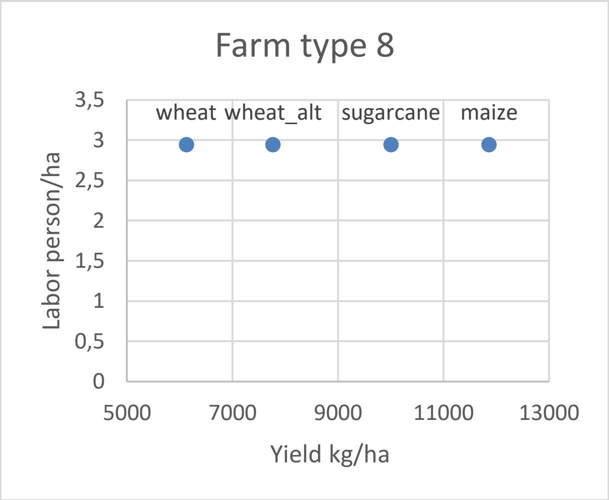


Figure 43: Labor and yield type 8



This graph demonstrates the amount of labor used by each crop as well as the level of production. Farmers of farm type 1 have less available labor than farmers of farm type 8 because their land is smaller and they cultivate less wheat compared to the other farm. According to the graphs, all crops use the total labor availability, which is 2.88 persons per ha for each crop, while wheat of type 1 uses only 2.2 persons per ha.

Part IV

Conclusions and discussions

We used a dynamic bio-economic model to assess the impact of climate change on agricultural production, specifically rainfall and high temperatures. After making some simulations, we found out that farmers were utilizing all of their available land and labor. Furthermore, it was discovered that a decrease in precipitation level will reduce future production, and that an increase in temperature of only 2 degrees Celsius will reduce wheat yields by 7% and the rest of the crops by 11%. After running the scenario of new heat resistant varieties, we discovered that the model was not always selecting these alternative crops. These new crops helped farmers increase their revenues, but they didn't increase the level of production. In economic terms, they appeared to be as profitable as the other crops, but they were not increasing the production itself.

A large amount of data was required for this bioeconomic model to be as complete as possible. One of the major challenges we encountered while developing this model was that we took a database from previously collected surveys and had to clean and correct it. We faced many problems, and in order to overcome them, we made some assumptions, one of which was that all farmers were homogeneous, so we took the average of farmers of the same farm type and ignored the small differences between them in our calculations. In the end is reasonable to expect results that don't accurately reflect the reality, for example we obtained high yields, but this is something that won't change future trends. As a result, we can conclude that the fact that we didn't work on specific data for each farm type will have little impact on the final analyse.

Another significant limitation that must be mentioned is that we didn't account for livestock, which means that the level of total production and income for each farmer are not exactly what we could get in reality, because farmers can sell the products of the animals and increase their revenues. This is expected to have a minor impact particularly on small farms, because large farms already have very high revenues in comparison to others, and even if we add livestock, they will remain wealthy. It would be interesting to see in future studies the inclusion of livestock in the model and compare the outcomes.

To summarize, these types of issues can arise in any study that involves data collection and analysis, but as long as the results of the bioeconomic model represent the trends of reality, they can be used for future studies or to test policies, because a percentage of error is always to be expected because the model isn't the reality itself.

One of the principal advantages of the model we used is that it tests all possible types of farms in the Luxor area of Egypt. So, it takes into account various farm characteristics and specifically tests what you want to get as an answer, which in our case was the farmer's level of production and income. Through preliminary testing, it is possible to determine whether or not an intervention will be effective. It also creates a model representation that roughly describes the situation in reality.

Given the importance of climate change in the Mediterranean region, any small change will have a significant impact on production and farmers' attitudes toward the practices they will adopt. Many solutions have been proposed, and some have been theoretically tested using various models to forecast future production under specific climatic conditions. As we can see from the above results, since the rainfall is almost non-existent and there is no variability, the effect of rainfall on production had no significant impact in Luxor area. Also, because the Mediterranean region has similar climatic conditions, the impact is expected to be similar, especially in areas of Egypt that are not affected by rainfall. Another test we conducted was related to Egypt's high temperatures, and we discovered that an excessive increase in temperatures would result in a drastic decrease in production for many crops in the Luxor area. High temperatures in such arid, desert, and rainless areas only reduce output, not only in Egypt but throughout the Mediterranean region.

The other hypotheses tested in our models was the effectiveness of using heat-resistant varieties. Based on our findings, these new crops aren't very profitable, either economically or in terms of production. Despite occupying a considerable portion of the land, they don't give a high yield. As a result, farmers are unable to adapt new alternative varieties that require less water and are heat resistant. The issue is that these crops will provide more sustainable production in the future than what Egypt is currently planting. Farmers, on the other hand, want a high level of income, which comes from production, and they will usually choose the crop that gives them the most profit at the time. No farmer considers the long term, especially in developing countries like Egypt, where poverty is prevalent and agriculture is seen as the only means of providing food for survival as well as income from sales.

Bibliography

BIBLIOGRAPHY

Abou-Ali H., Kheir-El-Din H. (2010). *Economic efficiency of crop production in Egypt.* Cairo (Egypt): Egyptian Center for Economic Studies. 28 p. (Working paper, n. 155). https://www.eces.org.eg/cms/NewsUploads/Pdf/2019_1_14-0_0_4831.pdf

Abu-Zeid M.A., El-Shibini F.Z. (1997). Egypt's High Aswan Dam. *International Journal of Water Resources Development*, vol. 13, n. 2, p. 209–218. https://doi.org/10.1080/07900629749836

Ahmed A.A., Fogg G.E., Gameh M.A. (2014). Water use at Luxor, Egypt: consumption analysis and future demand forecasting. *Environmental Earth Sciences*, vol. 72, n. 4, p. 1041–1053. https://doi.org/10.1007/s12665-013-3021-8

Belhouchette H., Blanco M., Wery J., Flichman G. (2012). Sustainability of irrigated farming systems in a Tunisian region: a recursive stochastic programming analysis. *Computers and Electronics in Agriculture*, vol. 86, p. 100–110. https://dx.doi.org/10.1016/j.compag.2012.02.016

Berge H.F.M. ten, Ittersum M.K. van, Rossing W.A.H., Ven G.W.J. van de, Schans J. (2000). Farming options for The Netherlands explored by multi-objective modelling. *European Journal of Agronomy*, vol. 13, n. 2, p. 263–277. https://doi.org/10.1016/S1161-0301(00)00078-2

Bergh J. van den, Barendregt A., Gilbert A., Herwijnen M. van, Horssen P. van, Kandelaars P., Lorenz C. (2001). Spatial economic–hydroecological modelling and evaluation of land use impacts in the Vecht Wetlands area. *Environmental Modeling & Assessment*, vol. 6, n. 2, p. 87–100. https://doi.org/10.1023/A:1011591306323

Bertsimas D., Brown D.B., Caramanis C. (2011). Theory and applications of robust optimization. *SIAM Review*, vol. 53, n .3, p. 464–501. https://epubs.siam.org/doi/10.1137/080734510

Bouman B.A.M., Jansen H.G.P., Schipper R.A., Nieuwenhuyse A., Hengsdijk H., Bouma J. (1999). A framework for integrated biophysical and economic land use analysis at different scales. *Agriculture, Ecosystems & Environment*, vol. 75, n. 1-2, p. 55–73. https://doi.org/10.1016/S0167-8809(99)00059-6

Brouwer F.M., Ittersum M.K. (2010). *Environmental and agricultural modelling. Integrated approaches for policy impact assessment.* Dordrecht (The Netherlands): Springer Dordrecht. 322 p. https://doi.org/10.1007/978-90-481-3619-3

Castro L.M., Härtl F., Ochoa S., Calvas B., Izquierdo L., Knoke T. (2018). Integrated bio-economic models as tools to support land-use decision making: a review of potential and limitations. *Journal of Bioeconomics*, vol. 20, n. 2, p. 183–211. https://doi.org/10.1007/s10818-018-9270-6

Dasgupta S., Laplante B., Meisner C., Wheeler D., Yan J. (2009). The impact of sea level rise on developing countries: a comparative analysis. *Climatic Change*, vol. 93, n. 3–4, p. 379–388. https://doi.org/10.1007/s10584-008-9499-5

Delmotte S., Lopez-Ridaura S., Barbier J.-M., Wery J. (2013). Prospective and participatory integrated assessment of agricultural systems from farm to regional scales: comparison of three modeling approaches. *Journal of Environmental Management*, vol. 129, p. 493–502. https://doi.org/10.1016/j.jenvman.2013.08.001

Deybe D. (1998). Can agricultural sector models be a tool for policy analysis? An application for the case of Burkina Faso. *Agricultural Systems*, vol. 58, n. 3, p. 367–380. https://doi.org/10.1016/S0308-521X(98)00036-5

Dimov D., Kuhn J., Conrad C. (2016). Assessment of cropping system diversity in the Fergana Valley through image fusion of Landsat 8 and Sentinel 1. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. III–7, p. 173–180. https://doi.org/10.5194/isprsannals-III-7-173-2016

Eid H.M, El-Marsafawy S.M., Ouda S.A. (2007). *Assessing the economic impacts of climate change on agriculture in Egypt: a Ricardian approach*. Washington D.C. (USA): The World Bank. 39 p. (Policy Research Working Papers). http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-4293

El Bahrawy A. (2011). *Egypt's national strategy for adaptation to climate change and disaster risk reduction.* Cairo (Egypt): Egypt's Cabinet Information and Decision Support Centre (IDSC). 167 p. http://www.climasouth.eu/docs/Adaptation011%20StrategyEgypt.pdf

El Raey M. (2010). *Impact of sea level rise on the Arab Region. New York (USA): Regional Bureau* for *Arab States*. 89 p. https://www.researchgate.net/publication/266454174_Impact_of_Sea_Level_Rise_on_the_Arab_Region

Elshinnawy I.A., Almaliki A.H. (2021). Vulnerability assessment for sea level rise impacts on coastal systems of Gamasa Ras el Bar area, Nile Delta, Egypt. *Sustainability*, vol. 13, n. 7, p. 3624. https://doi.org/10.3390/su13073624

FAO. (2012). *Coping with water scarcity: an action framework for agriculture and food security*. Rome (Italy): Food and Agriculture Organization of the United Nations. 100 p. (FAO water reports, n. 38). https://www.fao.org/3/i3015e/i3015e.pdf

Frihy O.E., El-Sayed M.Kh. (2013). Vulnerability risk assessment and adaptation to climate change induced sea level rise along the Mediterranean coast of Egypt. *Mitigation and Adaptation Strategies for Global Change*, vol. 18, n. 8, p. 1215–1237. https://doi.org/10.1007/s11027-012-9418-y

Gad W.A. (2017). Water scarcity in Egypt: causes and consequences. *IIOABJ*, 2017, vol. 8, n. 4, p. 40-47. https://www.iioab.org/IIOABJ_8.4_40-47.pdf

Gouda D.M. (2020). Climate change, agriculture and rural communities' vulnerability in the Nile Delta. In: Ewis Omran E.-S., Negm A.M. (eds.). *Climate change impacts on agriculture and food security in Egypt: land and water resources—smart farming—livestock, fishery, and aquaculture*. Cham (Switzerland): Springer International Publishing. p. 525–576. (Springer Water). https://doi.org/10.1007/978-3-030-41629-4_22

Hazell P.B.R., Norton R.D. (1986). *Mathematical programming for economic analysis in agriculture*. New York (USA): Macmillan Publishing Company. 400 p.

Hesham Y., Khalil A. (2015). *Atlas for drought monitoring over Egypt*. Giza (Egypt): Central Laboratory for Agricultural Climate (CLAC). 246 p. https://www.academia.edu/17344925/atlas_for_drought_monitoring_over_egypt

Hoekstra A.Y., Chapagain A.K. (2007). Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management*, vol. 21, p. 35–48. https://doi.org/10.1007/s11269-006-9039-x

IPCC. (2014). *Climate change 2014. Impacts, adaptation and vulnerability. Part A. Part B.* Cambridge (United Kingdom): Cambridge University Press. 1132 p. https://www.ipcc.ch/report/ar5/wg2/

Janssen S., Ittersum M.K. van. (2007). Assessing farm innovations and responses to policies: a review of bio-economic farm models. *Agricultural Systems*, vol. 94, n. 3, p. 622–636. https://doi.org/10.1016/j.agsy.2007.03.001

Jat M.L., Chandna P., Gupta R., Sharma S.K., Gill M.A. (2006). *Laser land leveling: the precursor technology for resource conservation in irrigated eco-system of India.* New Delhi (India): ICAR. 48 p. Rice-Wheat Consortium for the Indo-Gangetic Plains, 2006, New Delhi (India). https://www.researchgate.net/publication/307587973_Laser_land_leveling_The_precursor_technology_for_resource_conservation_in_irrigated_eco-system_of_India

Kamel A.S., El-Masry M.A., Khalil H.E. (2010). Productive sustainable rice-based rotations in saline-sodic soils in Egypt. *Egyptian Journal of Agronomy*, 2010, vol. 32, n. 1, p. 73–88.

Karrou M., Oweis T., Abou El Enein R., Sherif M. (2012). Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt. *African Journal of Agricultural Research*, vol. 7, n. 11, p. 1755-1760.

Khan N.A., Qiao J., Abid M., Gao Q. (2021). Understanding farm-level cognition of and autonomous adaptation to climate variability and associated factors: evidence from the rice-growing zone of Pakistan. *Land Use Policy*, vol. 105, p. 105427. https://doi.org/10.1016/j.landusepol.2021.105427

Knowler D. (2002). A review of selected bioeconomic models with environmental influences in fisheries. *Journal of Bioeconomics*, vol. 4, n. 2, p. 163–181. https://doi.org/10.1023/A:1021151809501

Kopke E., Young J., Kingwell R. (2008). The relative profitability and environmental impacts of different sheep systems in a mediterranean environment. *Agricultural Systems*, vol. 96, n. 1-3, p. 85–94. https://doi.org/10.1016/j.agsy.2007.06.003

Kragt M.E., Robertson M.J. (2012). *Modelling trade-offs between ecosystem services and agricultural production in Western Australia*. In: Seppelt R., Voinov A.A., Lange S., Bankamp D. (eds.). *Managing Resources of a Limited Planet, Sixth Biennial Meeting.* Leipzig (Germany): International Environmental Modelling and Software Society (iEMSs). p. 9. International Congress on Environmental Modelling and Software, 2012, Leipzig (Germany). https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.689.4740&rep=rep1&type=pdf

Kruseman G., Bade J. (1998). Agrarian policies for sustainable land use: bio-economic modelling to assess the effectiveness of policy instruments. *Agricultural Systems*, vol. 58, n. 3, p. 465–481. https://doi.org/10.1016/S0308-521X(98)00041-9

McCarl B.A., Musumba M., Smith J.B., Kirshen P., Jones R., El-Ganzori A., Ali M.A., Kotb M., El-Shinnawy I., El-Agizy M., Bayoumi M., Hynninen R. (2015). Climate change vulnerability and adaptation strategies in Egypt's agricultural sector. *Mitigation and Adaptation Strategies for Global Change*, vol. 20, n. 7, p. 1097–1109. https://doi.org/10.1007/s11027-013-9520-9

Molden D.J., El Kady M., Zhu Z. (1998). Use and productivity of Egypt's Nile water. In: Burns J.I., Anderson S.S. (dirs.). *Contemporary challenges for irrigation and drainage: proceedings from the Uscid 14Th technical conference on irrigation, drainage and flood control.* Phoenix (Arizona): USCID. p. 99-116. The USCID 14th Technical Conference on Irrigation, Drainage and Flood Control, 1998/06/3-6, Phoenix (Arizona). https://mountainscholar.org/bitstream/handle/10217/210814/109_1998-USCID-Phoenix_Molden.pdf?sequence=1

Omar A.R., Nawar M.H., El Bendary A.T., Abou Bakr H.E. (2015). Farmers' perception of climate change in rural Damietta governorate. *Bulletin of Faculty of Agriculture, Cairo University,* 02/01/2015, vol. 66, n. 1, p. 1–9. https://dx.doi.org/10.21608/ejarc.2015.213106

Omar A.R.A. (2021). *Egyptian agriculture in transition: farmer perceptions of risks and adaptation opportunities in a changing climate*. Thesis (PHD) in Philosophy: The University of Adelaide, Adelaide (Australia). 323 p. https://digital.library.adelaide.edu.au/dspace/bitstream/2440/133732/1/Omar2021_PhD.pdf

Ouda S.A.H., Zohry A.E.-H. (2016). Introduction. In: Ouda S.A.H., Zohry A.E.-H. (eds.). *Management of climate induced drought and water scarcity in Egypt: unconventional solutions*. Cham (Switzerland): Springer International Publishing. p. 1–4. (SpringerBriefs in Environmental Science). https://doi.org/10.1007/978-3-319-33660-2_1

Rosenzweig C., Hillel D. (1994). *Egyptian agriculture in the 21st century.* Laxenburg (Austria): International Institute for Applied Systems Analysis. 33 p.

Sheha A.M., Ahmed N.R., Abou-Elela A.-A.M. (2014). Effect of crop sequence and nitrogen levels on rice productivity. *Annals of Agricultural Science, Moshtohor*, vol. 52, n. 4, p. 451–460. https://doi.org/10.21608/ASSJM.2014.111894

Swain A. (2011). Challenges for water sharing in the Nile basin: changing geo-politics and changing climate. *Hydrological Sciences Journal*, 2011, vol. 56, n. 4, p. 687–702. https://doi.org/10.1080/02626667.2011.577037

Tellioglu I., Konandreas P. (2017). *Agricultural policies, trade and sustainable development in Egypt*. Geneva (Switzerland): ICTSD. 60 p. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/899518/

Verner D. (2012). *Adaptation to a changing climate in the Arab countries: a case for adaptation governance and leadership in building climate resilience*. Washington D.C. (USA): The World Bank. 442 p. (Mena Development Report).

Waha K., Krummenauer L., Adams S., Aich V., Baarsch F., Coumou D., Fader M., Hoff H., Jobbins G., Marcus R., Mengel M., Otto I.M., Perrette M., Rocha M., Robinson A., Schleussner C.-F. (2017). Climate change impacts in the Middle East and Northern Africa (MENA) region and their implications for vulnerable population groups. *Regional Environmental Change*, 08/2017, vol. 17, n. 6, p. 1623–1638. https://doi.org/10.1007/s10113-017-1144-2

Weersink A., Jeffrey S., Pannell D. (2002). Farm-level modeling for bigger issues. *Review of Agricultural Economics*, vol. 24, n. 1, p. 123-140. https://www.jstor.org/stable/1349824

Zohry A.E.H., Ouda S.A.H. (2016). Upper Egypt: management of high-water consumption crops by intensification. in: Ouda S.A.H., Zohry A.E.-H. (eds.). *Management of climate induced drought and water scarcity in Egypt: unconventional solutions*. Cham (Switzerland): Springer International Publishing. p. 63–76. (SpringerBriefs in Environmental Science). https://doi.org/10.1007/978-3-319-33660-2_5

WEBOGRAPHY

Adaptation fund. *Building resilient food security systems to benefit the Southern Egypt Region.* [Consulted in 2022-07-08]. https://www.adaptation-fund.org/project/building-resilient-food-security-systems-to-benefit-the-southern-egypt-region/.

Britannica. *Nile River.* [Consulted in 2022-09-11]. https://www.britannica.com/place/Nile-River.

FAO. *Aquastat*. [Consulted in 2022-09-14]. https://www.fao.org/aquastat/statistics/query/results.html.

FAO. *Sprinkler irrigation*. [Consulted in 2022-09-11]. https://www.fao.org/3/s8684e/s8684e06.htm.

Flichman G., Allen T. (2013). *Bio-economic modeling: state-of-the-art and key priorities.* Biosight – IFPRI. [Consulted in 2022-08-04]. https://www.ifpri.org/publication/bio-economic-modeling-state-art-and-key-priorities.

ICARDA. (2013). *Water and Agriculture in Egypt*. [Consulted in 2022-06-18]. https://www.icarda.org/publications/6486/water-and-agriculture-egypt.

Knoema. *Egypte – Rapport de dépendance.* [Consulted in 2022-09-11]. https://knoema.fr//atlas/Égypte/Rapport-de-dépendance.

Power L. (2014). *Death on the Nile: Egypt's burgeoning food and water security crisis*. Dalkeith (Austalia) : Future Directions International. [Consulted in 2022-07-25]. https://silo.tips/download/death-on-the-nile-egypt-s-burgeoning-food-and-water-security-crisis.

Tyson P.J. (2014). *Sunshine guide to Luxor and the Valley of the Kings, Egypt*. [Consulted in 2022-09-11]. https://www.climates.com/AFRICA/egypt.htm.

USAID. (2022). *Agriculture and Food Security.* [Consulted in 2022-09-12]. https://www.usaid.gov/egypt/agriculture-and-food-security.

World Bank. *World Bank Climate Change Knowledge Portal*. [Consulted in 2022-09-14]. https://climateknowledgeportal.worldbank.org/.

Worldometer. *Egypt Water*. [Consulted in 2022-09-14]. https://www.worldometers.info/water/egypt-water/.