Overview of the Greek Biofuel Potential of Surplus Agricultural Biomass from Economic, Social, Environmental and Technical Perspective

2015

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Part of this work has been presented in Hellenic Open Business Administration International Conference (HOBA) 2015, (13/3, Patras Greece). The relevant paper, authored by A. Papavangeli, C.G. Siontorou and D. Sidiras, is included in HOBA Conference Proceedings, ISBN: 978-960-538-950-5.

Contents

ABSTRACT

Biomass is a renewable and cheap resource for biofuel production. Yet, the viability and feasibility of biofuel production from agricultural biomass depends upon its availability at a competitive cost. The present study investigates the Greek biomass potential for bioethanol and biodiesel production, as well as the energy potential of agricultural residues using a GIS-based management application built on a relational database system. The computations were based on geographical and time-depending data provided by the National Statistical Service of Greece, while the digital maps of land cover overlaid provides by Marathon Data Systems. Typical input data included cultivation areas sorted by geographical region, agricultural production of the crops, by-product factors, availability factors, and energy factors, for the period 2000-2010. The output included the productivity of the main crops in the corresponding areas, as well as their by-products and available energy. The study concludes with a discussion on the significance and the challenges of biomass supply, including brief descriptions about economical, social, environmental and technical aspects of biofuel production.

KEYWORDS: biomass, biodiesel, bioethanol, agricultural residues, GIS, Greek potential, perspectives.

Introduction

People make use of energy in various ways aiming to improve their living standards. The global energy demand is increasing as a result of the increased consumption due to overpopulation. According to the International Energy Outlook 2010 (EIA U.S. Energy Information Administration 2010) a growth in the global energy consumption of 49% from 2007 to 2035 is expected in the foreseeable future (Firrisa et al., 2013). Fossil fuels are the primary source of energy that drives the world economy. However, the supply of fossil fuels is increasingly unable to meet the growth in demands for several reasons. Year after year, reserves of fossil fuels are reduced and their extraction is becoming increasingly expensive and risky. Moreover, they constitute the main source of the already hazardous emission levels of greenhouse gases and consequently they have great contribution to climate change.

Alternative sources of energy, solar, wind, hydro-power, are most promising in terms of environmental impacts, energy security and socioeconomic externalities (Bomb et al. 2007; Cherubini et al. 2009; European Biodiesel Board 2011; Mc Alister and Horne 2009; Nanaki and Koroneos 2009). Another important source of alternative energy is bioenergy, where energy derives from plants and used directly for electricity generation, heating, but most importantly for the production of liquid biofuels. According to Cherubini et al. (2009), 10% of the global primary energy supply comes from bioenergy which is mainly used for domestic purposes.

Given the strong concerns regarding the use of fossil fuels, as well as problems related to their supply the use of alternative energy sources is growing. The energy demands of the transportation sector account for 37.1% of total global needs and rely mostly on fossil fuels (Van Hoesen and Letendre, 2010). Consequently, the perspective of direct substitution of fossil fuels with biofuels in the existing transport infrastructure makes biofuels particularly attractive and thus in many cases their production is supported by the government with economical subsidies.

On the other hand, due to the fact that biofuels are mainly produced by crops such as maize, wheat, barley, sugarcane, potato, sunflower, rapeseed, oil palm, soybean and sugar beet, which constitute crops that are also used for consumption as food, a major concern has been created. Inevitably, in view of this fact the food prices are increasing and the increased interest in the production of biofuels due to subsidies and growing demand is indirectly affect the land use and biodiversity. The chemical compounds produced from the abovementioned crops are biodiesel, bioethanol, methane and methanol, while they constitute the main alternative to liquid fossil fuels. According to Baka and Roland-Holst (2009), the European Union held the first place in the production of biodiesel in 2005, while in 2007 held 60% of the world's biodiesel production. Therefore it is apparent that biodiesel is the most common type of biofuel used in the transport sector in Europe, unlike America where greater emphasis is given to ethanol.

Recently has been adopted by the European Union a Directive describing the objectives relating to the use of biofuels in the transport sector. In more detail, Directive 2003/30/EC on the use of biomass-derived and other renewable fuels, supports their gradual penetration scheme in the EU market (Sidiras, 2014) to counteract EU's imported energy demands and to promote climate change mitigation policies. Despite the intense efforts and the political willingness to align to a common EU certification system, the technical standardization of biofuels, on the basis of their highly variable, between- and within-country, biomass resources, is not an easy task. Reformulated gasoline with bioethanol (5% v/v, waterless, according to EN 228:2004) is highly corrosive, inhomogeneous and incompatible with conventional engines (Baena et al., 2012); in order to be used, it should be transformed into the more compatible (Baena et al., 2012) but less environmental-friendly (Yee et al., 2013) ethyl tertiary butyl ether (ETBE), at mixtures up to 15% (v/v) with gasoline. Conversely, the implementation of biodiesel is quite straightforward on the current diesel infrastructure for mixtures up to 5% (v/v), according to EN 590:2004, or even larger (Boukis et al., 2009).

Domestically speaking, Greece has enforced Directive 2003/30/EC with Act 3423/2005, enabling the production, import and trading of biofuels, struggling towards a 10% substitution target in fuels by 2020 (EREC, 2010). In the midst of the economic crisis and the bunch of constraints imposed by EU policy in agriculture and energy, Greece seems reluctant to comply, especially with the lack of a long-term national energy strategy (Eleftheriadis and Anagnostopoulou, 2015; Smyth et al., 2010). Currently, Greece hosts fourteen biodiesel producing units (Sidiras, 2014) and six importers (according to government gazette 1452/2013); 70% of the resources utilized are imported oils (rapeseed, soybeans) and only 30% correspond to domestically produced cotton-seed, sunflower and used cooking oils (Eleftheriadis and Anagnostopoulou, 2015). After a decade of European Directive implementation, bioethanol plants are yet to be installed; this fact along with the existing legislation implies that the construction of such units could be crucial. The Greek Sugar Company had expressed its interest to convert two of its existing sugar factories in Larissa (continental district) and Ksanthi (northern district) to bioethanol production units with an annual capacity of 0.1 Mt each, on beet, grain and corn crops feedstock, which are quite common and easily cultivated in Greece.

Even if, at present, economic activities like manufacturing, construction, trade and tourism are very strong, the rural production remains one of the major sectors of the Greek economy (Nannos et al., 2013). That ensures the availability of high amounts of agricultural residues that could be utilized as feedstock in biofuel production, although the economical costs associated with this resource might become an important drawback. The integration of residual biomass in the energy planning of a region requires the development of advanced tools that allow for cost assessment and optimization as per localization, valorization and storage issues.

The dispersed spatial distribution of biomass and the strong seasonality of its availability necessitate the use of geographical information system (GIS) tools for assessing supply, physicochemical characteristics and transportation costs. Voivontas et al. (2001) developed a GIS decision support system to estimate the potential for power production from agriculture residues in Crete (Greece). Recently, Fernandes and Costa (2010) used GIS tools for the evaluation of the economically exploitable forest biomass resources in Portuguese regions, while Sidiras (2014) used GIS to map the Greek biodiesel productivity changes occurred within a 13-year period and fit biodiesel market penetration to an S-shaped forecasting model.

GIS tools have proved indispensable for determining the geographical context of a wide range of bioenergy aspects, such as energy demand and biomass supplies (Fernandes and Costa, 2010; Sidiras, 2014). This environment allows for efficient data storage, readily retrievable, customizable, and easily displayed in a comprehensive form, while it facilitates modeling and analysis of systems that have a significant spatial and temporal component. Indeed, these modeling capabilities may become the backbone of any decisionmaking support scheme by highlighting, in qualitative and quantitative terms, the variation of the geographical factors that affect the supply and the cost of the biomass production (Voivontas et al., 2001).

This study reports on the development of a GIS-based management application, built on a relational database system, for the evaluation of the Greek biomass agricultural residues potential that could be used in the production of biofuels. The computations were based on geographical and time-depending data provided by the National Statistical Service of Greece. Typical input data included cultivation areas sorted by geographical region, agricultural production of the crops, by-product factors, availability factors, and energy factors, for the period 2000-2010. The output included the productivity of the main crops in the corresponding areas, as well as their by-products and available energy. Several conclusions have been drawn by this work; besides the estimation of annual feedstock availability and spatiotemporal variances, the study indicates that any assessment relying solely on mapping is not objectively justifiable unless combined with two more levels of analysis to determine the technological and economically exploitable biomass potential, while public acceptance and environmental impact aspects should be, also, taken into account.

1. Biomass Definition

According to Directive 2000/28/EC, *“ ‘biomass’ means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste”.*

A tremendous number of experts advocate that Biomass (plant material and animal waste) is the oldest source of renewable energy, used since our ancestors learned the secret of fire. However, few people are familiar with this form of renewable energy, which provides far more biopower than wind power and solar power combined.

In ancient times the energy needs of people (cooking, heating) covered exclusively by the energy use of biomass (wood, crop residues, etc.). In recent years the biomass (primarily wood) continued to have a dominant role in meeting the energy needs until the industrial revolution where its use was abandoned and replaced by coal. To this contributed the increasing demand that led to deficiencies of raw materials and price increase, as well as the new technologies that favor the use of carbon which had higher energy potential.

Sustainable, low carbon biomass has the potential to provide a great amount of biopower, which can reduce the emissions of gases like carbon dioxide to levels that according to scientist will avoid the worst impacts of global warming. Nevertheless, as with all energy sources, biopower also has environmental risks that need to be tempered. Some of the negative effects of biopower such as air pollution, huge water consumption, ecosystem damages etc can be avoided or reduced to minimal harm with the implementation of proper policy.

The production of biomass is based on the sunlight conversion that green plants do through photosynthesis. During this process, plants’ chlorophyll absorbs solar energy by converting the air’s carbon dioxide and the ground’s water into carbohydrates. When the carbohydrates are burned, they turn back to their first form and release their embodied captured energy. In other words, biomass resource can be considered as an organic matter, in which the sunlight energy is stored in chemical bonds. By the time the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion, combustion, or decomposition, these substances release their stored, chemical energy.

2. Advantages and Disadvantages of Biomass energy

In order to better comprehend the basic characteristics of biomass as a renewable energy source and whether or not it is a valuable solution to fossil fuel implications it is important to analyze the advantages and disadvantages of biomass.

2.1 Advantages

- Biomass is a completely renewable resource. Biomass energy is generated from organic material, plant or animal waste, which constitutes living sources that never run out.
- Waste products generated by human activity, such as paper and household garbage, organic waste in the form of dead trees, leaves, grass clipping and animal carcasses can be can be collected and used to produce biomass energy. As a result, this could have the effect of reducing the amount of waste generated and sent to landfills or placed on barges and sent out to sea.
- The combustion of biomass has a zero contribution to the greenhouse effect as the amounts of carbon dioxide released during the combustion of biomass bound again from plants. Additionally, biomass energy contributes to the reduction of sulfur dioxide emissions (which is responsible for acid rain) as it has minimal sulfur content.
- Since biomass is and indigenous energy resource, its exploitation for energy contributes significantly to diminish the dependence on imported fuels and improving the trade balance, as well as securing energy supply and saving of foreign exchange.
- The energy exploitation of biomass increases employment in rural regions with the use of alternative crops and the creation of alternative markets for traditional crops contributing to the socio-economic development of the region. Studies have demonstrated that the production of liquid biofuels has positive effects on employment both in agricultural and industrial areas.

2.2 Disadvantages

- The production of biomass energy is extremely expensive. Modern and improved biomass conversion technologies as well as the transportation and gathering of biomass materials require high equipment costs, compared to that of conventional fuels.
- Biomass energy is inefficient compared to fossil fuels. Ethanol, as a biodiesel is inefficient compared to gasoline, and usually needs to be mixed with gasoline. Additionally, ethanol may harm the combustion engines when used for a long time.
- Using animal and human waste to produce energy may contribute on the reduction of carbon dioxide emissions, but it increases methane gases, which are harmful to the Earth's ozone layer.
- The increased volume and high moisture content of biomass sources make the energy exploitation of biomass a hard task. The great dispersion and seasonal production of biomass hinder the continuous supply of raw material used by biomass energy production plants.

3. Types of Biomass

There are two types of biomass. First, the biomass produced from energy crops and second, the residual forms, while some aqueous biomass forms are also considered suitable for energy applications. The main forms of beneficial biomass are presented below.

- **Agricultural residues and waste**. Includes agricultural crop residues (stems, twigs, vine shoots. leaves straw, pruning, reeds, seaweed, etc.) and processing of agricultural products residues (cotton ginning residues, pomace wood, fruit core, etc), waste fruit. It is worth saying that certain fraction of crop residues should not be removed from the field in order to maintain cover against erosion and to recycle nutrients. However, some fraction of crop residues can be collected to produce renewable energy in a sustainable way.

- **Forest residues and waste.** Includes crop residues and residues from the cleaning of forests (rarefaction, logging) as well as forest wastes, wood wastes etc. After timber-harvesting operations a substantial amount of limbs and tops remain in the forest and can be collected for energy use. It is beyond a doubt that using these residues for biomass production, reduces impacts on wildlife and soils and is cheaper than making additional trips into the woods.

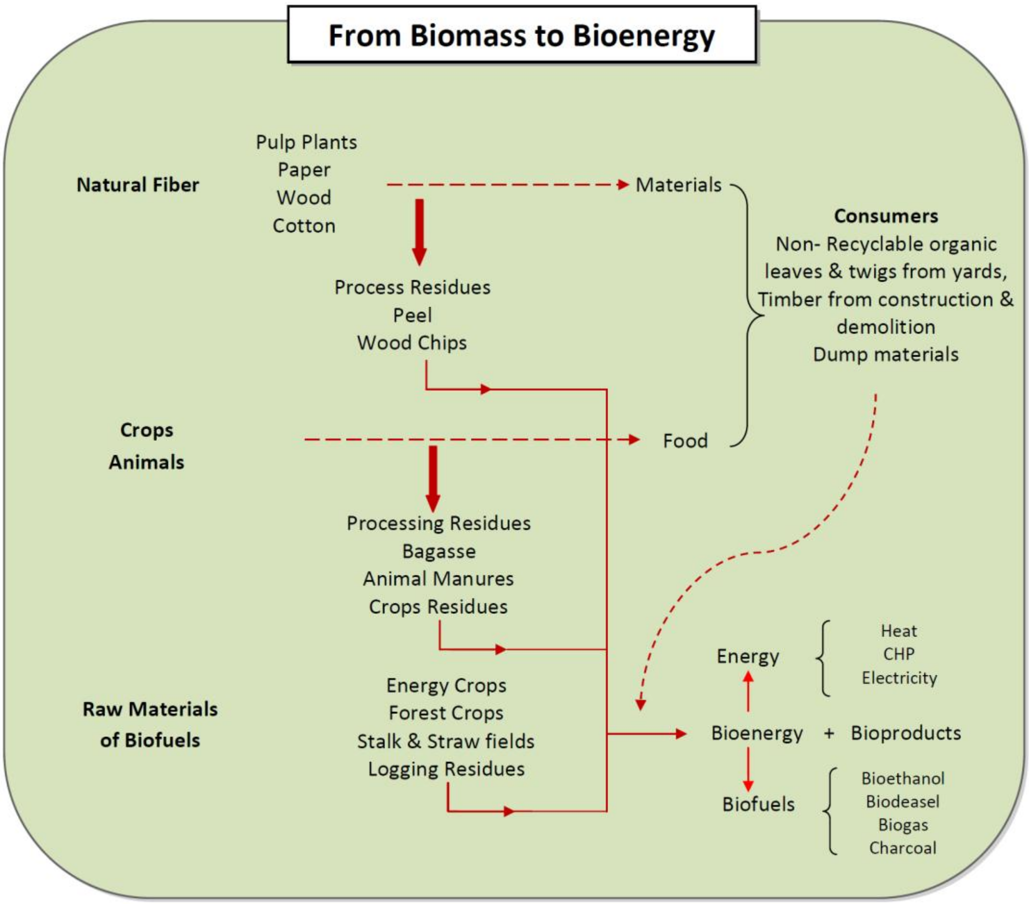


Figure 1. Biomass to Bioenergy conversion

- **Livestock farming waste.** Includes intensive livestock waste from cow houses, pig farms, poultry farms etc. (animal manure, straw beds, inappropriate - waste milk etc.), fish waste and waste etc. The manure which produced from livestock and poultry farms contains valuable nutrients. Hence, if managed properly, it can play a major role in management of solid fertility. Additionally, with processes such as combustion and gasification or through anaerobic digesters, it is feasible that some manure can be converted to renewable energy. The anaerobic digesters produce biogas which can be burned to generate biopower or can either directly displace propane or natural gas. For example, dairy farms that convert cow manure with methane digesters in order to produce biogas, they can use the generated biogas in three different or combined ways. Firstly, they can replace for the farm's natural gas or propane with the produced biogas. Secondly they can clean up the biogas pressurize and inject it into natural gas pipelines and thirdly, they can burn it and produce steam which will run through a turbine in order to generate renewable electricity. There are many aspects that need to be taken into account in order to decide which application is the most suitable and effective. Some of them are the type of manure that has been used for the production of biogas, the ability to displace natural gas or propane use, the local energy markets etc.

- **Other agro-industrial wastes and residues.** Includes byproducts and slaughterhouse waste, waste and residues from food industries such as dairy factories, oil factories, pomace factories etc.

- **Oily substances.** Includes neutralized vegetable oils and animal fats, waste and used vegetable oils (cooking oil, etc.), and residual waste animal fats, fatty acids etc.

- **Energy crops.** Includes plant crops that can lead to the production of liquid, gas and solid biofuels such as sunflower, soybean, rapeseed, sorghum, cardoon, corn, clover etc. Large quantities of energy crops can be grown on farms in ways that don't displace or reduce food production. Methods such as growing the plants on marginal lands or pastures or as double crops that fit into rotations with food crops have been proved very effective. In addition trees and grasses that are native to a region do not require big amounts of synthetic inputs and they do not disrupt the agro-ecosystems, at least not in a high level.

According to recent calculations carried out by OPEKEPE, the amount of energy crops in Greece is estimated at about 730,000 acres in 2010. Energy crops in Greece refer mainly to sunflower and rapeseed secondarily, while few land planted with soybeans.

- **Municipal and industrial waste.** Includes the organic fraction of municipal solid waste and municipal wastewater, as well as residual urban solid biomass (pruning etc.). Citizens generate many types of biomass wastes such as urban wood waste (tree trimmings, shipping pallets and clean, leftover construction wood), biodegradable garbage (non-recyclable paper, leftover food, yard waste, etc.). Apart from those mentioned above, methane can be produced from sewage treatment plants or extracted by landfills. Thereafter, the methane can be used for heating and power purpose, reducing the emissions of global warming gases and the air pollution in general.

The case of Greece

Greece produces about 4.6 million tons of municipal waste, which mainly include waste from residences, and a part of the solid waste generated by commercial activities. This number may be increased to 5.2 million by 2016. Over time, there is a trend towards significant increase in production of municipal waste, due to the growth of large urban centers. According to the last count, the average daily production of municipal waste per person in Greece, stood at 1,1 kg/ habitant, a figure much lower than the corresponding European average (1.48 kg / habitant).

Considering the establishment of municipal waste in the European Union, in Greece there is greater participation of organic waste (food waste, vegetable waste, etc.), but smaller quantities of packaging waste. The packaging materials constitute about 20% $^{w}/_{w}$ of the total waste generated. The special hazardous waste contained in discarded urban mainly include medicines, cleaning materials, paint, solvents, batteries and pesticides, which are either households or produced by various professional activities. The total amount of this waste is estimated at approximately 0.12% of the total. The amount that can be recycled or exploited is 8.2% biodegradable waste, 24% metal, 33% glass, 29.2% of paper and 5% of the plastics.

The only method applied in Greece until recently, was the soil waste disposal in unsupervised or semi-supervised disposal facilities. The situation has improved since the collection and transportation system has been organized, while the fist modern waste management projects has been built and operated.

4. Converting Biomass to Bioenergy

In ancient times, burning the biomass to produce heat was the most common way to capture its embodied energy. Years later the purpose of burning biomass was to produce steam power, and more recently the steam power has been used to generate electricity. The environmental advantaged of burning biomass in conventional boilers instead of burning fossil fuels are numerous. There are various methods for processing biomass. These may be liquid or dry, thermochemical, chemical, biological or mechanical methods consisting of various subcategories.

The main biomass processing methods are shown in the next figure:

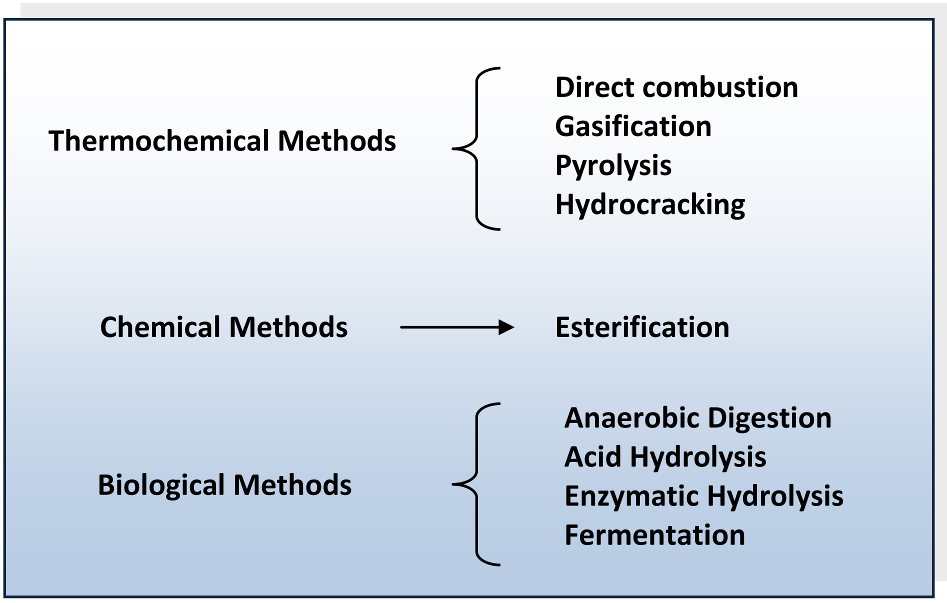


Figure 2. Biomass Processing Methods

4.1 Thermochemical Methods

4.1.1 Direct Combustion

Combustion is a process of converting chemical energy of biomass into heat. As indicated above, since the dawn of time the most widely used method for the conversion of biomass to electricity was by burning it in order to produce steam which would be used afterwards to move the turbine and produce electricity.

Wood is the raw material mainly used for combustion, as the efficiency of electricity exceeds 30% in small and medium scale heat plants. At the same time a decrease in emission (relative to conventional fuels) can be observed. To be more precise, a small scale of environmental pollution by sulfur dioxide (SO_2), concentrations of carbon monoxide (CO), nitrogen oxides (NOx) and unburned hydrocarbon gases, may occur. However, taking into account that a significant amount of energy is wasted, it is of outmost urgency to be controlled as it can cause some pollution.

The amount of heat produced by combustion depends on the content of biomass in water and the amount of air required for combustion. Usually, the required content of biomass in water is less than 15%. Nonetheless, new technologies target to the use of biomass with higher content in water.

4.1.2 Gasification

Gasification is an incomplete combustion of biomass in presence of a small amount or no oxygen, to produce a gas that is a mixture of carbon monoxide (CO) and hydrogen (H2), dissolved in nitrogen. The precise characteristics of this mixture of gases depend on the gasification parameters, such as temperature, and the oxidizer used for the process. Subsequently, in presence of catalysts the mixture intends to be converted into substitute natural gas or methanol or ammonia. Last but not least, the gas retrieved from the biomass can me burned with the gasification method and release chemical energy in the form of heat.

Gasification technology can be implemented for:

- Heating water in central heating, district heating or process heating applications
- Steam for electricity production or motive force
- As part of systems generating electricity or motive force
- Transport using a combustion engine.

4.1.3 Pyrolysis

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. The required pressure for the process of pyrolysis is slightly higher than

1atm, the temperature between 500° C and 700 ° C, while the content of biomass in water must be less than 40%. In addition, the energy efficiency of biomass with the method of pyrolysis reaches 90% and the main products of the process are bio-oil, biochar (at 450 ^{0}C) and gases such as methane, hydrogen, carbon monoxide, and carbon dioxide (at 800 ^{0}C).

There are two types of pyrolysis process which are slow pyrolysis and fast pyrolysis. The second is the most widely used type of pyrolysis considering that needs only seconds to complete and the products derive from the process as 60% bio- oil, 20% biochar and 20% syngas. On the other hand, the first needs several hours to complete and the products are mainly biochar.

The products of pyrolysis can be used for:

- Household use (space heating and water heating)
- Greenhouse Heating
- Drying of agricultural products
- Industrial applications (production of gaseous and liquid fuels).

4.1.4 Hydrocracking

Hydrocracking is a process of enriching biomass with hydrogen in order to produce fuel. The required temperature and pressure for the process is 250-500 ^{0}C and 150 atm respectively. However, this method is not widely applicable considering the high cost and the environmental impact that is accompanied with.

4.2 Chemical Methods

4.2.1 Esterification

Esterification is the process of the conversion of carboxylic acids to monoesters in the presence of an acid catalyst. Generally, esterification is the reaction of an acid with an alcohol in order to form an ester and water. The most suitable alcohols for this process are methanol, ethanol, propanol and butanol. Methanol is used more frequently because of low cost as well as physical and chemical advantages that has compared to the others. The parameters affecting the rate of esterification are the reaction temperature, the molar ratio of alcohol or free oily acids, the type and the amount of catalyst, the type of process, the agitation rate, and finally the composition and purity of the reaction mixture.

Firstly, the vegetable oils (sunflower, cottonseed, rapeseed, etc.) are obtained using a compression process and various separation technologies, while the rest of the seed material can then be used as animal's food.

The vegetable oils in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide) and ethyl or methyl, are converted to corresponding methyl or ethyl esters (biodiesel) that can be used as biofuel on machines. Biodiesel is currently the biofuel with the highest growth rate.

4.3 Biological Methods

4.3.1 Anaerobic Digestion

In this process, micro-organisms break down biomass to produce methane and carbon dioxide for energy generation (the required temperature is 20-45°C). Apart from methane and carbon dioxide, the produced biogas consists of water vapor and hydrogen sulfide which with the proper treatment can be removed.

It is worth be mentioned that in addition to producing biogas, this procedure protects from the escaping of methane to the atmosphere, preventing the emission increase of a powerful global warming gas.

The burning biogas can be used for heating or for modern production of thermal energy and electricity in internal combustion engines, with efficiency that can reach 85%. Burning biogas can also be used in vehicles with internal combustion engines.

4.2.2 Acidic/ Enzymatic Hydrolysis

The Hydrolysis is applied to biomass consisting mainly of cellulose and hemicelluloses in order to extract glucose which then will be fermented to produce ethanol. The difference between acidic and enzymatic hydrolysis is that the first is taking place in presence of acid and heat, while the second in presence of genetically modified enzymes.

During acidic hydrolysis, the concentrated acid of biomass disrupts the hydrogen bonding between cellulose chains, converting it to a completely amorphous state. Once the cellulose has been decrystallized, it forms a homogeneous gelatin with the acid. The cellulose is extremely susceptible to hydrolysis at this point. Thus, dilution with water at modest temperatures provides complete and rapid hydrolysis to glucose, with little degradation (Pandey, Larroche, Ricke, Dussap, Gnansounou, 2011).

However, both acidic and enzymatic hydrolysis are not yet economically attractive technologies, since only 45% of the energy content of the biomass is converted to alcohol (comparison, 85% of the crude oil is converted to gasoline).

4.2.3 Fermentation

Fermentation is an anaerobic process that breaks down the glucose contained in organic materials. It represents a series of chemical reactions which convert sugars to ethanol.

The biomass material is injected with yeast or bacteria which feed on the sugars in order to produce ethanol and carbon dioxide. The ethanol needs to achieve a specific rate of purity, so it can be used as automotive fuel. For this purpose the ethanol is distilled and dehydrated to obtain higher concentration of alcohol. During the fermentation, about 10% of the energy of the biomass fermented is lost, while the remaining 90% is included in the produced ethanol.

The most common forms of biomass that are used in the production of bio-ethanol are those with high sugar concentration (such as sugarcane, sweet potatoes and corn) or they are starchy materials (such as wheat, barley, oat and rice) or they are lingo-cellulosic materials (such as agricultural wastes and woody materials).

5. Biomass Properties

The properties of biomass have a key role to the selection of the suitable conversion process. Equally, the source of biomass is determined by the type of energy is requested. According to the above, the main properties that need to be taken into consideration are:

- moisture content,
- ash content,
- calorific value,
- fixed carbon and volatiles content,
- alkali metal content,
- density and volume
- cellulose/lignin ration

5.1 Moisture

The moisture content is defined as the amount of water in biomass, measured as a percentage of the weight of the material. There are two types of moisture content that interests us in terms of biomass, the intrinsic moisture and the extrinsic moisture. The fist type refers to the inherited moisture content of the material, while the second type refers to the obtained moisture depending on the prevailing weather conditions during the harvesting. Table 1 presents the moisture content of some biomass materials.

The biochemical processes, such as anaerobic digestion, require materials with a high moisture content to achieve efficient energy conversion, in contrast to the thermo-chemical processes, such as incineration, where high moisture content has a negative effect on their energy performance.

Table 1. Typical moisture content of various biomass sources

Biomass source	Moisture Content (%) (calculated on wet basis)
Wood chips	10-60 %
Wood pellets	8-12 %
Straw	20-30 %

Sawdust	15-60%
Cotton stalks	10-20%
Switchgrass	30-70 %
Bagasse	40-60 %
Cow manure	88-94 %
Pig manure	90-97 %
Chicken droppings	75-80 %
Cheese whey	93-97 %
Maize silage	65-75 %
Sweet Sorghum	20-70 %
Cardoon	15-20%

5.2 Ash Content

During chemical cleavage of biomass, a solid residue is produced, regardless of whether the cleavage is carried out by thermo-chemical or biochemical methods. If the residue is produced by combustion in air, then it is called 'ash'. Note that when the processing of biomass is carried out biochemically the produced solid residue is greater than the ash produced during the combustion of the same material.

The cost of management the overall biomass as well as the process of conversion to produce energy depends on the ash content of biomass (Table 2 gives the ash content of some biomass materials). In addition, elevated ash content has a negative impact on the energy exploitation of biomass. The chemical synthesis of the ash during a thermo-chemical conversion process, may adversely affect the operation. Especially during a combustion process, at high temperatures, the ash can produce a liquid phase called 'slag', which has the ability to reduce the plants' yield and therefore increase the processing costs.

Table 2. Approximate analysis of some biomass feedstock

Biomass	Moisture (%)	VM (%)	FC (%)	Ash (%)	LHV (MJ/kg)
Wood	20	82	17	1	18.6
Wheat straw	16	59	21	4	17.3

Barley straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.8
Bituminous coal	11	35	45	9	34

5.3 Calorific Value

The energy content of a material or the heat released during the combustion in air constitutes the caloric value of the material. The measurement of calorific value is usually performed regarding the energy content of the material per unit of mass or volume, hence MJ/kg for solids, MJ/l for liquids, or MJ/Nm^3 for gases.

The calorific value of a fuel can be expressed as higher heating value (HHV) or lower heating value (LHV). The first represent the released energy during the combustion in air, and the latent heat contained in the water vapor. Consequently, represents the maximum amount of energy that can be recovered from a biomass resource. However, the actual recoverable energy as well as the form of this energy varies depending on the conversion technology used. As a result, the lower heating value (LHV) is more suitable for measuring the available useful energy obtained. Table 2 presents the calorific value of a range of biomass materials.

It is important to mention that the moisture content needs to be taken into account as it reduces the available energy of biomass.

5.4 Fixed Carbon and Volatile Content

Solid fuels such as coal, consists two types of chemical energy, fixed carbon and volatiles. The volatiles content represents a portion of the solid fuel which when is heated to 950 °C for 7 minutes, exits in a gas form (including moisture). On the other hand, the fixed carbon content refers to the remaining mass after releasing the volatiles (excluding the moisture and ash content). The FC and VC of some typical biomass sources are presented in Table 3.

The content of biomass in fixed carbon and volatile indicates how easily the biomass can be combusted and then gasified or oxidized, depending on the use of biomass as an energy source. The biggest part of a biofuel is vented before homogeneous combustion reactions starting to take place during the gaseous phase, thereby influencing the thermal decomposition and the behavior of the combustion of solid fuels. Table 4 summarizes the fuel properties of selected biomass materials.

Table 3. Properties of selected biomass materials

Material	Moisture content (% H_20)	HHV (MJ/kg)	FC content (%)	VM content (%)	Ash content (%)	Alkali metal content (as Na and K oxides) (%)
Fir	6.5	21	17.2	82.0	0.8	—
Danish pine	8.0	21.2	19.0	71.6	1.6	4.8
Willow	60	20.0	—	—	1.6	15.8
Poplar	45	18.5	—	—	2.1	16
Cereal straw	6	17.3	10.7	79.0	4.3	11.8
Miscanthus	11.5	18.5	15.9	66.8	2.8	—
Bagasse	45-50	19.4	—	—	3.5	4.4
Switchgrass	13-15	17.4	—	—	4.5	14
Bituminous coal	8-12	26-2	57	35	8	—

5.5. Alkali metal Content

The content of biomass in alkali metals is particularly important during thermo-chemical processes. The reaction of alkali metal in the presence of silica in the ash produces a sticky fluid which may lead to blockages of the airways in furnace and boiler plant. It should be pointed out that whereas the endogenous content of a biomass source in silica may be low, contamination with soil during harvesting can significantly increase the total silica content, so while the silica content of the material is not alarming, the increased silica content may cause difficulties in operation.

5.6 Density and Volume

The density or volume of biomass material is essential before and after the conversion process as impacts on raw material and fuel storage and transportation, increasing the costs.

5.7 Cellulose/ lignin ratio

This parameter is important only in biochemical conversion process. Considering that the biodegradability of cellulose compared to that of lignin is higher, it is essential that this parameter is taken into account during the selection of biomass plant material for biochemical processing. Table 4 gives the proportions of cellulose/ hemicellulose/ lignin for selected biomass materials.

Table 4. Cellulose/lignin content of selected biomass

Biomass	Lignin (%)	Cellulose (%)	Hemi-cellulose (%)
Softwood	27-30	35 40	25 30
Hardwood	20-25	45-50	20-25
Wheat straw	15-20	33-40	20-25
Switchgrass	5-20	30-50	10-40

6. Biomass energy applications

Biomass can be exploited to meet energy needs such as heat, cooling, electricity etc. either by direct combustion or by conversion to gas, liquid or solid fuel through thermo-chemical or biochemical processes.

6.1 Domestic and Industrial Heating applications

Heat production is the most widespread conversion system for utilization of biomass. The produced heat from wood and other biomass is used in cooking, domestic heating as well as the production of steam for industrial use.

Biomass can be used to heat buildings in the fireplace, stove or central heating system. However traditional fireplaces have low efficiency, ranging between 10-20%, while some modern fireplace constructions achieve high efficiency rates, around 60-80% and may be used for heating an entire residence. The central heating systems using wood or pomace used as alternative heating systems with oil or gas burner. The energy value of wood and pomace is about 3500 kcal/ Kg, approximately one third of oil's energy value.

On a larger scale, biomass, such as firewood, forest residues, and municipal solid waste can be burned in furnaces and boilers to generate heat for industrial processes or to produce steam for use in steam turbine generators. The capacity of power plants is limited by the local availability of raw materials and is generally less than 25MW. However, the exclusive use of raw materials, such as short rotation plantations or energy crops, may allow the development of plants with capacity from 50 MW to 70MW.

6.2 Greenhouse Heating

In regions where there are large amounts of available biomass, biomass is used as fuel in boilers for greenhouse heating. The last 15 years the heat generation by burning biomass for greenhouse heating purposes spread rapidly in our country. This is due to the abundance and the minimal cost of raw materials which are by-products or residues of the installation itself. In fact, almost 10% of the country's greenhouses are heated with biomass energy.

A common method of greenhouse heating using biomass is by burning pomace. Water is heated to approximately 50°C while flowing into an underfloor pipe system and heats the greenhouse. A significant advantage of these systems is that is fully automated and can achieve full control of the temperature inside the greenhouse, while they are particularly recommended for use in oil producing regions, where there is sufficient available oil-pomace.

6.3 District Heating

District heating is to provide hot water for both heating and direct use in a building, a settlement, a village or a city, by a single central heating plant. District heating is growing rapidly in many countries, as it presents considerable advantages such as the achievement of high efficiency, reduction environmental pollution and the possibility of using non-conventional fuels when proven necessary.

The existed district heating networks in Greece are in Ptolemaida, Kozani, Amyndeo and Megalopolis, although none of them produce heating by burning biomass. The only heating plant using biomass in Greece, located in Arcadia. It has nominal power 1.200.000 kcal/ h and covers the heating needs of 80 houses and 600 m^2 communal areas. The biomass fuel being used derives from wood trimmings of logging residues from the adjacent fir forest.

6.4 Electricity Production

The main biomass combustion sector for electricity production is the pulp and paper industry. Biomass is burned to produce steam which rotates a turbine and drives a generator to produce electricity. Usually these plants have large capacity round 1 Mt per unit per year while the power efficiency levels are between 15 and 20%. The mass combustion has become the main technology, used for the conversion of waste into energy in Europe, but is relatively expensive. Capacity levels of independent biomass combustion plants ranging between 20-50 MWe while the corresponding power efficiency levels ranging between 25 and 30%. These units are economically sustainable when fuel is available at low cost or where a carbon tax is established or whether a special purchase invoice of electricity produced from renewable sources is applicable.

Furthermore, the use of biomass as a supplementary fuel in plants which burn coal is a particularly attractive method considering the high transformation efficiency achieved in these plants. Overall, the net efficiency for biomass combustion plants ranges from 20% to 40%. The highest yields are obtained in power systems above 100 MWe or in respect of co-combustion of biomass technologies with other fuels.

6.5 Cogeneration of Electricity and Heat

It is a fact that more than 30% of total energy production in the industrialized countries is used for heating offices, homes and factories. Some countries with pre-existing district heating network can use combined heat and power technology (CHP), for the replacement of boilers, which are already used. Through cogeneration strong profitability can be achieved, as well as rational use of fuel, primary energy saving, reduction of emissions and energy independence. This constitutes a widespread method of energy exploitation which has constant development throughout the world, using different fuel types as input.

6.6 Biofuels

Vehicles such as cars are a major source of carbon dioxide which is the main greenhouse gas that causes global warming. Many countries around the world are using various types of biofuels. For many years, Brazil converts sugar cane into ethanol for driving cars, the majority of which moves with pure ethanol rather than as an impurity in fossil fuels. Additionally biodiesel is particularly common in Europe in recent years, especially in Germany.

Table 5. Comparison of various biofuels with their fossil fuel counterparts (http://biofuel.org.uk/)

Biofuel	Fossil Fuel	Differences
Ethanol	Gasoline/Ethane	Ethanol has about half the energy per mass of gasoline, which means it takes twice as much ethanol to get the same energy. Ethanol burns cleaner than gasoline, however, producing less carbon monoxide. However, ethanol produces more ozone than gasoline and contributes substantially to smog. Engines must be modified to run on ethanol.
Biodiesel	Diesel	Has only slightly less energy than regular diesel. It is more corrosive to engine parts than standard diesel, which means engines have to be designed to take biodiesel. It burns cleaner than diesel, producing less particulate and fewer sulfur compounds.
Methanol	Methane	Methanol has about one third to one half as much energy as methane. Methanol is a liquid and easy to transport whereas methane is a gas that must be compressed for transportation.
Biobutanol	Gasoline/Butane	Biobutanol has slightly less energy than gasoline, but can run in any car that uses gasoline without the need for modification to engine components.

According to LAW 3423/2005 - Government Gazette 304/ A'/13.12.2005, biofuel is the liquid or gaseous fuel produced from biomass, and in particular:

a) *Biodiesel*: Methyl esters of fatty acids (Member of - FAME) produced from vegetable or animal oils and fats and it has diesel oil quality, for use as biofuel.

b) *Bioethanol*: Ethanol produced from biomass or from biodegradable fraction of waste, for use as biofuel.

c) *Biogas*: The fuel gas produced from biomass or from biodegradable fraction of industrial and municipal waste, which may purified and upgraded to natural gas quality, for use as Biofuel, or wood gas.

d) *Biomethanol*: methanol produced from biomass, to be used as biofuel.

e) *Biodimethylether*: dimethylether produced from biomass, to be used as biofuel.

f) *Bio-ETBE*: Ethyl tert - butyl ether (ETBE) produced by bioethanol for use as biofuel. The percentage by volume of bio-ETBE that calculated as biofuel is 47% of the total.

g) *Bio-MTBE*: methyl O - tert - butylether (MTBE) produced by biomethanol, for use as biofuel. The percentage by volume of bio-MTBE that calculated as biofuel is 36% of the total.

h) *Synthetic biofuels*: synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass.

i) *Biohydrogen*: hydrogen produced from biomass or biodegradable fraction of industrial and municipal waste, for use as biofuel.

j) *Pure Vegetable Oil*: The oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but not chemically unmodified, when compatible with the type of engine or equipment and the corresponding emission requirements, according to the existing legislation.

Generations of Biofuels

Biofuels may be derived from a wide range of materials and divided into four categories or "generations":

- *First generation biofuels* are produced directly from food crops such as sugars, starchy materials, oil, and animal fats by abstracting the oils converted into fuel. These fuels include biodiesel, ethanol, bio-alcohols and biogas, such as methane captured from landfills. Crops such as wheat and sugar are the most widely used feedstock for the production of bioethanol while rapeseed oil has proved a very effective crop for the production of biodiesel.

- *Second generation biofuels* are produced from non-food crops or agricultural waste products, especially lignocellulose biomass such as switch-grass, willow, or wood chips. Second Generation biofuels have been developed to overcome the limitations of first generation biofuels and are aimed at being more cost competitive in relation to existing fossil fuels (Review of EU Biofuels Directive, 2006).
- *Third generation biofuels* are based on improvements in the production of biomass and produced from algae and other fast growing biomass plants. Particularly, the algae are cultured to act as a low-cost, high-energy and entirely renewable feedstock as it is considered to have the potential to produce more energy per acre in relation to conventional crops. In addition, a further important advantage is that it can be converted to many forms of fuel such as diesel, petrol and jet fuel.
- *Fourth generation biofuels* are aimed at not only producing sustainable energy but also a way of capturing and storing CO_2. The biomass materials that have absorbed CO_2, during their development, are converted into fuel using the same conversion processes as second generation biofuels. The difference between this process and the second and third generation process is that during the production stages, carbon dioxide is captured using processes such as oxy-fuel combustion and then is geosequestered by storing it in old oil and gas fields or saline aquifers. Consequently, the fourth generation biofuels are not simply carbon neutral but have negative carbon production and their use instead of conventional fuels reduce CO_2 emissions.

7. Bioethanol

7.1 Bioethanol Definition

Bioethanol is ethanol or ethyl alcohol (C_2H_5OH), i.e. and is so named because it is produced from biomass. It is a clear, colorless liquid used as a petroleum substitute and is seen as a good fuel alternative considering that the crops that is derived from can be grown renewably and in most climates around the world. It is a fuel of high energy content and environmentally cleaner than gasoline. Additionally, it is biodegradable, low toxic and causes very little environmental pollution if discharged into the environment.

The use of bioethanol is generally CO_2 neutral. This is achieved because in the growing phase of the source crops, CO_2 is absorbed by the plant and oxygen is released in the same volume that CO_2 is produced in the combustion of the fuel (RESMAC project, EREC). During the perfect combustion is produced carbon dioxide and water. Bioethanol represents a high octane rate fuel and can be used as additive to increase the octane number of gasoline. By blending with gasoline fuel enrichment in oxygen can be achieved, resulting in a more complete combustion, and hence reduced emissions of dangerous exhaust gases.

Bioethanol can be added at a rate of 5% in gasoline according to standard EN 228. This mixture does not require modification of the engine and covered by the guarantees of the vehicle. By proper transformation of the engine, bioethanol can be used at higher levels, for example, 86% (E85).

Bioethanol is mainly produced from sugar by the process of fermentation but it can also be synthesized industrially by the chemical reaction of ethylene with steam. The most common sources for the production of bioethanol are sugar cane, corn, wheat and sugarbeet. Cellulosic biomass, like grasses, woody crops, and organic wastes can also be used for the production of bioethanol through advanced processing techniques.

7.2 Sources of Bioethanol

First generation bioethanol is produced by sweetened and starchy products (beets and cereals), while the second generation bioethanol is produced by woody (cellulosic) agricultural forest residues and by-products. The following figure shows the various sources used for bioethanol production.

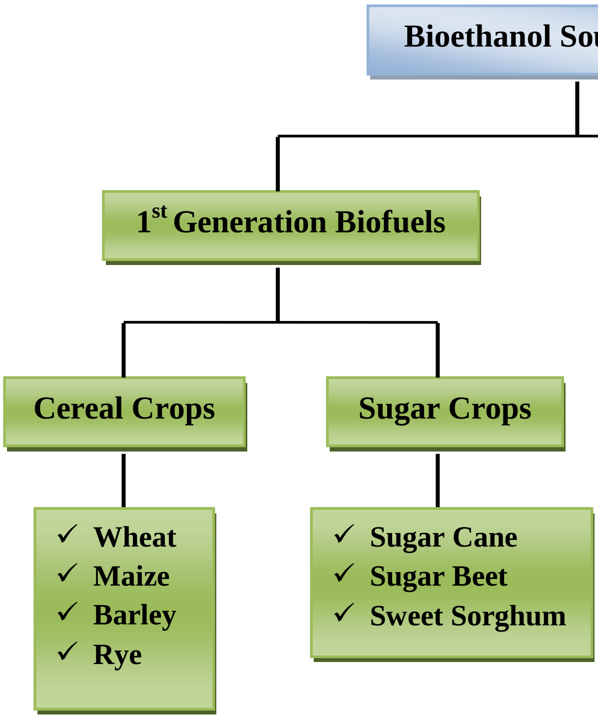


Figure 3. Bioethanol Source Crops

The raw materials examined in this study are maize, wheat, barley, sugar beets as well as potato.

- ***Maize (corn)***

Maize is a cereal which comes from the America continent. It is an alternative energy crop being used as feedstock for bioethanol production for the past fifteen years. The main producer country is the United States of America. Maize produces large amounts of soluble sugars in its stalks and creates a large amount of biomass. To be more precise, the seed yield (% of the total weight) ranging from 35 to 50%. An acre of maize produces 240-360 liters of bioethanol. However, it is worth to be mentioned that the potential for bioethanol production from maize lies not only in converting the grain to ethanol but also in applying cellulose conversion technology to the pericarp that covers the grain (Schwietzke et. al, 2009). The corn cob, stalks, and leaves can be converted to fermentable sugars with cellulose processing technology that consists of pretreatment hydrolysis, and fermentation using yeast or other microorganisms, while grain-based feedstocks, require microorganisms that are capable of producing ethanol from both glucose and xylose (Schwietzke et. al, 2009).

- ✓ ***Wheat***

Wheat is a cereal grain, originally from the Levant region of the Near East but is a widely grown crop, cultivated in over 115 nations under a wide range of environmental conditions. In 2013, wheat was the third most produced cereal after maize (1,016 million tons) and rice (745 million tons) with 713 million tons production (FAOStat). There are six wheat classifications: hard red winter, hard red spring, soft red winter, durum (hard), hard white and soft white wheat. An acre of wheat produces an average of 150-800 kg seed with corresponding output 45-240 liters of bioethanol. Moreover, wheat straw can be used for 2^{nd} generation bioethanol. However, because of the structural complexity of the lignocellulosic matrix of wheat straw, the ethanol production process requires four major operations including pretreatment (in order for wheat straw to be cellulose accessible for efficient enzymatic depolymerization), hydrolysis, fermentation and distillation (Telebnia et al, 2010).

- ✓ ***Barley***

Barley is a member of the grass family and a major cereal grain. It constistues one of the first cultivated grains and is now grown widely. It is mainly used as animal feed and the production of alcoholic beverages, while in recent years there has been a vigorous activity in the use of barley as a raw material for the production of bioethanol. The annual global production of dry barley averages about 124 Tg while the major production regions are Europe (62%), Asia (15%), and North America (14%) (Han et al, 2013). Moreover, barley yield ranges from 0.74 to 2.8 dry Mg/ha with a global average of 2.3 dry Mg/ha (Kim, Dale, 2004). Considering that the annual world production of barley straw is about 94,24 Tg and the most of it is burned or discarded, it constitutes a significant feedstock for bioethanol production (Han et al, 2013). The chemical composition of barley straw varies according to location, season, harvesting method as well as the analytical procedure while its transformation process is similar to that of wheat.

- ✓ ***Sugar beet***

Sugar beet is a type of beet which is grown commercially due to the high content of sugar in its roots and can grow in a wide variety of soil types and climates. The roots of beets contain up to 20% sugars, making it the second most important source of sugar after sugar cane. In recent years, sugar beets are used as a feedstock for the production of bioethanol, while France is the largest producer of bioethanol from sugar beet in the world. In comparison to sugar cane, sugar beets take more energy in order to produce sugar because they do not have a byproduct like bagasse that can be burned for energy (Bowen et al, 2010). Although they have other byproducts (the tops of sugar beets and the pulp left after the extraction of sugar) used as animal feed. It is considered that an average of 13 to 25 tonnes/ acre of sugar beets can be grown to non-irrigated land, while this yield increases by 15-30 % in case of irrigated land.

- ✓ ***Potato***

Potato is a starchy, tuberous crop which is mainly produced for human consumption. It is widely produced, as it constitutes a major food type. Waste potatoes (high quality potatoes but with incorrect size) can be used as a raw material for bioethanol production. The following figure presents the bioethanol production process using waste potatoes.

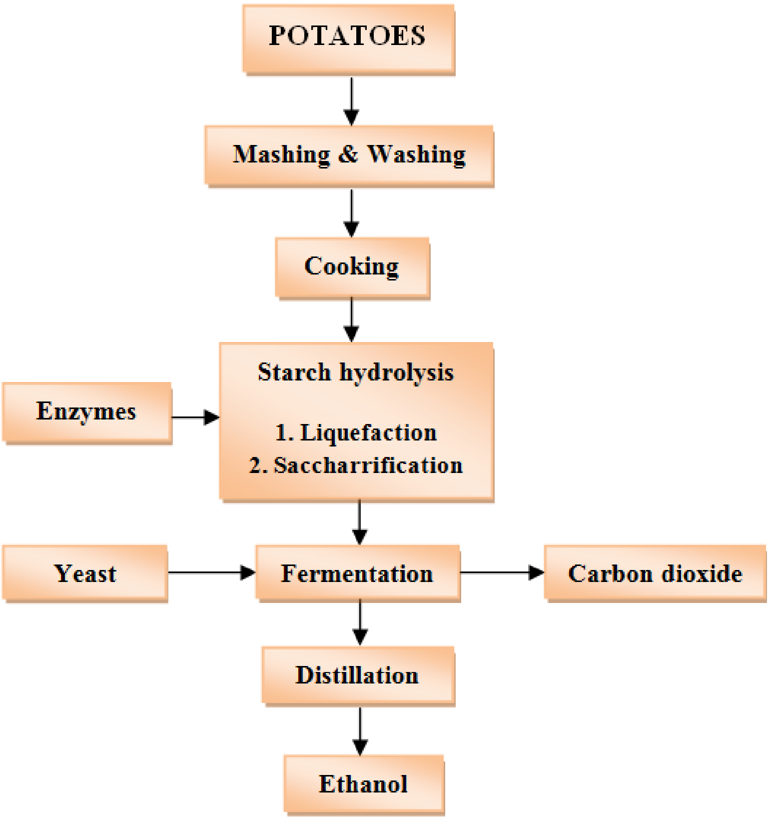


Figure 4. Potato based bioethanol production process (Kilpimaa et al, 2009)

7.3 Bioethanol Production

The production of bioethanol from 1st Generation Biofuels is based upon starch crops like corn, wheat, potato etc, and from sugar crops like sugar cane and sugarbeets. In addition, the development of lingo-cellulosic technology has meant that not only high energy content raw materials like starch and sugar crops can be used for bioethanol production but also woody biomass or waste residues from forestry. This is a development known as the 2nd Generation of Biofuels.

Depending on the biomass source used for the production of bioethanol, the steps generally include (RESMAC project, EREC):

- ✓ Storage
- ✓ Cane crushing and juice extraction
- ✓ Dilution
- ✓ Hydrolysis for starch and woody biomass
- ✓ Fermentation with yeast and enzymes

- ✓ CO_2 storage and ethanol recapture
- ✓ Evaporation
- ✓ Distillation
- ✓ Waste water treatment
- ✓ Fuel Storage

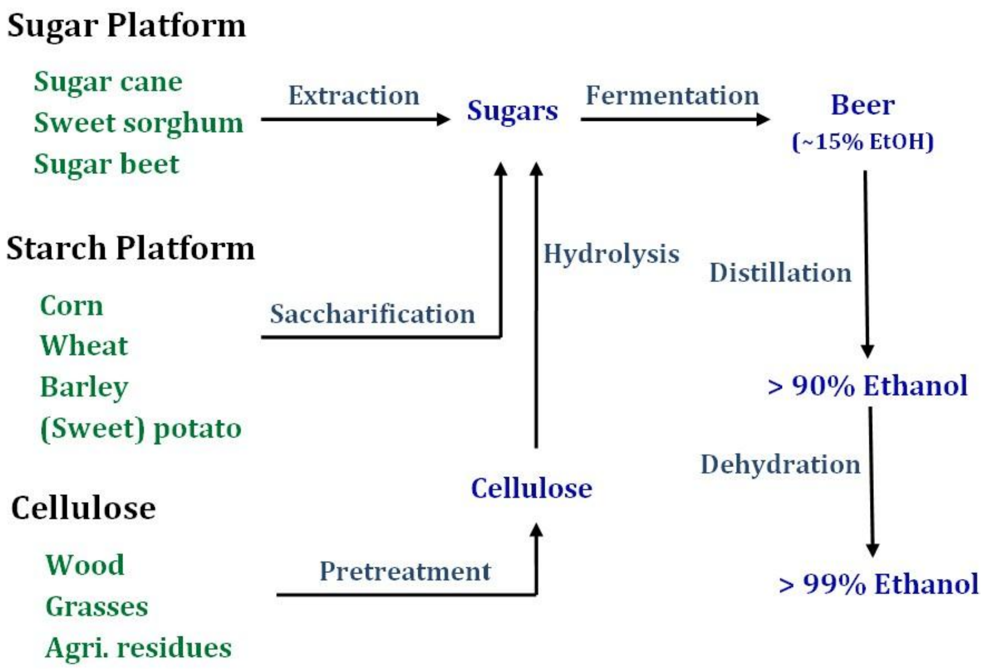


Figure 5. Bioethanol Production Process

When a sugar-based raw material is used, the crop is first crushed and soaked to separate the sugar component. Thereafter, the process of Fermentation with yeast and enzymes is carried out, which leads to the production of alcohol and carbon dioxide. Subsequently, the liquid fraction is distilled to produce ethanol to the required concentration. If the ethanol is to be blended with petroleum, the remaining water is removed to produce "anhydrous ethanol".

Moreover, the production process of bioethanol, in the case of cereal feedstock, begins by separating, cleaning and milling the crop. Enzyme amylases are used in order to convert the starches into fermentable sugars. Afterwards, the process is similar to that for sugar crops. The conversion process of grain to ethanol yields several co-products, such as protein-rich animal feed and in some cases sweetener, depending on the specific feedstock and process used.

Table 6. Starch to Bioethanol Process

PROCESS	TEMPERATURE	PH	TIME
Liquefaction Starch $\xrightarrow{\alpha\text{-amylase}}$ Oligosaccharides + Dextrins	60-65 C° from Fungi 65-70 C° from Bacteria	5.0-6.5 from Fungi 6.0-7.5 from Bacteria	~120 min
Saccharification (can be combined with fermentation) Oligosaccharides Dextrins $\xrightarrow{\text{Glucomylase}}$ Glucose	58-60 C°	4.0-4.5	~30 min
Fermentation Glucose $\xrightarrow{\text{Yeast}}$ Ethanol + CO_2	-5-38 C° (optimum ~30 C°)	2.0-8.0 (optimum 4.8-5.0)	60-72 h

7.4 Advantages and Disadvantages of Bioethanol

7.4.1 Advantages

Main advantages of bioethanol given in the literature include:

- ✓ It is not a fossil fuel. As a result, its production and combustion do not contribute to the greenhouse effect.
- ✓ It is a renewable energy source, since it is derived from biomass.
- ✓ It is easily produced and yields 34% more energy than that required for its production.
- ✓ It is biodegradable, non-toxic and water soluble, hence it does not cause negative effects on the environment in case of leakage.
- ✓ By using 10% ethanol in mixture with gasoline, carbon monoxide is reduced by 25-30% (as a better combustion of the fuel is achieved) as well as carbon dioxide by 10,6%.
- ✓ In low concentration mixture of ethanol the emissions of volatile organic compounds is reduced by 7%, considering that ethanol oxygenate the fuel.

- ✓ The high concentration of ethanol blends reduces nitrogen oxide emissions by about 20%.
- ✓ Does not contain sulfur. This contributes to the improvement of fuel's combustion and the protection of catalytic converters of vehicles that reduce emissions.
- ✓ Increases the number of octane gasoline at low cost and replaces other harmful additives such as lead.
- ✓ It reduces, although not eliminate, the dependence of countries on imported fuels.
- ✓ It creates new job opportunities in the agricultural sector.

7.4.2 Disadvantages

The main disadvantages of bioethanol as a fuel are:

- ✓ It is widely believed that biomass should be used as food (considering the world hunger phenomenon), rather than be used as feedstock for bioethanol production.
- ✓ The cost of sugar-based and starchy products from which bioethanol originates, is high.
- ✓ The by-products are lignocellulosic residues which are difficultly hydrolyzed and have a high cost of collection, transport and storage.
- ✓ The production cost of ethanol is even higher than that of gasoline.
- ✓ Many advocate that the emissions reduction by the use of bioethanol is very low and does not have substantial contribution to the environmental protection.
- ✓ The energy content of ethanol is equivalent to 2/3 of that of gasoline. Therefore a vehicle needs more ethanol to cover the same distance.

7.5 Bioethanol Economy

The production costs are difficult to be estimated as they are based on the commodity price of the feedstock crop/fuel, the fuel processing method, and national variations that include agricultural practices and fuel taxation. In general, the high production costs can be offset by fuel excise duty benefits to stimulate production (BioNETT Handbook, 2011).

Bioethanol production cost from wheat and sugar beet is estimated around 0.60 €/litre (excluding taxes) and it is broadly similar. Given bioethanol's significant fuel economy penalty, this cost translate to a petrol equivalent unit cost of around 0.90 €/litre (BioNETT Handbook, 2011). In case considerable tax concessions, bioethanol compete the conventional fuels. However, in EU where there are no tax incentives for bioethanol production, the fuel is much more expensive for the consumers.

7.6 The EU Bioethanol market

The European Union is the third largest market for ethanol in the world. Although the EU biofuels market is dominated by biodiesel (80%), ethanol consumption has increased more rapidly than other biofuels in recent years. Current production is largely based on fermentation of plants rich in sugar or starch.

The Directive on the promotion of the use of energy from renewable sources that requires 10% of the energy used in transport to come from renewable sources by 2020 as well as the fuel quality Directive which requires greenhouse gas emissions from transport fuels to be reduced by 6% by 2020, have led to the need for strategic planning for the promotion bioethanol.

EU member states have elaborated their national action plans in order to reach the 10% target. Most of them have adopted mandatory blends and some countries provide fiscal incentives. The EU imposes approximately € 0.19/liter tariff on undenaturated ethanol, while the import duty for denaturated ethanol is € 0.10/liter. In the following table, an increase in bioethanol consumption between 2011 and 2012 is presented. As illustrated, the overall bioethanol consumption in the European Union has been increased, the growth among the countries was not equal. The consumption decreased in 10 countries and increased in 14 countries. To be more precise, France and Germany holds the highest bioethanol consumption, while the greatest increase from 2011 to 2012 was in the Netherlands and the biggest decrease in the United Kingdom.

Table 7. Bioethanol fuel output across the EU in 2011 and 2012 (in million liters)

Country	2011	2012
France	1007	1200
Germany	770	773
Belgium	400	450
Netherlands	275	450
Spain	463	381
Sweden	200	230
Hungary	173	220
Austria	195	216
Poland	167	212
United Kingdom	320	167
Italy	60	150
Czech Republic	110	130
Slovakia	130	130
Bulgaria	10	40
Lithuania	18	27
Romania	65	20
Latvia	5	15
Finland	10	10
Ireland	10	10
Denmark	5	5
Cyprus	0	0
Estonia	0	0
Greece	0	0
Luxembourg	0	0
Malta	0	0
Slovenia	0	0
Portugal	0	0
TOTAL Biofuels EU-27	**4393**	**4836**

(http://www.ethanolproducer.com/articles/10093/report-eu-biofuel-consumption-increased-in-2012#)

Moreover, the bioethanol production in several EU members from 2006 until 2013 presented below. According to the data in Table 8, the overall bioethanol production has gradually increased, as well as the individual production in most of the countries. As observed with the consumption of bioethanol, respectively the largest production is noted in France and Germany, followed by Benelux (Belgium, The Netherlands and Luxemburg) and Spain.

Table 8. Bioethanol fuel production-Main producers (in million liters)

Country	2006	2007	2008	2009	2010	2011	2012	2013
Benelux	19	37	76	143	380	696	1013	1013
France	294	539	746	906	942	949	949	949
Germany	430	397	580	752	765	730	759	823
United Kingbom	0	44	70	70	278	190	253	316
Spain	405	359	346	465	471	465	465	465
Poland	162	120	114	165	194	171	203	228
Other Countries	323	310	655	970	1147	1419	1295	1396
TOTAL	**1633**	**1806**	**2587**	**3471**	**4177**	**4620**	**5000**	**5380**

(http://www.biofuels.gr/bioethanol/bioethanol-production-in-europe/)

7.7 The Greek bioethanol market

Unfortunately in Greece there is almost no domestic production of bioethanol and relies entirely on imports. After a decade of European Directive implementation, bioethanol plants are yet to be installed and this fact along with the existing legislation implies that the construction of such units could be crucial. The Greek Sugar Company had expressed its interest to convert two of its existing sugar factories in Larissa (continental district) and Ksanthi (northern district) to bioethanol production units with an annual capacity of 0.1 Mt each, on beet, grain and corn crops feedstock, which are quite common and easily cultivated in Greece.

The output per acre varies depending on the type of crop, the cultivation method used, the climatic conditions, as well as various production factors. A major challenge of Greece is to expand the amount of energy crops as well as to replace some of the usual existing cultivation options like wheat, which is cultivated without irrigation and with relatively low secondary inputs (Rizopoulou, 2011). According to an experimental study, energy crops like sweet sorghum have a relatively high output, even when cultivated with low imputs (irrigation, fertilization, herbicides), which constitutes a highly beneficial fact for the greek agriculture.

8. Biodiesel

8.1 Biodiesel Definition

Biodiesel is produced from the early 1990s and used as fuel in the transport sector. Although the produced biodiesel is much less than bioethanol, its production has increased significantly in recent years and it is widely used in countries of the European Union.

Biodiesel constitutes a clean burning renewable fuel made using natural vegetable oils and fats. It is made through a chemical process which converts oils and fats of natural origin into fatty acid methyl esters (FAME) and is intended to be used as a replacement for petroleum diesel fuel, or as a mixture with petroleum diesel fuel in any proportion. It is a mixture of fatty acid esters with low molecular mass alcohols predominantly methanol. It is usually a mixture of esters (Sidiras, 2014):

$$\mathrm{CH_3[CH_2]_{14}COOCH_3},\quad \mathrm{CH_3[CH_2]_7CH = CH[CH_2]_7COOCH_3},\quad \mathrm{CH_3[CH_2]_{16}COOCH_3}$$

Biodiesel is produced from vegetable or animal fats through a chemical process called transesterification. The final product has similar behavior in internal combustion engines with diesel.

$$\begin{array}{l} \mathrm{CH_2OCOR} \\ | \\ \mathrm{CHOCOR'} \end{array} + 3\mathrm{CH_3OH} \longrightarrow \mathrm{RCOOCH_3} + \mathrm{R'COOCH_3} + \mathrm{R''COOCH_3} + \begin{array}{l} \mathrm{CH_2OH} \\ | \\ \mathrm{CHOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

$$\begin{array}{l} | \\ \mathrm{CHOCOR''} \end{array}$$

Biodiesel and diesel are different chemicals. Diesel is a mixture of hydrocarbons, while biodiesel is a mixture of esters, usually methyl palmitate, methyl oleate and methyl stearate. Biodiesel is easily biodegradable and has reduced exhaust emissions, lower toxicity, and is safer to handle compared to petroleum diesel fuel. Generally requires no major modifications to existing vehicle engines, although in the case of using large quantities of biodiesel, it may require some modifications in tanks, fuel pipes, valves or engine parts.

Table 9. European standards for biodiesel (DIN EN 14214).

Specifications	**Unit**	**Threshold values** min.	max.	**Test method**
Ester content	% (m/m)	96.5	- - -	prEN 14103
Density (15 °C)	g/cm³	0.86	0.90	DIN EN ISO 3675
KIN viscosity (40 °C)	mm²/s	3.50	5	DIN EN ISO 3104
Flashpoint (PM)	°C	101	- - -	DIN EN ISO 22719
CFPP				
- 15.04. to 30.09.	°C	- - -	0	DIN EN 116
- 01.10. to 15.11.	°C	- - -	- 10 CFPP	DIN EN 116
- 16.11. to 29.02.	°C	- - -	- 20 CFPP	DIN EN 116
- 01.03. to 14.04.	°C	- - -	- 10	DIN EN 116
Sulphur content	mg/kg	- - -	10	DIN EN ISO 20846
Carbon residue (of 10% residue)	% (m/m)	- - -	0.3	DIN EN ISO 10370
Cetane number		51	- - -	ISO/DIS 5165:1996
Ash	% (m/m)	- - -	0.02	DIN ISO 3987
Water content	mg/kg	- - -	500	DIN EN ISO 12937
Total contamination (3h at 50 °C)	mg/kg	- - -	24	DIN EN 128B2
Copper strip corrosion		- - -	1	DIN EN ISO 2160
Oxidation stability	h	6	- - -	DIN EN 14112
Acid value	mg KOH/g		0.50	DIN EN 14104
Iodine value	- - -	- - -	120	DIN EN 14111
Linolenic acid methyl ester content	% (m/m)	- - -	12	DIN EN 14103
Fatty acid methyl ester content with ≥ 4 double bonds	% (m/m)	- - -	1	- - -
Methanol	% (m/m)	- - -	0.2	DIN EN 14110
Monoglycerides	% (m/m)	- - -	0.8	DIN EN 14105
Diglycerides	% (m/m)	- - -	0.2	DIN EN 14105
Triglycerides	% (m/m)	- - -	0.2	DIN EN 14105
Free glycerol	% (m/m)	- - -	0.020	DIN EN 14105
Total glycerol	% (m/m)	- - -	0.25	DIN EN 14105
Alkali content (Na+K)	mg/kg	- - -	5	DIN EN 14108
Alkaline-earth content (Ca+Mg)	mg/kg	- - -	5	prEN 14538
Phosphorus content	mg/kg	- - -	10	DIN EN 14107

8.2 Biodiesel Production

The production of biodiesel is achieved by transesterification of the parent oil in order to produce a viscosity similar to that of petroleum. This chemical conversion of oil to biodiesel is called transesterification and its purpose is to lower the oil's viscosity. The transesterification reaction proceeds with catalyst or without catalyst by using primary or secondary monohydric aliphatic alcohols having 1–4 carbon atoms as follows (Demirbas, 2007):

Triglycerides + Monohydric alcohol $\longrightarrow$ Glycerin + monoalkyl esters (biodiesel)

Typical engine combustion reaction:

$$\text{Biodiesel + Air } (N_2+O_2) \longrightarrow CO_2 + CO + H_2O + N_2 + O_2 + (HC) + O_3 + NO_2$$

Transesterification refers to a reaction between an ester (triglyceride) of one alcohol (glycerin) and a second alcohol (methanol) to form an ester of the second alcohol (methylester). Figure 6 shows the biodiesel processing flow.

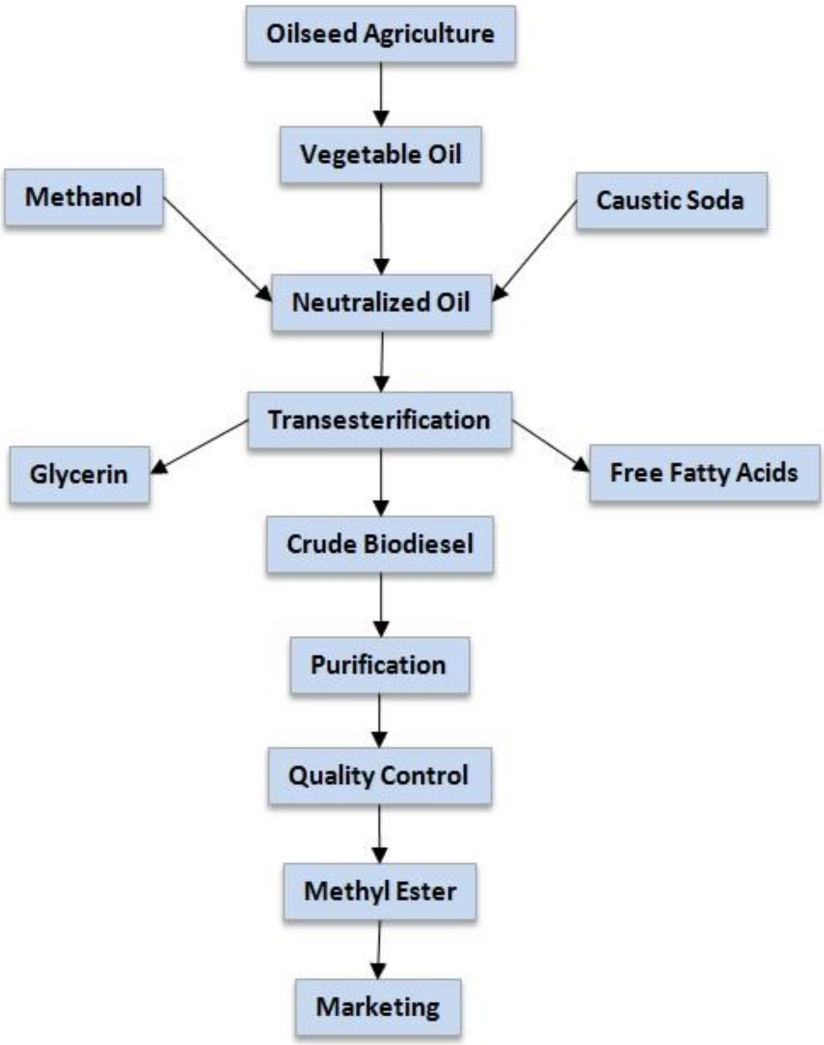


Figure 6. Biodiesel processing flow diagram

8.3 Sources of Biodiesel

Among the 350 recognized oil crops, only soybean, palm, sunflower, safflower, cottonseed, rapeseed and peanut oils are considered as potential alternative fuel for diesel engines (Demirbas, 2007). Vegetable oils constitute a renewable and potentially inexhaustible source of energy and their embodied energy is similar to that of diesel fuel. An extensive variety biolipids can be used to produce biodiesel. These may be either virgin vegetable oils such as rapeseed, soybean oil and sunflower, or residues of vegetable oils, non-edible oils such as castor oil, tall oil, etc and animal fats. In the present study the vegetable oils which have been considered are rapeseed, soybean, cottonseed and sunflower.

- ✓ ***Sunflower***

Sunflower is an annual plant belonging to the family Compositae. Its seeds are rich in oil, which makes sunflower a popular biofuel crop. The plant's oil is processed in refineries to produce biodiesel or used as biomass waste to produce electricity in plants. It should be noted that is recommended the sunflower oil to be refined and de-waxed before blending with diesel fuel. In addition, according to the National Sunflower Association, 1 acre (4 hectares) of sunflowers can produce 600 pounds (272.1 kilograms) of oil. Sunflower is one of the main crops grown in Greece, is found mainly in the northern regions of the country as in Macedonia and Thrace and is mostly cultivated as a source of vegetable oil for human consumption.

- ✓ ***Rapeseed***

The rapeseed is an annual plant and is widely considered as the third most important grower plant after soybean and palm. It is cultivated primarily as a raw material for the production of oil and to a lesser extent for its leaves (for human consumption, animal feed and fertilization). Its small round seed has average high oil content (30-50%). After the extraction of oil the residues (known as pie) are used in livestock as they have rich protein content (10-45%). The fact that it can be grown as a winter plant at low temperatures makes it a very important plant compared with other oleaginous plants. From experiments carried out in recent years in the Mediterranean countries positive results were exported, in terms of adaptability and productivity of the crop. In particular, the seed yield and dry biomass, depending on the variety, cultivation techniques and the prevailing soil conditions ranged from 150 to 300 kg/acre and 300 to 800 kg/acre, respectively. The rapeseed is grown experimentally in the regions of Macedonia and Thrace, and Crete.

- ***Cottonseed***

The cotton plant (genus Gossypium) is a member of the Malvaceae, or mallow, family and it is known as nature's unique food and fiber plant. It produces both food for consumption by people or animals in addition to a highly versatile fiber for clothing, home furnishings, and industrial uses. More than 20 percent of the weight of each seed is recoverable oil. Compared to sugarcane or rapeseed, cottonseed is a low performer in turning the sun’s energy into fuel. It yields 35 gallons of oil per acre, or a little less than one-third the yield of rapeseed (Browning, 2008). According to the National Cottonseed Products Association, cottonseed oil is among the most unsaturated oils, while others include safflower, corn, soybean, canola and sunflower seed oils. In addition, its fatty acid profile generally consists of 70% unsaturated fatty acids including 18% monounsaturated (oleic) and 52% polyunsaturated (linoleic) and 26% saturated (primarily palmitic and stearic). Currently, three to four biodiesel refineries are using cottonseed oil as a feedstock.

- ***Soybean***

Soybean oil (Glycine max) is a cool season legume which currently holds a major feedstock for production of biodiesel. Although the origins of soybean are in Southeast Asia, the United States of America produces 32% of global quantity of soybeans followed by Brazil with 28%. Motor vehicles, especially heavy equipment and buses, can run on pure soybean biodiesel, or a blend of biodiesel and diesel. According to the National Academy of Sciences, soybean biodiesel is more environmentally friendly and yields more energy than corn ethanol (Barrionuevo, 2006). It is worth mentioning that soybean biodiesel returns 93 percent more energy than is used to produce it, while corn grain ethanol currently provides only 25 percent more energy (University of Minnesota, 2006). Furthermore, even though the amount of land devoted to soybean production in USA is much greater than the amount of acreage devoted to other oilseed crops, soybeans leads to less biodiesel production. Soybeans contain approximately 18% to 20% oil compared to other oilseed crops such as canola (40%) and sunflower (43%) (Berglund et al., 2007). Additionally, one bushel of soybeans yields 1.5 gallons (5.68 liters) of biodiesel. In Greece the soya production is quite limited.

8.4 Advantages and Disadvantages of Biodiesel

8.4.1 Advantages

Main advantages of biodiesel given in the literature include:

- ✓ Biodegradability,
- ✓ Nontoxicity,
- ✓ Availability and renewability,
- ✓ Carbon neutrality,
- ✓ Lower sulfur and aromatic content,
- ✓ It can be used as it is or as a mixture in existing diesel engines,
- ✓ It requires no engine modifications,
- ✓ It can be produced from used oils and animal fats,
- ✓ It has a higher flash point (therefore it is safer), higher cetane number and better fertilising capacity compared to diesel,
- ✓ It helps to reduce a country’s reliance on crude oil imports and supports agriculture by providing a new labor and market opportunities for domestic crops (Demirbas, 2007).

In the following Table, a comparison between the fuel B100 (100% biodiesel) and B20 (mixture of 20% biodiesel and 80% diesel) has been made.

Table 10. Biodiesel vs. Petroleum Diesel

Biodiesel vs. Petroleum Diesel		
Emission	**B100**	**B20**
Carbon Monoxide	-47%	-12%
Hydrocarbons	-67%	-20%
Particulate Matter	-48%	-12%
Sulfates	-100%	-20%
Nitrogen Oxides	+/-??	+/- ??
Ozone formation (speculated HC)	-50%	-10%
PAH	-80%	-13%

(Source: EPA, 2002 Biodiesel Emissions Database; McCormick, Bob, 2007, Presentation: The Truth about NOx Emissions & TxLED Update)

8.4.2 Disadvantages

The main disadvantages of biodiesel as a fuel are (Balat et al, 2010, Demirbas, 2007):

- ✓ Lower energy content (8% less BTU per gallon),
- ✓ Higher nitrogen oxides (NOx) emissions,
- ✓ Higher cloud point and pour point,
- ✓ Engine compatibility,
- ✓ Lower engine speed and power,
- ✓ Injector coking,
- ✓ Less oxidative stability than diesel,
- ✓ High price and higher engine wear,
- ✓ Poor performance in cold weather (This can be mitigated by blending with diesel fuel or additives, or by using raw materials with low gel-point such as rapeseed.

Table 11. ASTM standards of biodiesel and petrodiesel fuels (Demirbas, 2007)

Property	**Test Method**	**ASTM D975 (petroleum diesel)**	**ASTM D6751 (biodiesel, B100)**
Flash point	D 93	325 K min	403 K
Water and sediment	D 2709	0.05 max vol%	0.05 max vol%
Kinematic viscosity (at 313 K)	D 445	1.3-4. lmm^2/s	1.9-6.0 mm^2/s
Sulfated ash	D 874	—	0.02 max wt%
Ash	D 482	0.01 max wt%	—
Sulfur	D 5453	0.05 max wt%	—
Sulfur	D 2622/129	—	0.05 max wt%
Copper strip corrosion	D 130	No 3 max	No 3 max
Cetane number	D 613	40 min	47 min
Aromaticity	D 1319	35 max vol%	—
Carbon residue	D 4530	—	0.05 max mass%
Carbon residue	D 524	0.35 max mass%	—
Distillation temp. (90% volume recycle)	D 1160	555 K min-611K max	—

Be noted that the reduction of emissions of nitrogen oxides during burning of biodiesel, cannot be achieved by the producers, but is a challenge for engine/ vehicles manufacturers (Niederl et al. 2004).

8.5 Biodiesel Economy

Although biodiesel production, contribute to a country's economy, offering independence from imported fuels as well as new labor, it has high production costs, almost 1.5-3 times higher than diesel cost in developed countries. The cost of biodiesel fuels varies depending on the base stock, the price of the crude petroleum, the variability in crop production from season to season, as well as the geographic area (Demirbas, 2007). In detail, the distribution of biodiesel production cost is presented by Figure 7.

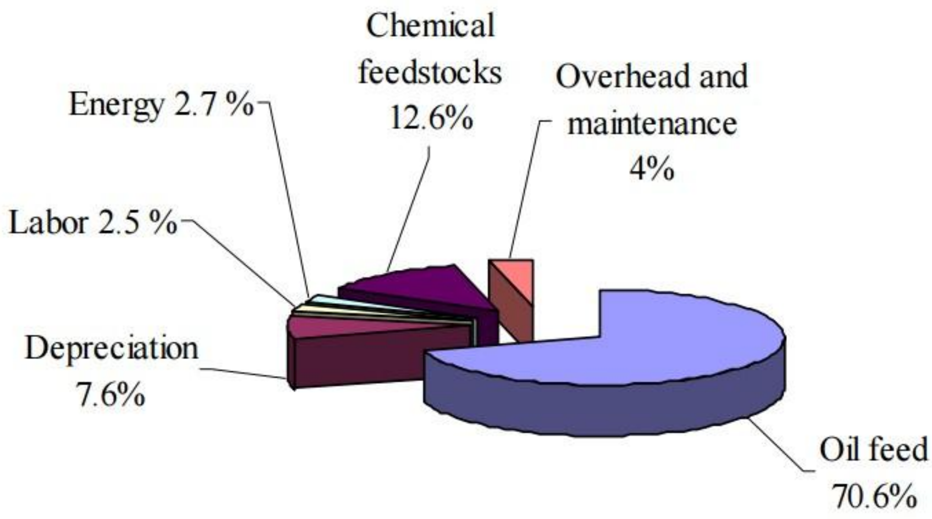


Figure 7. Distribution of biodiesel production costs (Chhetri et al, 2008)

It is noteworthy that biodiesel's competitiveness does not rely on petrodiesel's economy, but is linked to the prices of biomass feedstock and costs, as well as to the conversion technology. The main factor that modulates the economy of biodiesel is the feedstock, which holds approximately 80% of the total biodiesel operating costs.

The reduction of cost of biodiesel can be achieved by using cooking oils as raw material and by achieving the viability of continuous transesterification and recovery of high quality glycerol as a byproduct of biodiesel. Nevertheless, it is not feasible to all used low cost oils to be converted into biodiesel, as many of these contain large amounts of free fatty acids that cannot be converted into biodiesel in the presence of an alkaline catalyst.

Some of the variables that the cost of biodiesel is depending on are (Groschen, 2002):

- ✓ *Cost of design, permitting, construction and start-up of a biodiesel facility*. These costs vary depending on site specific issues such as the local cost and water availability, waste treatment, professional services, labor and transportation. In greater detail, the pant's location should provide adequate access rail or road, as well as facilities for water and sewage treatment etc.
- ✓ *Cost of production inputs.* That includes operation costs such as electrical power, process energy, labor, service and supplies, as well as fat and oil products, catalysts and reagents.

8.6 The EU biodiesel market

A combination of factors such as the increased petroleum prices, the uncertainties concerning petroleum availability as well as the numerous environmental benefits of biofuels produced by vegetable oils and animal fats, has led to a continuously increased production of liquid biofuels within the European Union (Figure 8).

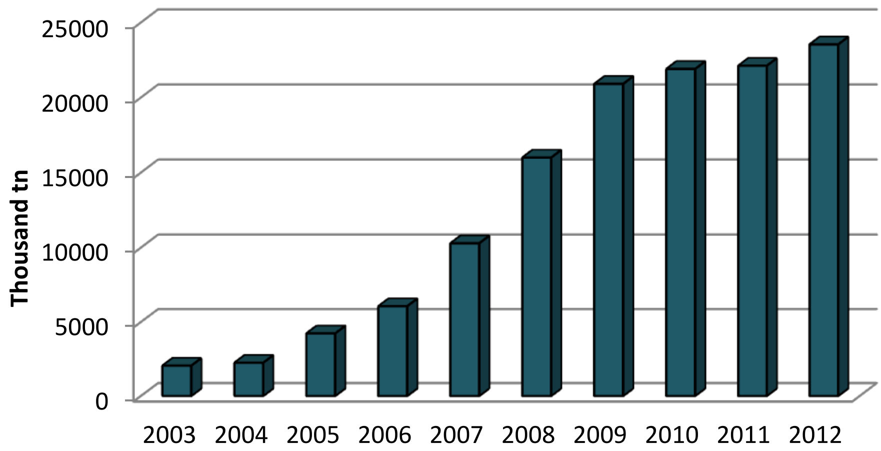


Figure 8. The biodiesel production capacity of European Union from 2003 to 2012.
(Data: http://www.ebb-eu.org/stats.php)

With the implementation of the directive on the promotion of the use of biofuels and other renewable fuels for transport (Directive 2003/30/EC) which has been forced in May 2003, the countries of the European Union had to conform in order to achieve the requirements of the Directive. In more detail, In fact the Directive stipulates that national measures to be taken by countries across the EU aiming at replacing 5.75% of all fossil transport fuels (gasoline and diesel) with biofuels by 2010. By 2007, biofuels were holding a share of only 1%, not reaching the target of 2% or the combined goals of the EU countries, which was 1,4%. However, the target for 2010 has changed with the implementation of Directive 2009/28/EC, which replaces the Directive 2003/30/EC. The new target now is the participation of biofuels by 10% by 2020.

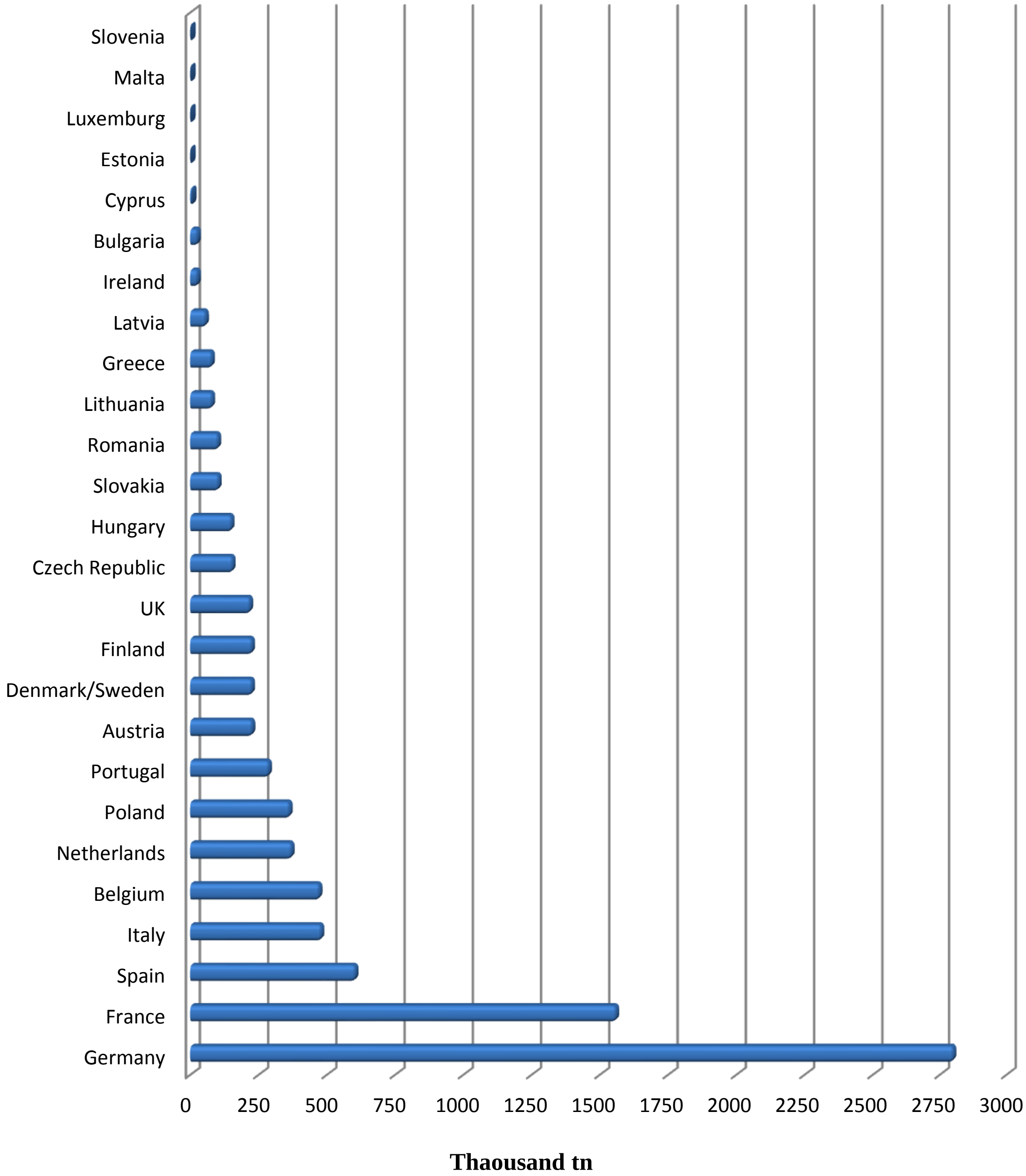


Figure 9. Biodiesel real production of EU countries for the year 2011
(Data: http://www.ebb-eu.org/stats.php)

In 2011, the annual biodiesel production of EU was 22.1 Mt and further increases to 23.5 Mt in 2012 (Sidiras, 2014). However, the actual biodiesel production was limited to 39% of this quantity. In further detail, Germany, France and Spain held the first three positions, with 2.8 Mt, 1.6 Mt and 0.6 Mt biodiesel production respectively, for the year 2011, while Greece was at the 18th with 0.08 Mt production (Figure 9). A year later (Figure 10), Germany reached 4.9 Mt, Spain and the Netherlands increased to 4.4 Mt, and 2.5 Mt, respectively, while Greece held the 7th position with 0.8 Mt (Sidiras, 2014).

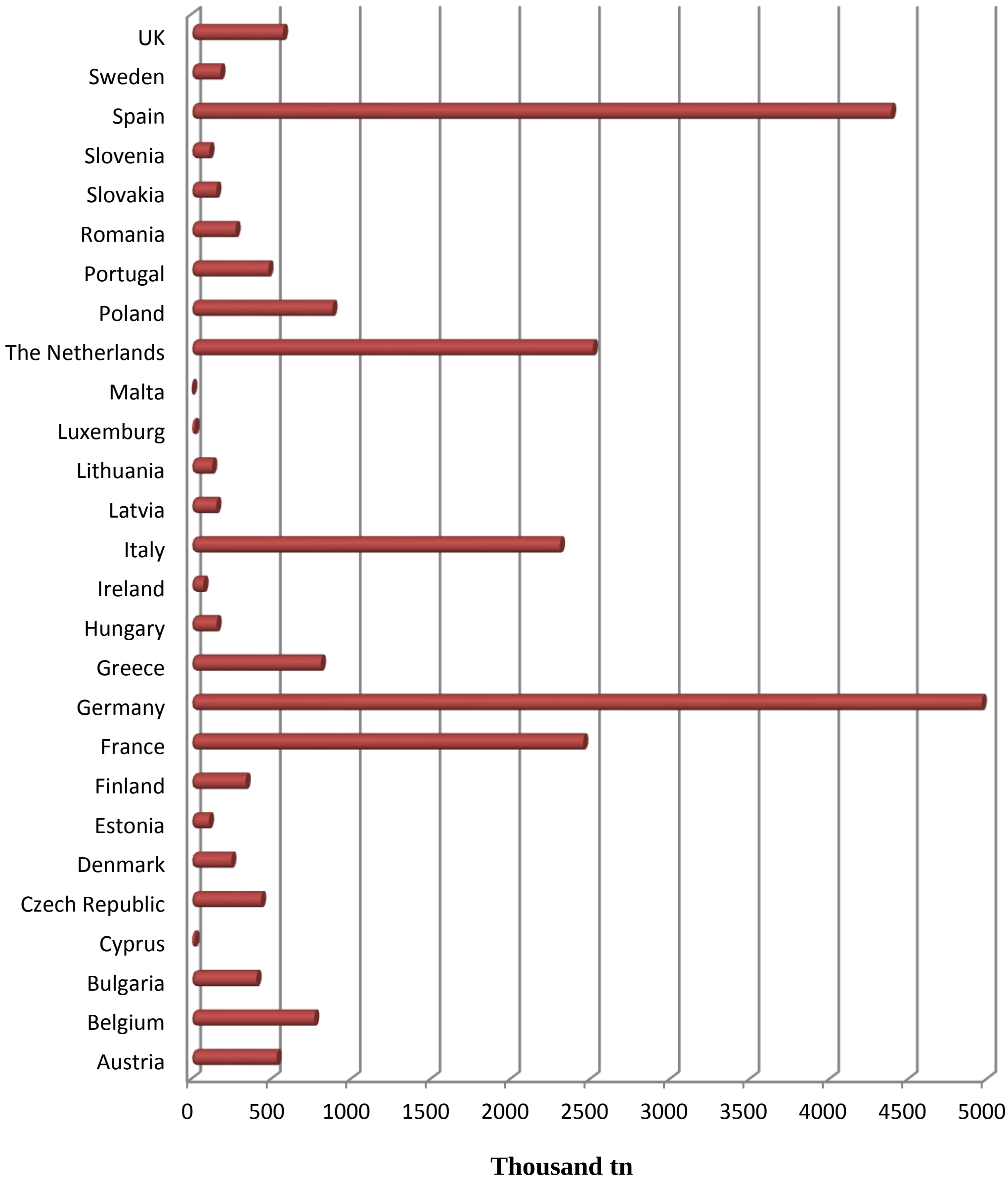


Figure 10: Biodiesel production of EU countries for the year 2012
(Data: http://www.ebb-eu.org/stats.php)

8.7 The Greek biodiesel market

It is a fact that the CO_2 emissions in Greece are elevated mainly because of the fuel used in the transport sector which are gasoline, diesel oil and jet fuel. Nevertheless, a strong interest in biofuels has been created as a result of the increased energy prices as well as the uncertainty of the future availability of oil supplies. In addition, Greece had to comply with the legislation of the European Union, although progress towards achieving the targets is low compared to the average of the member states.

It is beyond a doubt that biomass could play a significant role in achieving the 2010 national target of 20% electricity production from agricultural residues. Greece should form a political framework on biomass and biofuels to assess the availability of biomass and the amount that can be converted into energy projects. This is encouraged by the European target of 2010 that has been set by the European Union with the RES Directive 2001/77, as well as the corresponding 2020 target set by the RES Framework Directive (Sidiras, 2014).

Directive 2003/30 has been transposed through the Greek Act 3423/2005 on the introduction of biofuels and other renewable fuels on the Greek market. This legislation sets down a national indicative target of 5,75% for 2010. In addition, following the Law 3054/2002, the main biofuel for the Greek transport sector was biodiesel and bioethanol afterwards. Biodiesel production in Greece started in 2005 with 3.000 tonnes biodiesel produced by the Hellenic Biopetroleum, while the production soared to 43.000 tonnes the following year (CRES).

About 70% of the biodiesel agricultural feedstock including rapeseed and soybean oils is imported by Greek producers while the remaining 30% of raw materials like cottonseed and sunflower, is domestically produced. Additionally, used cooking oil and animal fats must be considered as they can play a major role to the domestic production of biodiesel.

A SWOT analysis of the Greek production of biodiesel conducted by the Centre for Renewable Energy Sources and Saving (CRES) is presented in the following table.

Table 12. SWOT Analysis of the Greek biodiesel production (CRES).

STRENGTHS	WEAKNESSES
✓ Beside a quite high and encouraging awareness about biodiesel among Greek citizens, Greece can count on diverse feedstock options: e.g. sunflower, rapeseed, soy and especially cotton (because of the flourishing Greek cotton industry). Biodiesel production capacities are very high. Uncertain policy framework (CAP reform) leads farmers to seek new cropping options. Another asset is represented by the establishment of some regional support for the first Biofuels Platform (in central Greece).	✓ Semi-arid climate conditions restrict yield potentials and lack of available cultivable land: average yields for rape and sunflower seed are about 1,75 tonnes/ hectare which is nearly half of the EU average. Oil yields of cotton seeds are low (about 325 liters of oil/ ha). Dry arid conditions prevailing in the country restrict yielding potential without irrigation. ✓ Small farming size and low yields prevent cost effectiveness; therefore most of the biodiesel plants rely on imports. It is estimated that only about 1/3 of the feedstock for biodiesel production may be supplied domestically. The current quota system does not create secure market conditions for investors. There is also an ongoing quality debate on biodiesel versus pure plant oil.
OPORTUNITIES	**THREATS**
✓ There is a need to identify low input supply options as part of land use strategies to cope with more stringent future restrictions (e.g. water restrictions, etc.). Optimization of the use of residues and processing of by-products could also be crucial to improve biodiesel economics. ✓ Increase biodiesel uses for heating applications may also provide more market opportunities. The introduction of a 'policy mix' with tax exemptions & mandatory targets will enable to create more certain market conditions.	✓ *Quality:* Variety of feedstock with different physical and chemical properties. ✓ *Market:* not well established, limited end uses (only transport sector in certain areas for certain end users) and inflexible production quotas. ✓ *Policy:* uncertainty deriving from the annual quota system and annual allocation of detaxation. ✓ *Sustainability:* careful selection of crops to minimize risks of erosion, water scarcity, etc. in the future supply chains. 9International trade: low cost supply from neighboring Balkan countries although this is also an opportunity for cheap raw materials use. ✓ *Awareness:* Create communication channels & synergies with the farming community.

Greek Refineries

According to the Greek Act 3423/2005, a disposal and final blending of biodiesel in the country's refineries must be made, as it is not indicated the direct trafficking of biodiesel to the market through fuel service stations. There are two refineries in Greece, the Hellenic Petroleum and Motor Oil Hellas.

- *Hellenic Petroleum:* The Group's primary activity is the refining sector, accounting for approximately 62% of the capital employed. In Greece, the Group holds approximately 65% of the Greek oil products wholesale market as it owns three out of the four refineries operating in the country. It also owns the sole refinery in Skopje, FYROM. The domestic refineries in Aspropyrgos, Elefsina and Thessaloniki cover approximately 65% of the country's total refining capacity, with a composite Nelson complexity index of 9.3. Their location (coastal refineries) and high complexity give them the competitive advantage of easy access to and processing of all types of crude oil that are available in the region. Moreover, the logistics infrastructure offers a storage capacity of 7 million m^3 of crude and products (http://www.helpe.gr/).
- *Motor Oil (Hellas):* Motor Oil refinery forms the largest privately held industrial complex in Greece and is considered as one of the most modern refineries in Europe. It has the ability to process crude oils of various characteristics and produce a full range of petroleum products, complying with the most stringent international specifications, serving major petroleum marketing companies in Greece and abroad. The Refinery production operations are located in Agii Theodori, in the province of Corinth, and covers approximately 30% of the country's refining capacity (http://www.moh.gr/).

Table 13. Percentages (%) of produced biodiesel supplied to the Greek Refineries to be mixed with diesel according to the regulations (Sidiras, 2014)

Year	MOTOR OIL (HELLAS)	ELPE SA
2006	24	75
2007	26	72
2008	27	73
2009	27	73
2010	33	67
2011	34	66

Greek biodiesel production units and importers

There are twenty biodiesel production units and importers in Greece where only two of them hold almost 42% of the produced/ imported quantity of biodiesel. Table 14 presents the biodiesel quantity distribution by the government as a duty to the Greek production companies for the year 2014.

Table 14. Biodiesel distribution in Greece, for the year 2014 (Government Gazette no. 2220, 2014)

No	Factories	Biodiesel (Thousand liters/ yr)	Participation percentage (%)
1.	AGROINVEST SA	28.307,42	21.28%
2.	BIODIESEL SA	903,933	0,68%
3.	AVIN	1.689,74	1,27%
4.	BIOENERGIA	3.152,50	2,37%
5.	BIODIESEL LTD	3.189,41	2,40%
6.	EL.VI ABEE	1.758,13	1,32%
7.	ELIN BIOFUELS SA	11.471,44	8,63%
8.	EPILEKTOS ENERGY SA	737,295	0,55%
9.	GF ENERGY ABEE	20.358,20	15,31%
10.	HELLENIC PETROLEUM SA	1.014,81	0,76%
11.	PETSAS SA	1.006,78	0,76%
12.	MANOS SA	6.640,93	4,99%
13.	MIL OIL HELLAS SA	6.640,93	4,99%
14.	MOTOR OIL (HELLAS) KORINTHOS REFINERIES SA	2.000,73	1,50%
15.	NEW ENERGY SA	10.436,84	7,85%
16.	NORTH GREECE EKKOKKISTIRIA KLOSTIRIA SA	720,956	0,54%
17.	PAYLOS PETTAS ABEE	28.007,53	21,06%
18.	REVOIL BIOFUELS SA	849,493	0,64%
19.	STAFF COLOR ENERGY ABEE	3.914,26	2,94%
20.	TAILORS CONSULTANTS & COLORS LTD	840,69	0,63%
	Total	**133.000**	**100.00%**

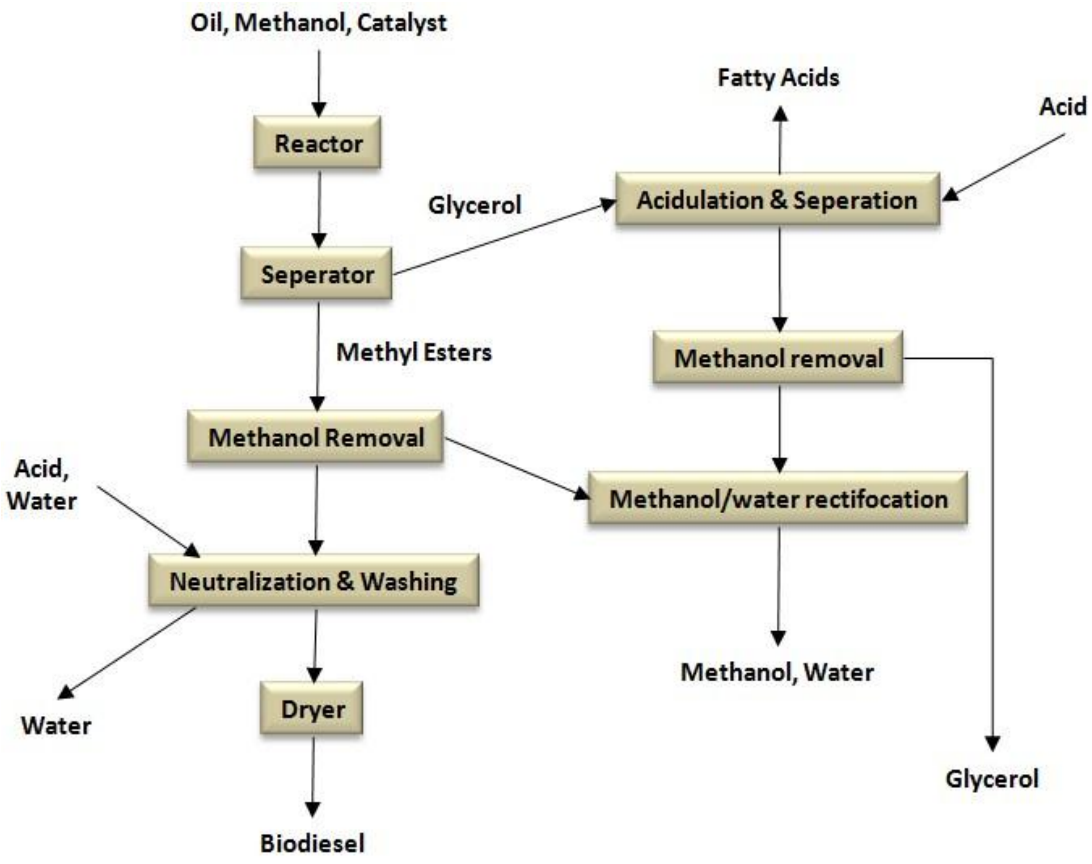


Figure 11. The flowchart of a typical Greek biodiesel factory

9. Assessment of the potential production of biofuels from agricultural residues in Greece.

9.1 Methodology Overview

9.1.1 Geographical Information Systems (GIS)

The importance of Geographic Information Systems (GIS) can hardly be overemphasized in today's academic and professional arena. Their importance remains steady due to their key coordinating principles, the specific techniques that have been developed for the management of spatial data, the specialized analysis methods which are of great importance for spatial data, as well as the special management issues arising from the operation of geographical information.

Many professionals and academics have been using GIS; urban and regional planners, civil engineers, geographers, spatial economists, sociologists, environmental scientists, criminal justice professionals, political scientists, and alike. Several case studies have been conducted in different parts of the world for several purposes. Regarding applications in the field of biofuels, some valuable examples are presented.

A study for the special distribution of biofuel crops in the European Union has been conducted by Hellman and Verburg, using a multi-scale, multi-model approach while the biofuel crops area at the national level were determined by a macro-economic model. (Sidiras, 2014). In addition, Nibick, Monnell and Zahao developed a GIS framework combining urban development data with solid classification data in order to determine the potential of biodiesel production according to the availability of urban marginal land. Another notable case study is the evaluation of technical potential of biodiesel and ethanol production from energy crops in Spain conducted with the use of GIS by Gomez et al in 2011. Last but not least, Ragaglini et al, made an assessment considering the viability for local biodiesel production from sunflower in Italy, in order to comply with the demands of the European Directives and also to meet the inland biodiesel requirements (Sidiras, 2014).

9.1.2 Information Sources

For the assessment of bioethanol and biodiesel production potential from 2000 to 2010, information was provided by the National Statistical Service of Greece for the purposes of this study. The cultivated area and the productivity of various crop species constitute the base information to begin the analysis (input data). The study was conducted according to a sectorial approach to handle (a) Kapodistrias administrative divisions, (b) cultivated areas, crop types and crop yields (c) differences in residue production, energy factors and availability of the various crop types, and (d) other variables, such as the logistics involved for harvesting, handling, storage and physicochemical characteristics.

For the estimation of the residual biomass according to crop productivity and cultivated area, as well as the biomass properties and energy factors, literature values have been used (Boukis et al., 2009; Rentizelas et al., 2009; Roinioti et al., 2012; Voivontas et al., 2001), cross-referenced with some recent data from the Agricultural

University of Athens (http://www.aua.gr) and the Centre for Renewable Energy Sources (http://www.cres.gr) (Papavangeli, Siontorou, Sidiras, 2015). Be noted that the production of crops measured in tones and the cultivable land in hectares.

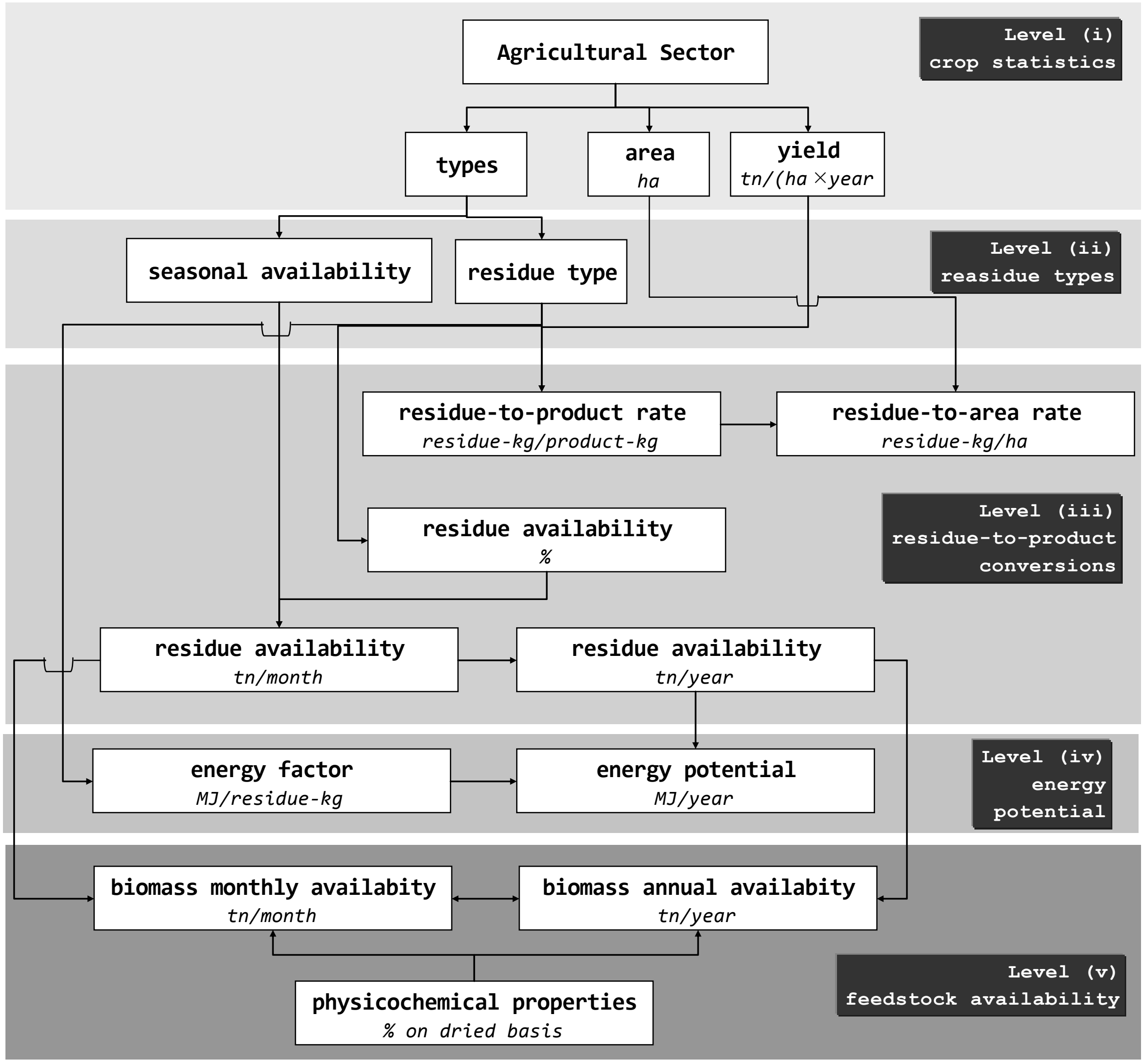


Figure 12. Overview of system's architecture for biomass to biofuels potential assessment.

9.1.3 Relational Database

The database developed for this study constitutes a decision-making tool, which aims to help the biofuel stakeholders making decisions regarding the type, the number, the location, as well as the capacity of biofuel production plants. Figure 12 presents the architecture of the database that has been used. Data processing was based on a five-level scheme including:

1. the creation of a statistical database with the cultivated areas and productivity of each biomass-producing species,
2. the identification and characterization of available biomass in each district in terms of crop types, harvest periods, and geographic allocation,
3. the conversion of crop production to residue generation and residue availability for each biomass species,
4. the computation of the energy potential according to the estimated amount of available biomass residues,
5. the merging of residual biomass types and species with physicochemical properties that are considered critical to both, processing and biofuel quality: lipids, volatiles, moisture, lignocellulosics, etc. (Bergthorson and Thomson, 2015).

The residue-to-product rates, the energy factors, and the availability factors per species used for conducting the results, are presented in Tables 15, 16 and 17.

Table 15. Residue-to-product rates per biomass-producing cultivated species in Greece

	Species	Residue Rate (kg of residue per kg of product)						
		Straw	*Wood*	*Tops*	*Cobs*	*Hull/Pod*	*Cake/Pulp*	*other*
Herbaceous	Barley	1.30				0.10		
	Cotton	1.00				0.20	0.30	0.10
	Maize	1.50			0.30			
	Oat	1.40						
	Rice	0.90				0.30		
	Rye	1.50						
	Soya	1.30			0.20			
	Sugar beet			0.10			0.06	0.02
	Sunflower	1.80			1.00	0.20	0.50	
	Wheat, hard	0.90				0.40		
	Wheat, soft	0.90				0.40		
Horticultural	Beans	0.50				0.10		
	Potato	0.20						
	Vegetables			0.10				
	Water melon			0.40				
Pomol ogical	Dry fruit		0.20			0.20		
	Citrus trees		0.30				0.10	

	Fruit trees		0.30					
	Groundnut	2.70				0.20		
Ornamental	Grape, edible		0.30					
	Grape, for wine		0.30				0.10	
	Olive, edible		0.50					
	Olive, for oil		0.50				0.40	0.10

Table 16. Energy factors per biomass-producing cultivated species & residue in Greece.

	Species	**Energy factor (MJ per kg of residue on dried basis)**						
		Straw	*Wood*	*Tops*	*Cobs*	*Hull/Pod*	*Cake/Pulp*	*other*
Herbaceous	Barley	15.80				15.80		
	Cotton	12.76				12.76	12.76	12.76
	Maize	16.70			19.20			
	Oat	15.80						
	Rice	14.50				15.10		
	Rye	17.40						
	Soya	15.80			15.80			
	Sugar beet			16.70			16.70	16.70
	Sunflower	16.70			16.70	16.70	16.70	
	Wheat, hard	16.00				16.00		
	Wheat, soft	16.00				16.00		
Horticultural	Beans	16.40				16.40		
	Potato	16.70						
	Vegetables			16.70				
	Water melon			14.20				
Pomological	Dry fruit		17.60			18.80		
	Citrus trees		13.64				17.60	
	Fruit trees		13.64					
	Groundnut	16.70				16.70		
Ornamental	Grape, edible		18.90					
	Grape, for wine		18.90				18.90	
	Olive, edible		18.10					
	Olive, for oil		18.10				15.70	15.70

Table 17. Availability factors per biomass-producing species and residue in Greece

	Species	Availability factor (kg of available residue per kg of residue)						
		Straw	*Wood*	*Tops*	*Cobs*	*Hull/Pod*	*Cake/Pulp*	*other*
Herbaceous	Barley	0.15				0.15		
	Cotton	0.60				0.60	0.60	0.60
	Maize	0.30			0.30			
	Oat	0.15						
	Rice	0.25				0.25		
	Rye	0.15						
	Soya	0.80			0.80			
	Sugar beet			0.90			0.90	0.90
	Sunflower	0.90			0.90	0.90	0.90	
	Wheat, hard	0.15				0.15		
	Wheat, soft	0.15				0.15		
Horticultural	Beans	0.80				0.80		
	Potato	0.90						
	Vegetables			0.90				
	Water melon	0.30			0.30			
Pomological	Dry fruit		0.90			0.90		
	Citrus trees		0.90				0.90	
	Fruit trees		0.90					
	Groundnut	0.90				0.90		
Ornamental	Grape, edible		0.90					
	Grape, for wine		0.90				0.90	
	Olive, edible		0.90					
	Olive, for oil		0.90				0.50	0.50

9.1.4 The GIS-Based Management Application

For the needs of this study, the regional database for Greece has been constructed on digital maps of land cover overlaid with the map of rivers and roads provided by Marathon Data Systems (http://www.marathondata.gr). The database joined with these GIS layers, initially with statistics for cultivated areas and types of cultivation for each year within the study period. The colour gradations of the maps show the rates of crop production and yields by area. Lighter colours represent lower rates while the more intense shades represent the highest rates respectively.

The GIS software used was ArcMap (ArcInfo) version 10; in this version, ArcMap has the ability to directly extract data from the database through an OLE DB provider interface, such as Jet Database 4.0. Many thematic maps can be created by combining data treatment levels, such as residues yields, potential and distribution for a specific year, region, or crop type.

In the following chapters, calculations concerning the bioethanol and biodiesel production capability for the decade 2000-2010 are separately presented and analyzed.

9.2 Potential biomass residues for bioethanol production

9.2.1 Crops production and yield per hectare

As referred to previous chapter, 1st generation bioethanol can be produced by wheat, maize, barley, sugar beet, potato, sweet potato, sugar cane and sweet sorghum. In the present study, the first five crops from those referred have been studied for the period 2000-2010. Note that soft wheat and hard wheat have been studied separately as they are separately cultivated in Greece.

9.2.1.1 Maize

According to Figure 13, maize is mostly cultivated in northern and eastern Greece. To be more precise, the highest maize production in 2000 was in Evros with 188.773 tonnes while Kavala and Ilia where the next in line. Although, in 2010 the production in Evros is much lower with only 25.889 tonnes. Serres holds the highest maize production rate for 2010, with 254.461 tonnes, followed by Kavala. However, the country’s total maize production from 2000 to 2010, increased by 3,1%.

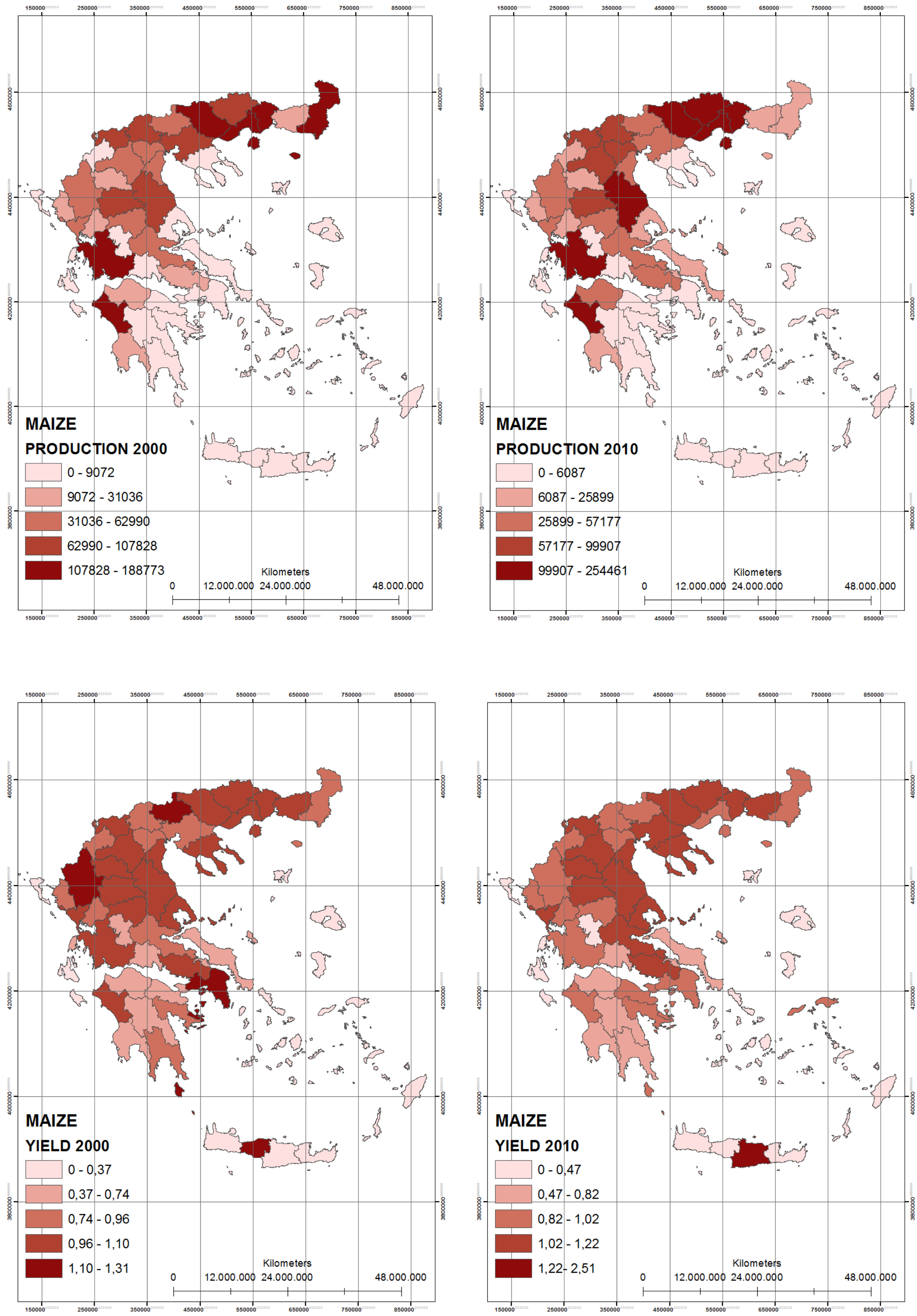


Figure 13. GIS maps for 2000 and 2010 maize production and yield

Figure 14 presents the fluctuations in production of maize within the decade. As can be noted, maize mostly cultivated in 2008 where the production was 2.813.952 tonnes. More specifically, the production in Evros was 195.240 tonnes, in Kavala 214.182 tonnes and in Serres 316.216 tonnes (Figure 16). On the other hand, in 2000 and 2010 the lowest production rate has been noted, with 2.069.035 and 2.033.302 tonnes respectively. From 2008 to 2010 the maize production plummeted while the previous years have been many ups and downs.

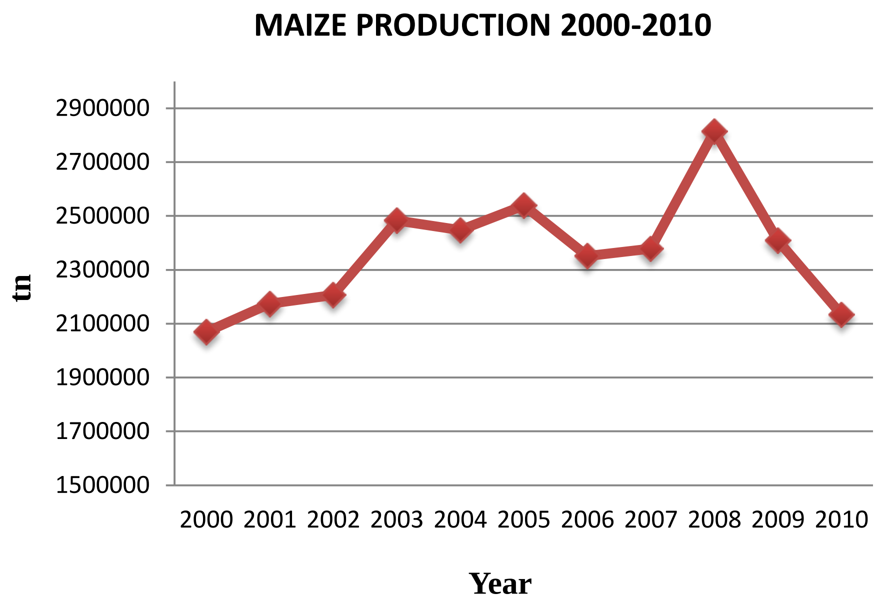


Figure 14. Maize production from 2000 to 2010

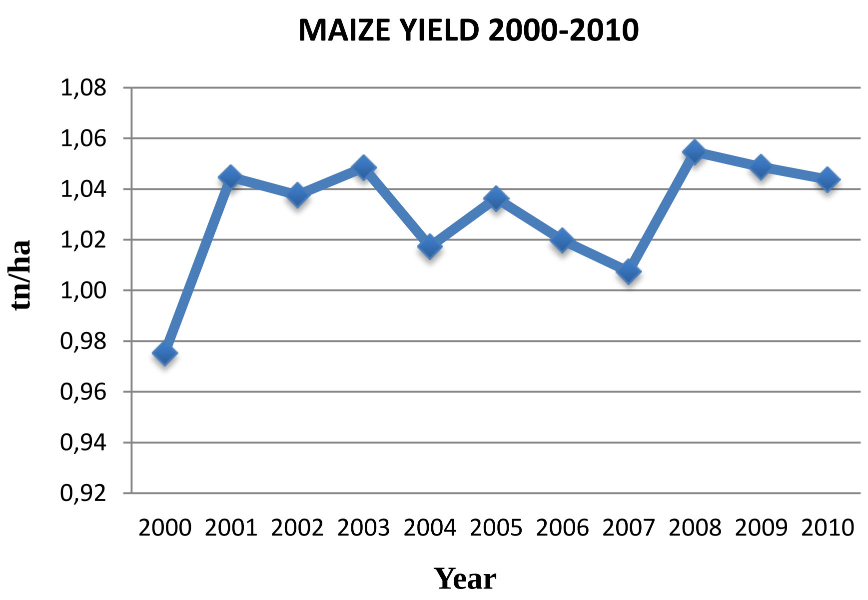


Figure 15. Maize yield from 2000 to 2010

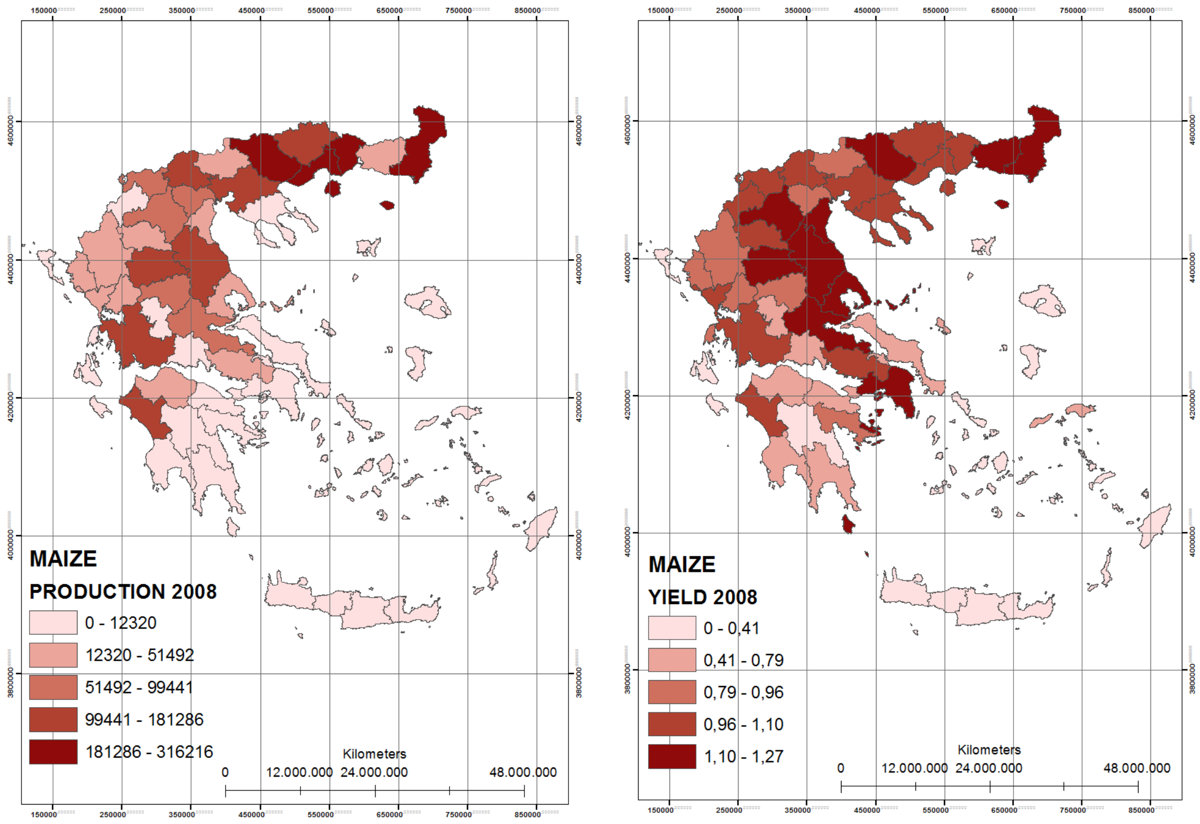


Figure 16. GIS maps for maize production and yield for the year 2008

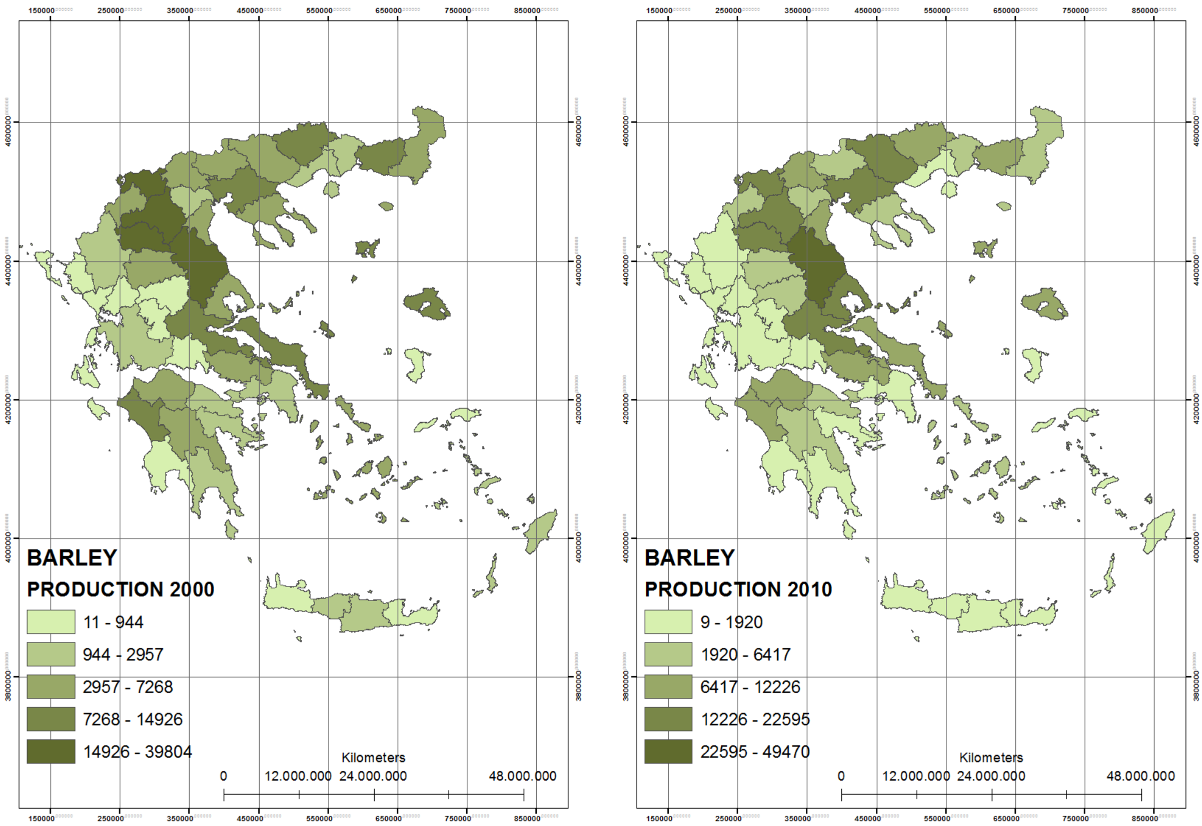
As far as maize yield per hectare is concerned, there are many differences between 2000 and 2010 (Figure 13). The highest yield for 2000 was 1,31 tn/ha in Rethymno followed by Kilkis and Attiki with 1,21 tn/ha and 1,14 tn/ha respectively. In 2010, Iraklio had the highest yield of about 2,51 tn/ha, followed by Attiki, while the maize yield in Rethymno and Kiklis, decreased by 80,9% and 26,5% respectively. However, the total maize yield per hectare between 2000 and 2010 increased by 6,12%.

According to Figure 15, the yield of maize had many ups and downs within the decade. For accuracy, the lowest yield was 0,98 tn/ha in 2000, while the next year increased by 5,76%. From 2001 to 2007 the maize yield fluctuated almost every year. The highest rate has been noticed in 2008 where it was about 1,05 tn/ha yield. Concluding, the yield per hectare of maize in 2010 was very high compared with the general picture of the decade, of around 1,04 tn/ha.

9.2.1.2 Barley

The total production of barley in the beginning of the studied period was 292.155 tonnes. As illustrated in Figure 17, barley mostly cultivated in Larisa with 39.804 tonnes production in 2000 followed by Grevena with 27.812 tonnes as well as Kozani and Florina with 23.293 and 22.012 tonnes of barley produced respectively. On the other hand, in 2010, the country's total produced amount of barley increased by 7,16%, compared to 2000. Additionally, the production in Florina and Kozani remained almost constant, while in Larisa rose up by 19,5% and in Grevana went down by 39,1%.

The general development of barley's production in Greece during the period 2000-2010, is shown in Figure 18. The largest production observed in 2008 where the production amounted to 354.515 tonnes of barley. In more detail, as illustrated in Figure 20, barley production was 45.968 tonnes in Larisa, 27.507 tonnes in Grevena while in Kozani and Florina was 26.032 and 25.505 tonnes respectively.



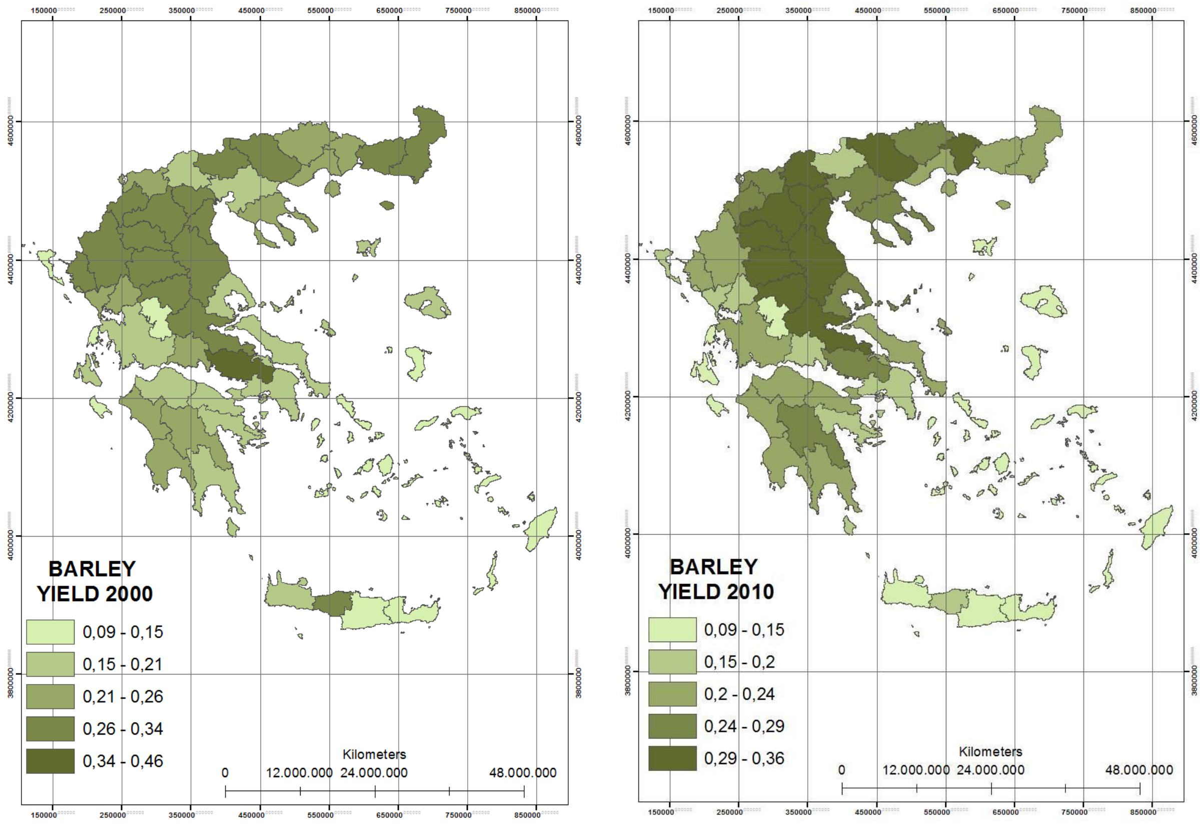


Figure 17. GIS maps for 2000 and 2010 barley production and yield

On the other hand the lowest barley production occurred in 2003 where the produced amount was 227.221 tonnes. In addition, the production between 2000 and 2002 had slight fluctuations, while in 2003 fell by almost 20%. From 2005 to 2008, barley production showed a steady upward trend, and by 2010 had decreased by 13.2%.

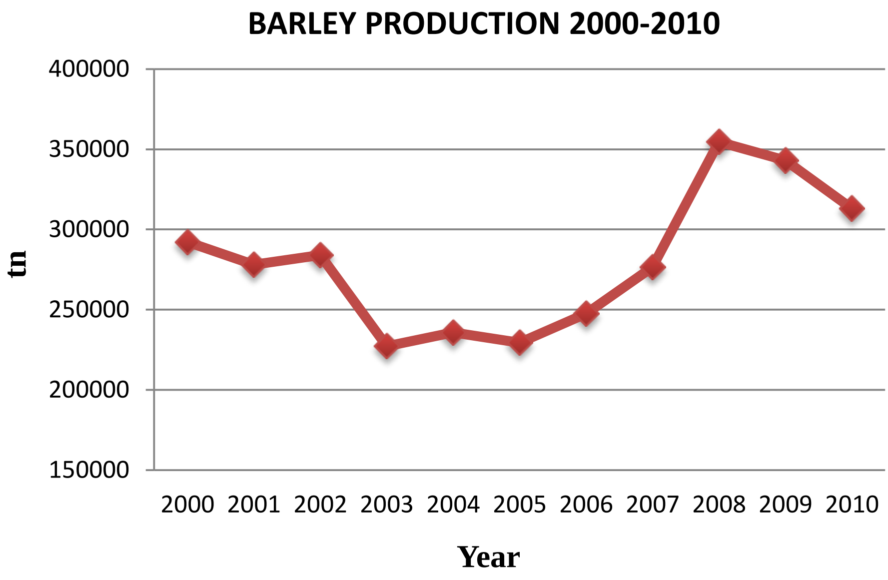


Figure 18. Barley production from 2000 to 2010

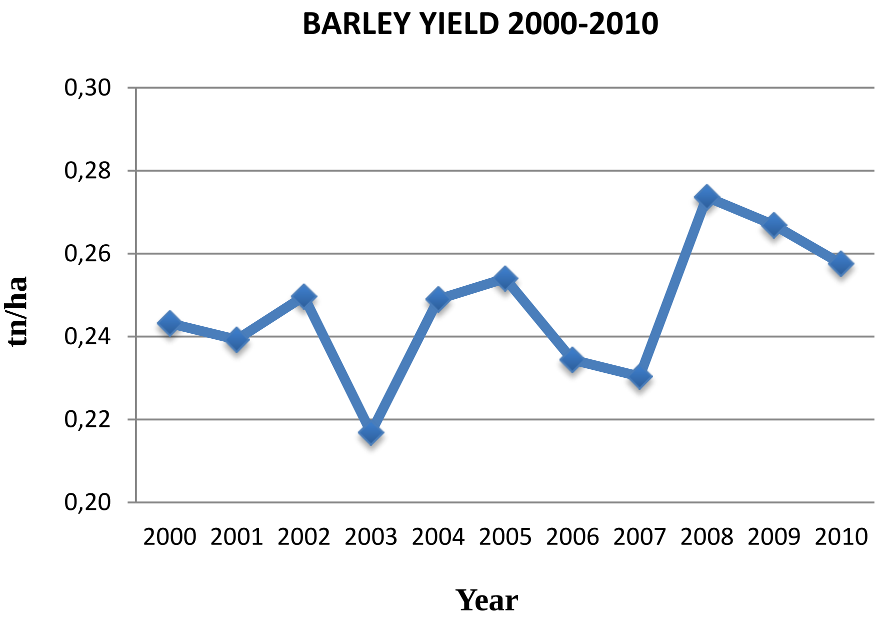


Figure 19. Barley yield from 2000 to 2010

Regarding barley's yield per hectare, as stated in Figure 17, there was about 0,24 tn/ha total yield in 2000, while in 2010 was 0,26 tn/ha. More specifically, the highest yield in 2000, was 0,46 tn/ha in Viotia, followed by Larisa and Kozani with 0,34 tn/ha and 0,31 tn/ha respectively. However, the highest yield of barley in 2010, appeared to be in Pella where it was 0,34 tn/ha, followed by Larisa with 0,33 tn/ha. Generally, the country's barley yield per hectare from 2000 to 2010 rose by 8,33%.

As it is clearly illustrated by Figure 19, the barley's yield per hectare in Greece during the decade, ranged between 0.22 tn/ha and 0.27 tn/ha. The greatest change is observed between 2002 and 2004, where the yield of barley varied from 0.25 tn/ha in 2002 to 0.22 tn/ha in 2003 and increased again to 0.25 tn/ha in 2004. Moreover, another big change has been noticed between 2007 and 2008 where the yield went up by 14,8%.

The highest barley yield per hectare was in 2008 while the lowest in 2003. In more detail, the greatest barley yield for 2008 was 0,38 tn/ha in Karditsa, followed by Imathia and Trikala (Figure 20).

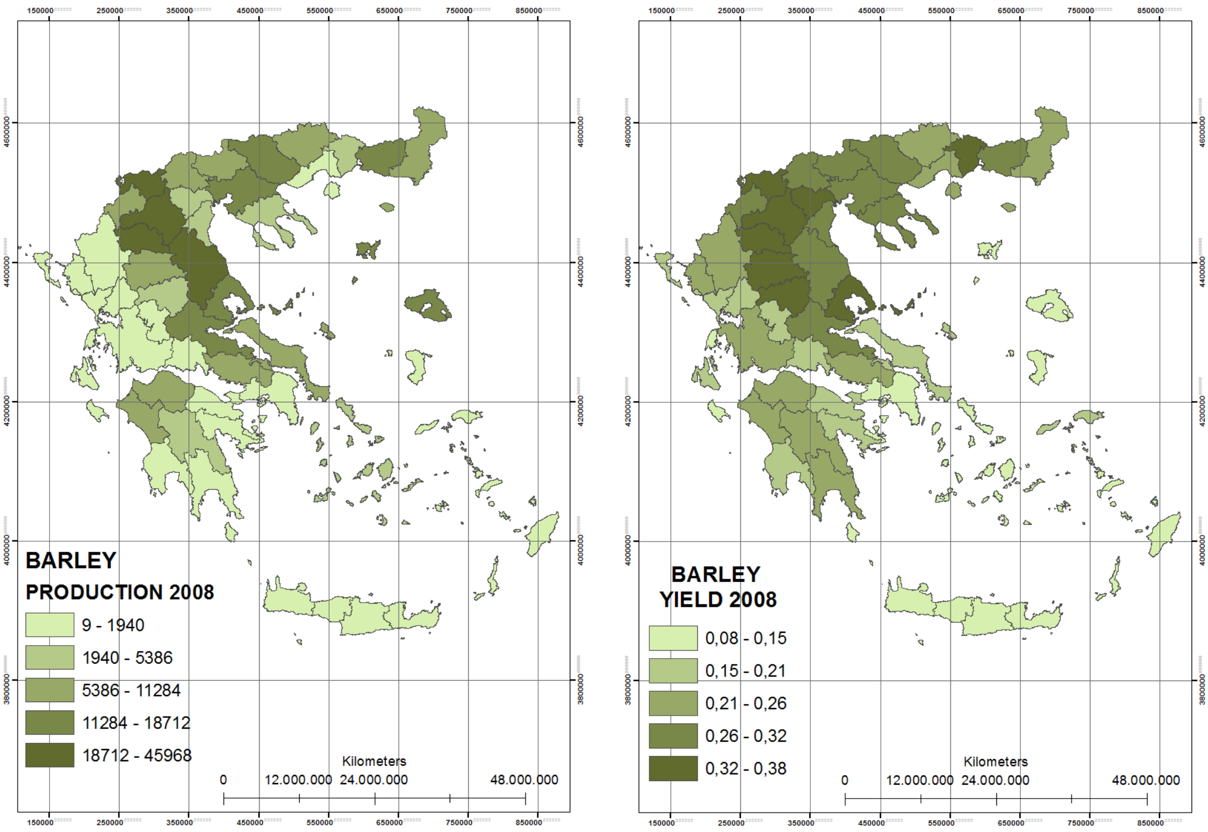


Figure 20. GIS maps for barley production and yield for the year 2008

9.2.1.3 Hard Wheat

In 2000, the total amount of hard wheat produced was about 1.823.067 tonnes, while by 2010 had plummeted by 17,47%. According to Figure 21, the biggest production of hard wheat in 2000 noted in Larisa, where it was about 304.302 tonnes, followed by Evros with 222.116 tonnes. Correspondingly, the greatest amount of hard wheat produced in 2010 was 305.713 tonnes in Larisa, while the produced hard wheat in Evros decreased to 86.902 tonnes.

If one examines Figure 22 will notice that the year with the highest production of hard wheat was 2000. Nonetheless, the years 2001, 2002 and 2005 had also experienced a high rate of production, and fluctuated between 1.721.200-1.771.600 tonnes. On the other hand, from 2004 to 2007, the production dropped by 25,35%. It is worth to be mentioned that 2007 was the year with the lowest production with 1.193.932 tonnes of hard wheat produced. However, the cultivation of hard wheat seems to picked up fast after 2007, possibly due to the bilateral trade agreement with Russia, exhibiting an annual increase or 9,1% on hard wheat production.

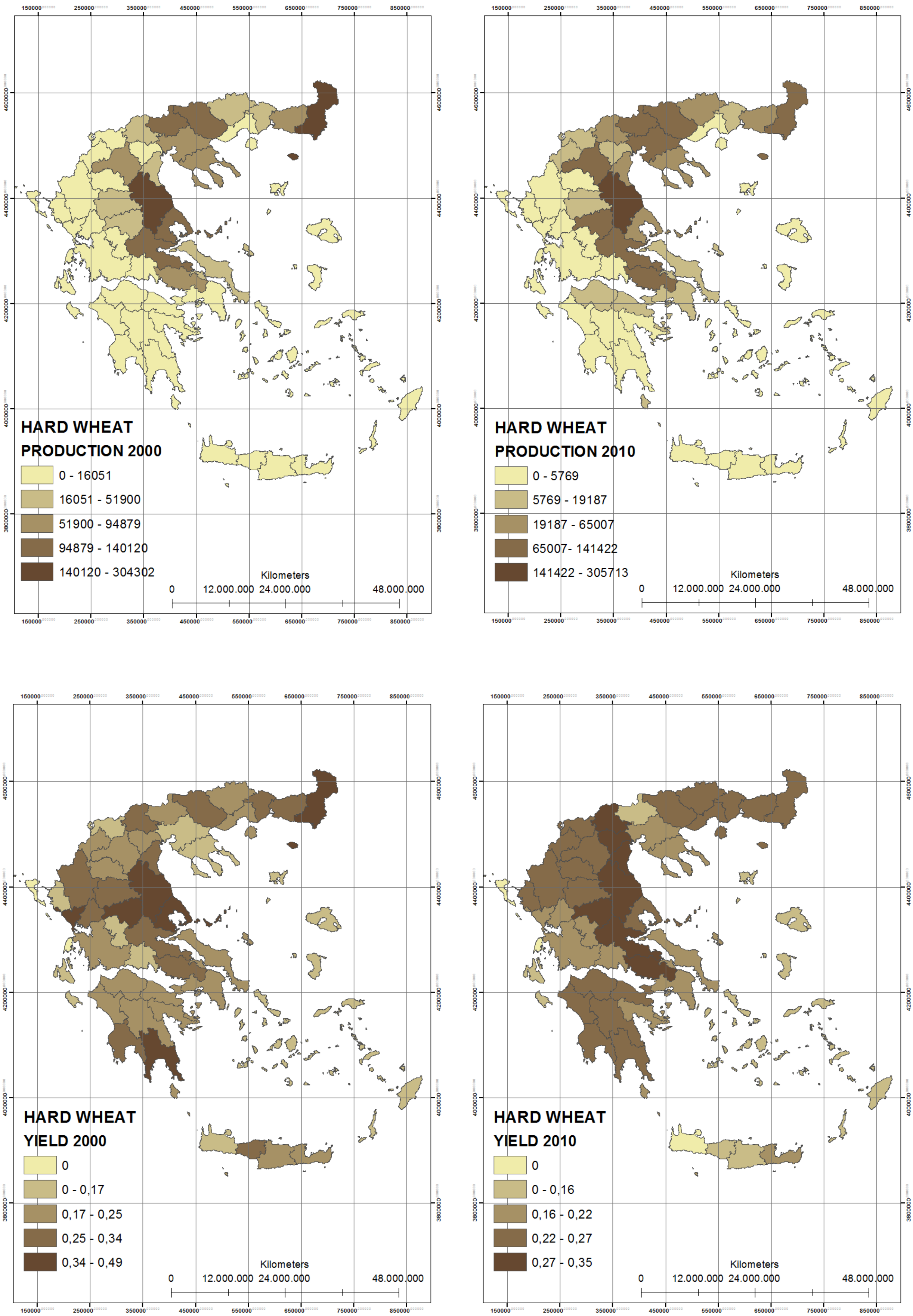


Figure 21. GIS maps for 2000 and 2010 hard wheat production and yield

Regarding the per hectare yield of this particular crop, it was about 0,27 tn/ha in 2000 while in 2010 was 0,26 tn/ha. As one can conclude by the yield map of 2000 in Figure 21, the Magnissia Prefecture held the highest yield which was about 0,49 tn/ha. Larisa and Preveza were next in line with 0,40 tn/ha, followed by Lakonia with 0,39 tn/ha. Respectively, the greatest yield per hectare for the year 2010 was about 0,35 tn/ha in Karditsa, followed by Larisa, Pella and Viotia where the yield was about 0,34 tn/ha.

If one examines the overall trend of hard wheat yield in Greece for the period 2000-2010 can notice that the lowest yield was in 2003 (0,20 tn/ha), while the highest was in 2000 (0,27 tn/ha). It is worth noting that the greatest fluctuations took place between 2002 and 2003 where the yield fell by 27.2%, as well as between 2007 and 2008 where there was an increase in yield per hectare of hard wheat by 21.3%. All the aforesaid are presented in Figure 23.

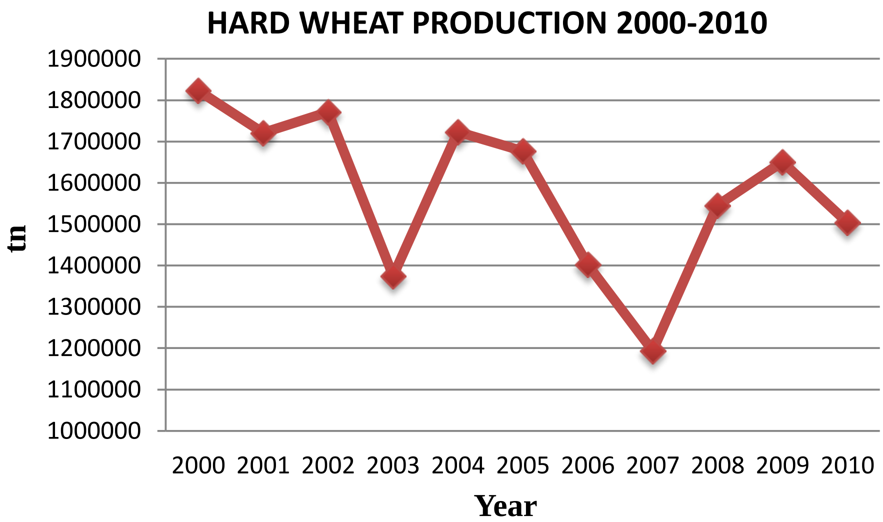


Figure 22. Hard Wheat production from 2000 to 2010

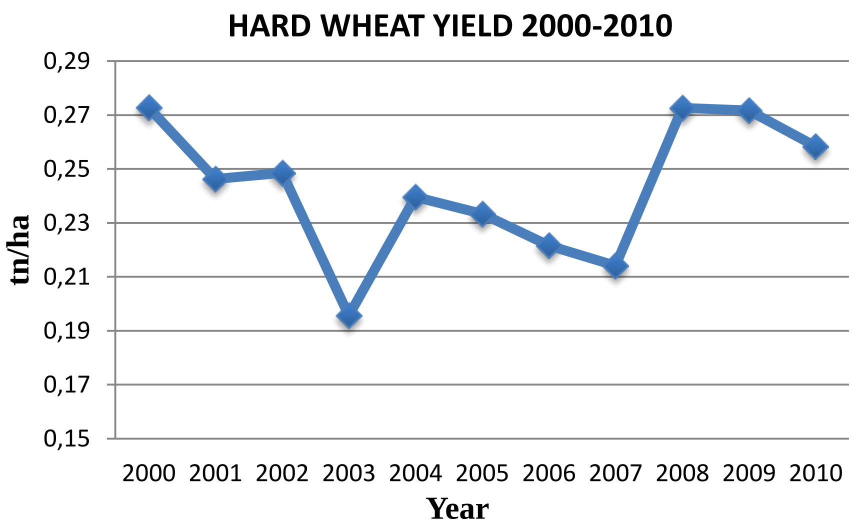
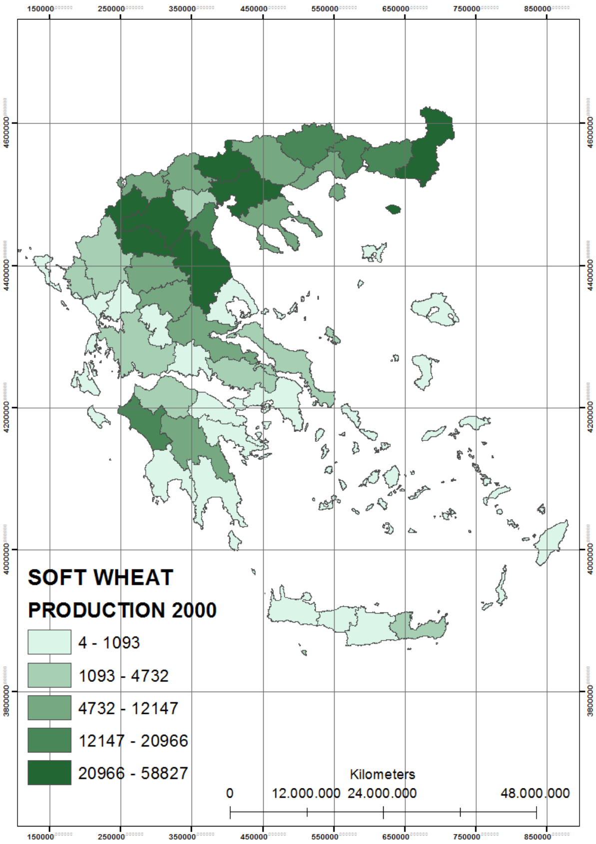
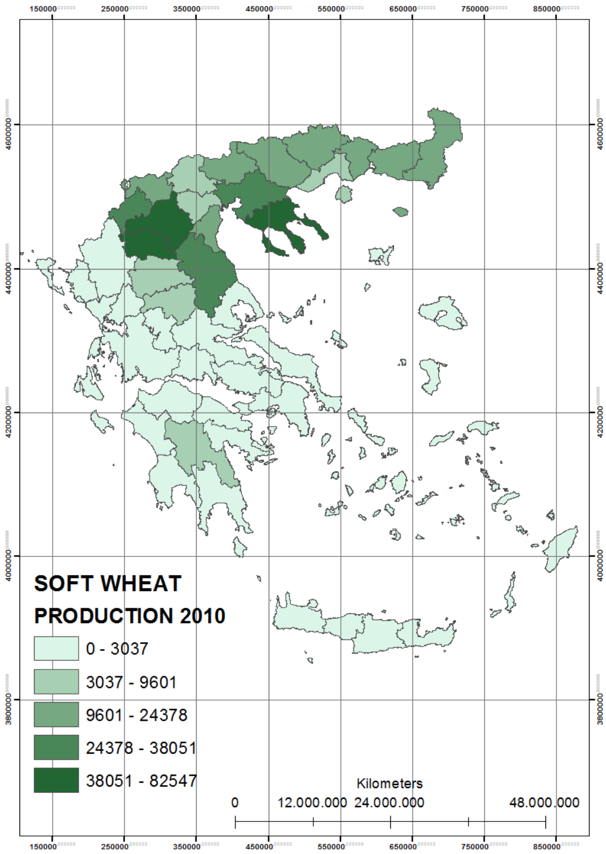


Figure 23. Hard Wheat yield from 2000 to 2010

9.2.1.4 Soft Wheat

The total production of soft wheat at the beginning of the studied period was 502.765 tonnes. As it is clearly illustrated by Figure 24, soft wheat mostly cultivated in Macedonia and Thaki. In more detail, the highest soft wheat production was 58.827 tonnes in Grevena, followed by Kozani and Evros where the produced amount of soft wheat was 58.494 and 53.001 tonnes respectively. One the other hand, Chalkidiki held the first place in 2010, as the production of soft wheat was about 82.547 tonnes. In Kozani and Grevena the production was 52.852 and 52.699 tonnes respectively, while the produced soft wheat in Evros decreased by 63,72%.





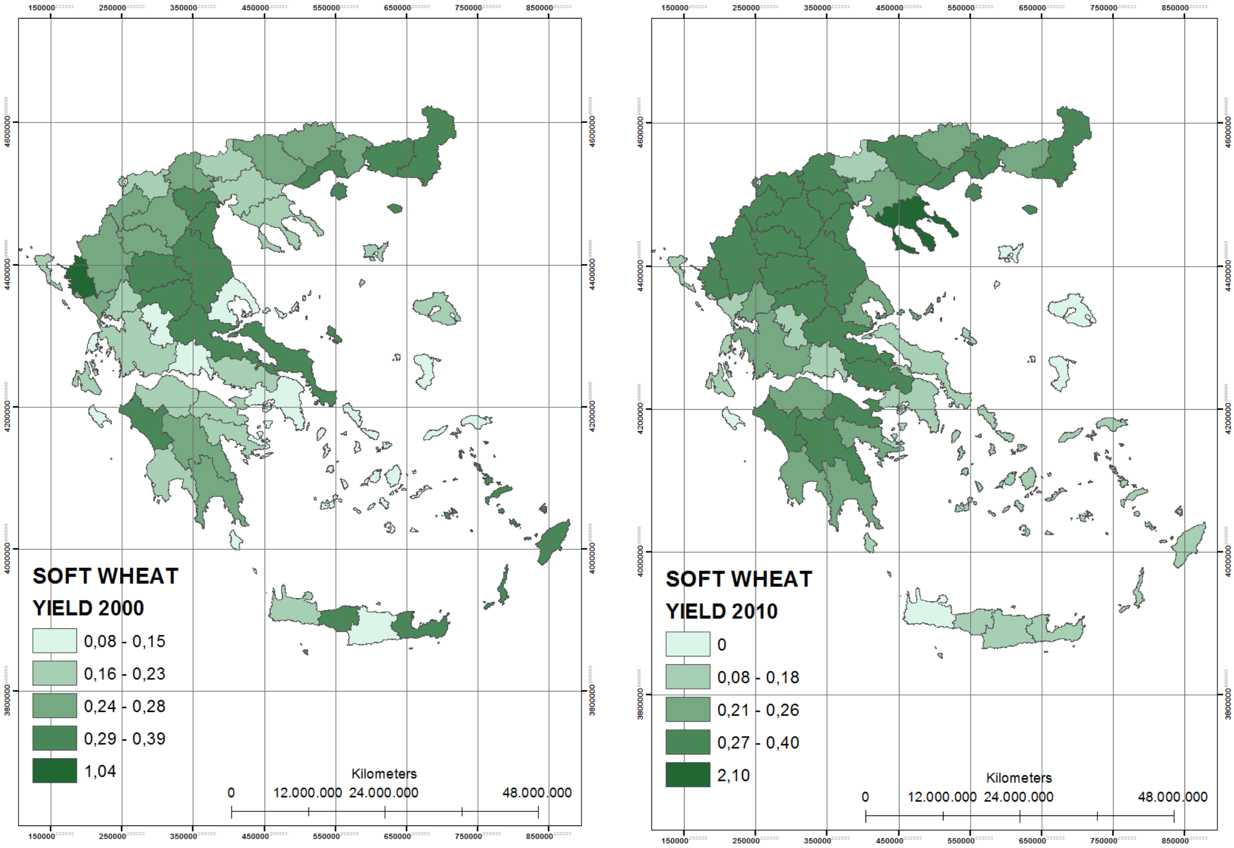


Figure 24. GIS maps for 2000 and 2010 soft wheat production and yield

Taking into consideration the results in Figure 25, the year with the highest production was 2008, where the produced amount was about 536.995 tonnes. More specifically, once again Grevena, Kozani and Evros have the greatest output (Figure 26). The production in Kozani was 63.026 tonnes, while in Grevena was 61.918 tonnes, followed by Evros where the produced soft wheat was 58.206 tonnes. Correspondingly, the year with the minimum production was 2003, where the produced quantity was 327.220 tonnes, 64,11% less than that of 2008.

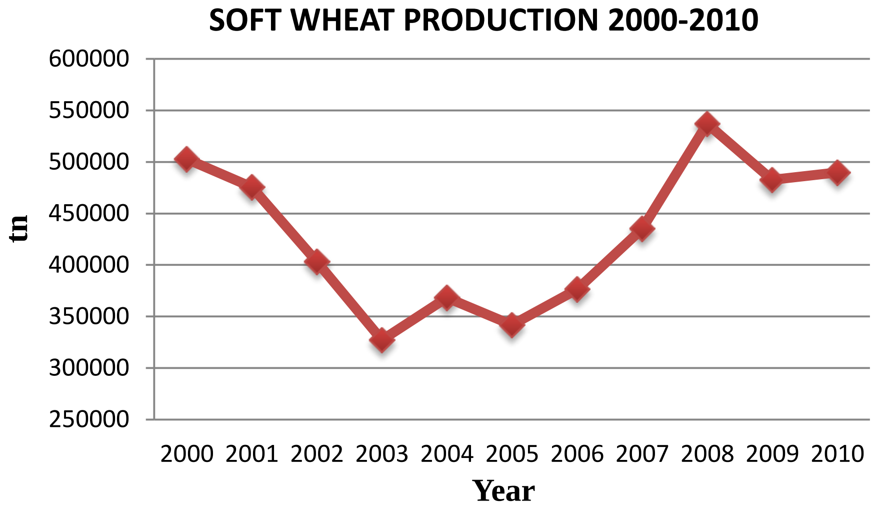


Figure 25. Soft Wheat production from 2000 to 2010

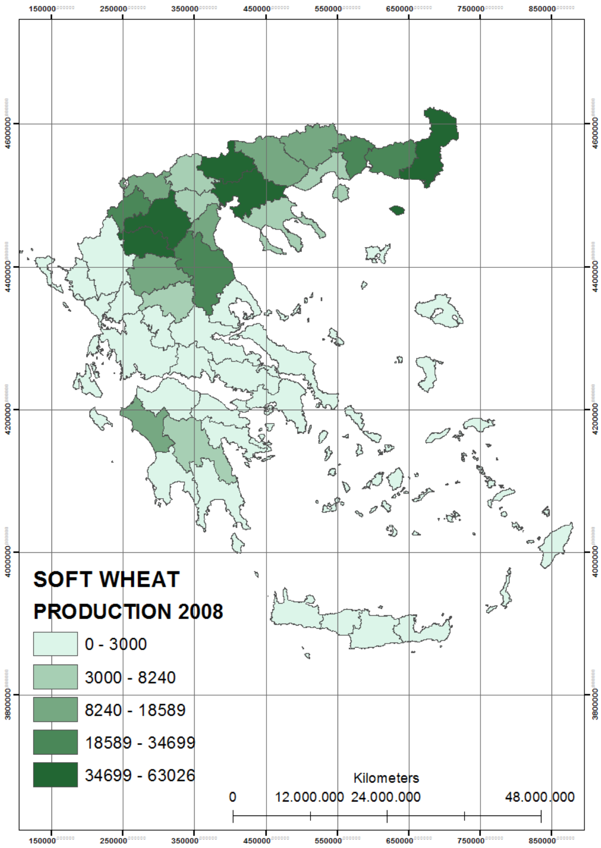


Figure 26. GIS map for soft wheat production for the year 2008.

The main changes within the decade were the continuous decline that took place from 2000 to 2003 which was around 53,65%. Moreover, important was the continuous increase between 2005 and 2008 of about 36,35%. Finally, in 2009 a slight decrease has been observed of about 11,26% and then the production of soft wheat increased again to 489.755 tonnes produced.

The yield per hectare of soft wheat at the beginning of the decade was 0.27 tn/ha. More specifically, as shown on the corresponding map of Figure 24, the greatest yield per hectare is located on the eastern Greece and particularly in Thesprotia where it was 1.04 tn/ha. The next areas are Fthiotida with 0.35 tn/ha as well as Kavala, Karditsa and Rethymno with a yield of 0.34 tn/ha. In 2010 the yield per hectare of soft wheat was higher by 18,51%. Halkidiki had by far the largest yield of soft wheat, reaching 2.10 tn/ha. Other areas with high yield per hectare was Thesprotia and Imathia which had 0,40 tn/ha and 0,38 tn/ha respectively.

Observing Figure 27, one can notice that the greatest yield per hectare of soft wheat was in 2010 where it was 0.32 tn/ha, while the lowest was in 2003 where it was about 0,23 tn/ha. As indicated in the graph, the yield fluctuated almost every year. However, the biggest change observed was between 2004 and 2005 where a rise in yield of about 22.78% took place, as well as from 2005 to 2006 where there was a reduction of about 26.1%.

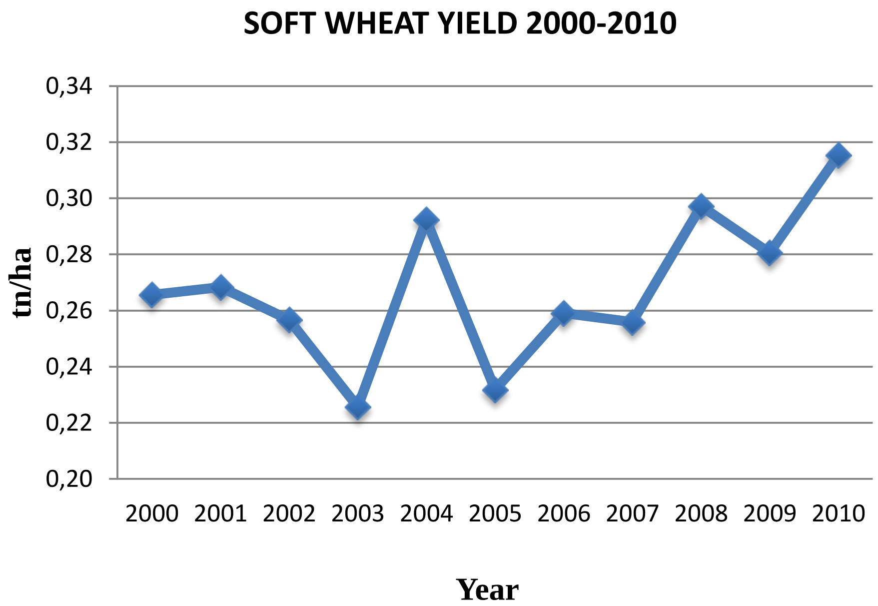
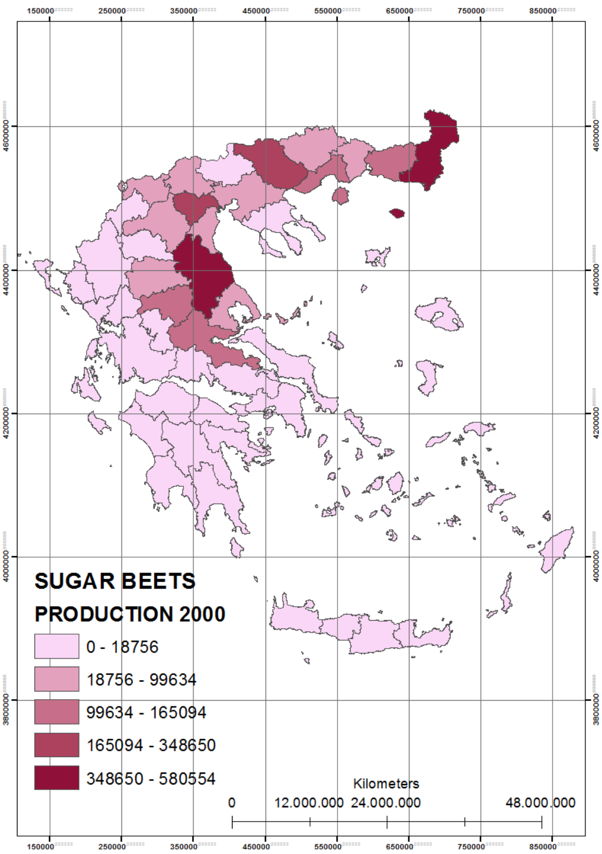


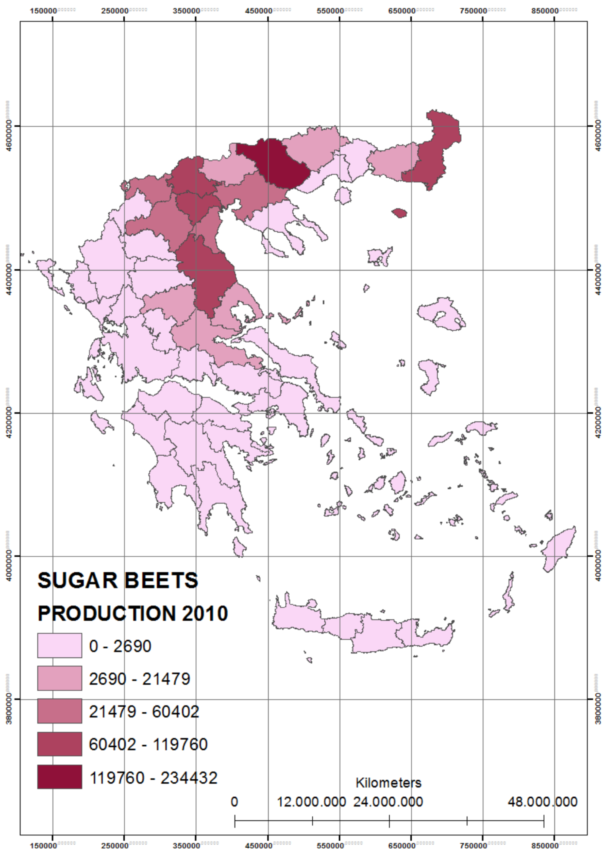
Figure 27. Soft wheat yield from 2000 to 2010

9.2.1.5 Sugar beet

As discussed in a previous chapter, sugar beet is one of the most important crops the production of bioethanol. As shown in Figure 28, sugar beet mainly cultivated in the northern part of the country and in particular only in Macedonia, Thrace and Thessaly. The largest sugar beet production in 2000 was held in Larissa, where

580.554 tonnes have been produced. Additionally, a considerable quantity of around 564.865 tonnes noted in Evros, followed by Serres with 348.650 tonnes. The production of sugar beet in 2010 was 70,5% less than that of 2000. The largest production took place in Serres and it was 234.432 tonnes. The produced amount of sugar beet in Evros dropped to 115.304 tonnes, while in Larissa sharply decreased to 78.585 tonnes. A striking example that is worth to be mentioned is the case of Xanthi (Figure 29), which had a considerable sugar beet production by 2006. In 2007 the production of sugar beet has been terminated and started again in 2008. This seems to be due to the reform of the sugar CMO, decided under the Common Agricultural Policy, in November 2005.





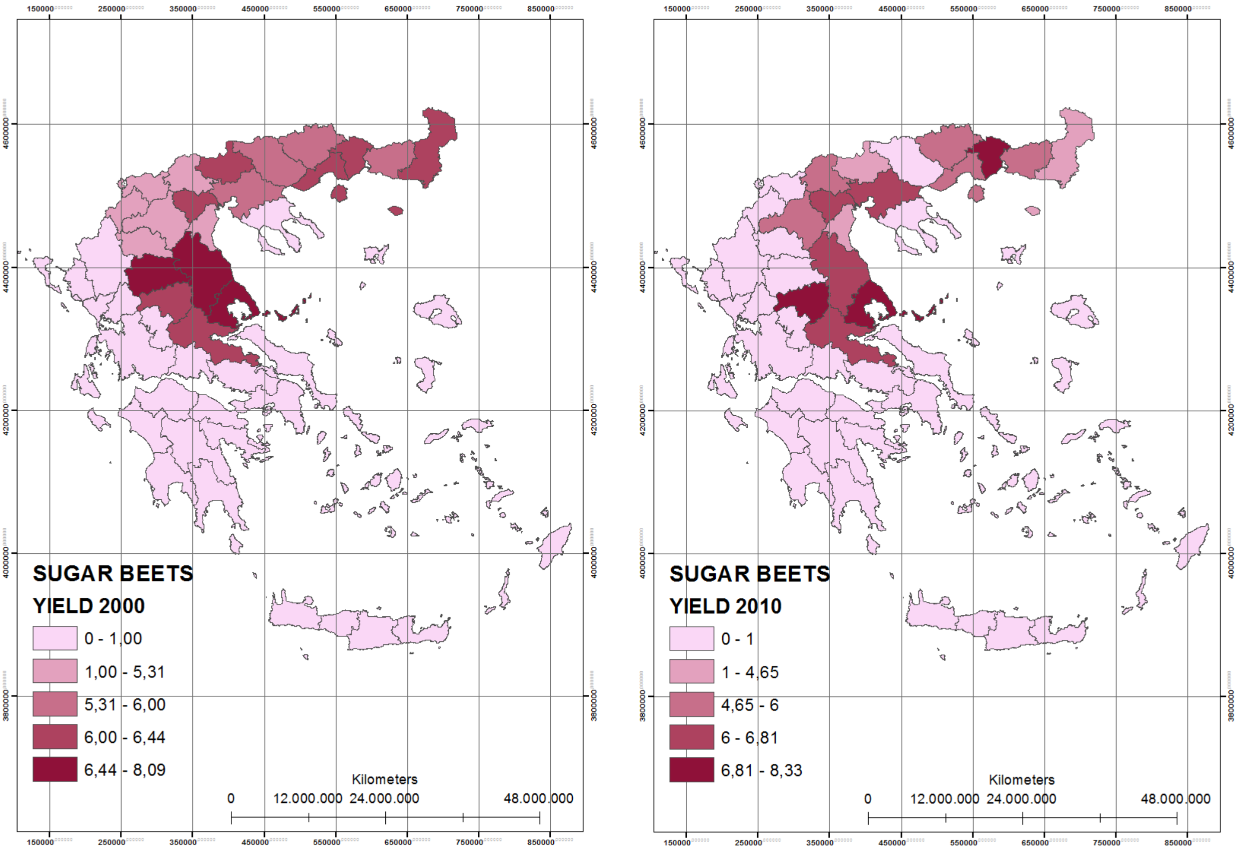


Figure 28. GIS maps for 2000 and 2010 sugar beet production and yield.

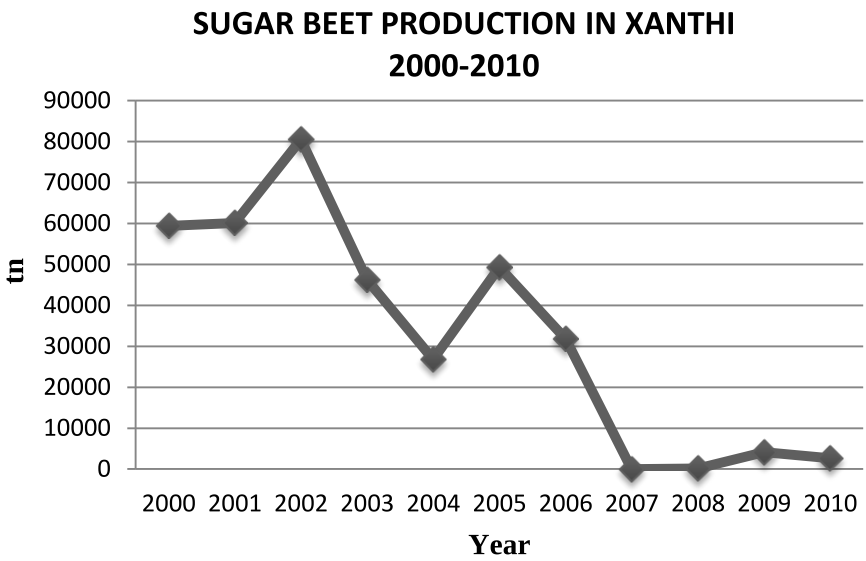


Figure 29. Sugar beet production in Xanthi from 2000 to 2010

The overall trend of sugar beet production in Greece during the decade 2000-2010, is shown in Figure 30. As it is clearly illustrated, the highest production was held in 2000 where the production was 3.010.334 tonnes, while the lowest amount has been produced was 816.308 tonnes in 2008. The biggest change that occurred within the study period was between 2005 and 2007, where the produced quantity of sugar beet fell from 2.603.071 tonnes to 816.308 tonnes. The following year, a significant increase of 72.64% was observed, but in 2010 fell again to 889.402 tonnes.

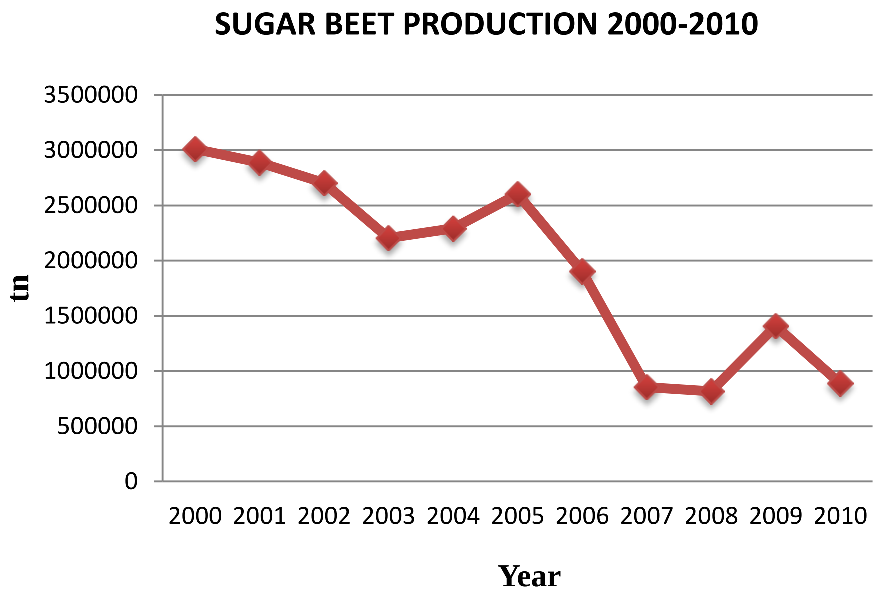


Figure 30. Sugar beet production from 2000 to 2010

Regarding the yield of sugar beets per hectare in Greece, it is shown in Figure 31. The yield per hectare of the crop was 6.27 tn/ha in 2000, while the highest yields are observed mainly in the central and northern Greece. More specifically, the greater yield held by Trikala where it was 8,09 tn/ha, followed by Larissa and Magnisia with 7.40 tn/ha and 7.14 tn/ha respectively. On the other hand, the per-hectare yield of sugar beets was even higher in 2010, as it reached 7.91 tn/ha. To be more precise, Magnesia had the peak yield that reached the 8,33tn/ha, namely 16.67% higher than that of 2000. The successor region was Karditsa which had 7,57 tn/ha, followed by Xanthi with 7,27 tn/ha.

If one take a look at Figure 31 will notice that the per-hectare yield of this particular crop was quite high throughout the decade, as it ranged between 5,40 tn/ha in 2003 and 7,91 tn/ha in 2010. There were some ups and downs, yet variations were not particularly major. Perhaps it is worth noting the upward trend that followed after 2007, which as has already mentioned above is likely due to the trade agreement with Russia. Specifically, the change from 2007 to 2010 was about 30,97%.

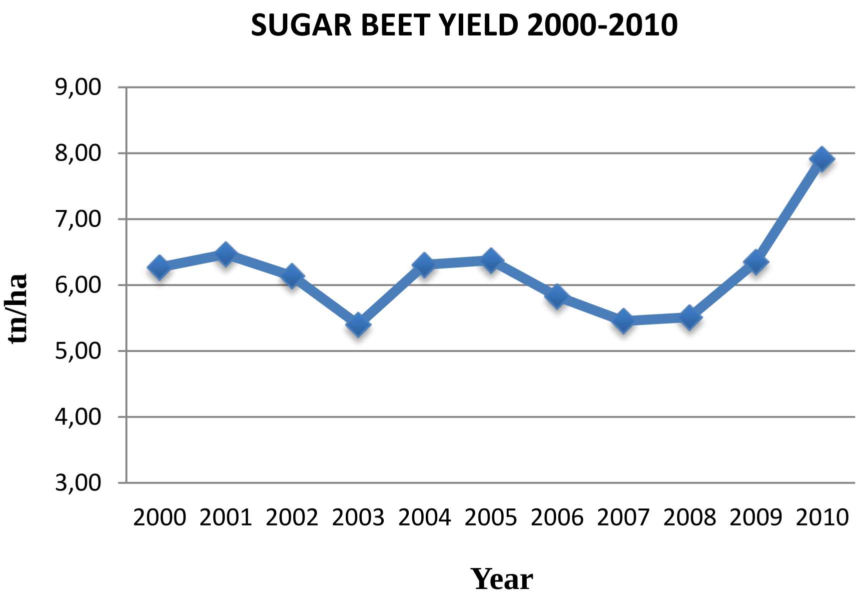


Figure 31. Sugar beet yield from 2000 to 2010

9.2.1.6 Potato

The potato cultivation is performed on every prefecture of Greece. However, most production is concentrated in Peloponnese and particularly in Achaia and Ilia. In fact, in 2000, the potato production in Ilia was 159.951 tonnes and in Achaia 142.215 tonnes, followed by Drama which produced 60.533 tonnes of potatoes that year. Correspondingly in 2010, the largest potato production has been concentrated again in these three prefectures. Production in Drama seems increased by 39.47%. Ilia still is the leading prefecture, but the output is reduced by 12.54%. Similarly, the produced amount of potatoes in Achaia, ranged close to 132.000 tonnes.

The potato production from 2000 to 2010 reduced by 9.74%. However, there were several variations within this period. As shown in Figure 33, the greatest potato quantity during the study period occurred in 2000. The next two years, the drop in production was rapid and reached 11.9%. From 2002 onwards, there were wide fluctuations in the produced quantity. However, the year with the lowest result was 2005, where production was 892.139 tonnes of potatoes.

Regarding the yield per hectare of potato, one observes that it is not conform to the trend of production. According to Figure 32, the highest yields are occurred in Arkadia (3,95 tn/ha), Evros (3,08 tn/ha) and Serres (3,06 tn/ha), for the year 2000. On the other hand, the per-hectare yield of potato in 2010 was the same as 2000. In more

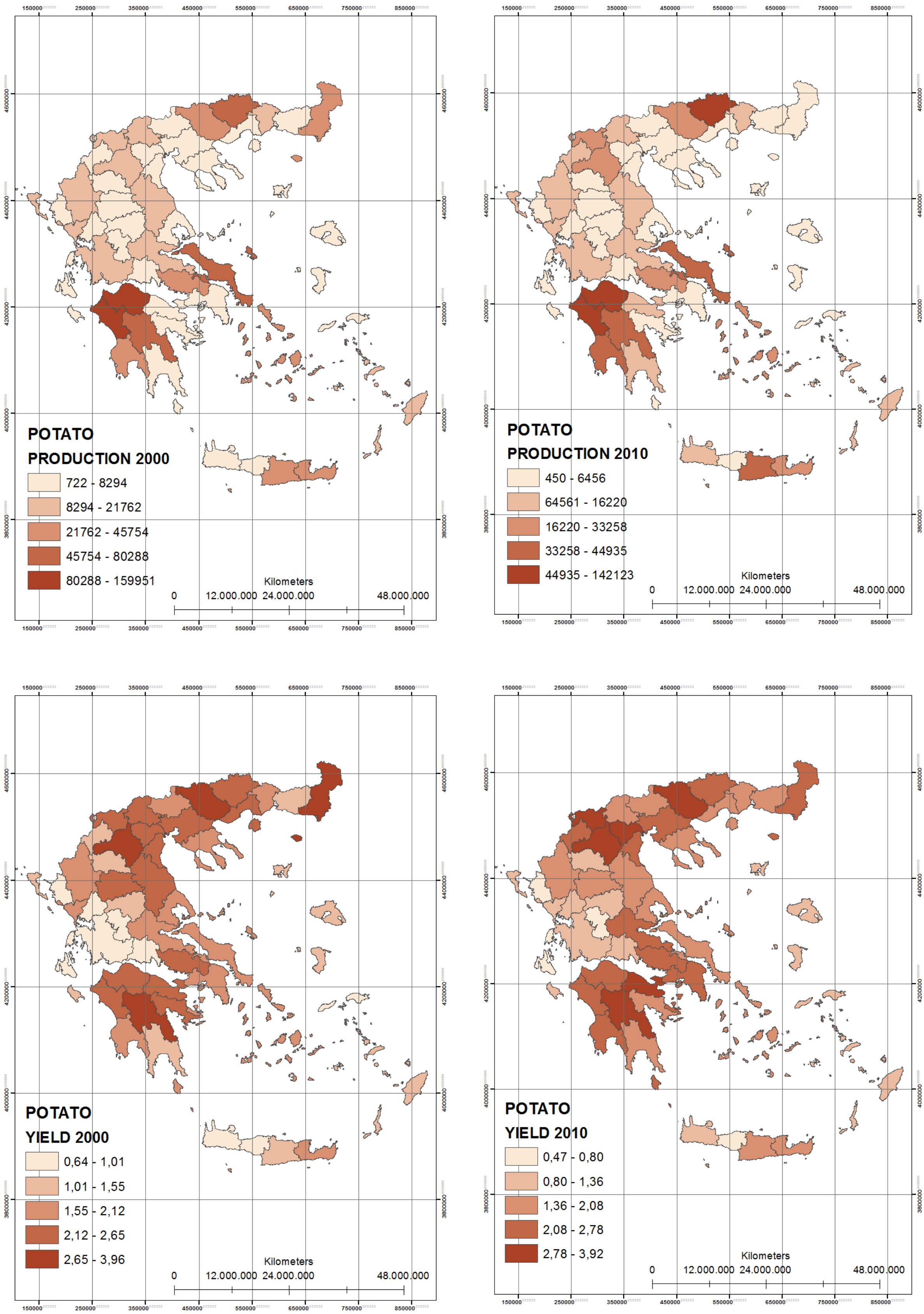


Figure 32. GIS maps for 2000 and 2010 potato production and yield

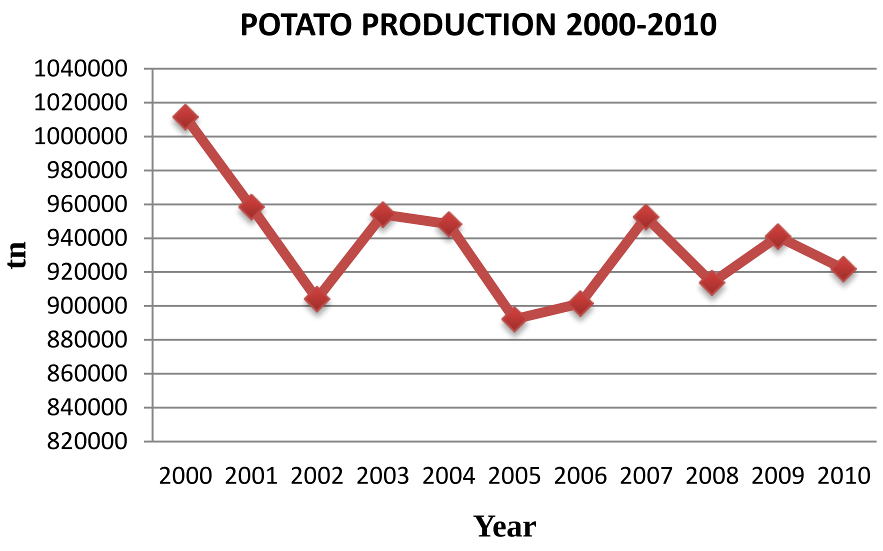


Figure 33. Potato production from 2000 to 2010

detail, the highest yield per hectare was in Florina and it was about 3,92 tn/ha. Moreover, the yield in Serres went up by 11,82%, while in Arkadia and Evros went down by 20,5% and 17,86% respectively.

Observing Figure 34, one can detect the various alterations in the potato's yield per hectare. As shown, the yield ranged between 1.95 tn/ha in 2002 and 2.07 tn/ha that recorded in five years within the decade. The greatest fluctuations were between 2000 and 2002 where the yield fell by 5.8% and among 2002 and 2003 where it witnessed an increase of the same level.

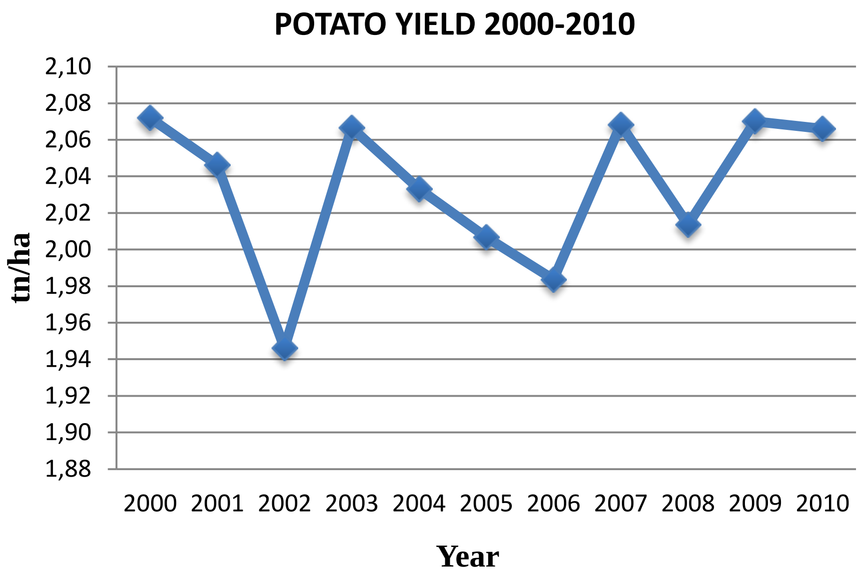


Figure 34. Potato yield from 2000 to 2010.

9.2.2 Available biomass residue for bioethanol production and energy potential.

It is essential that availability factors be considered as indicative for the potential assessment; note that in all biomass harvesting methods, there is a high percentage of loss of organic material, probably as high as 20–25% by weight (Boukis et al., 2009). Ji (2015) assessed the agricultural residue resources of China for biofuel production and commented on a 32% difference between available biomass, calculated on literature-based coefficients, and collectable biomass, obtained from a sampling survey.

The relation between crop production, residual biomass and available residue is presented in Figures 35 to 40 using a 10-year span for each crop studied for bioethanol production. Should be recalled that the data presented in Tables 15, 16 and 17 were used for the analysis.

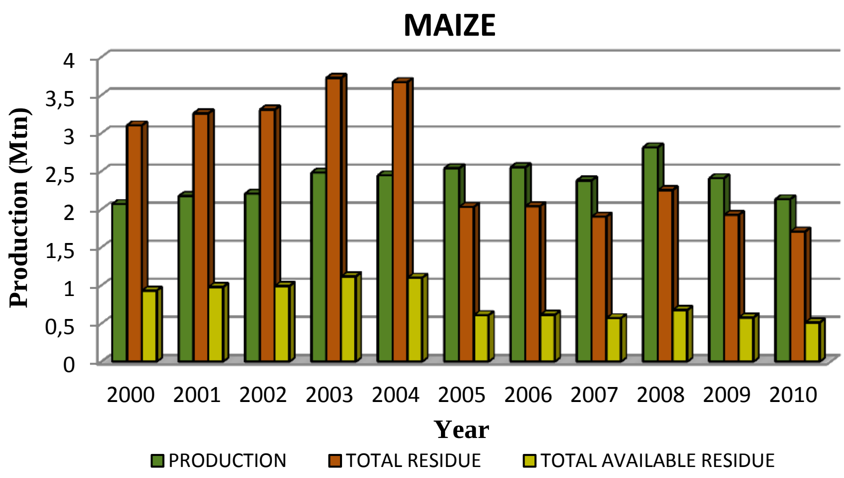


Figure 35. Maize production, theoretical residue yield and available residue for the period 2000-2010.

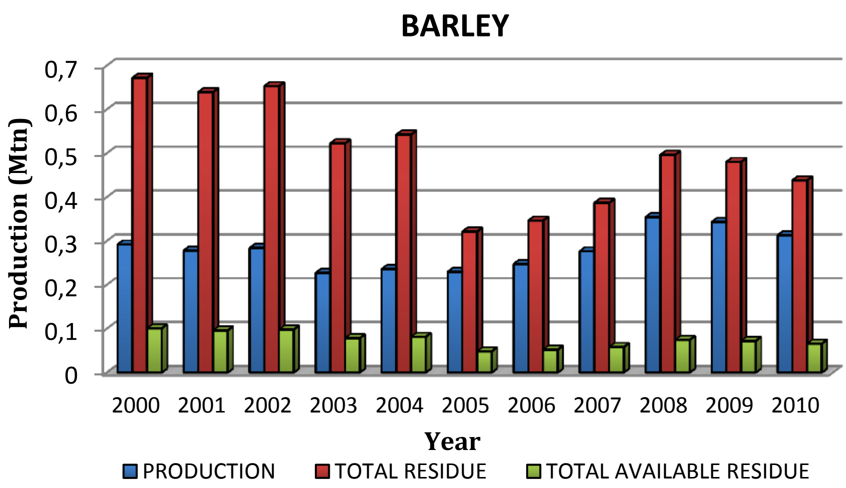


Figure 36. Barley production, theoretical residue yield and available residue for the period 2000-2010.

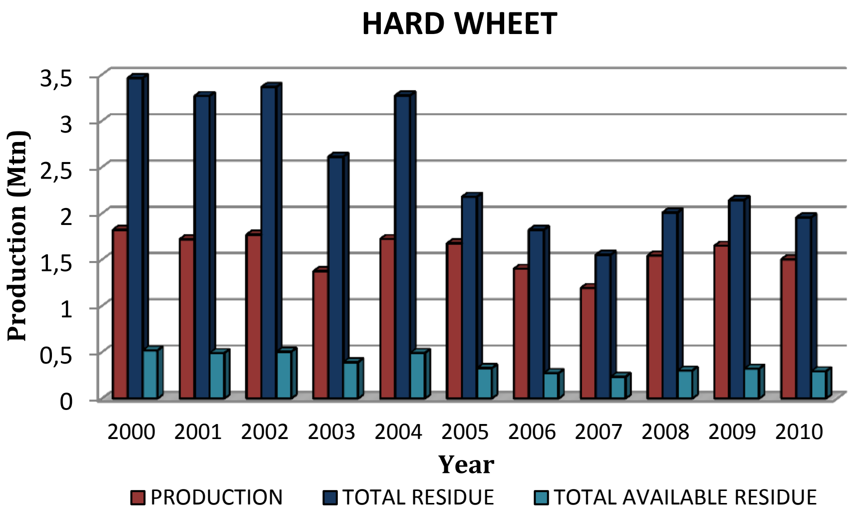


Figure 37. Hard wheat production, theoretical residue yield and available residue for the period 2000-2010.

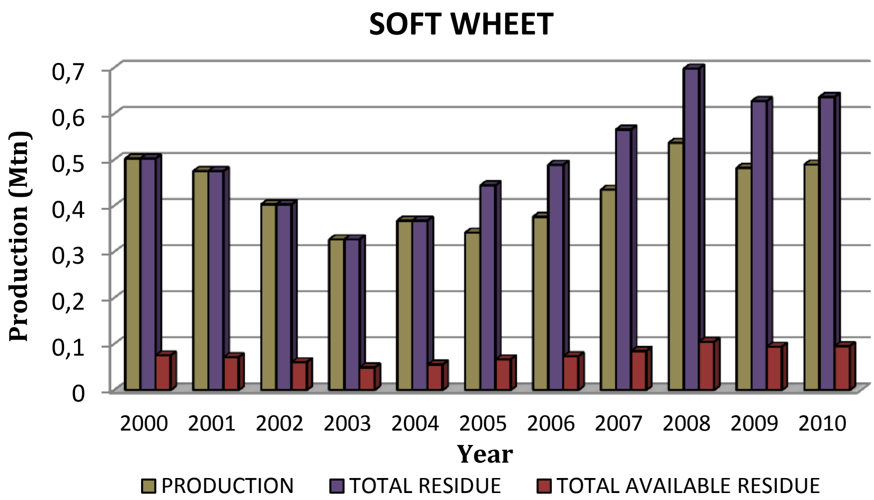


Figure 38. Soft wheat production, theoretical residue yield and available residue for the period 2000-2010.

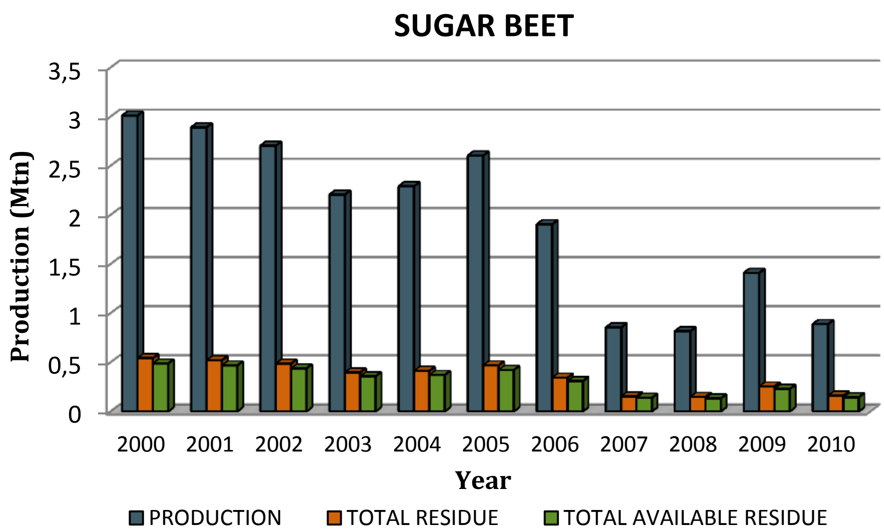


Figure 39. Sugar beet production, theoretical residue yield and available residue for the period 2000-2010.

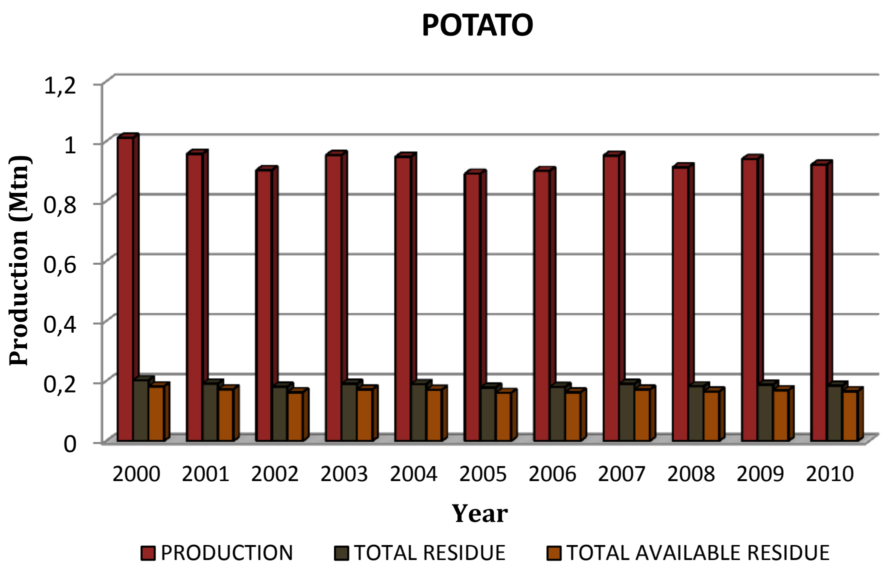


Figure 40. Potato production, theoretical residue yield and available residue for the period 2000-2010.

According to Figures 36 to 38, both soft and hard wheat, as well as barley share large residue yields, yet low availability potential. For the accuracy, the available residual amount for all three crops is only 15%. However, the theoretical residue yield of hard wheat is 1,55-3,46 Mtn, while the residues derive by soft wheat and potato are 0,33-0,70 Mtn and 0,18-0,20 Mtn respectively. Therefore, we conclude that the available residue arising from hard wheat is more, compared with the other two crops.

Additionally, one could advocate that the percentage of maize residue availability is also low, as only 30% of the crop's total residues may be available for use for the production of bioethanol (Figure 35). However, taking into consideration the amount of residues produced from maize, which is between 1,71 Mtn and 3,73 Mtn, we perceive that maize is more efficient compared to the crops mentioned above.

Furthermore, the yield of potato and sugar beet availability residue is very high, as 90% of total residues could be used in both cases (Figures 39,40). Nonetheless, the total residue rate of those two types o crop is only 0,18-0,20 Mtn and 0,15-0,54 Mtn respectively.

Taking all the above into consideration, one can reach to the conclusion that the crops with the greatest participation in bioethanol production is maize followed by hard wheat, whereas the crops with lowest participation are soft wheat and barley.

The potential of energy production for each year within the studied period, calculated based on the total biomass potential and the energy capacity (Table 16) of each biomass residue and is shown in Table 18. A conversion efficiency of 70% was also taken into account to perform this estimative.

Table 18. Potential of residues production and energy from agriculture residues for bioethanol production

Potential of residues production and energy from agriculture residues for bioethanol production				
RESIDUE SOURCE	**COVERED AREA (ha)**	**PRODUCTION (tn/ha)**	**AVAILABLE BIOMASS RESIDUE PRODUCTION (tn)**	**ENERGY POTENTIAL (GJ)**
		2000		
Barley	1193170	0,24	61352,55	678559,203
Maize	2121266	0,98	496568,4	20435858,7
Hard Wheat	6685185	0,27	355498,065	3981578,328
Soft Wheat	1892598	0,27	98039,175	1098038,76
Potato	488278	2,07	182104,92	2128806,515
Sugar Beets	480115	6,27	487674,108	5700910,323
TOTAL	12860612		1681237,22	**34023751,82**
		2001		
Barley	1153612	0,24	58393,65	645833,769
Maize	2080906	1,04	521708,16	21470464,57
Hard Wheat	6987568	0,25	335635,17	3759113,904
Soft Wheat	1771507	0,27	92707,485	1038323,832
Potato	468396	2,05	172523,7	2016802,053
Sugar Beets	870604	3,32	468289,026	5474298,714
TOTAL	13332593		1649257,19	**34404836,84**
		2002		
Barley	1129012	0,25	59630,13	772210,1835
Maize	2125673	1,04	529382,16	21786281,64
Hard Wheat	7129048	0,25	345460,635	3869159,112
Soft Wheat	1570965	0,26	78622,44	880571,328
Potato	464617	1,95	162749,88	1902546,097
Sugar Beets	440385	6,14	437945,778	5119586,145
TOTAL	12859700		1613791,02	**34330354,51**
		2003		
Barley	1038581	0,22	47716,41	527743,4946
Maize	2368447	1,05	596008,8	24528245,49
Hard Wheat	7028934	0,2	268130,265	3003058,968
Soft Wheat	1449721	0,23	63807,9	714648,48
Potato	461625	2,07	171720,18	2007408,904
Sugar Beets	408506	5,4	357422,22	4178265,752
TOTAL	12755814		1504805,78	**34959371,09**

2004				
Barley	939299	0,25	49535,85	547866,501
Maize	2405715	1,02	587345,76	24171725,3
Hard Wheat	7191196	0,24	336102	3764342,4
Soft Wheat	1259425	0,29	71778,915	803923,848
Potato	466458	2,03	170704,98	1995541,216
Sugar Beets	363018	6,31	371134,224	4338559,079
TOTAL	12625111		1586601,73	**35621958,34**
2005				
Barley	895341	0,25	48187,44	532953,0864
Maize	2449426	1,04	609248,4	25073110,2
Hard Wheat	7184743	0,23	326956,305	3661910,616
Soft Wheat	1474525	0,23	66651,585	746497,752
Potato	444549	2,01	160585,02	1877238,884
Sugar Beets	408245	6,38	421697,502	4929643,798
TOTAL	12856829		1633326,25	**36821354,33**
2006				
Barley	1047239	0,23	51971,22	574801,6932
Maize	2305762	1,02	612357,12	25201046,98
Hard Wheat	6326652	0,22	273361,725	3061651,32
Soft Wheat	1452361	0,26	73381,815	821876,328
Potato	454466	1,98	162271,08	1896948,925
Sugar Beets	326782	5,83	308575,494	3607247,525
TOTAL	11913262		1481918,45	**35163572,77**
2007				
Barley	1190766	0,23	58040,43	641927,1558
Maize	2361524	1,01	570966,96	23497669,43
Hard Wheat	5576073	0,21	232816,74	2607547,488
Soft Wheat	1700299	0,26	84852,105	950343,576
Potato	460487	2,07	171430,02	2004016,934
Sugar Beets	156538	5,46	138370,842	1617555,143
TOTAL	11445687		1256477,10	**31319059,73**
2008				
Barley	1288062	0,27	74448,15	823396,539
Maize	2668075	1,05	675348,48	27793403,9
Hard Wheat	5669636	0,27	301360,995	3375243,144
Soft Wheat	1806908	0,3	104714,025	1172797,08
Potato	453727	2,01	164457	1922502,33
Sugar Beets	148062	5,51	132241,896	1545907,764
TOTAL	12034470		1452570,55	**36633250,76**
2009				
Barley	1277676	0,27	72050,37	796877,0922
Maize	2297429	1,05	578236,32	23796833,89
Hard Wheat	6077388	0,27	321908,925	3605379,96
Soft Wheat	1720686	0,28	94118,505	1054127,256
Potato	454540	2,07	169369,74	1979932,261
Sugar Beets	221817	6,35	228298,824	2668813,253
TOTAL	12049536		1463982,68	**33901963,71**

2010				
Barley	1207597	0,26	65747,01	727161,9306
Maize	2043696	1,04	511992,48	21070623,85
Hard Wheat	5821822	0,26	293371,26	3285758,112
Soft Wheat	1553026	0,32	95502,225	1069624,92
Potato	446229	2,07	165944,16	1939887,23
Sugar Beets	112373	7,91	144083,124	1684331,72
TOTAL	11184743		1276640,26	**29777387,77**

The following graph, where the potential annual energy produced during the period 2000-2010 is presented, arose on the basis of the above table. According to Figure 41, the year with the highest energy potential was 2005, where the energy potential was 36.821.354 GJ, followed by 2008, where it was 36.633.251 GJ. On the other hand, 2007 and 2010 had the lowest energy potential as it was 31.319.060 GJ and 29.777.388 GJ respectively. It is worth noted that within the first five years there has been an increase of about 7,6%, while from 2005 to 2007 the energy potential fell by 14,94%. The energy potential rose in 2008, approaching that of 2005, only to fall again by 23,02% in 2010.

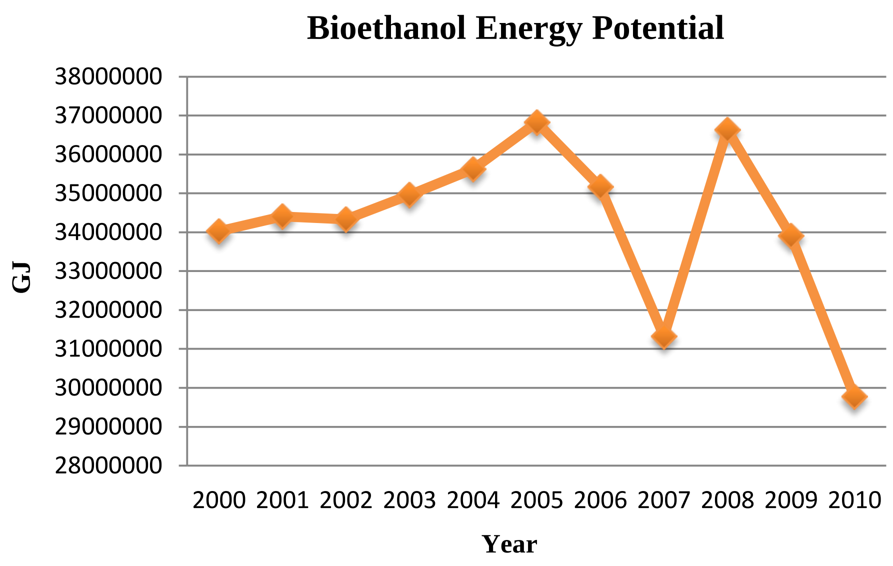


Figure 41. Bioethanol energy potential, for the period 2000-2010.

In Figure 42, the annual potential energy by crop is presented, for the years with the lowest and the highest energy potential. As one can easily perceive, maize is by far the most advantageous crop for bioethanol production in Greece as its energy potential ranges between 21.070.624 GJ and 25.073.110 GJ. The next most advantageous crops are hard wheat (3.285.758-3.661.991 GJ) and sugar beets (1.684.332-4.929.644 GJ).

It is observed that three out of the six types of crops contemplated, have been subjected to reduction as to the potential energy in 2010 compared to 2005. The most significant changes between these two years is the diminution in the potential energy of sugar beets which was about 193% and played a key role in the reduction of overall energy production of the year. Moreover, another significant change was the decrease in the potential energy derived from maize, which was about 19%, as well as the decline of hard wheat's potential energy by 11,45% Additionally, should be pointed that there was a considerable increment in the potential energy resulting from barley and soft wheat of about 26,7% and 30,2% respectively in 2010 compared to 2005.

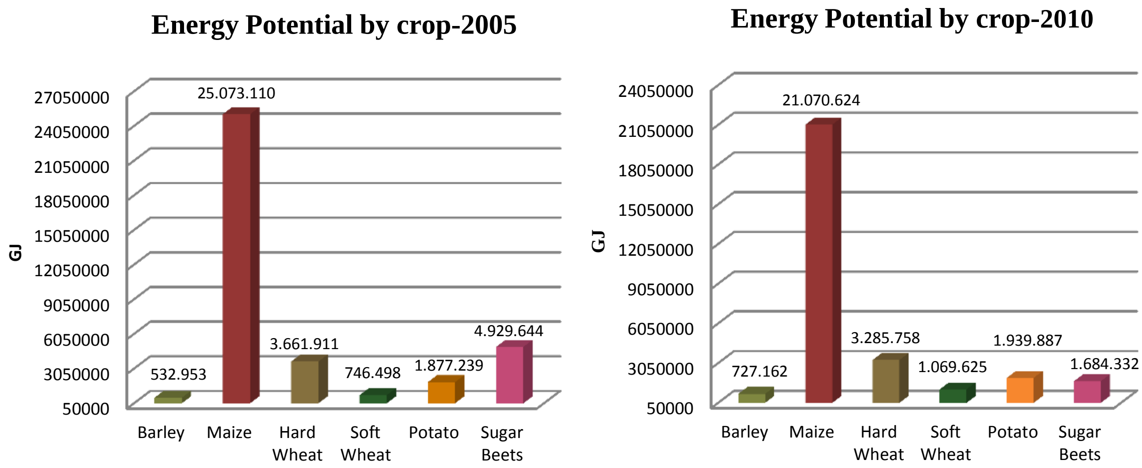


Figure 42. Energy potential by crop for the years 2005 and 2010

It is interesting to look at the contribution of each crop type in the overall potential energy in those two years. According to Figure 43, there are very little alterations considered between 2005 and 2010. The contribution of barley remained steady to 2% while the contribution of wheat (both soft and hard wheat) and potato rose in 2010. Maize also went up in 2010 and it is characteristic that it contributes with around 70% in both years. Last but not least, as far as sugar beet is concerned, the contribution went down to 6% in 2010, from 13% in 2005.

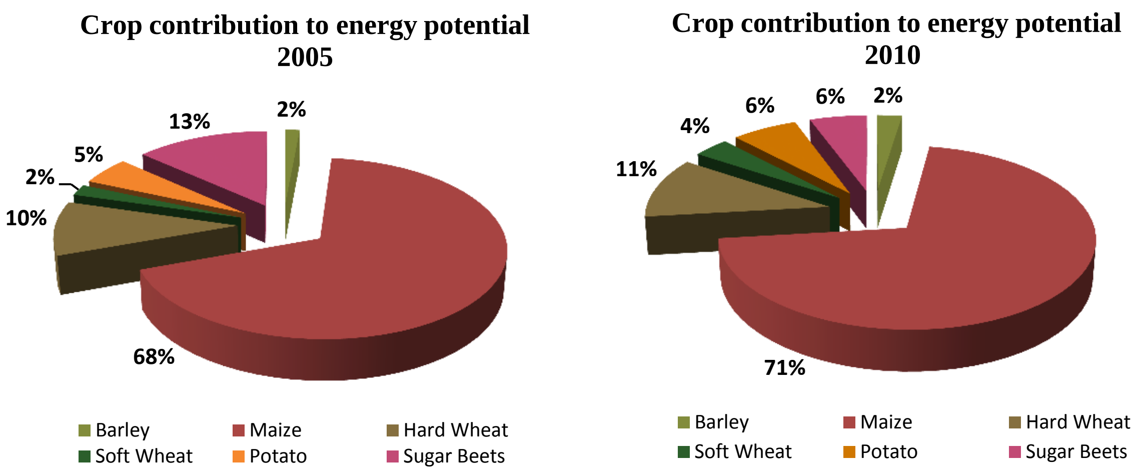


Figure 43. Crop contribution to energy potential for the years 2005 and 2010

Last but not least, it is important to take into account the dispersion of the available biomass residue potential in the various regions of Greece. Such a study can provide important information for the implementation of a suitable investment strategy for the production of bioethanol. Observing the whereabouts of the highest concentration of available biomass residue potential (derived from all the crops used in the production of bioethanol), as well as the amount of straw residue potential, contributes to a more targeted selection of region for installing a bioethanol production unit.

Analyzing the latest year of the study (Figure 44), the largest possible amount of available residues is concentrated mainly in northern and central Greece. In more detail, the greatest potential is concentrated in Serres and it is about 144.413 tonnes, followed by Larisa with 142.783 tonnes. However, big amounts are concentrated in Kozani, Drama, Ilia and Thessaloniki ranging between 88.349 tonnes and 60.741 tonnes. Respectively, the highest quantity of potential straw residue is located also in Larisa, Serres and Kozani, ranging between 527.532 tonnes and 314.335 tonnes.

Conclusively, one could advocate that the most preferable geographic regions for bioethanol production investments are Macedonia and Thessaly.

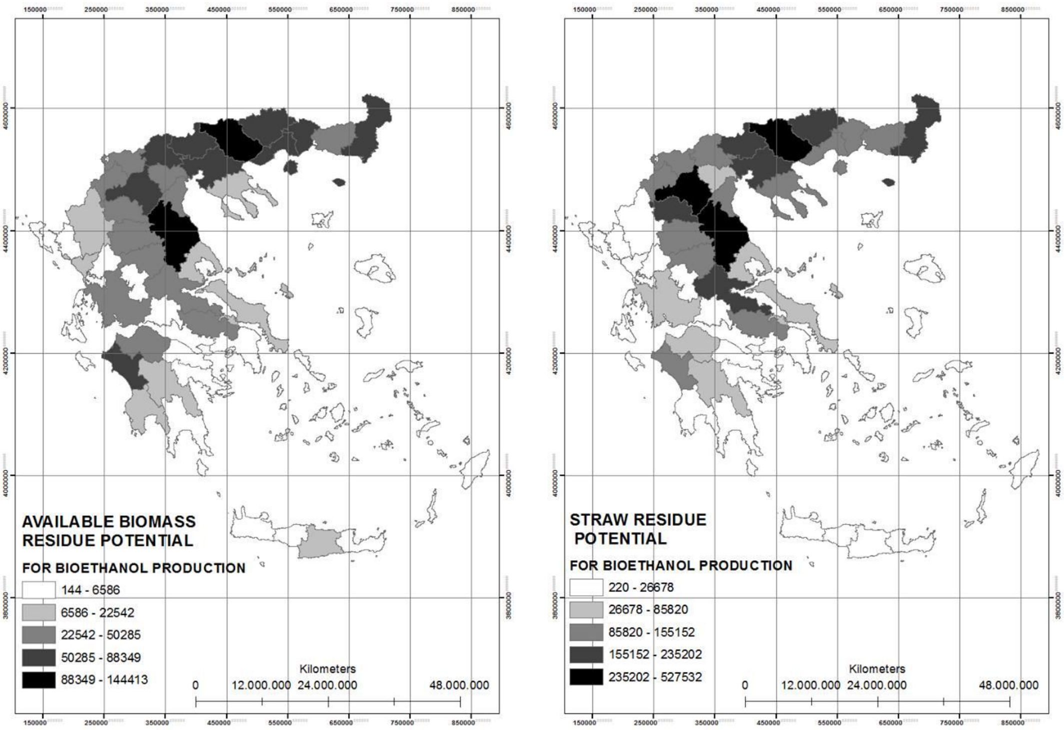


Figure 44. The available annual biomass residue potential and the available straw residue potential in Greece.

9.3 Potential biomass residues for biodiesel production

9.3.1 Crops production and yield per hectare

According to previous chapter, the crops mainly used for the production of 1st generation biodiesel are sunflower, rapeseed, cotton, soya, safflower, palm, peanut oils etc. In the present study, the first four crops from those referred have been studied for the period 2000-2010. Although, a distinction between irrigated and non-irrigated cotton has been made, in view of the fact that cotton is separately cultivated in Greece, but both irrigated and non-irrigated cotton are equally useful for the production of biodiesel.

9.3.1.1 Sunflower

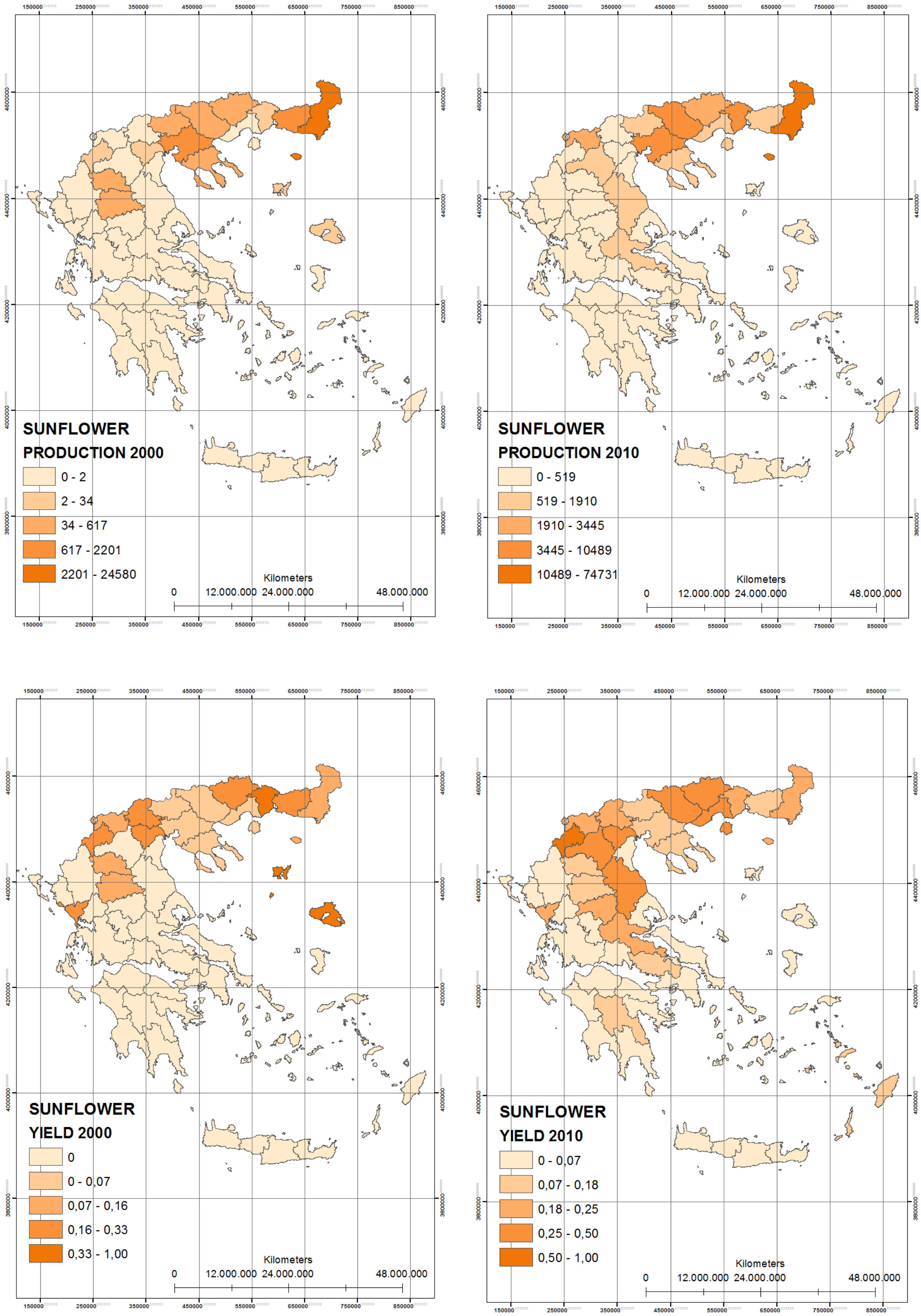


Figure 45. GIS maps for 2000 and 2010 sunflower production and yield

As is clearly shown from Figure 45, sunflower is mostly cultivated in the northern Greece. In 2000, the total sunflower production was 30.864 tonnes. It is worthnoted that almost 80% of the produced quantity is gathered in Evros, where the sunflower production was 24.580 tonnes, followed by Thessaloniki with 2.201 tonnes. In 2010, sunflower production rocketed to 116.027 tonnes and Evros still holds the primacy of sunflower production. However, this year's the production is more dispersed and other regions contribute significant amounts of sunflower as well. More specifically, the production in Evros was 74.731 tonnes, nearly three times higher than that of 2000. In addition, although the participation of Xanthi in 2000 was minimal, there were 10.489 tonnes of sunflower produced in that region in 2010. Furthermore, the production in Serres has also greatly increased, followed by Thessaloniki with 6.349 tonnes.

According to Figure 46, 2010 was the year with the highest production rate, while 2004 was the year with the lowest produced amount of sunflower, of about 7.641 tonnes. As one can easily notice, the production of sunflower decreased continuously from 2000 to 2004 and for the next six years was rising continuously. However, it is worth noting that the largest increase occurred from 2009 to 2010, where from 46128 tonnes in 2009, reached 116.027 tonnes in 2010.

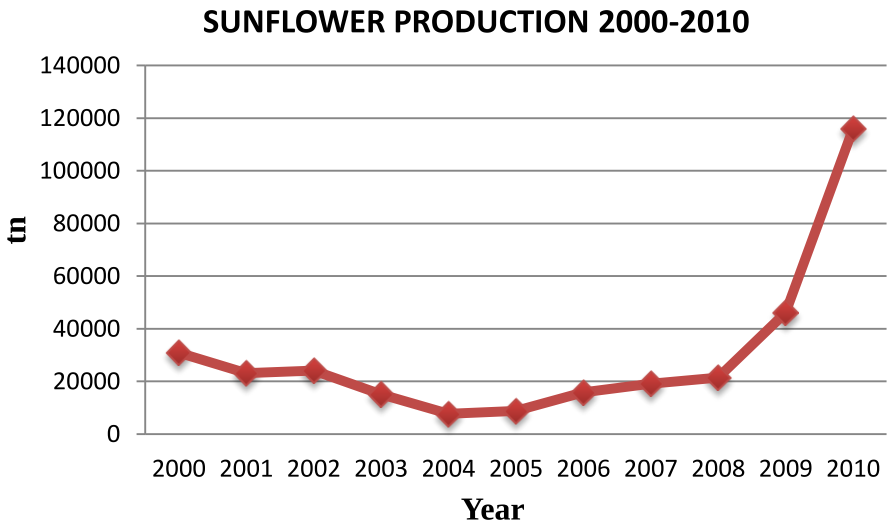


Figure 46. Sunflower production from 2000 to 2010

As far as the yield per hectare of sunflower is concerned, the overall was about 0,13tn/ha in 2000 while in 2010 was 0,22tn/ha. In greater detail, in 2000, the highest yield was occurred in Xanthi and Lesvos and it was about 1tn/ha. However, the picture is entirely different in 2010, as the sunflower yield in Lesvos dropped to zero and in Xanthi was just 0.25tn/ha. The highest yield for this year was in Kastoria where it was about 0,5tn/ha, followed by the Imathia with 0.5tn/ha.

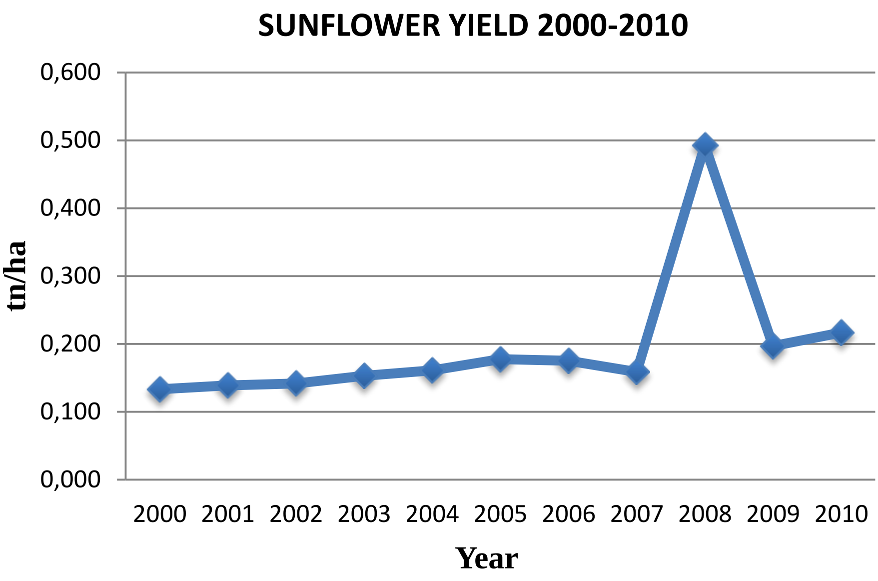


Figure 47. Sunflower yield from 2000 to 2010

If one examines Figure 47 can easily distinguish that the per hectare yield of sunflower has been steadily increased within the first five years of the studied period, noting minor alterations. Subsequently there was a slight decrease of 10%, and in 2008 the yield shot up to 0.49 tn/ha. This was the year with the greatest per hectare yield of sunflower. At a more local level is observed that the greatest yield for that year was in Evros and the Dodecanese where it was 1 tn/ha (Figure 48). The following year, the yield of sunflower declined again, reaching 0.2tn/ha and then increased by 9.22% in 2010.

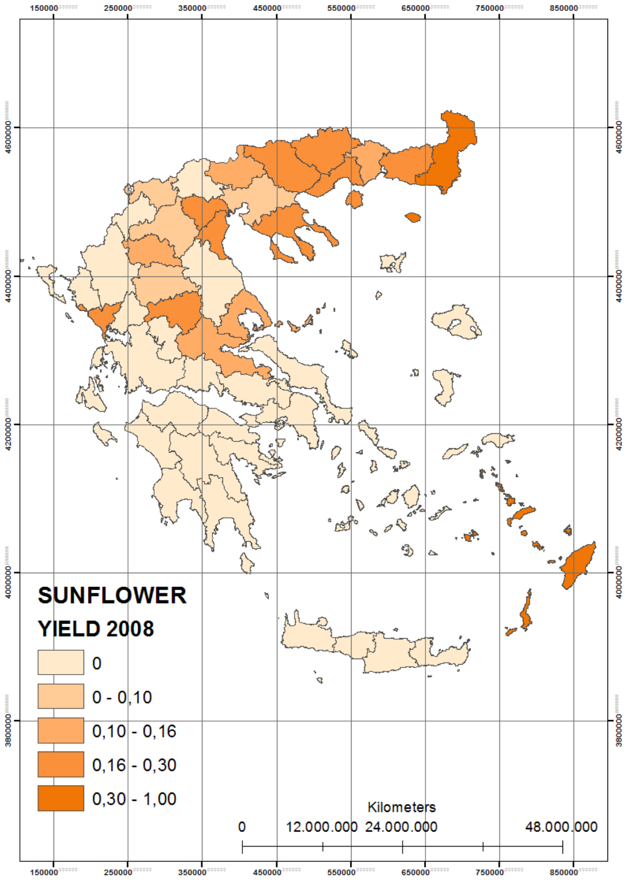


Figure 48. GIS map for sunflower yield for the year 2008

9.3.1.2 Irrigated Cotton

As it has been mentioned before, cottonseed has been studied separately as irrigated and as non-irrigated. The amount of irrigated cotton in Greece is greater than that of non-irrigated. Nevertheless the evaluation of both types has been considered necessary.

The irrigated cotton is mainly cultivated in the central and the northern Greece (Figure 49). In 2000, the total production was 1.297.154 tonnes, while in 2010, was higher by 37,54%. In 2000, the prefecture with the greatest irrigated cotton production was Larisa, where the produced amount was 266.592 tonnes, followed by Karditsa with 179.956 tonnes. Karditsa had the highest production in 2010, which rocketed to 1.222.133 tonnes, while Larisa held the second place despite the fact that the produced amount of irrigated cotton declined to 131.686 tonnes.

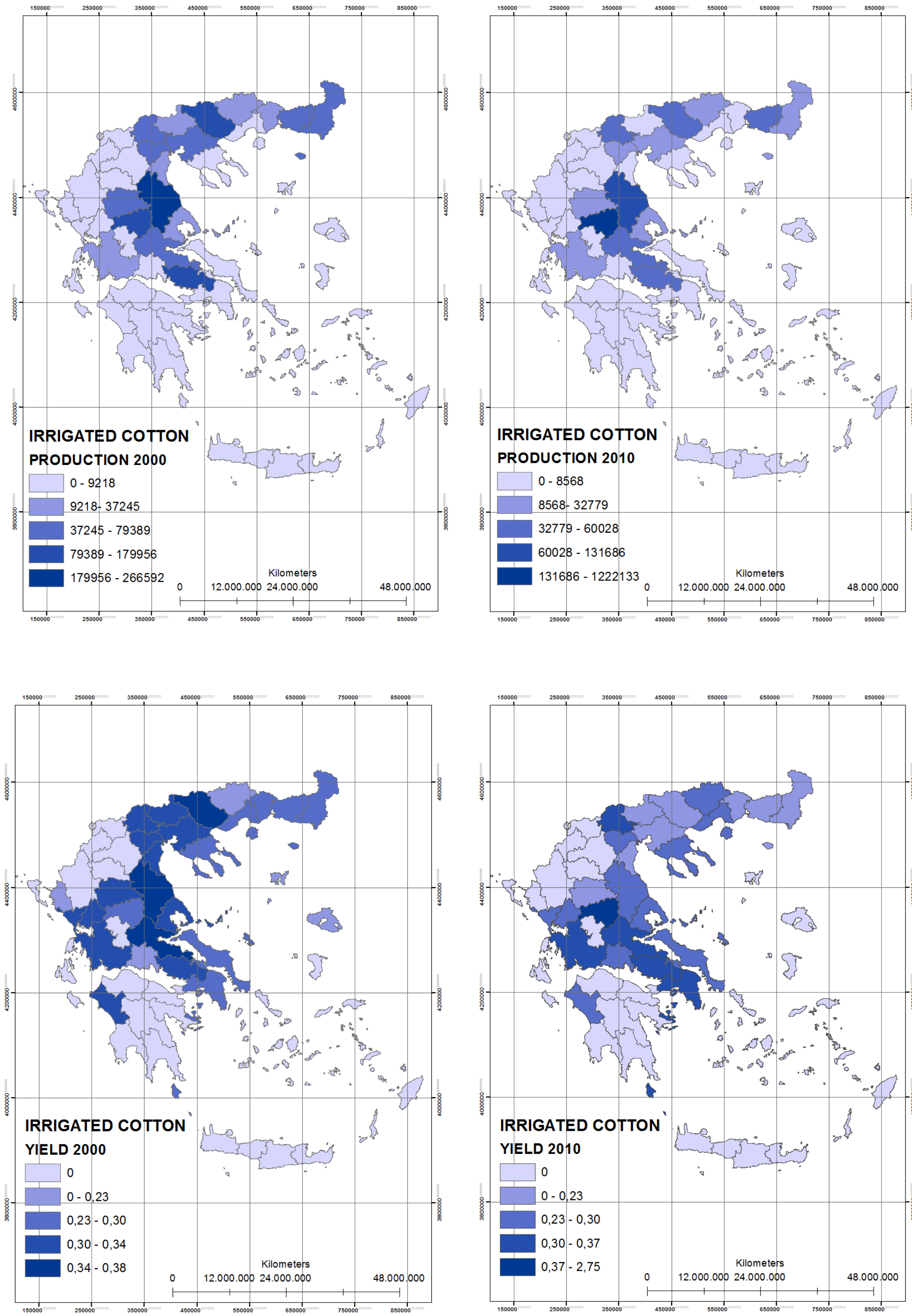


Figure 49. GIS maps for 2000 and 2010 irrigated cotton production and yield

As illustrated in Figure 50, the year with the highest production of irrigated cotton was 2002, where the produced amount was 2.096.467 tonnes, while the lowest production observed in 2009 with 804,925 tonnes of irrigated cotton. In 2002, the majority of production was concentrated in Viotia and it was about 1.158.705 tonnes, followed by Karditsa with 198.346 tonnes produced (Figure 51). Moreover, one can easily observe that between 2000 and 2002 the production was steadily increasing and the following year dropped dramatically. For the next six years, there have been minor alterations, first upward and then downward until the production shot up again in 2010.

Regarding the per hectare yield of irrigated cotton, it was about 0,32 tn/ha in 2000, while in 2010 was more than two times higher. More specifically, the greatest yield was pinpointed in Serres and Larisa where it was 0,37 tn/ha, followed by Fthiotida with 0,36 tn/ha. On the other hand, despite the fact that the overall yield was considerably higher in 2010, it went down in all three regions that held supremacy in 2000. The prefecture with the highest yield per hectare of irrigated cotton was Karditsa which had 2.74 tn/ha, followed by Etolia and Akarnania with 0,37 tn/ha yield (Figure 52).

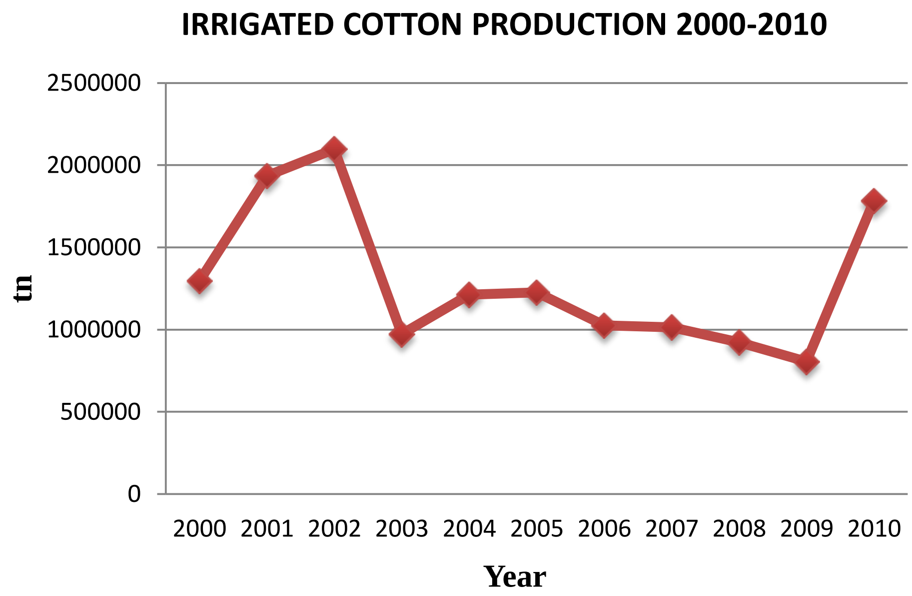


Figure 50. Irrigated Cotton production from 2000 to 2010

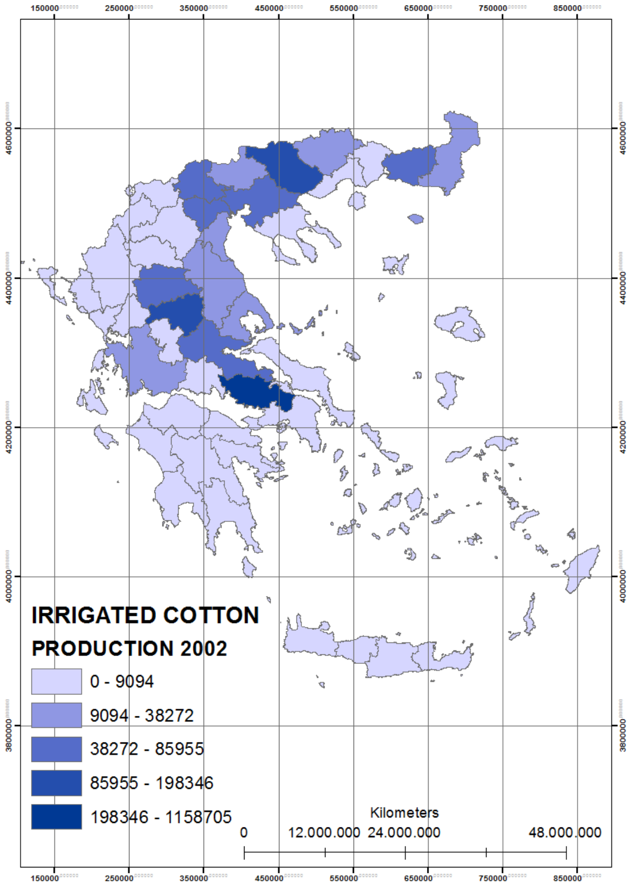


Figure 51. GIS map for irrigated cotton production for the year 2002.

In examining the trend of irrigated cotton's yield within the decade one observes that the progress of the curve in Figure 50 resembles very much that of Figure 52. However, the greater yield observed in 2010, which as mentioned above it was 0.69 tn/ha, followed by the years 2002 and 2001 which had 0.57 tn/ha and 0.50 tn/ha respectively. On the other hand, the lower yield within the decade has been pinpointed in 2003 and it was 0,27 tn/ha. The major changes generally observed were the great decline from 2002 to 2003 where the yield fell by half, as well as the big increase of the yield in 2010, which doubled compared to that of 2009.

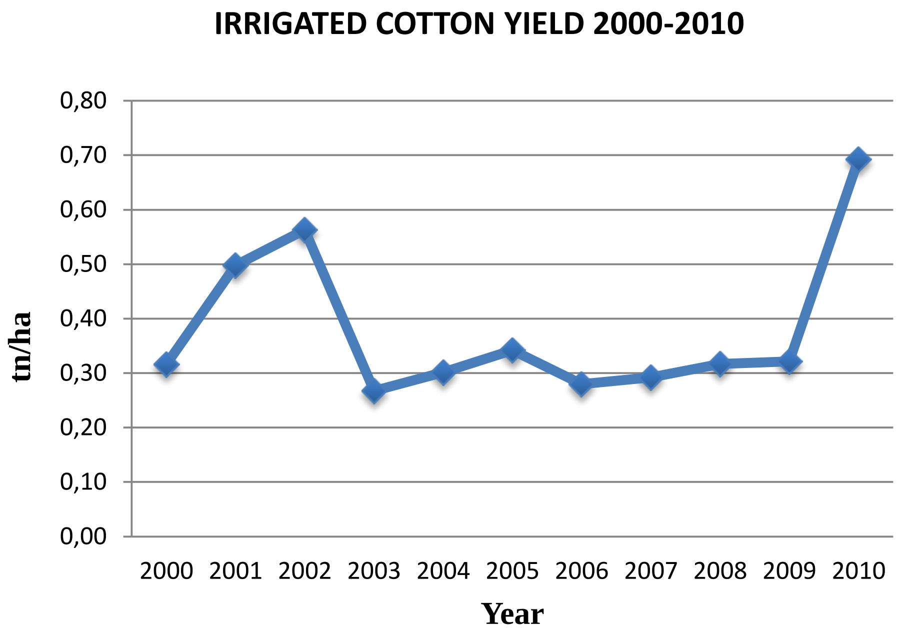


Figure 52. Irrigated Cotton yield from 2000 to 2010

9.3.1.3 Non-Irrigated Cotton

The production of non-irrigated cotton is more limited than that of irrigated cotton in Greece. Nevertheless is not negligible, so it has been examined for the needs of this study. The distribution of production to the various prefectures of Greece presented on the maps in Figure 53.

At the beginning of the decade the production of non-irrigated cotton was 28.998 tonnes throughout Greece. The greatest produced quantity located in Evros and it was about 9.256 tonnes, followed by Fthiotida, where it was 7.969 tonnes. In 2010, the overall production of non-irrigated cotton declined by 9,67%. However, the produced amount in Evros went up by 8,14% and still ranks first in the production of non-irrigated cotton. Lastly, Fthiotida comes second, although the production fell by 83,57%.

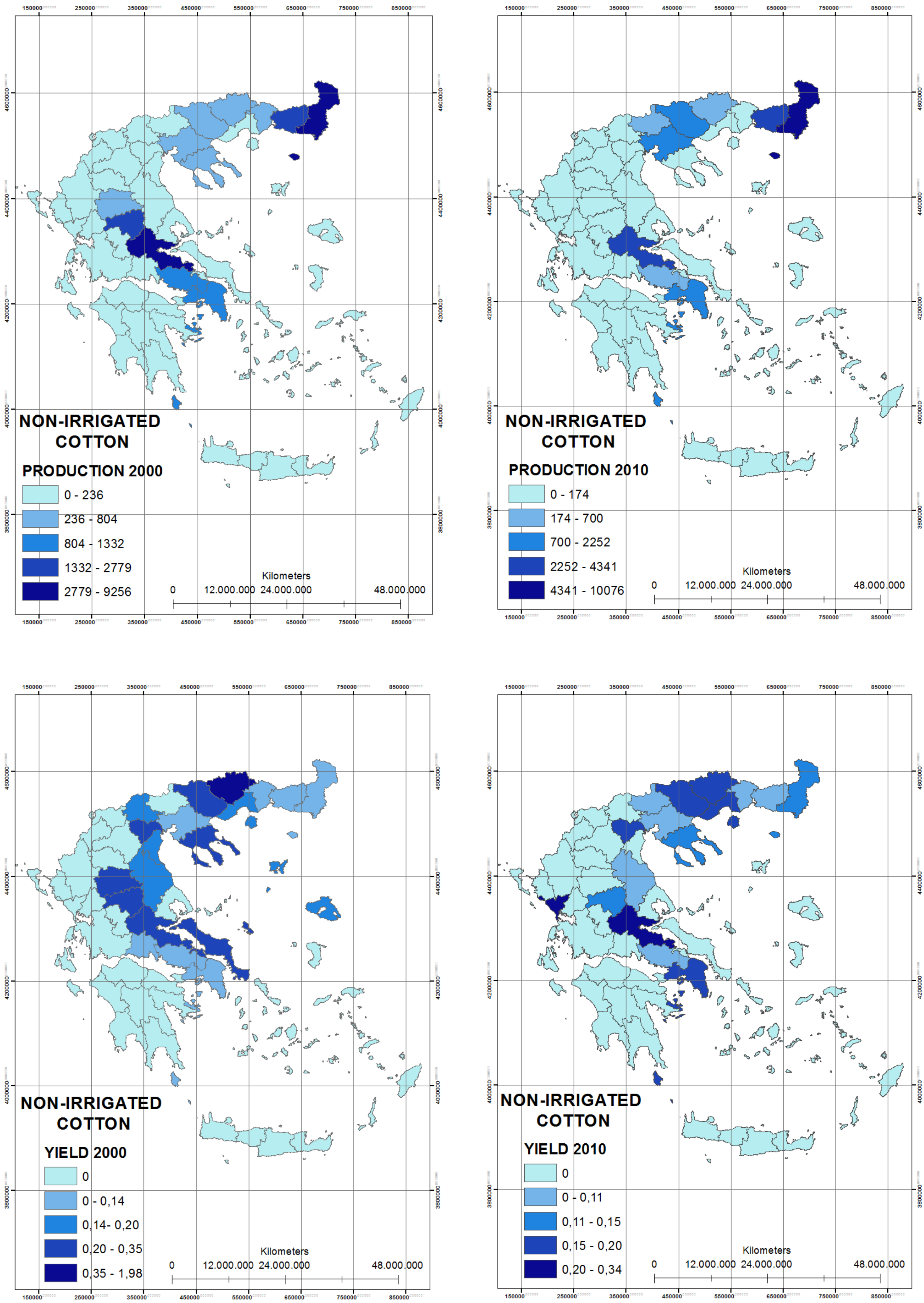


Figure 53. GIS maps for 2000 and 2010 non-irrigated cotton production and yield.

On the variation of the production during the whole period considered one observes that the year with the highest production was 2001 wherein produced 29.784 tonnes of non-irrigated cotton (Figure 54). The major production continues to be located in Evros and Fthiotida, where it was 7.354 tonnes and 9.498 tonnes respectively in that year (Figure 56). On the other hand, the minor production located in 2005, where it was 13.793 tonnes.

Generally there were several ups and downs in the produced quantity of non-irrigated cotton throughout the years. The most significant was the fall that occurred from 2001 to 2002 of around 35.25%, as well as the sharp drop from 2003 to 2005 which was as high as 60%. For the next three years there was a gradual increase which was slightly shaken in 2009, and strongly recovered in 2010 with an increase of 18.85% compared to the previous year.

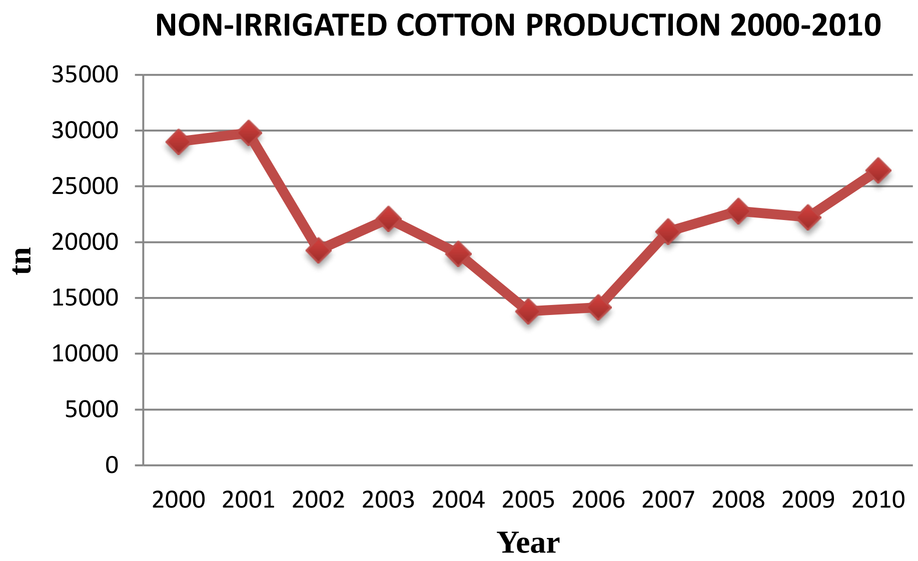


Figure 54. Non-irrigated Cotton production from 2000 to 2010

As far as the yield per hectare is concerned, it was about 0,18 tn/ha during the first year of the studied period, while in 2010, decreased by 27,77%. According to Figure 55, the prefecture with the highest yield in 2000, was Drama which had a yield of about 1,98tn/ha, followed by Trikala and Evia which both had 0.35 tn/ha. It is characteristic that in 2010, Trikala and Evia had zero yield per hectare of non-irrigated cotton, while Drama plummeted to 0.19tn/ha. The highest yield in 2010 was 0.34 tn/ha and it was located in Fthiotida, followed by Preveza with 0.33 tn/ha.

If one examines Figure 55, will notice that 2003 was the year with the biggest yield within the decade. More specifically, the yield of non-irrigated cotton in 2003, was 0,2 tn/ha, while the greatest rate was in Larisa and Fthiotida which had 0,32 tn/ha and 0,28 tn/ha respectively (Figure 56). In contrast, 2008 was the year with the lowest yield since it was only 0.11 tn/ha. It is worth noting that the most important change that took place within the decade was the continuous decline of the yield from the 2003 to 2008 of around 81.8%.

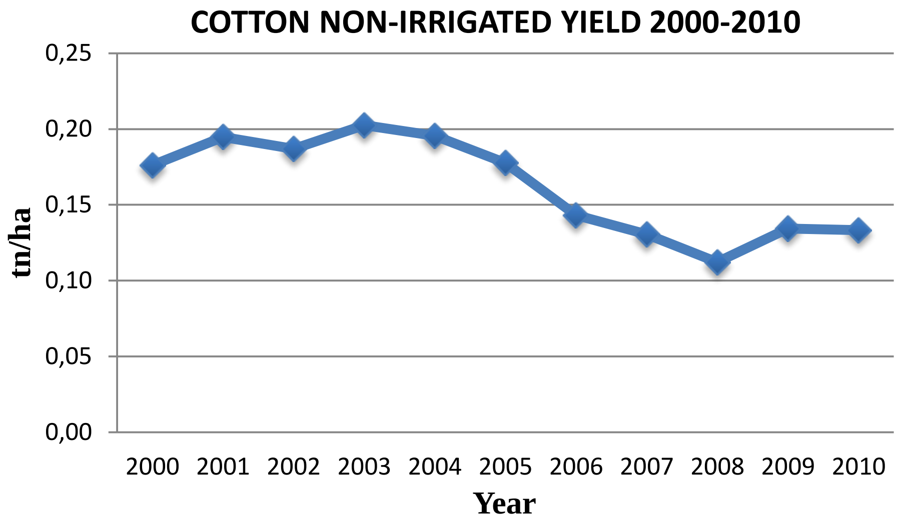


Figure 55. Non-irrigated Cotton yield from 2000 to 2010

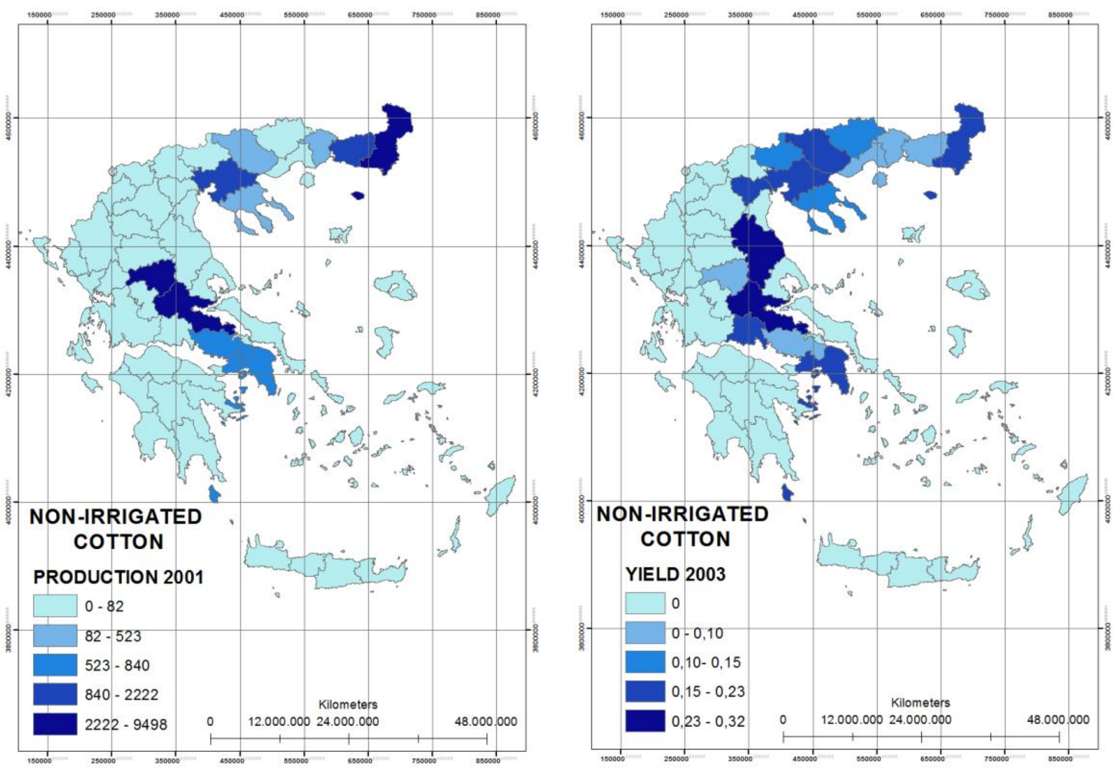


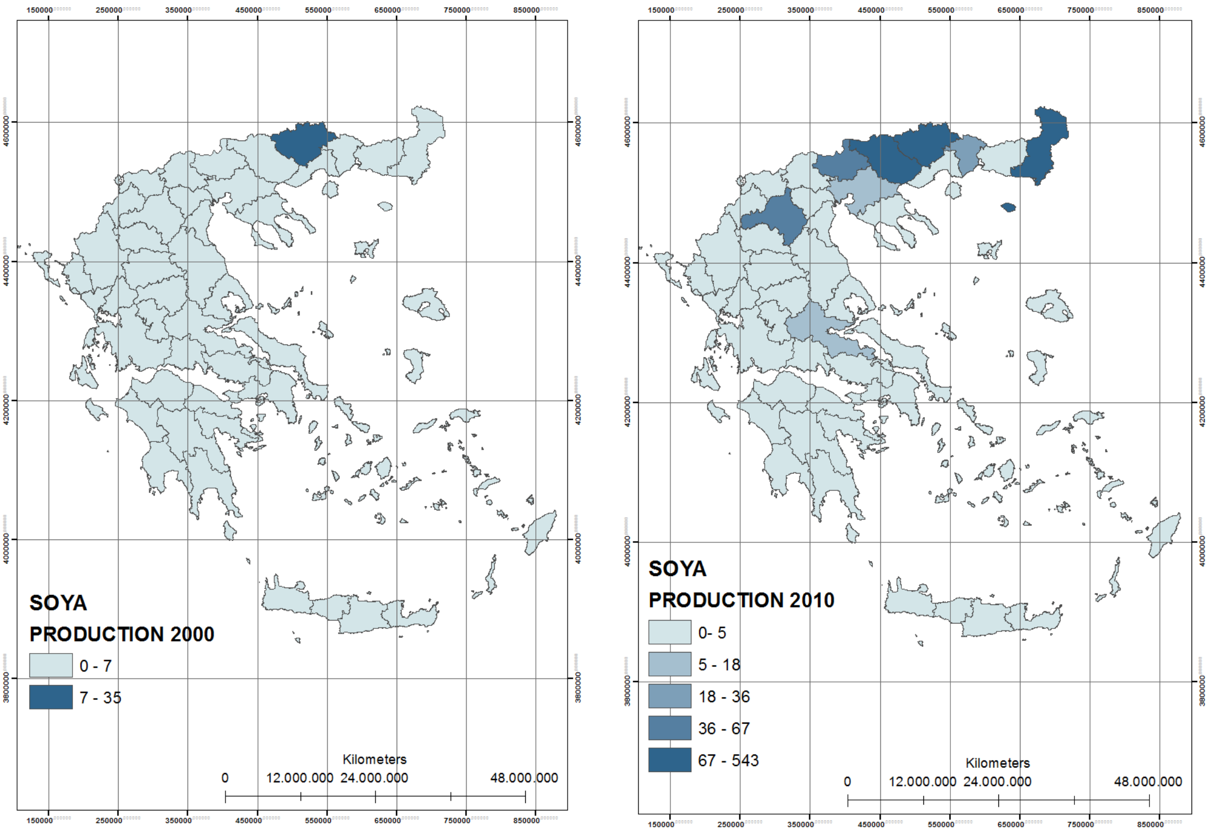
Figure 56. GIS maps for non-irrigated cotton production and yield for the years 2001 and 2003 respectively.

9.3.1.4 Soya

Soybean production in Greece is very limited. However, it constitutes a significant crop for the production of biodiesel and for that reason it has been included in the study. The maps in Figure 57, present the distribution of the soya production in Greece for the years 2000 and 2010.

As shown below, soya is cultivated in very few regions in Greece, mainly in the northern part of the country. In more detail, the overall production in 2000 was just 49 tonnes where 35 of them were cultivated in Drama. In 2010, production is remarkably increased as it reached 1.368 tonnes. In addition this year, a greater division of the produced amount of soya has been occurred. Serres involved with production of 543 tonnes, followed by Evros and Drama with 330 tonnes and 291 tonnes respectively.

The greatest amount of soya has been produced in 2010. That year was a breakthrough in the production of soya after years of meager production. In Figure 58,



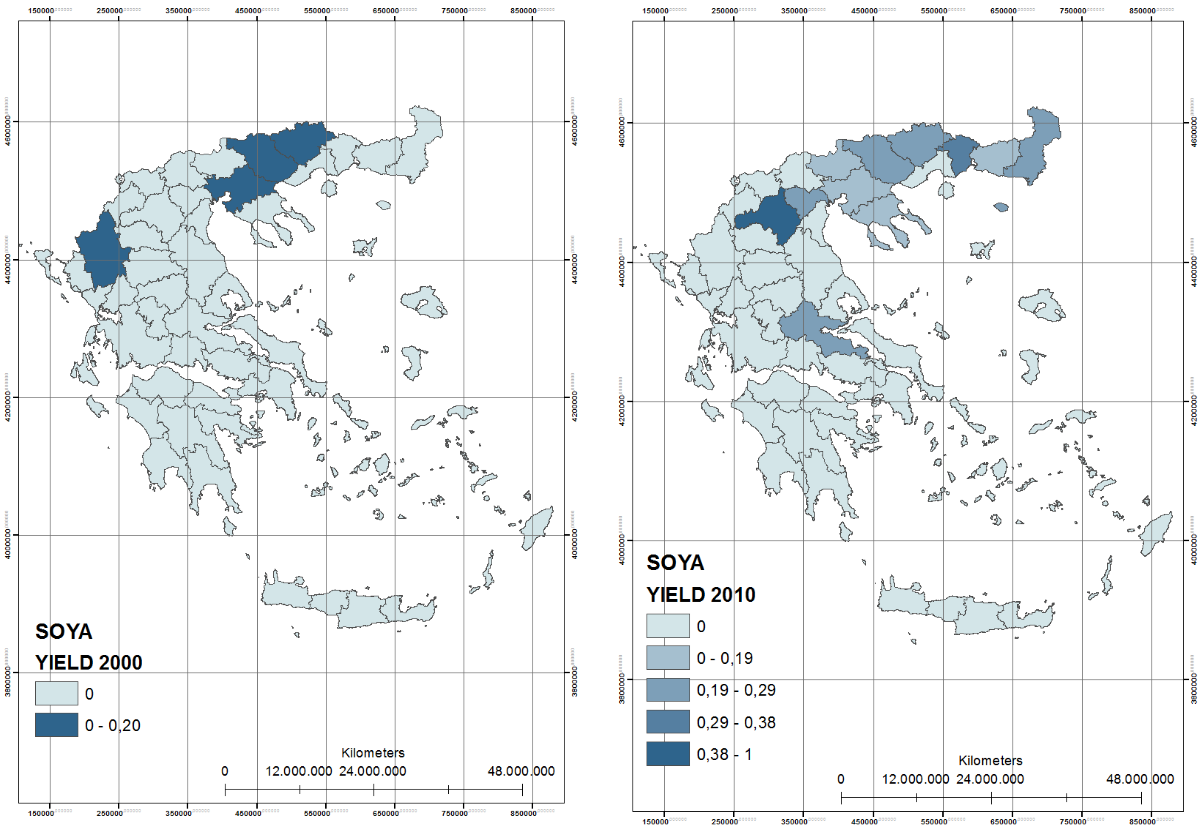


Figure 57. GIS maps for 2000 and 2010 soya production and yield.

the production trends from 2000 to 2009 are presented (note that 2010 is not included in the diagram as the value of the produced amount for that year was not comparable with the other years). As stated in the figure, there have been many ups and downs within the nine year period. For accuracy, the alterations with the greatest significance were the decrease between the years 2000 and 2001 where the produced amount of soya has been sub tripled. Furthermore, the increase from 22 tonnes in 2002 to 68 tonnes in 2003 was also of great importance, as well as the decline that took place the following year of about 423%. From 2004 to 2008, the production ranked between 4 tonnes and 13 tonnes, while in 2009, rose to 49 tonnes.

As far as the yield per hectare is concerned, it was 0,17 tn/ha in 2000, while it surged to 0,27 tn/ha in 2010. More specifically, Serres held the highest yield per hectare of soybean for the year 2000, where it was 0,2 tn/ha, followed by Ioannina and Drama with 0,18 tn/ha and 0,17 tn/ha respectively (Figure 59). In 2010, the highest yield occurred in Kozani where it was 1tn/ha, followed by Xanthi with 0,37 tn/ha. It is worth to be mentioned that these prefectures had both zero yield in 2000. On the other hand, the yield of soya in Ioannina sank to zero, while in Serres and Drama went up by 28,57% and 37,04% respectively.

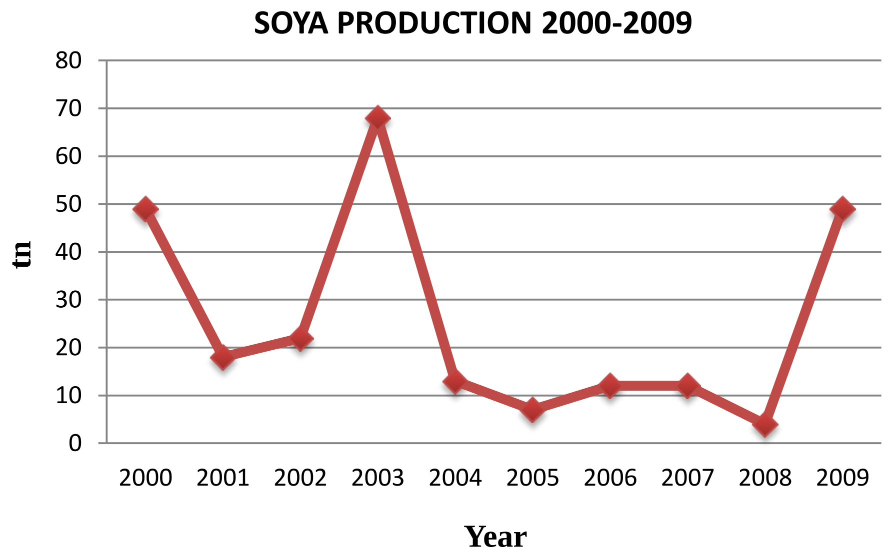


Figure 58. Soya production from 2000 to 2010.

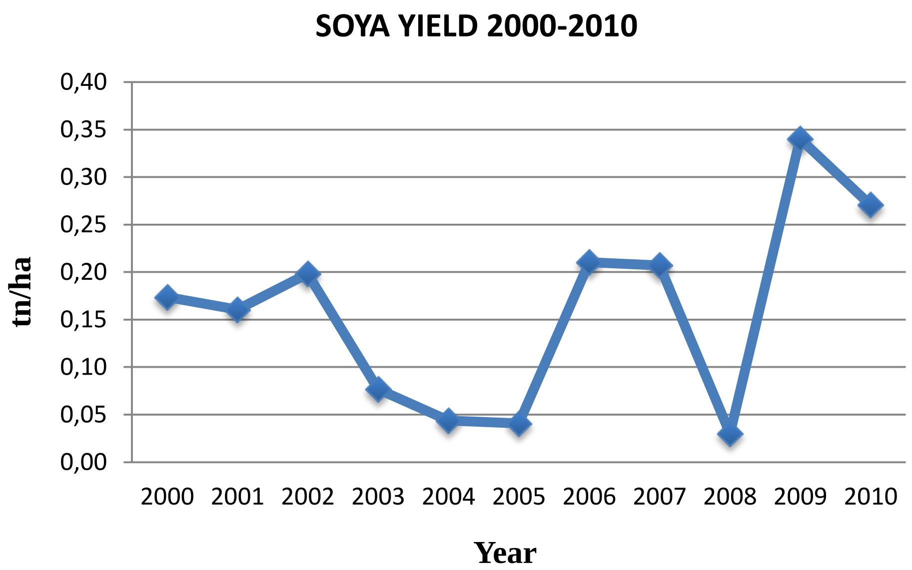


Figure 59. Soya yield from 2000 to 2010.

Examining the overall evolution of the yield per hectare of soya over the decade, multiple changes are observed. The highest yield detected in 2009, where it was 0,34 tn/ha, while the lowest was in 2008, where it was about 0,15 tn/ha. According to Figure 60, the greatest yield at a local level detected in Serres with 0,20 tn/ha, while Drama follows with 0.17 tn/ha. Moreover, the most important alterations noted within the 10 year study were the gradual decrease that took place from 2002 to 2005, the increase that followed the year after as well as the tremendous decline from 0,21 tn/ha in 2007, to 0,03 tn/ha in 2008. Last but not least, the most worth noted change was that of 2009, where the yield per hectare of soya rocketed to 0,34 tn/ha.

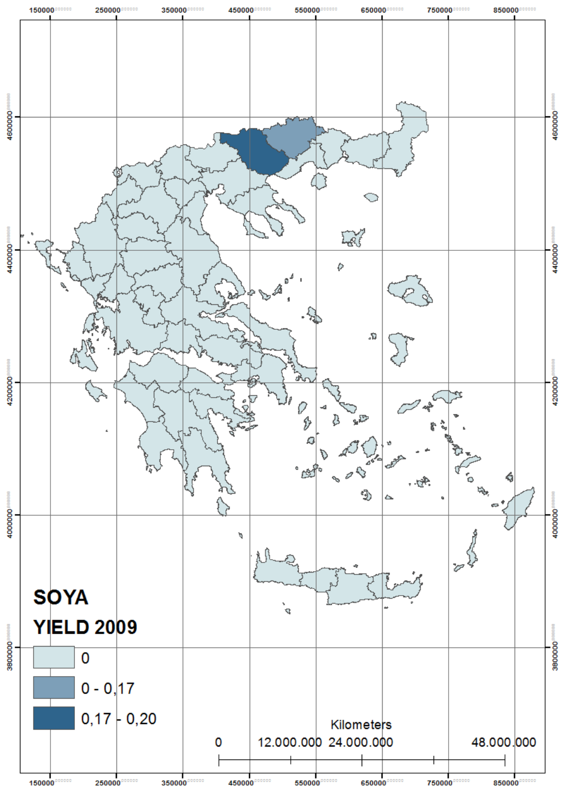


Figure 60. GIS map for soya yield for the year 2009.

9.3.1.5 Rapeseed

Rapeseed constitutes one of the most significant crops for biodiesel production. However, similarly to the case of soya, rapeseed production in Greece is very limited, while its cultivation began in 2007. In view of this fact, rapeseed has been taken into consideration only for the last four years of the studied period.

As presented in Figure 61, rapeseed is mostly cultivated in the northern Greece. The cultivation started in 2007, where the overall production was 711 tonnes and the biggest amount concentrated in Evros and Xanthi which produced 293 tonnes and 176 tonnes of rapeseed respectively. In 2010, the production rocketed to 25.176 tonnes. Serres held the highest amount of rapeseed which was about 8.488 tonnes, followed by Evros where the produced amount of rapeseed was 7.347 tonnes.

Encouragingly, Figure 62 shows that the production of rapeseed was gradually increasing throughout the years. Nonetheless, the growth did not have the same pace, from one year to another. For instance, the increase from 2007 to 2008 was about 68,7%, while from 2009 to 2010 rose by 370,8%.

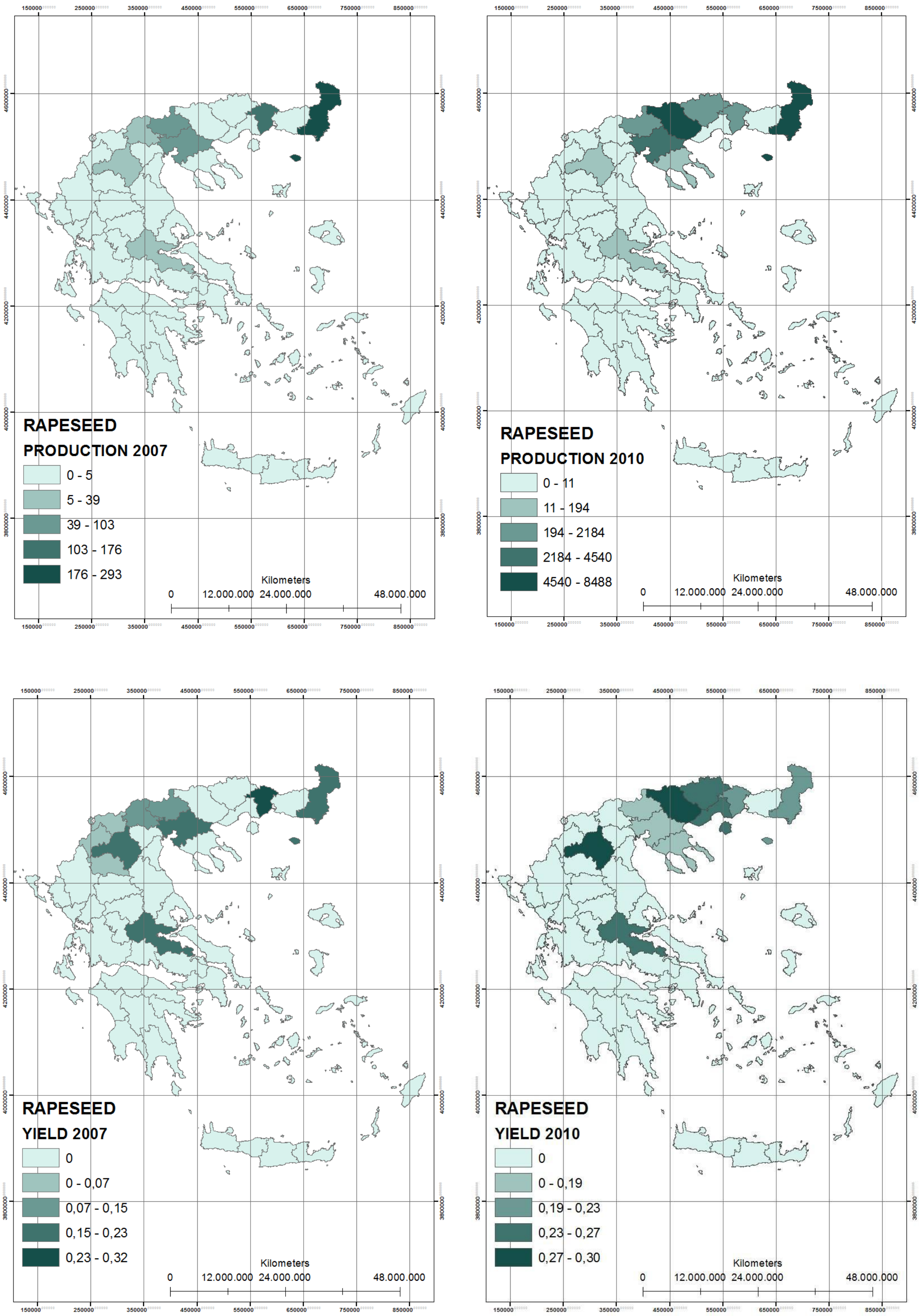


Figure 61. GIS maps for 2007 and 2010 rapeseed production and yield.

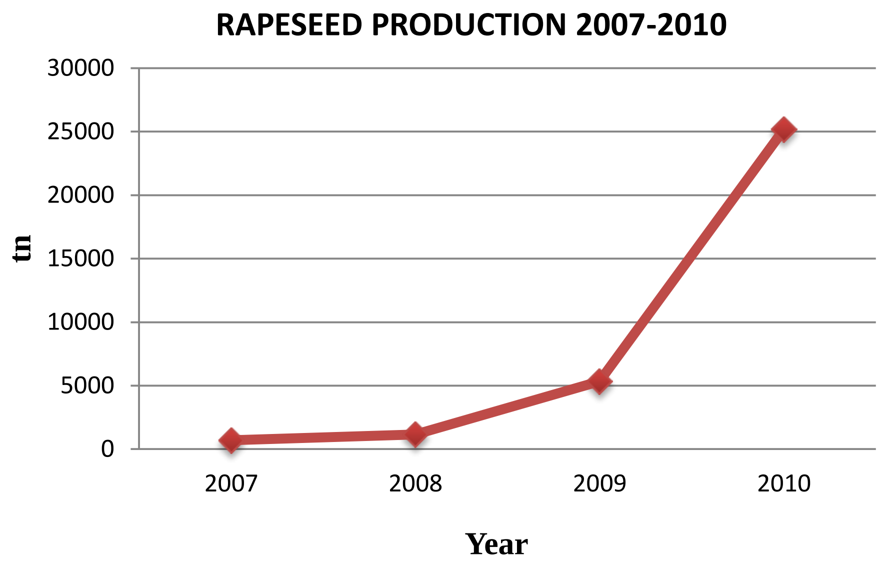


Figure 62. Rapeseed production from 2007 to 2010.

Regarding the per hectare yield of rapeseed, it was about 0,21 tn/ha in 2007, while in 2010 slightly grew to 0,22 tn/ha. In 2007, the highest yield occurred in Xanthi, followed by Thessaloniki with 0,32 tn/ha and 0,23 tn/ha respectively. In contrast, the highest yield rate of rapeseed in 2010, took place in Kozani where it was 0,30 tn/ha, followed by Serres with 0,29 tn/ha.

According to Figure 63, 2008 had the lowest yield per hectare which was 0,15 tn/ha. It is essential to mention that the yield of the three remaining years was about 0,21 tn/ha for 2007 and 2009, as well as 0,22 tn/ha for 2010. This fact implies that a large part of the available land for culturing was not utilized during that year.

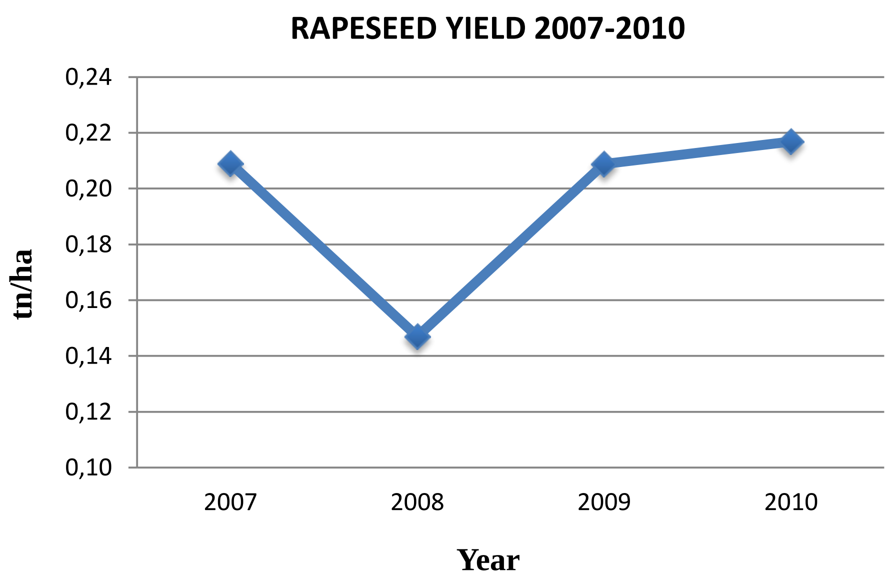


Figure 63. Rapeseed yield from 2007 to 2010.

9.3.2 Available biomass residue for biodiesel production and energy potential.

Similarly to bioethanol analysis process, availability factors were taken in to account as indicative for the potential assessment. As mentioned to previous chapter, in every biomass harvesting method, a high percentage of loss of organic material must be considered, of about 20–25% by weight (Boukis et al., 2009). The residue-to-product rates, the energy factors, and the availability factors per species used for conducting the results, are presented in Tables 15, 16 and 17. The ratios used for the analysis of rapeseed, are the following (Firrisa et al., 2013):

Table 19. Rapeseed Conversion Ratios

Rapeseed Conversion Ratios	
Seed Yield (tn/ha)	2-2,5 tn/ha
Oil Yield (%)	37,6%
Energy Ratio	1,5

The relation between crop production, residual biomass and available residue is presented in Figures 64 to 68 using a 10-year span for each crop studied for biodiesel production. Note that rapeseed has been considered only for the years 2007-2010, as it was not cultivated before 2007.

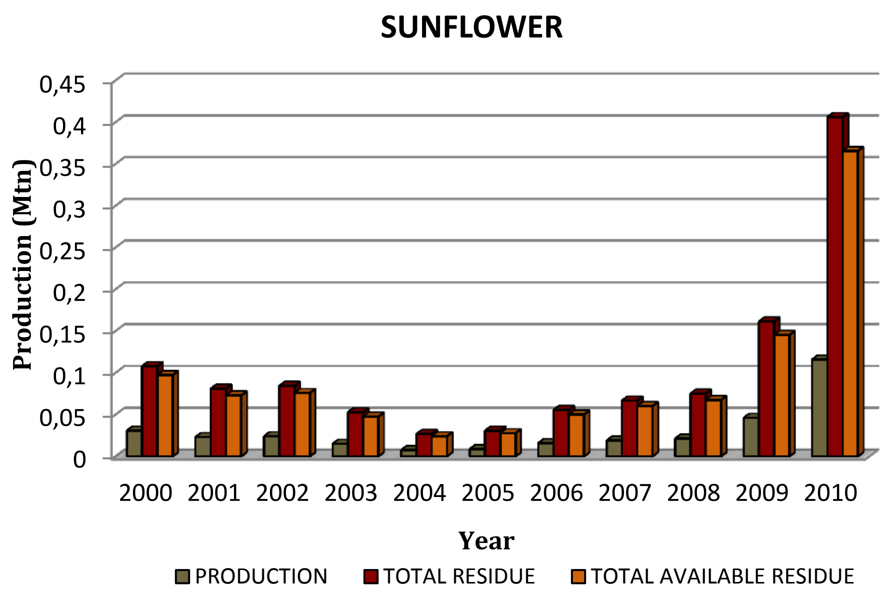


Figure 64. Sunflower production, theoretical residue yield and available residue for the period 2000-2010.

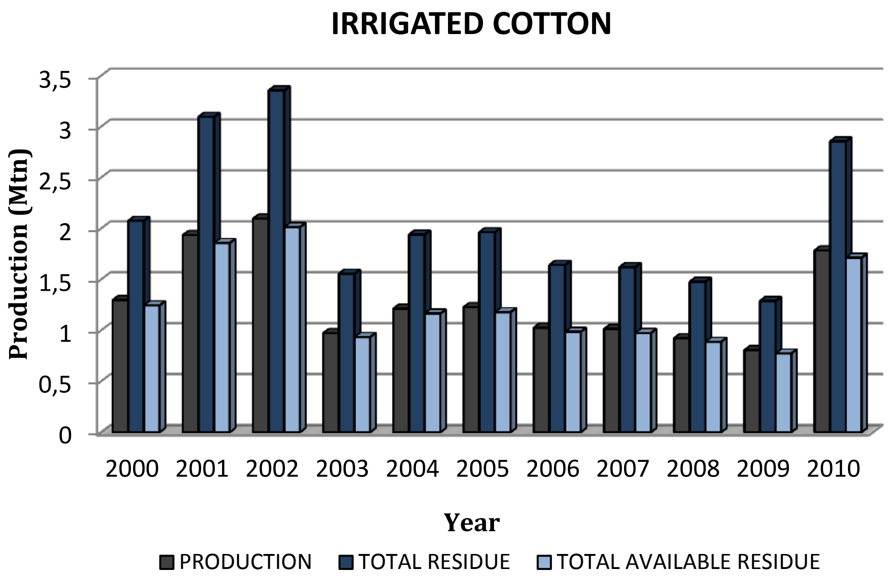


Figure 65. Irrigated cotton production, theoretical residue yield and available residue for the period

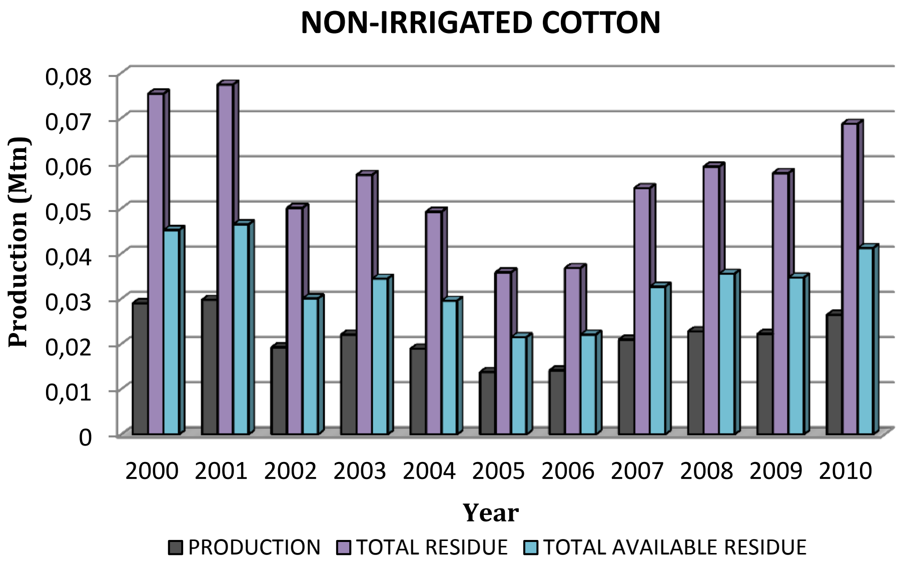


Figure 66. Non-Irrigated cotton production, theoretical residue yield and available residue for

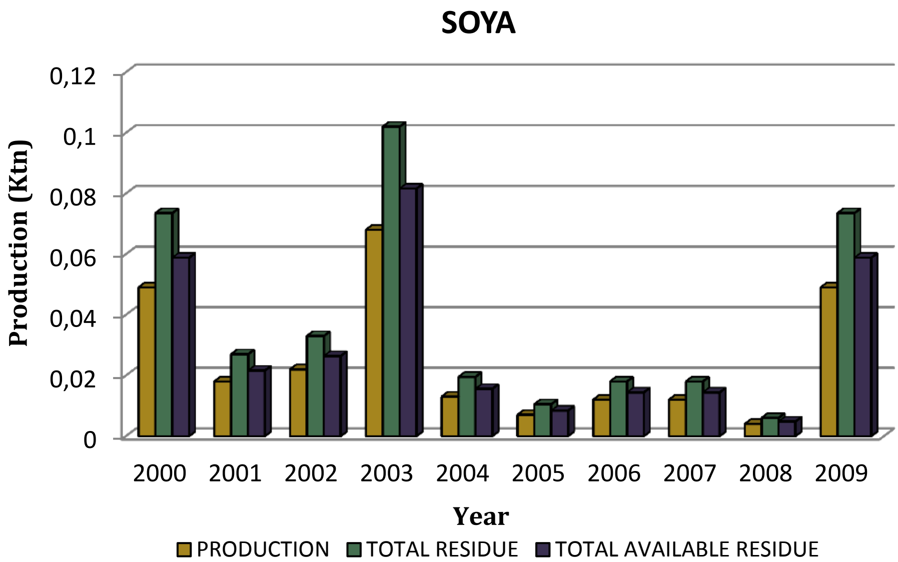


Figure 67. Soya production, theoretical residue yield and available residue for the period 2000-2010.

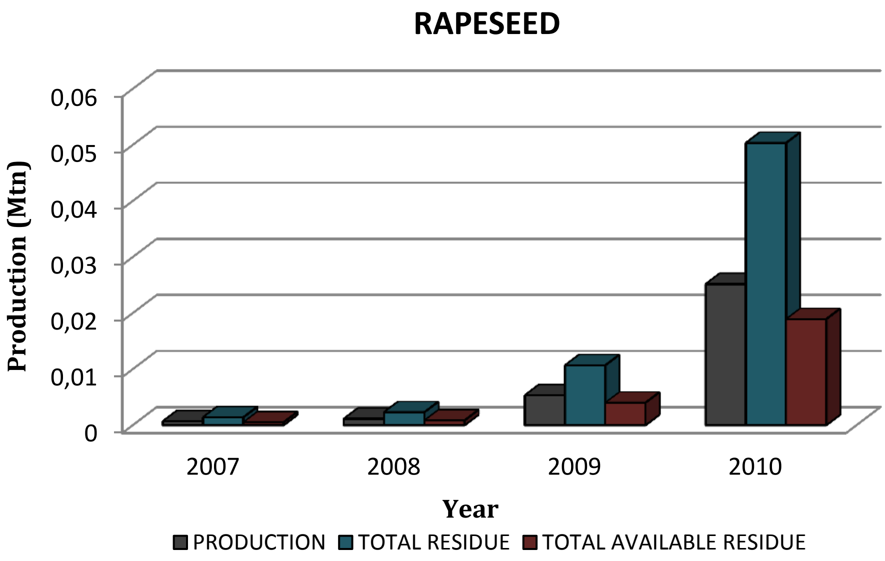


Figure 68. Rapeseed production, theoretical residue yield and available residue for the period 2000-2010.

According to Figures 64 and 67, despite their low residue yields, sunflower and soya share high availability potential. In more detail, the available residual amount for these crops is 90% and 80% respectively. Nevertheless, the theoretical residue yield of sunflower is 0,03-0,41 Mtn, while the residues derive by soya are just about 0,01-2,05 Ktn. Therefore, it is obvious that the available residue amount arising from sunflower is much more than that of soya.

Moreover, although the percentage of cotton residue availability is the same for both irrigated and non-irrigated cotton and it is about 60%, the total residues derive from irrigated cotton are far more than those arise by non- irrigated cotton (Figures 65-66). To be more precise, the total available residues produced by irrigated cotton are 1,29-3,35 Mtn, while from non-irrigated cotton are just 0,04-0,08 Mtn.

Last but not least, the available amount of residues originate from rapeseed in order to be used for biodiesel production is the lowest compared to the abovementioned types of crops (Figure 68). Additionally, the total amount of residues produced by rapeseed is also very low, as it is only 0,001-0,005 Mtn. As a result, rapeseed has little participation in the production of biodiesel in Greece, at least for the years studied.

Taking all the above into consideration, one can reach to the conclusion that the crops with the greatest participation in biodiesel production is irrigated cotton followed by sunflower and non-irrigated cotton, whereas the crops with the least contribution are rapeseed and soya. However, it must be noted that it has been a remarkable progress to the cultivation of rapeseed, which seems promising for the foreseeable future.

In Table 14, the potential of energy production for each year within the studied period is presented, as calculated based on the total biomass potential and the energy capacity (Tables 10, 13) of each biomass residue. As with bioethanol analysis, a conversion efficiency of 70% was also taken into account to perform this estimative.

Table 20: Potential of residues production and energy from agriculture residues for biodiesel production

Potential of residues production and energy from agriculture residues for biodiesel production				
RESIDUE SOURCE	**COVERED AREA (ha)**	**PRODUCTION (tn/ha)**	**AVAILABLE BIOMASS RESIDUE PRODUCTION (tn)**	**ENERGY POTENTIAL (GJ)**
2000				
Sunflower	231096	0,13	97221,6	1136520,504
Soya	282	0,17	58,8	650,328
Irrigated Cotton	4103954	0,32	1245267,84	11122732,35
Non-Irrigated Cotton	164660	0,18	45236,88	404055,8122
TOTAL	4499992	0	1387785,12	**12663958,99**
2001				
Sunflower	166489	0,14	72894,15	852132,6135
Soya	112	0,16	21,6	238,896
Irrigated Cotton	3884760	0,5	1857438,72	16590642,65
Non-Irrigated Cotton	152932	0,19	46463,04	415007,8733
TOTAL	4204293	0	1976817,51	**17858022,03**
2002				
Sunflower	169735	0,14	75911,85	887409,5265
Soya	111	0,2	26,4	291,984
Irrigated Cotton	3724204	0,56	2012608,32	17976617,51
Non-Irrigated Cotton	103144	0,19	30084,6	268715,6472
TOTAL	3997194	0	2118631,17	**19133034,67**
2003				
Sunflower	98435	0,15	47511,45	555408,8505
Soya	884	0,08	81,6	902,496
Irrigated Cotton	3635334	0,27	933528,96	8338280,671
Non-Irrigated Cotton	109068	0,2	34455,72	307758,491
TOTAL	3843721	0	1015577,73	**9202350,51**
2004				
Sunflower	47451	0,16	24069,15	281368,3635
Soya	297	0,04	15,6	172,536
Irrigated Cotton	4026442	0,3	1164796,8	10403965,02
Non-Irrigated Cotton	96881	0,2	29572,92	264145,3214
TOTAL	4171071	0	1218454,47	**10949651,24**

2005				
Sunflower	49377	0,18	27672,75	323494,4475
Soya	172	0,04	8,4	92,904
Irrigated Cotton	3586281	0,34	1177783,68	10519963,83
Non-Irrigated Cotton	77632	0,18	21517,08	192190,5586
TOTAL	3713462	0	1226981,91	**11035741,74**
2006				
Sunflower	90572	0,18	49984,2	584315,298
Soya	57	0,21	14,4	159,264
Irrigated Cotton	3669818	0,28	985247,04	8800226,561
Non-Irrigated Cotton	98905	0,14	22088,04	197290,3733
TOTAL	3859352	0	1057333,68	**9581991,5**
2007				
Sunflower	120154	0,16	60130,35	702923,7915
Soya	58	0,21	14,4	159,264
Rapeseed	3400	0,21	1422	561,4056
Irrigated Cotton	3469325	0,29	972715,2	8688292,166
Non-Irrigated Cotton	160481	0,13	32699,16	292068,8971
TOTAL	3753418	0	1066981,11	**9684005,53**
2008				
Sunflower	43549	0,49	67548,6	789643,134
Soya	133	0,03	4,8	53,088
Rapeseed	7920	0,15	2328	919,0944
Irrigated Cotton	2913859	0,32	886546,56	7918633,874
Non-Irrigated Cotton	202881	0,11	35549,28	317526,169
TOTAL	3168342	0	991977,24	**9026775,36**
2009				
Sunflower	234262	0,2	145303,2	1698594,408
Soya	144	0,34	58,8	650,328
Rapeseed	25609	0,21	10694	4221,9912
Irrigated Cotton	2504305	0,32	772727,04	6901997,921
Non-Irrigated Cotton	165600	0,13	34705,32	309987,9182
TOTAL	2929920	0	963488,36	**8915452,57**
2010				
Sunflower	534832	0,22	365516,55	4272888,47
Soya	5053	0,27	1641,6	18156,096
Rapeseed	116072	0,22	50352	19878,9696
Irrigated Cotton	2577022	0,69	1712767,68	15298440,92
Non-Irrigated Cotton	198192	0,13	41246,4	368412,8448
TOTAL	3431171	0	2171524,23	**19977777,3**

Based on the above table, the graph in Figure 69 has been created, where the potential annual energy generation during the period 2000-2010 is presented. As it is clearly illustrated from the graph, the year with the greatest energy potential was 2010, where the energy potential was 19.977.777 GJ, followed by 2002, where it was 19.133.035 GJ. On the other hand, 2009 and 2003 had the lowest energy potential as it was 8.915.453 GJ and 9.202.351 GJ respectively.

It is striking that while 2002 was one of the years with the highest energy potential, the year that followed was one of the years with the lowest potential. On the contrary, despite the fact that the energy potential of the year 2010 is the highest within the decade, it constitutes the successor of the year with the lesser energy generation potential. Furthermore, one may advocate that the potential of energy generation from 2007 onwards should have rose considerably due to the entry of rapeseed in the mixture. However, although the energy potential had a slight increase of around 1.06% in 2007, it went down by 7,28% from 2007 to 2009.

In general, while the potential energy of the first three years steadily increased, even starting from the considerable value of 12.663.959 GJ, after the sharp drop that followed in 2003, there were small fluctuations until 2009, keeping small amounts of possible energy generation.

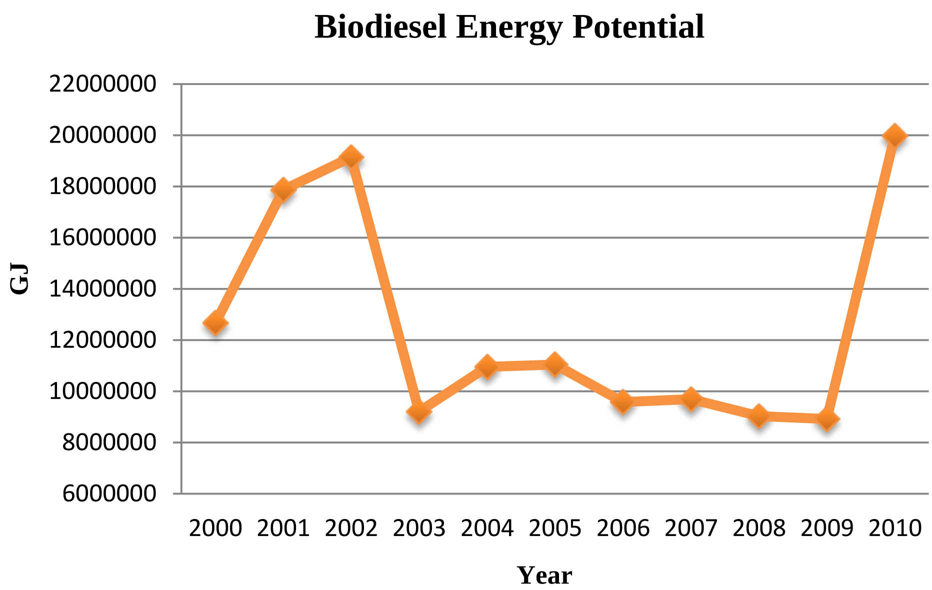


Figure 69. Biodiesel energy potential, for the period 2000-2010.

The annual potential energy by crop, for the years with the lowest and the highest energy potential is presented in Figure 70. One can easily observes that irrigated cotton is by far the most advantageous crop for biodiesel production in Greece as its energy potential ranges between 6.901.998 GJ and 15.298.441 GJ. The second most advantageous crop is sunflower, the energy potential of which ranges between 1.698.594 GJ and 4.272.888 GJ, while soya constitutes the crop with the lowest energy potential.

It is observed that all types of crops contemplated, have been increased as to the potential energy in 2010 compared to 2009. The most important alterations between these two years are the remarkable increase in the potential energy derived from soya which from 650 GJ in 2009 reached 18.156 GJ, as well as rapeseed's rise of 371%. Furthermore, the energy potential of irrigated cotton doubled in 2010 compared with 2009, while sunflower's potential energy in 2010 was two and a half times higher than that of 2009. Last but not least, a small increase in the potential energy of non-irrigated cotton has been occurred, of about 18,8%.

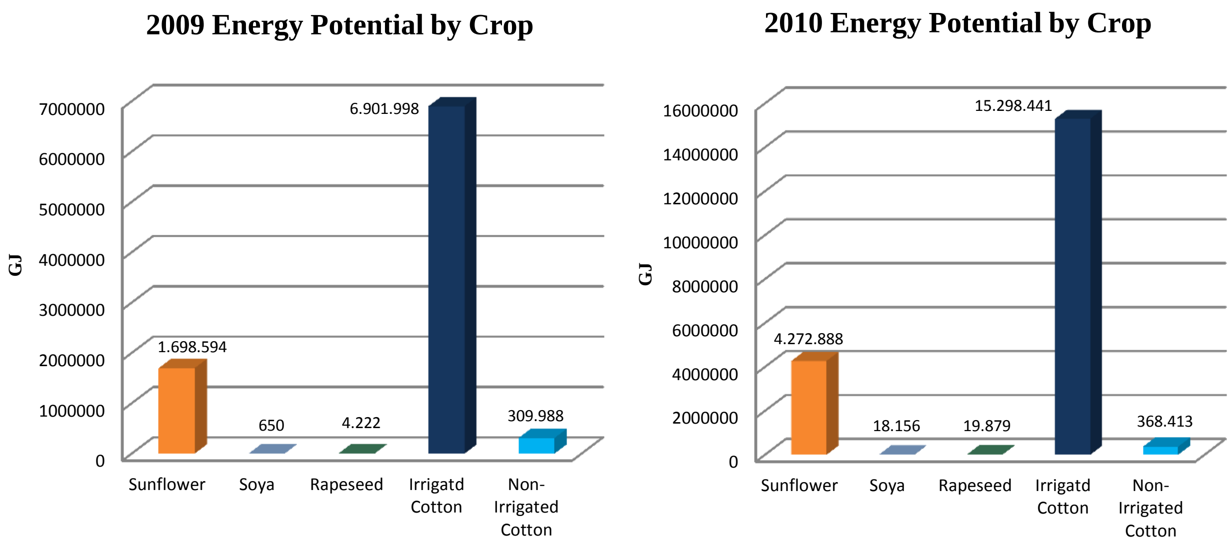


Figure 70. Energy potential by crop for the years 2009 and 2010

Impressive is the fact that despite the great deference between the two years, the contribution of each crop to the overall energy potential remained the same. This implies that the increase was similar for all types of crops and did not affect their contribution. According to Figure 71, soya and rapeseed have minor contribution to energy potential generation. The proportionate share of irrigated cotton is 77%, while the second largest share is 21% owned by sunflower. Lastly, the contribution of non-irrigated cotton is 2%.

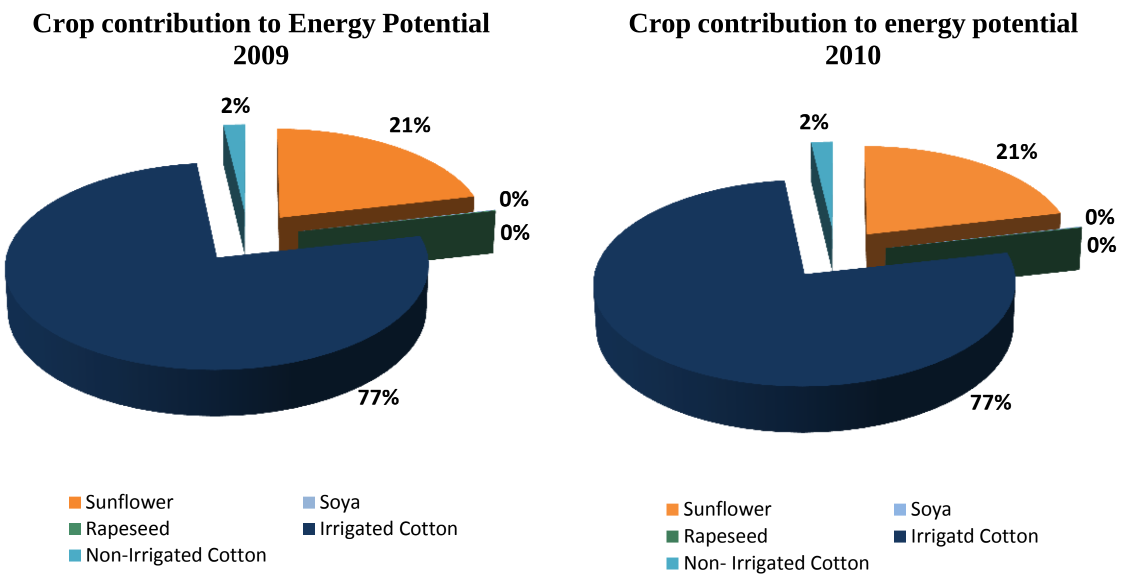


Figure 71. Crop contribution to energy potential for the years 2009 and 2010

Last but not least, it is essential to refer to the dispersion of the potential available biomass residue in the various prefectures of Greece. As it has been mentioned to a previous chapter, such a study can provide important information for the implementation of a suitable investment strategy for the production of biodiesel. Detecting the locations with the highest concentration of available biomass residue potential (derived from all the crops used in the production of biodiesel), as well as the amount of straw residue potential, can lead to a more targeted selection of region for installing a biodiesel production unit.

Figure 72 presents the largest possible amount of available residues of the latest year of the study. As it can easily be observed the highest amount of potential available residue is concentrated mainly in central and northern Greece. For accuracy, the greatest potential is concentrated in Karditsa and it is about 1.173.674 tonnes, followed by Evros and Larisa with 266.273 tonnes and 129.342 tonnes respectively. Furthermore, the greatest quantity of straw residue potential is located also in Karditsa, Evros and Larisa, ranging between 1.222.387 tonnes and 133.393 tonnes.

In conclusion, taking all the above into consideration, one could advocate that the most preferable geographic regions for biodiesel production investments are Thessaly and Thrace.

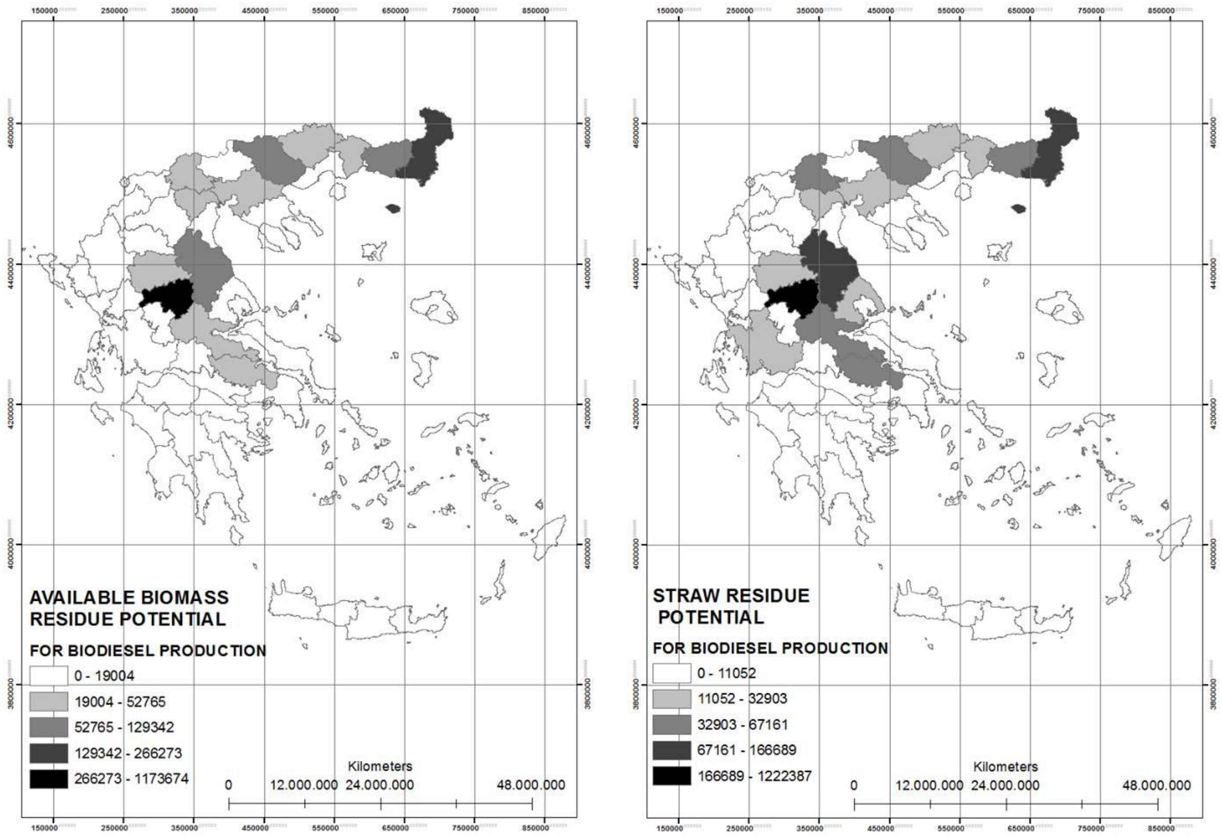


Figure 72. The available annual biomass residue potential and the available straw residue potential for biodiesel in Greece.

10. Discussion and Concluding Remarks

GIS-based applications have proved to be useful in assessing the bioenergy potential of regions, countries or continents. Merged with advanced modeling tools, decision making over plant capacity and localization, logistics infrastructure, or even technology selection can be readily supported. Yet, results relying on surface indices and conversion factors carry along a high degree of uncertainty. A major drawback of such assessments lies in the use of empirical or theoretical correlations between produced amounts and available amounts that cannot relate reliably to the technically and economically biomass fractions that can be actually exploited. While the former is deeply rooted to physicochemical properties of biomass, defined by the biohydrogeochemical area profile and cultivation practices, the latter involves logistic issues and supply costs within a sustainable framework of administrative and market infrastructure. To add further to the sustainability of any national energy policy measures, public acceptance and environmental issues cannot be overlooked.

10.1 Technological Exploitability

Biodiesel production technology reaches maturation while feedstock supply is reliably quantifiable on the basis of energy crops and governmental control over quanta. Greek bioethanol launching has more hurdles to overcome, while residue-derived feedstock increases uncertainty manifold. Biomass-to-bioethanol conversion routes are complex, involving multi-step pre-treatment of feedstock to release its sacharified fraction, hydrolysis under carefully controlled conditions to obtain the sugars and low yield fermentation (unless genetically modified organisms are utilized) to produce ethanol. Intensity of treatment, intermediate yields and product quality depend upon the physicochemical characteristics of the feedstock; the ideal residues come from good agricultural practices (free of overfertilizing, insecticidal and pesticidal carryovers), and have high cellulose and hemicellulose levels at low lignin and moisture content (Sidiras et al., 2011). Globally, bioethanol production from rice straw, wheat straw, corn straw and sugarcane bagasse has received much attention lately, owing to both, a high cellulosic and a low lignin profile; rice straw seems to concentrate the interest since it has, theoretically, the highest bioethanol conversion rate (Kim and Dale, 2004). On the other hand, although the technological challenges of biodiesel production considered being less extensive in comparison with bioethanol, taking into consideration a study conducted by Firrisa et al. (2013), regarding the energy efficiency for rapeseed biodiesel production (Figure 73), we conclude that higher yields (agricultural goal) do not necessarily translate into higher bioenergy potential and different inputs and processes have different impacts on overall energy efficiency. In conclusion, the technological aspects play major role to the sustainability and efficiency of the various crop species conversion process into biofuels.

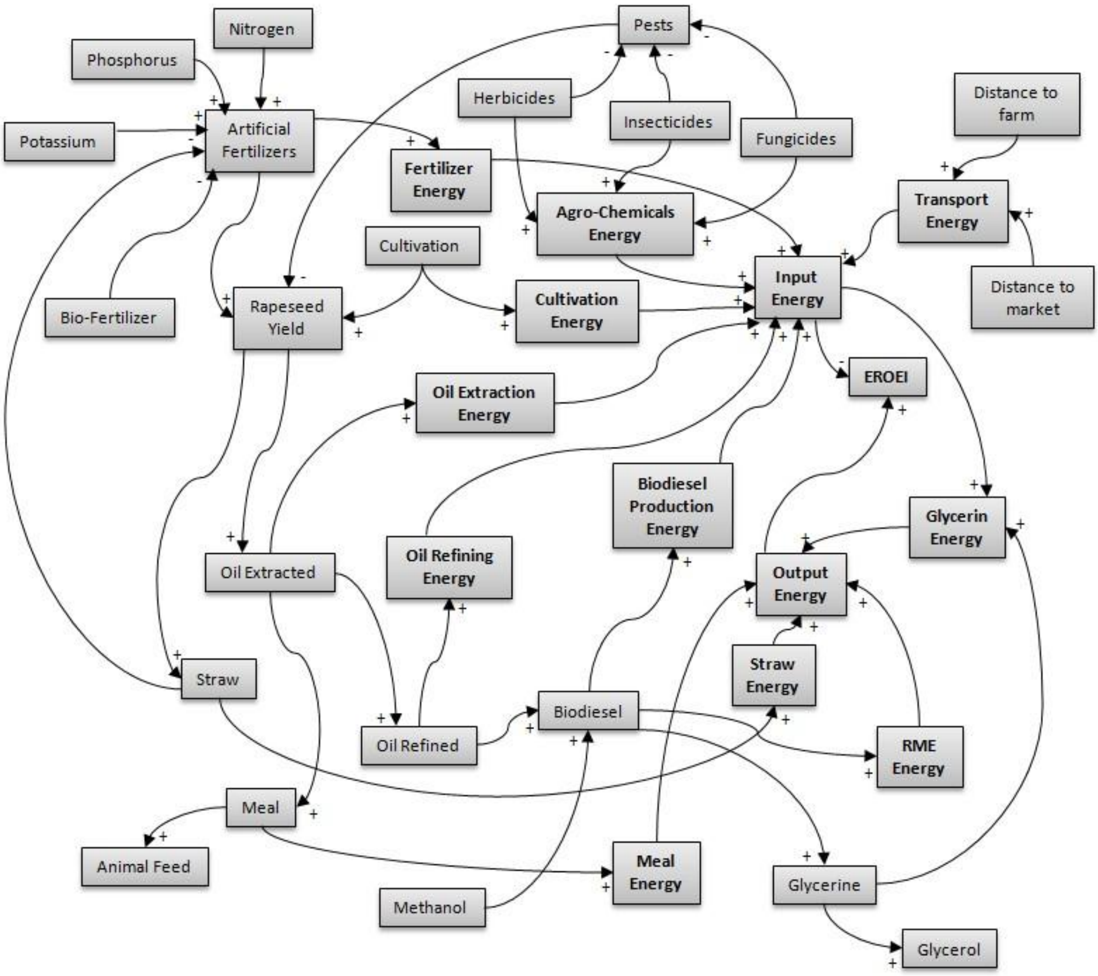


Figure 73. Diagram of Energy Return on Energy Input (EROEI) for the rapeseed biodiesel production system. All processes that require or produce energy (boxes with bold lines and text) are connected via positive or negative cause-effect relationships.

10.2 Economical Exploitability

Biofuel systems from energy crops are built on subsidies covering the entire supply chain, from farmers to distributors; yet, such provision may not be available for primary food producers which, if they want to join the biofuel chain, should, also, undertake the burden of a coordinated transition in their practices. Even then, the economically exploitable biomass potential should include only easily accessible and high yield areas, almost ruling out the high quality mountainous produce.

Despite, feedstock supply obeys the resource's seasonality. Calculated from the agricultural crops' harvest calendar (herbaceous and horticultural), the monthly distribution presents two peaks of production in the months of May–August, and

November–December. In the event of undersupply, imported feedstock should cover for five to six months of production. In the event of oversupply, the storage problem has to be dealt with. The biomass energy exploitation literature has rarely investigated the issue of biomass storage. Rather, researchers usually choose arbitrarily the lowest cost storage method available, ignoring the effects this choice may have on the total system efficiency Rentizelas et al., (2009), pointed out that the lowest cost storage method is more efficient for single-species resources, while the multi-species approach becomes more advantageous when combined with relatively expensive storage methods. However, low cost biomass storage methods bear increased health, safety and technological risks that should always be taken into account. That would certainly concentrate production units to eastern continental and northwestern regions, as the highly exploitable island produce would be hardly cost-effective.

10.3 Public Acceptance

The availability rate of residues should be, also, corrected to the fraction that does not present meaningful alternative uses. The agricultural biomass residues, especially in Greek districts involved in less organized farming (e.g., Epirus, Crete, mountainous Peloponnese and Evritania) are traditionally utilized as animal fodder and domestic fuel, while they could find more prominent uses in electricity production (Boukis et al., 2009).

Nonetheless, the degree of biofuel social acceptability has not been well established yet, at least at a level to ensure the participation of Greek farmers in a residue biofuel supply chain system. Savvanidou et al. (2010) conducted a small-scale survey for northern Greece; there work showed that there exists a significant lack of information and education background about biofuels, while the concern about energy costs is managed through saving schemes and the use of other renewable resources.

10.4 Environmental Impact Aspects

Among the numerous environmental concerns that alternative fuels bear, there are two aspects directly related to biomass potential estimations: profitability and soil organic carbon preservation. The profitability of biofuel production in most publications is based on gate biofuel prices, calculated on the assumption that the selling biofuel price will be the same as the price of the replaced fossil fuel. Because of this, the price ratio between biomass feedstock and crude oil has a crucial influence on the profitability of the biofuel production costs. Ilic et al. (2014) have shown that the profitability is much reduced compared to financial model-derived values due to a higher carbon dioxide charge (2.4 times higher) associated with the residues supply chain. For example, depending on bioethanol technology selected production costs are between 7% and 15% higher when lignocellulosics (e.g., wood and straw) are used. If such considerations are to be taken into account in biomass potential assessments, the Greek residue supply would certainly fall short to cover the demands.

The depletion of soil organic carbon, deriving from removing the residues from the fields, may partially offset the environmental suitability and convenience of a large-scale bioenergy production policy involving agricultural residues. Recent studies indicate that only 60% of the 2020 EU target can be safely obtained (Monforti et al., 2015). Evidently, safety factors should be, also, considering in converting surface production to available residues. Obtaining reliable and relevant data on soil carbon stock change requires long-term experiments in different soils and farming practices over several decades. In the majority of cases where such data are available, 45% straw removal may be considered safe. Nevertheless, the spatial pattern of results also clearly indicates regions and countries where residues exploitation should be handled with care and current practices on residues collection may be risky in environmental terms.

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Sunwind Energy For All: http://www.sunwindenergy.gr/

Union of Concerned Scientists: http://www.ucsusa.org/

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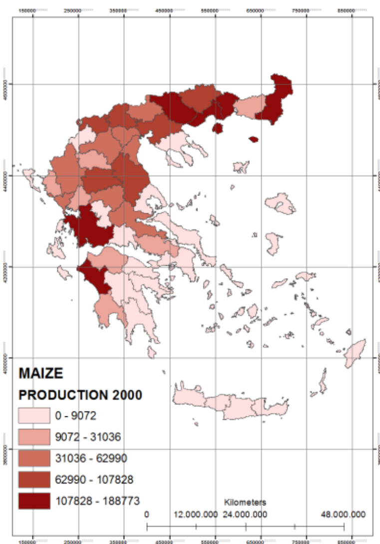
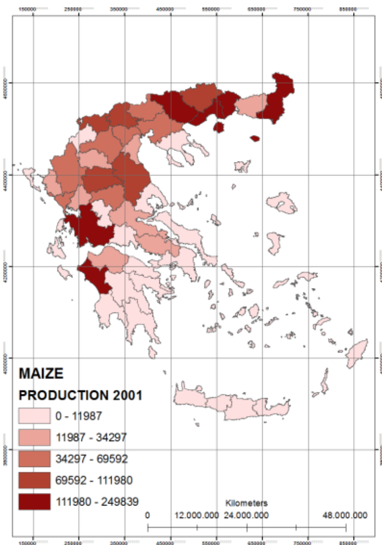
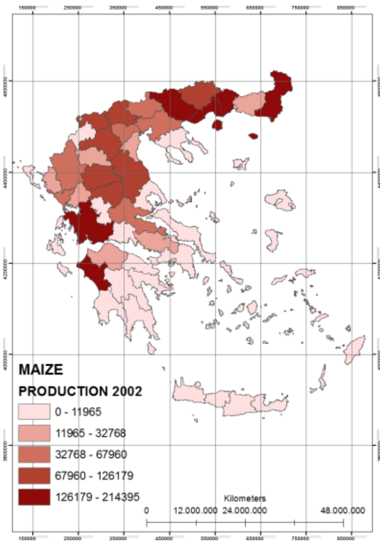
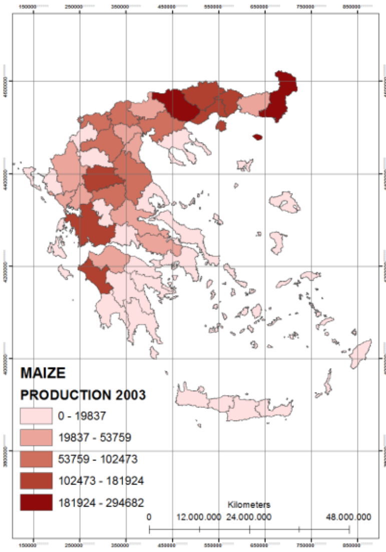
APPENDIX

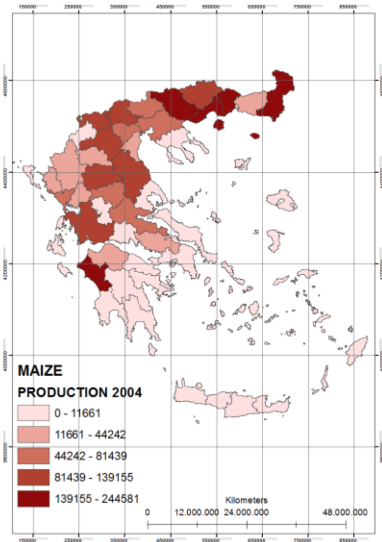
*GIS maps for the production of **Maize** from 2000 to 2010*

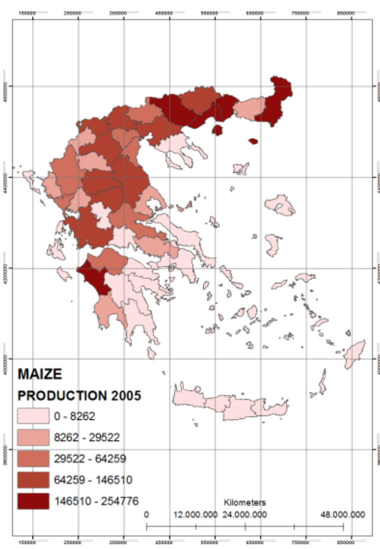


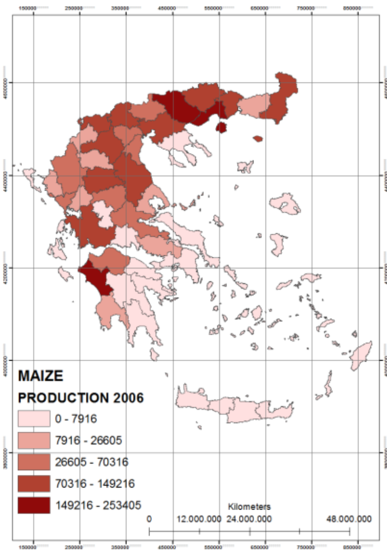


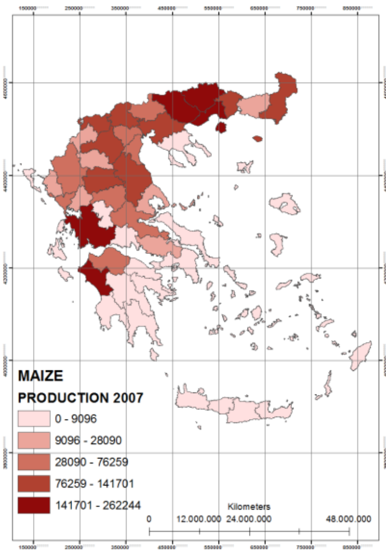


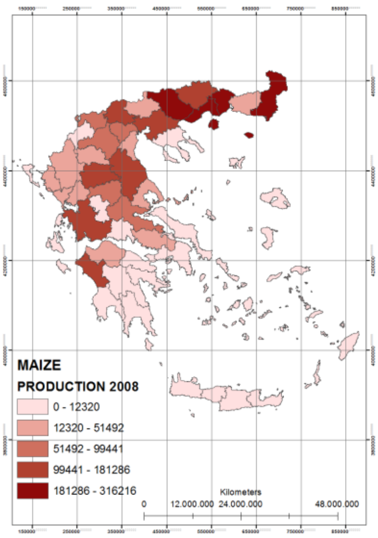


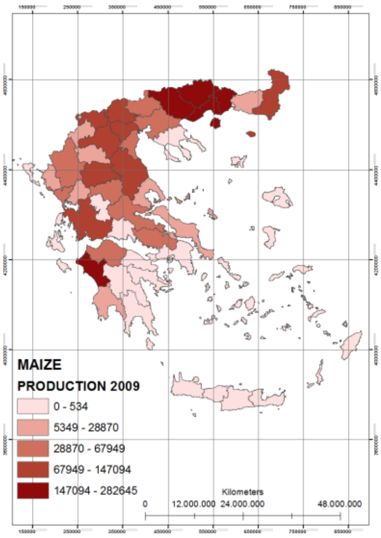


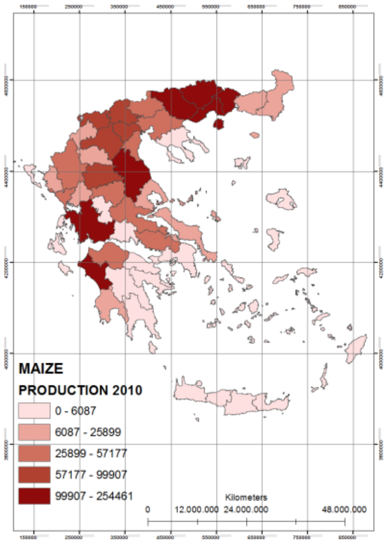




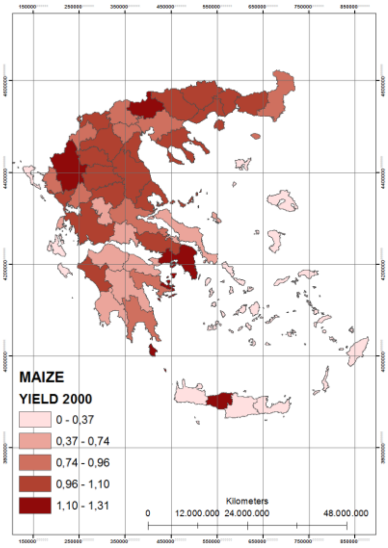


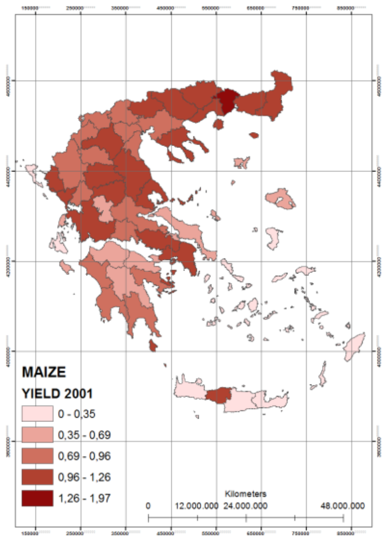


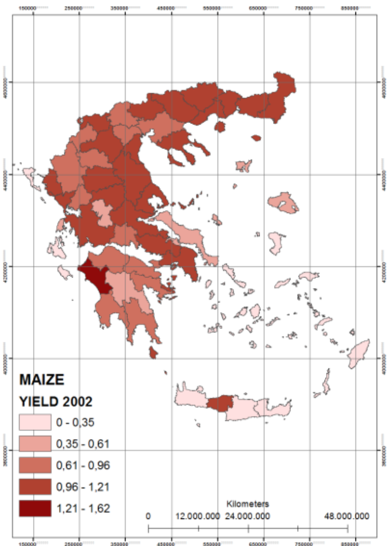


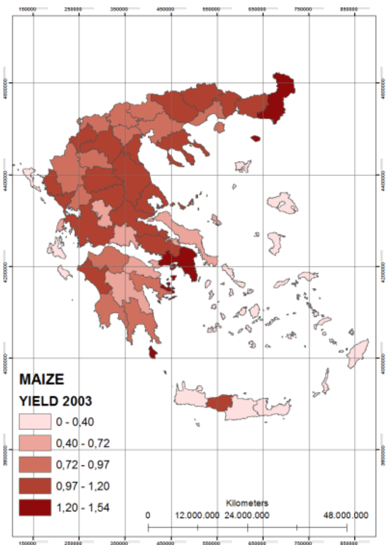


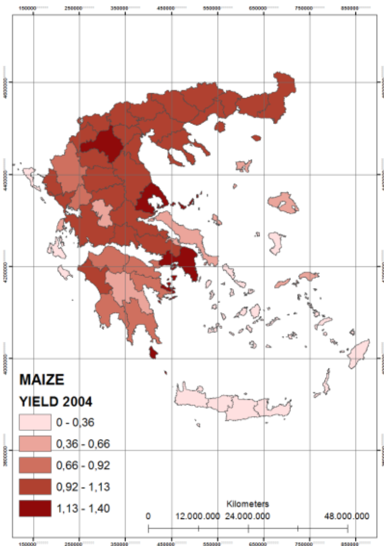
GIS maps for the yield of ***Maize*** *from 2000 to 2010*

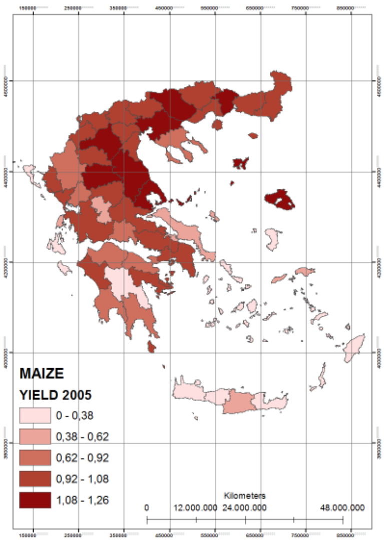


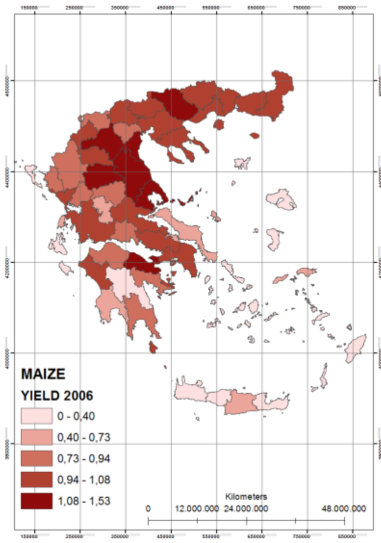


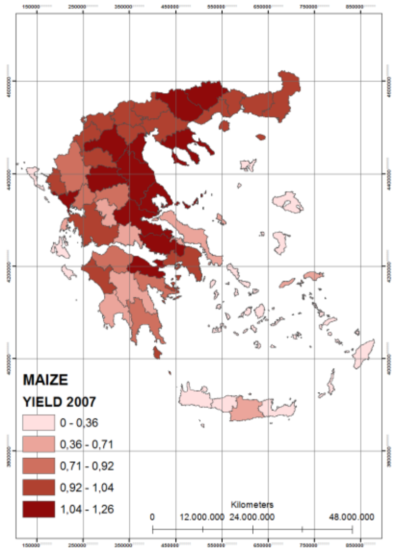


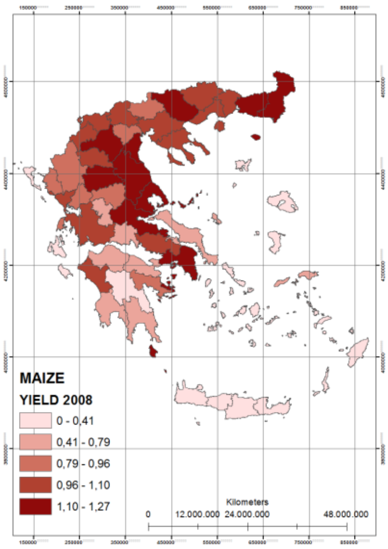


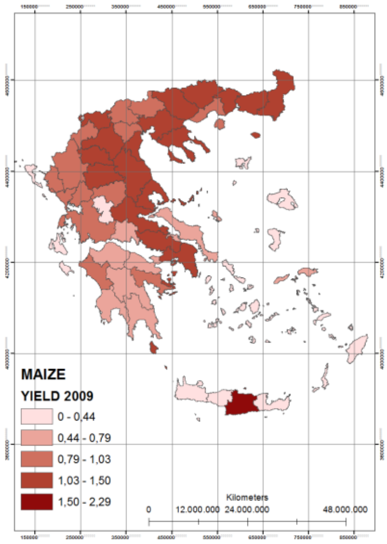


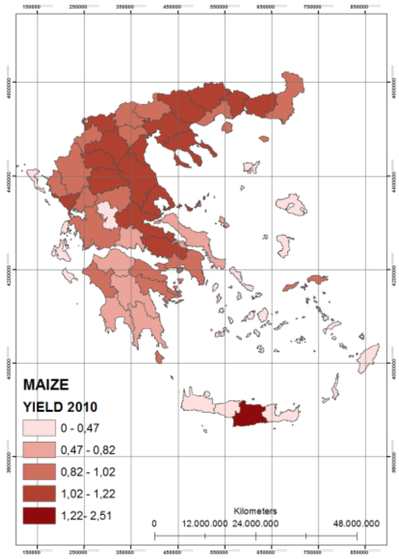




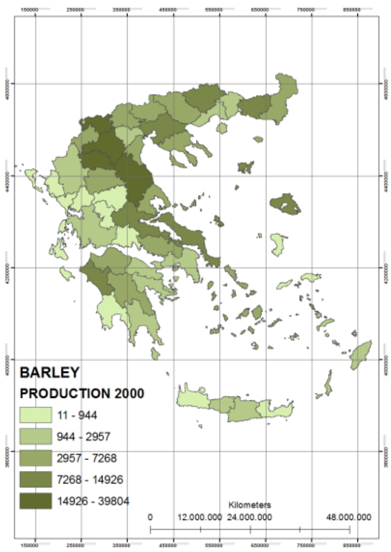


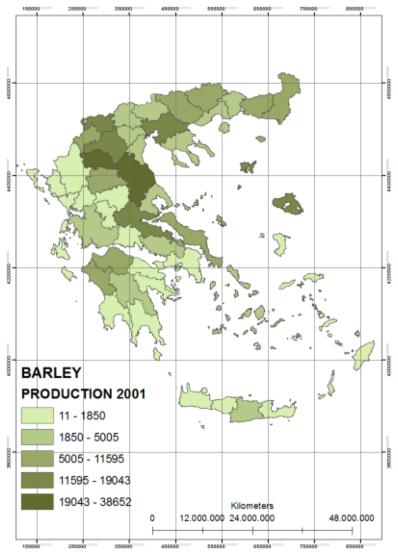


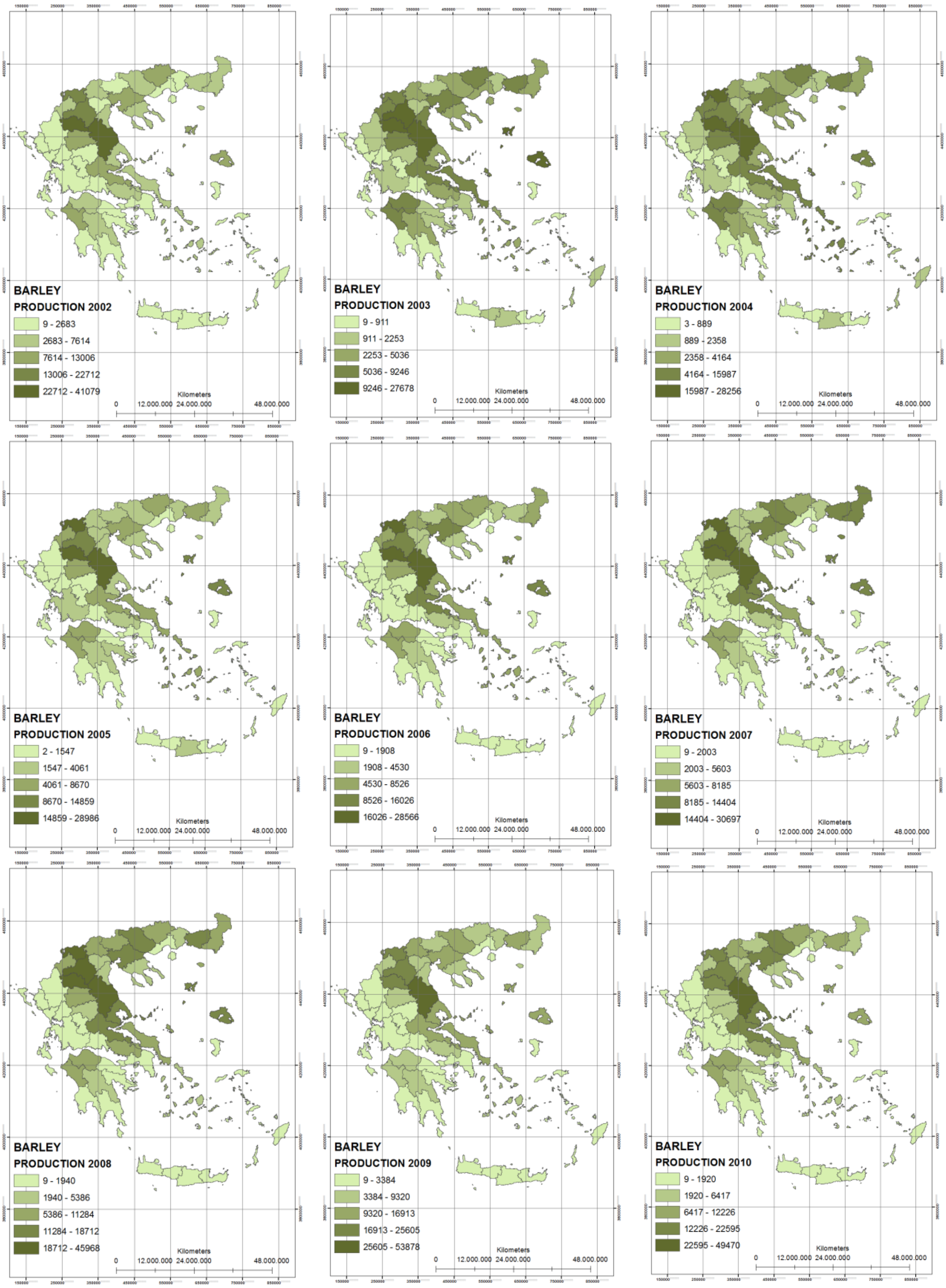




*GIS maps for the production of **Barley** from 2000 to 2010*






BARLEY
PRODUCTION 2002
9 - 2683
2683 - 7614
7614 - 13006
13006 - 22712
22712 - 41079
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2003
9 - 911
911 - 2253
2253 - 5036
5036 - 9246
9246 - 27678
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2004
3 - 889
889 - 2358
2358 - 4164
4164 - 15987
15987 - 28256
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2005
2 - 1547
1547 - 4061
4061 - 8670
8670 - 14859
14859 - 28986
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2006
9 - 1908
1908 - 4530
4530 - 8526
8526 - 16026
16026 - 28566
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2007
9 - 2003
2003 - 5603
5603 - 8185
8185 - 14404
14404 - 30697
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2008
9 - 1940
1940 - 5386
5386 - 11284
11284 - 18712
18712 - 45968
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2009
9 - 3384
3384 - 9320
9320 - 16913
16913 - 25605
25605 - 53878
Kilometers
0 12.000.000 24.000.000 48.000.000
BARLEY
PRODUCTION 2010
9 - 1920
1920 - 6417
6417 - 12226
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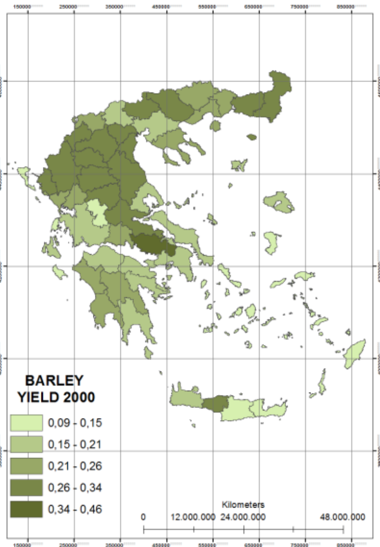
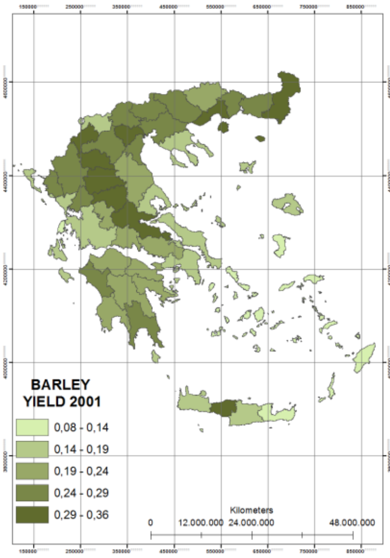
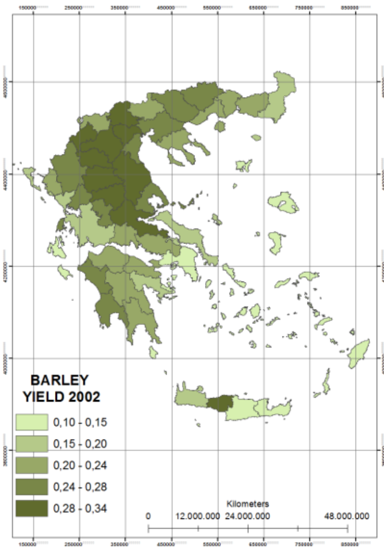
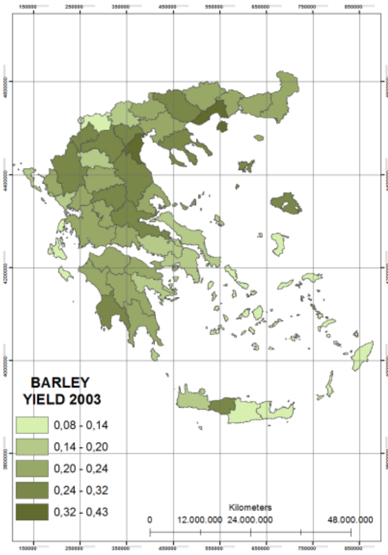
22595 - 49470
Kilometers
0 12.000.000 24.000.000 48.000.000

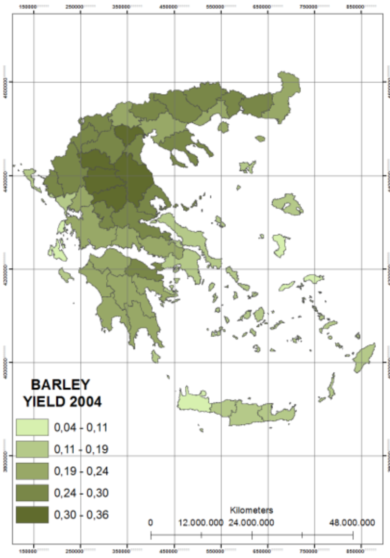
*GIS maps for the yield of **Barley** from 2000 to 2010*

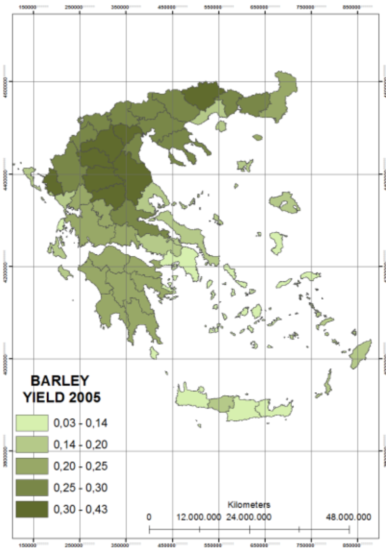


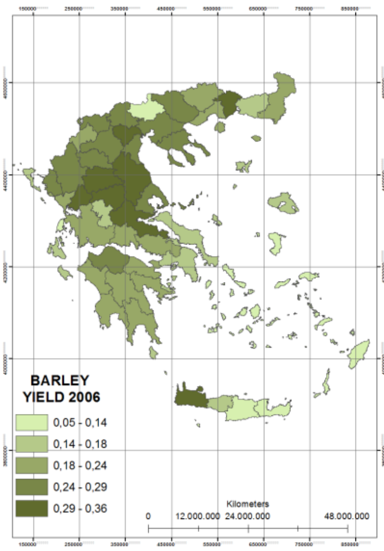


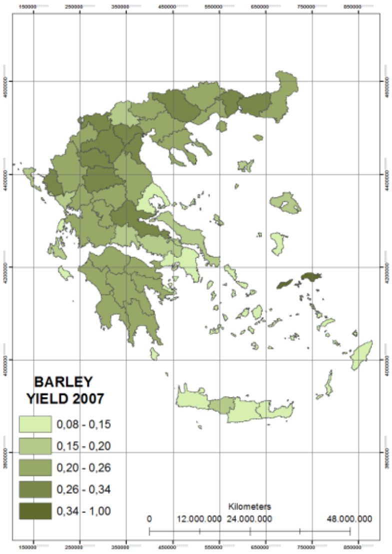


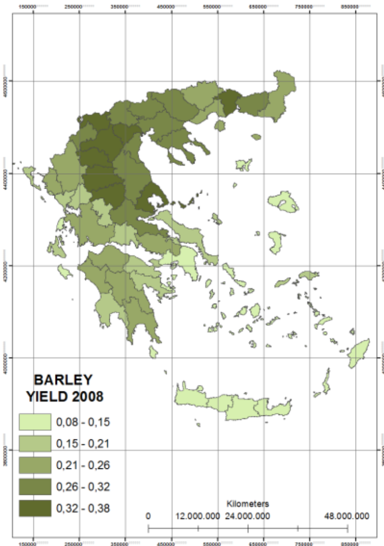


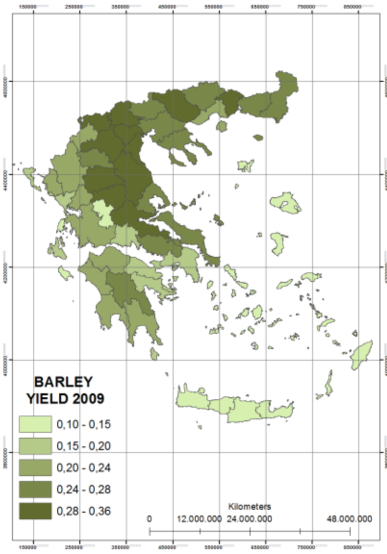


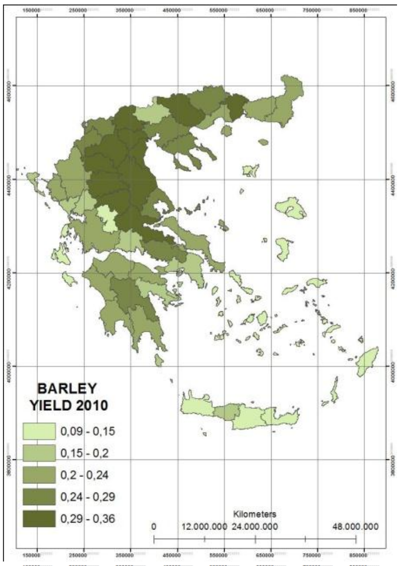


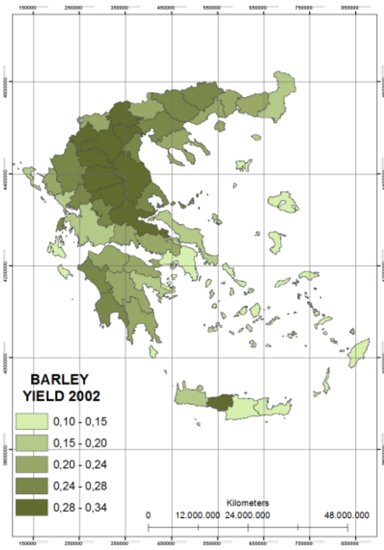


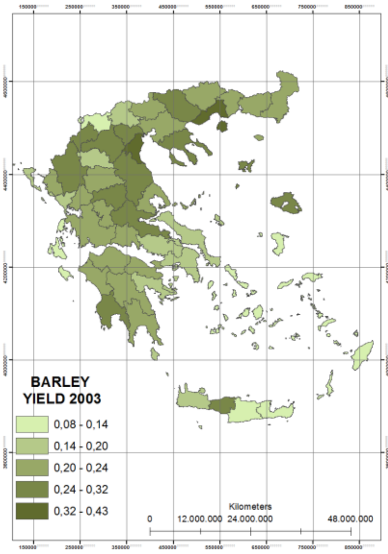


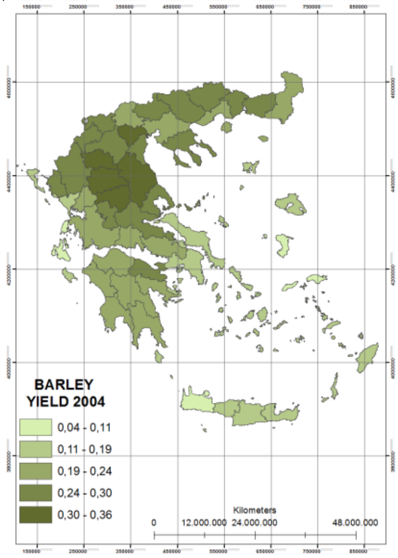




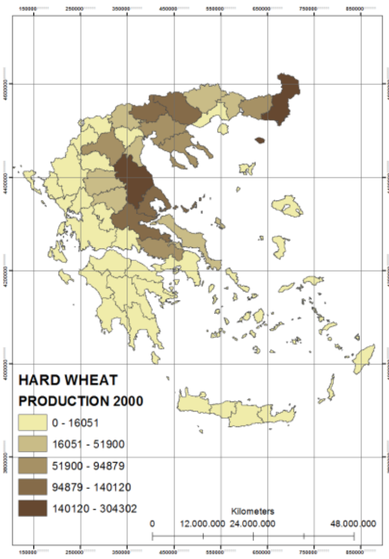


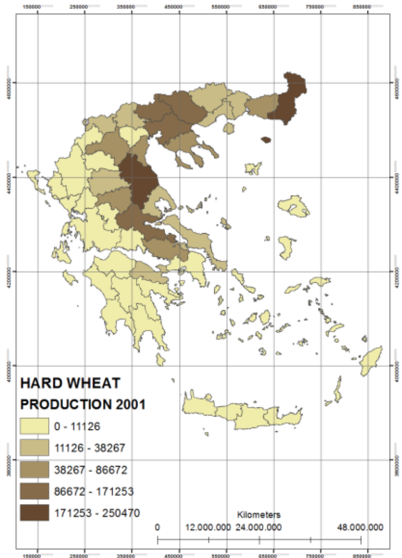


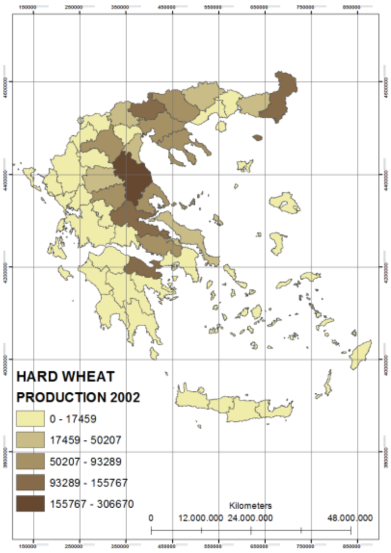


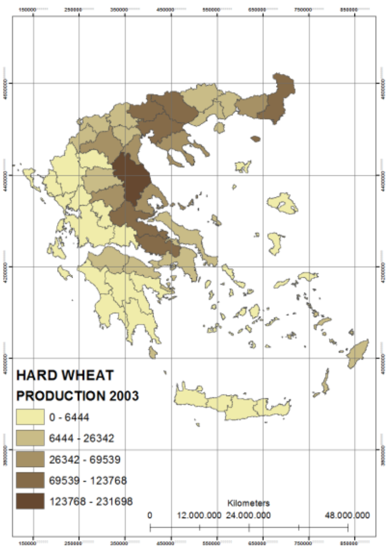


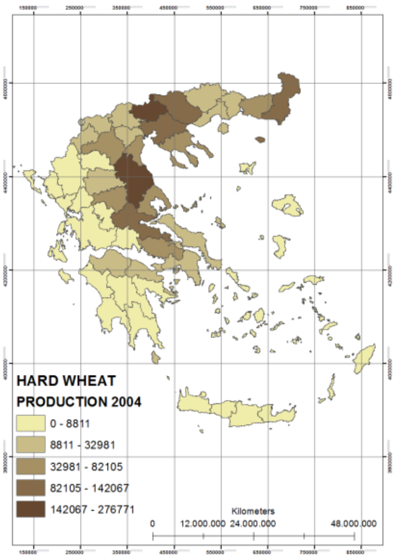
*GIS maps for the production of **Hard Wheat** from 2000 to 2010*

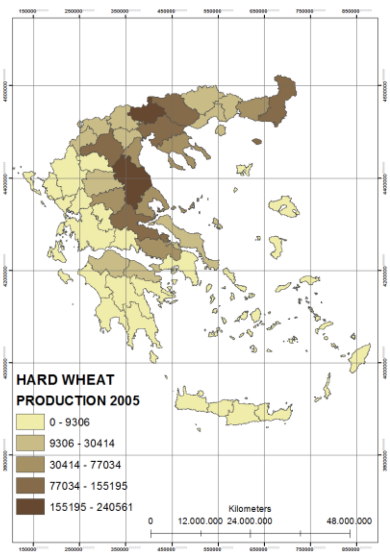


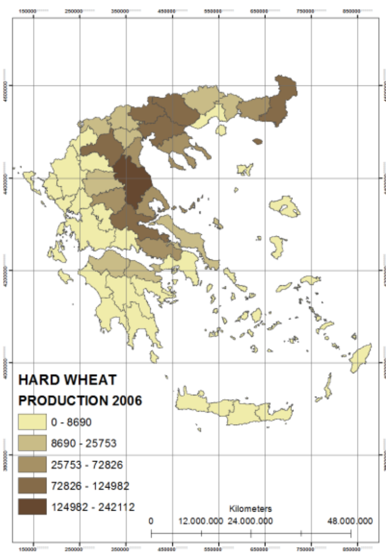


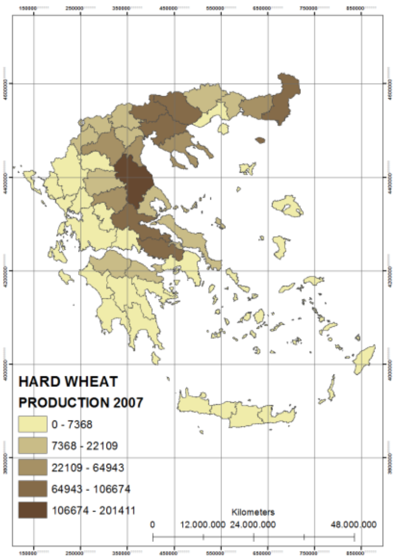

HARD WHEAT
PRODUCTION 2002
0 - 17459
17459 - 50207
50207 - 93289
93289 - 155767
155767 - 306670
Kilometers
0 12.000.000 24.000.000 48.000.000

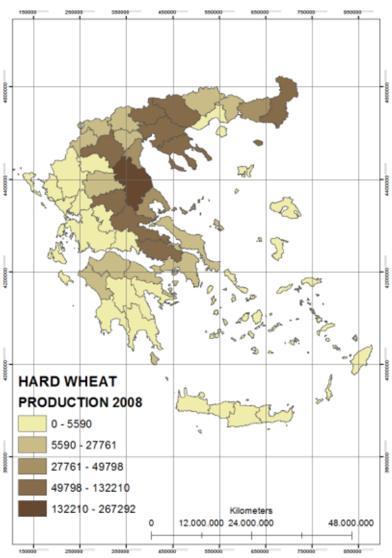

HARD WHEAT
PRODUCTION 2003
0 - 6444
6444 - 26342
26342 - 69539
69539 - 123768
123768 - 231698
Kilometers
0 12.000.000 24.000.000 48.000.000

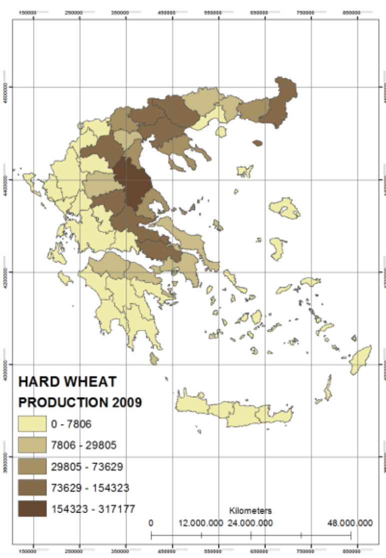

HARD WHEAT
PRODUCTION 2004
0 - 8811
8811 - 32981
32981 - 82105
82105 - 142067
142067 - 276771
Kilometers
0 12.000.000 24.000.000 48.000.000

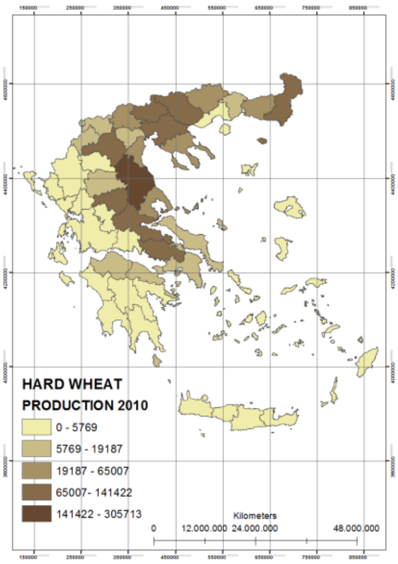

HARD WHEAT
PRODUCTION 2005
0 - 9306
9306 - 30414
30414 - 77034
77034 - 155195
155195 - 240561
Kilometers
0 12.000.000 24.000.000 48.000.000


HARD WHEAT
PRODUCTION 2006
0 - 8690
8690 - 25753
25753 - 72826
72826 - 124982
124982 - 242112
Kilometers
0 12.000.000 24.000.000 48.000.000

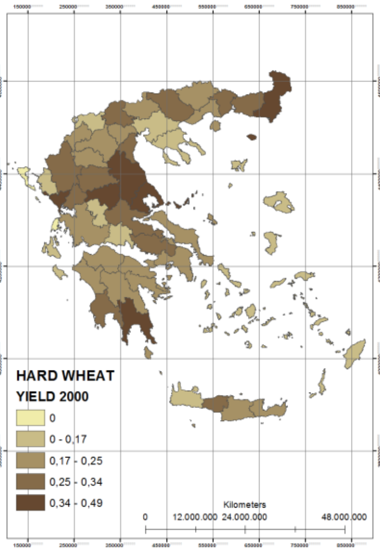

HARD WHEAT
PRODUCTION 2007
0 - 7368
7368 - 22109
22109 - 64943
64943 - 106674
106674 - 201411
Kilometers
0 12.000.000 24.000.000 48.000.000

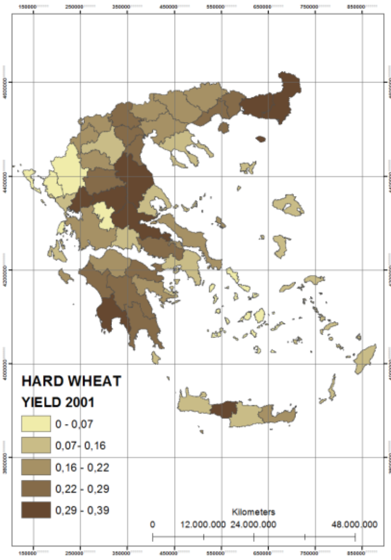

HARD WHEAT
PRODUCTION 2008
0 - 5590
5590 - 27761
27761 - 49798
49798 - 132210
132210 - 267292
Kilometers
0 12.000.000 24.000.000 48.000.000

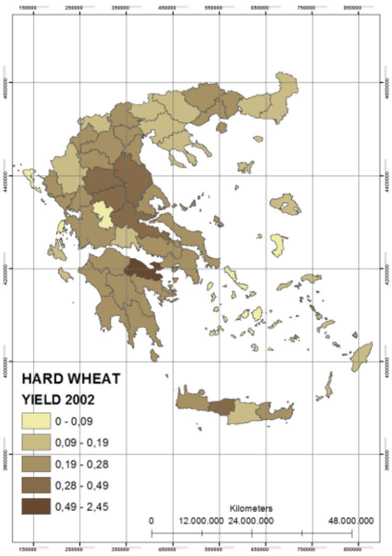

HARD WHEAT
PRODUCTION 2009
0 - 7806
7806 - 29805
29805 - 73629
73629 - 154323
154323 - 317177
Kilometers
0 12.000.000 24.000.000 48.000.000

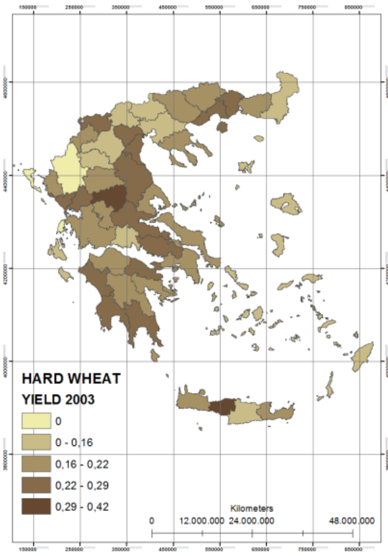

HARD WHEAT
PRODUCTION 2010
0 - 5769
5769 - 19187
19187 - 65007
65007- 141422
141422 - 305713
Kilometers
0 12.000.000 24.000.000 48.000.000

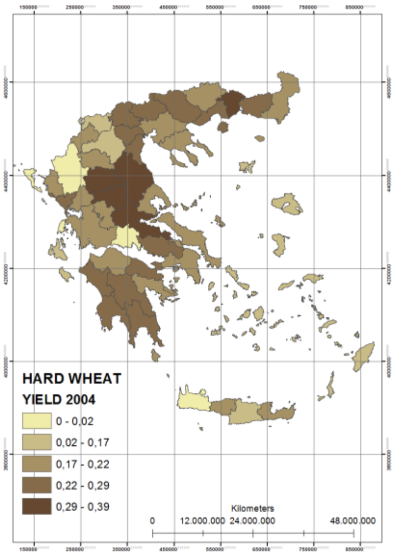
GIS maps for the yield of ***Hard Wheat*** *from 2000 to 2010*

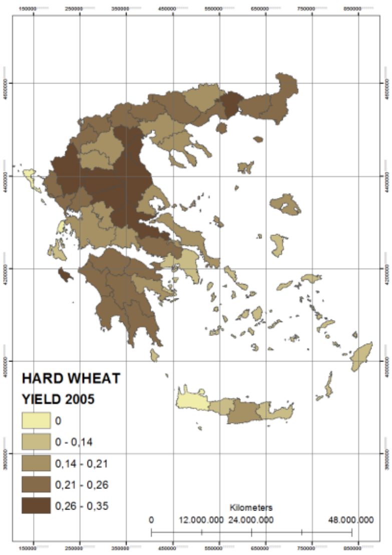


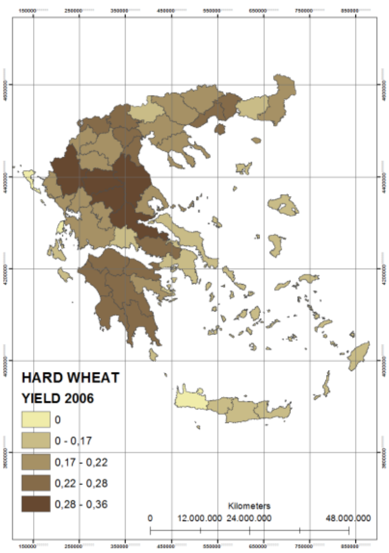


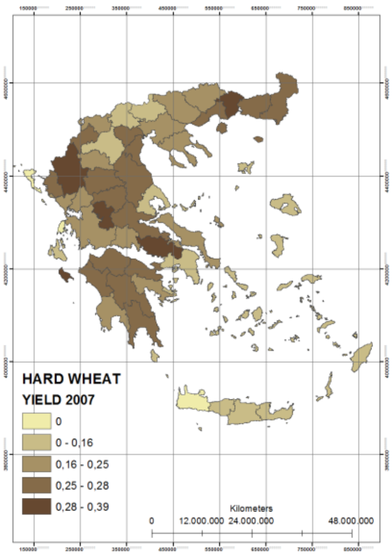


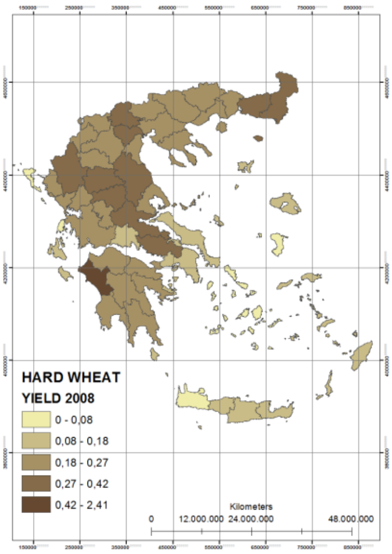


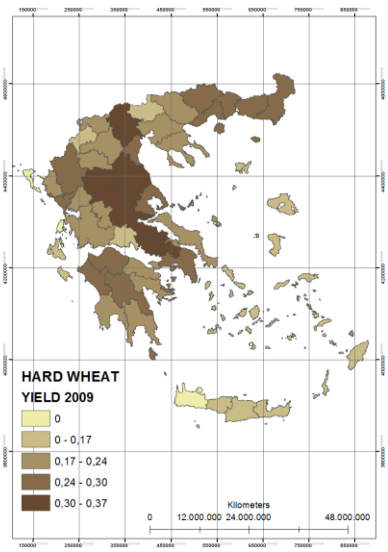


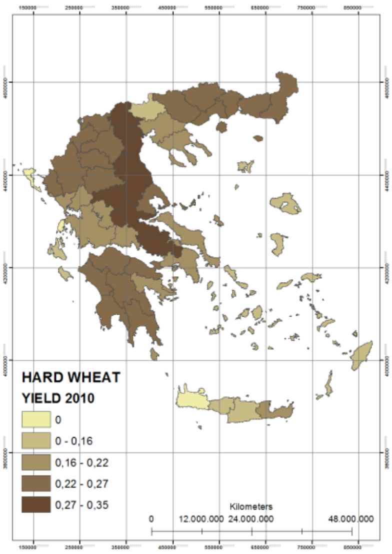




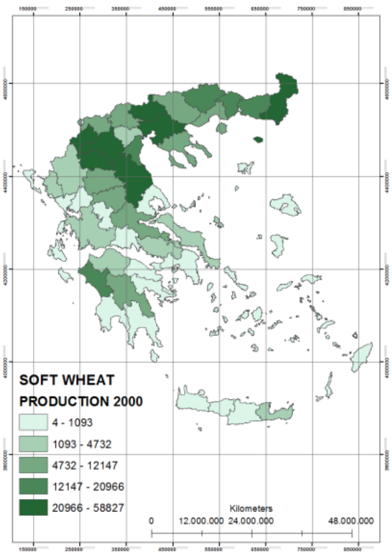


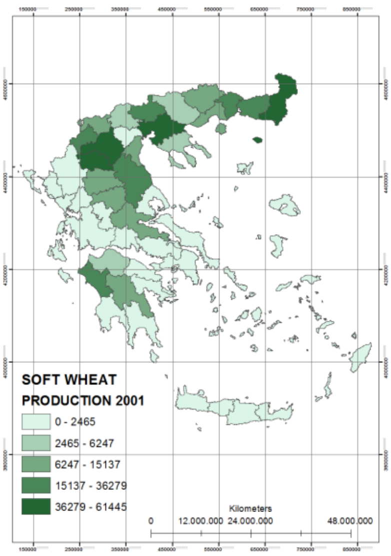


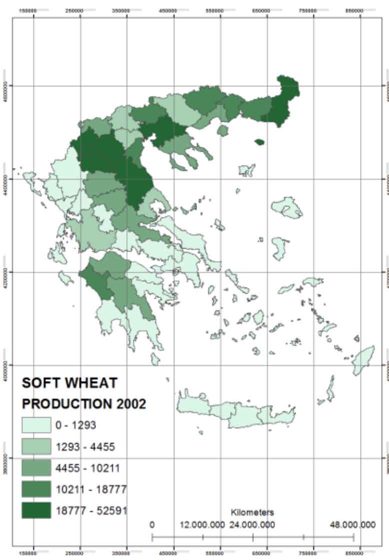


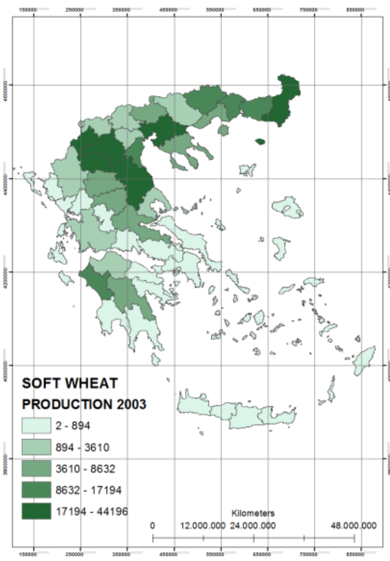


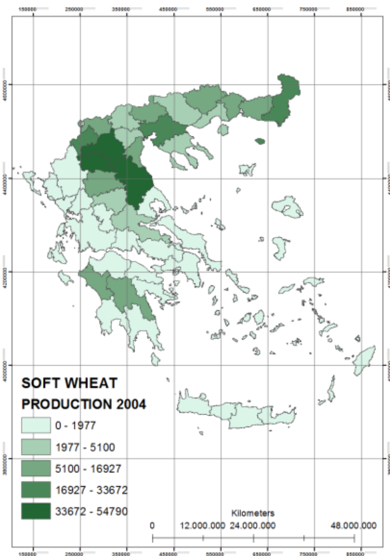
*GIS maps for the production of **Soft Wheat** from 2000 to 2010*

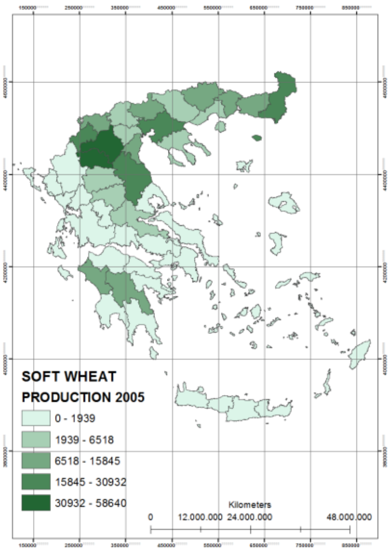


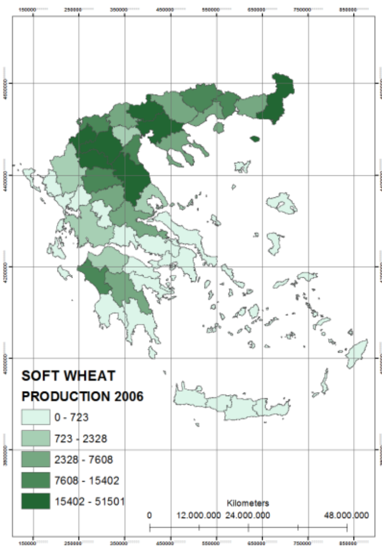


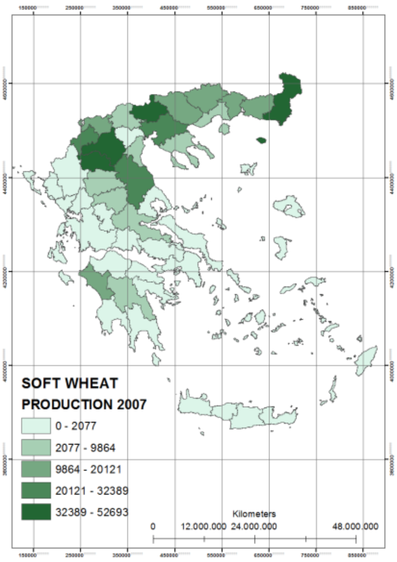


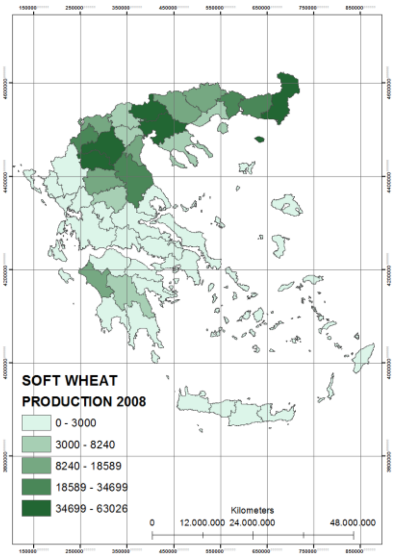


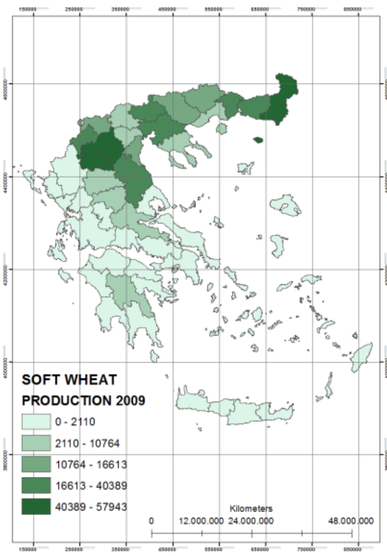


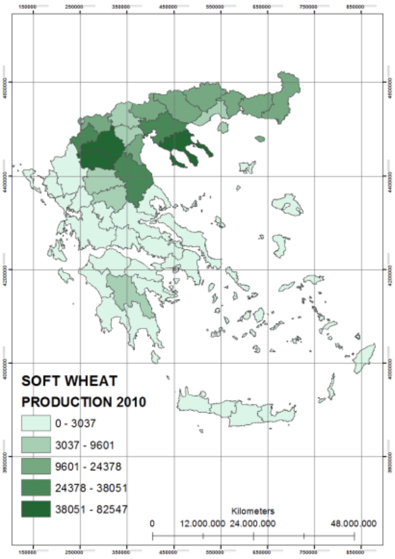


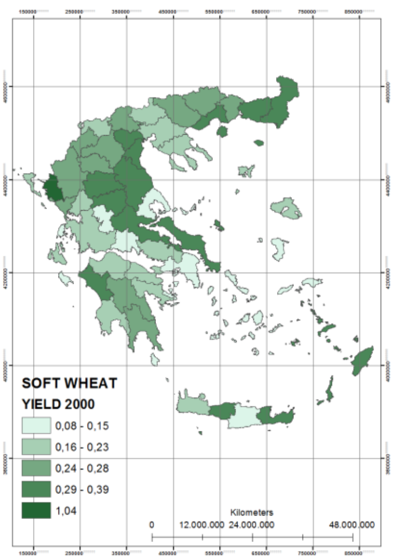


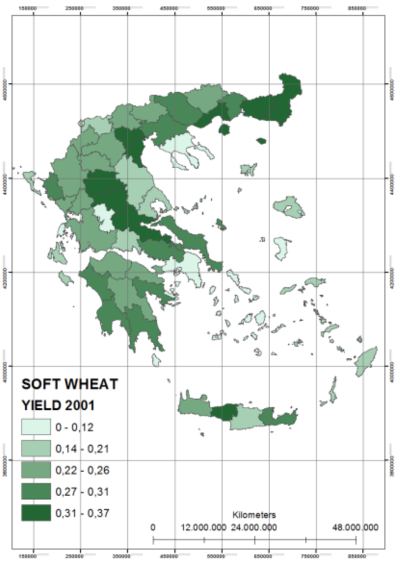




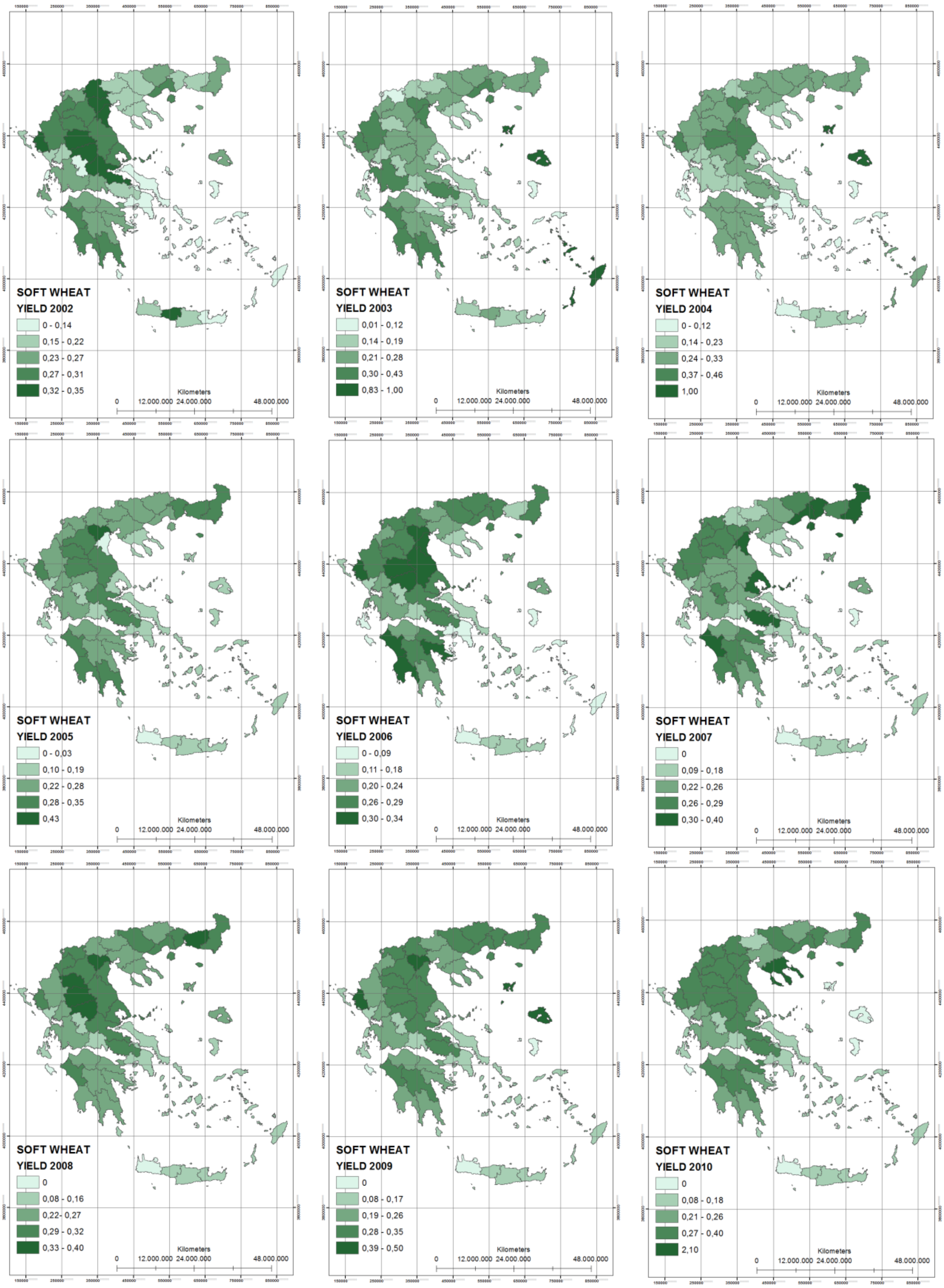




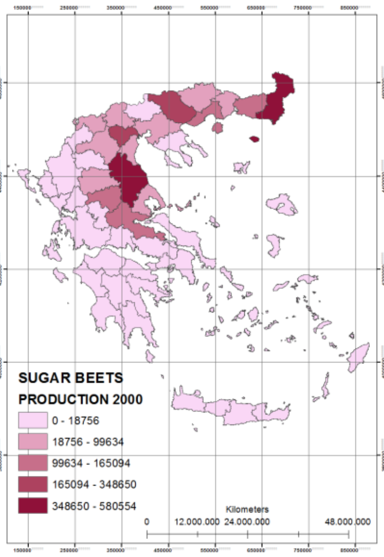


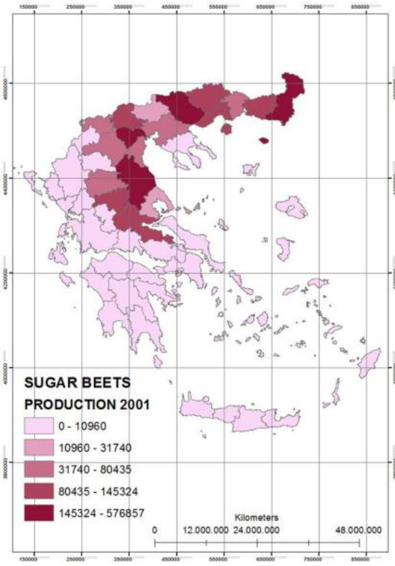


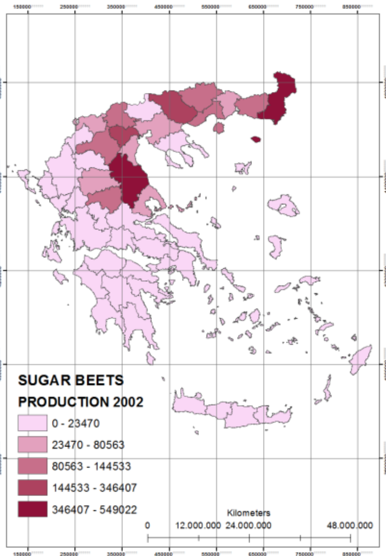
GIS maps for the yield of ***Soft Wheat*** *from 2000 to 2010*

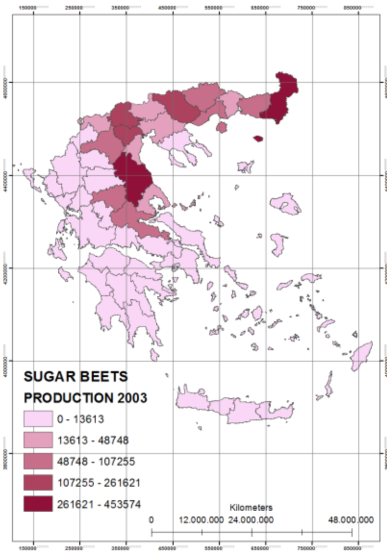

SOFT WHEAT
YIELD 2002
0 - 0,14
0,15 - 0,22
0,23 - 0,27
0,27 - 0,31
0,32 - 0,35
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2003
0,01 - 0,12
0,14 - 0,19
0,21 - 0,28
0,30 - 0,43
0,83 - 1,00
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2004
0 - 0,12
0,14 - 0,23
0,24 - 0,33
0,37 - 0,46
1,00
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2005
0 - 0,03
0,10 - 0,19
0,22 - 0,28
0,28 - 0,35
0,43
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2006
0 - 0,09
0,11 - 0,18
0,20 - 0,24
0,26 - 0,29
0,30 - 0,34
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2007
0
0,09 - 0,18
0,22 - 0,26
0,26 - 0,29
0,30 - 0,40
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2008
0
0,08 - 0,16
0,22- 0,27
0,29 - 0,32
0,33 - 0,40
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2009
0
0,08 - 0,17
0,19 - 0,26
0,28 - 0,35
0,39 - 0,50
Kilometers
0 12.000.000 24.000.000 48.000.000
SOFT WHEAT
YIELD 2010
0
0,08 - 0,18
0,21 - 0,26
0,27 - 0,40
2,10
Kilometers
0 12.000.000 24.000.000 48.000.000

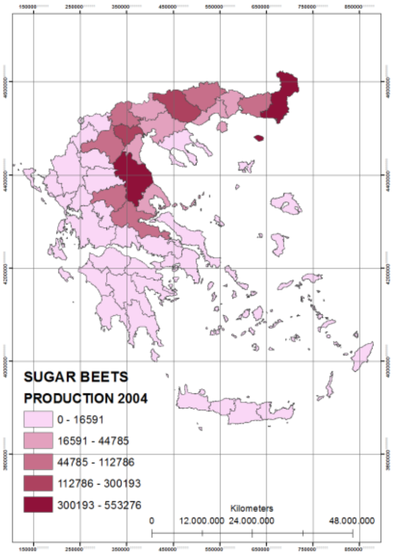
GIS maps for the production of ***Sugar Beet*** *from 2000 to 2010*

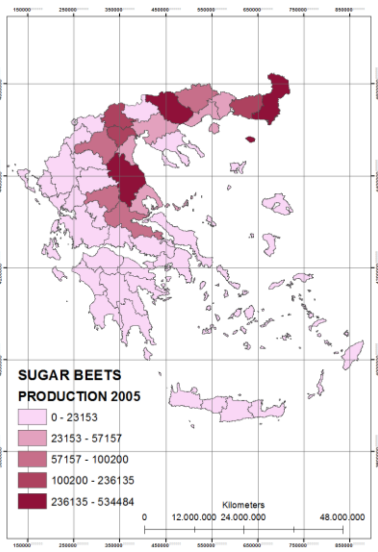


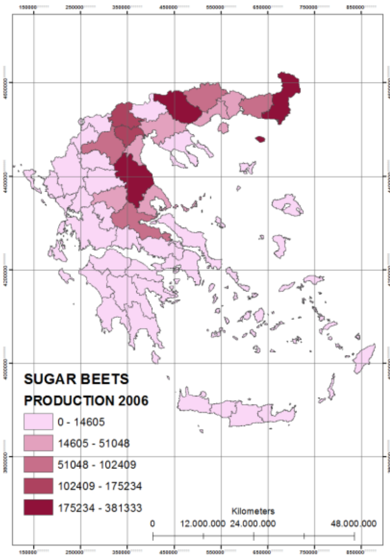


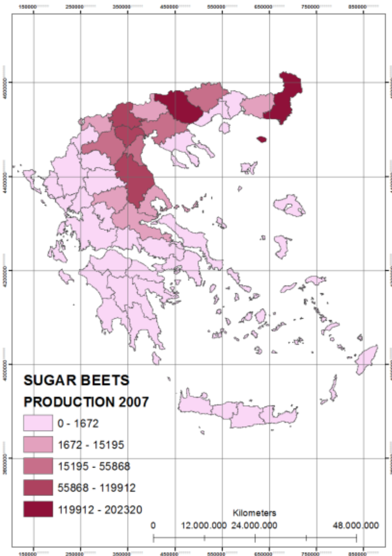


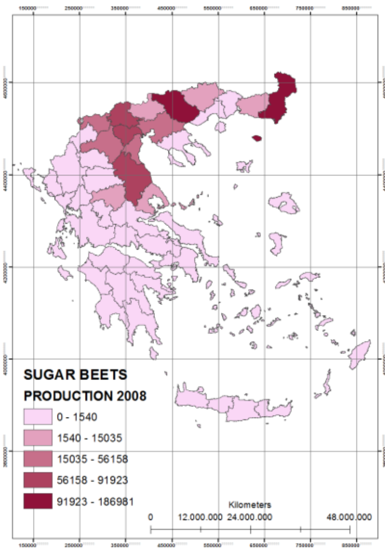


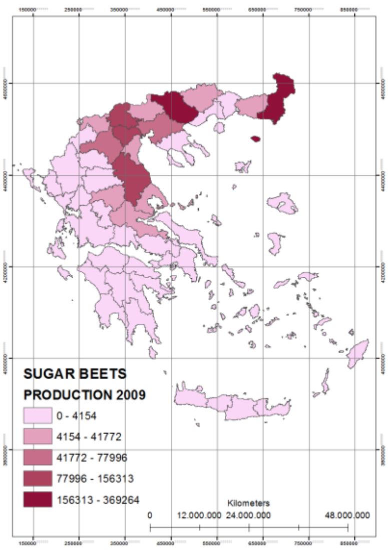


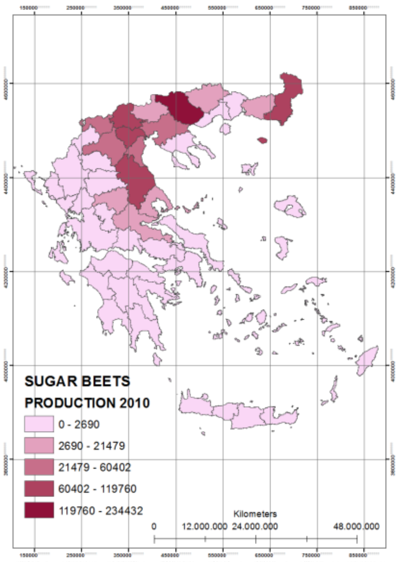




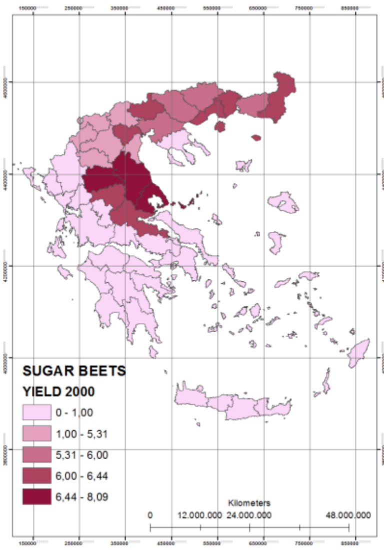


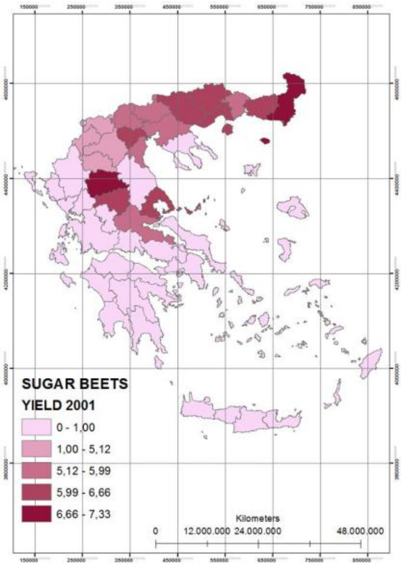


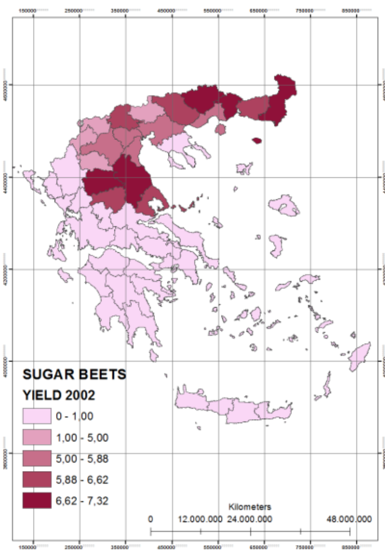


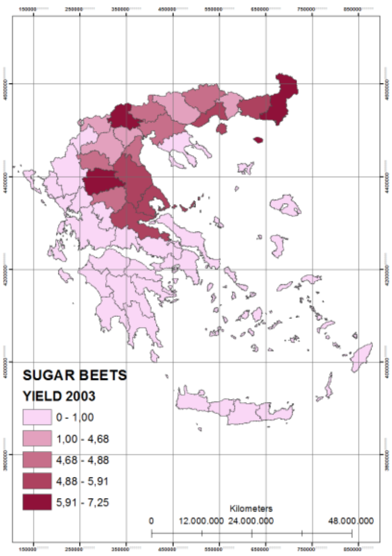


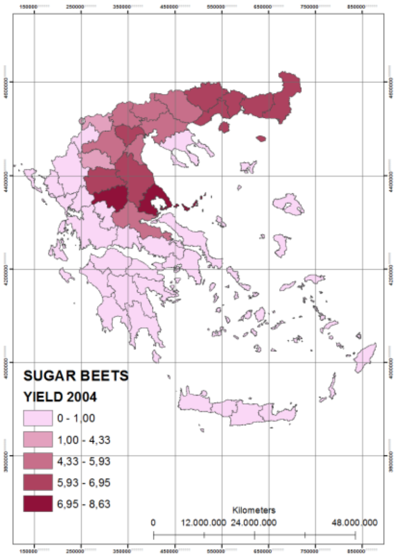
GIS maps for the yield of ***Sugar Beet*** *from 2000 to 2010*

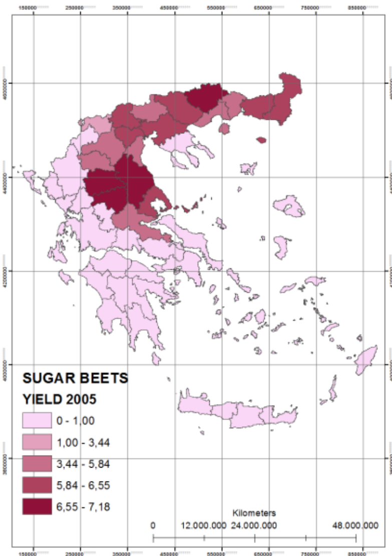


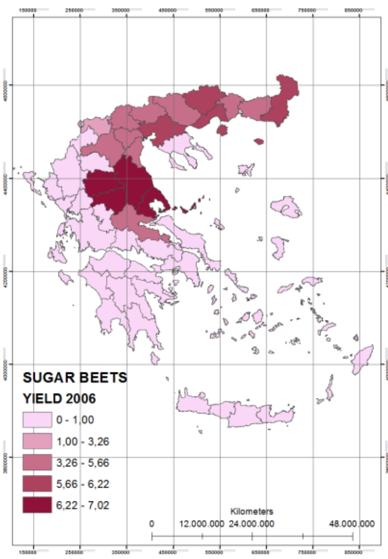


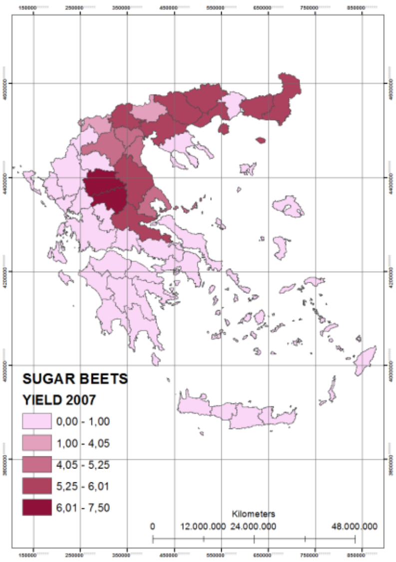


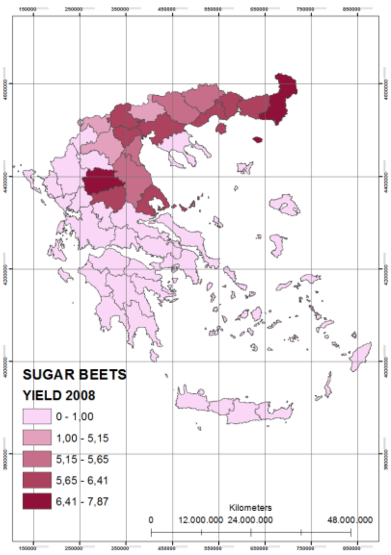


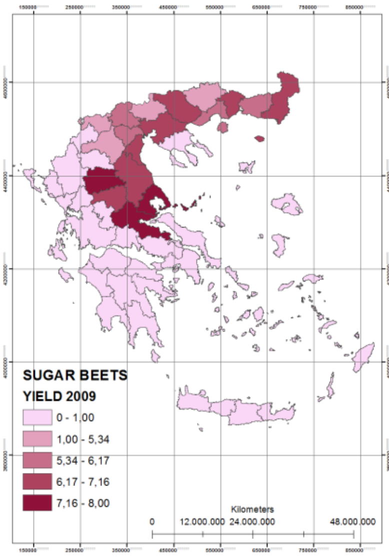


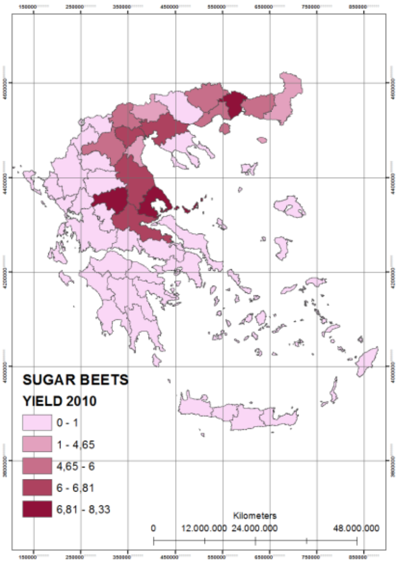




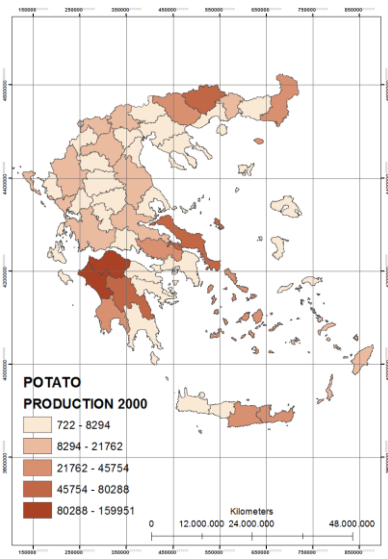


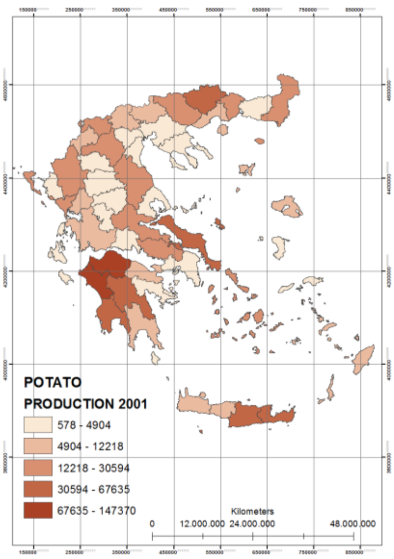


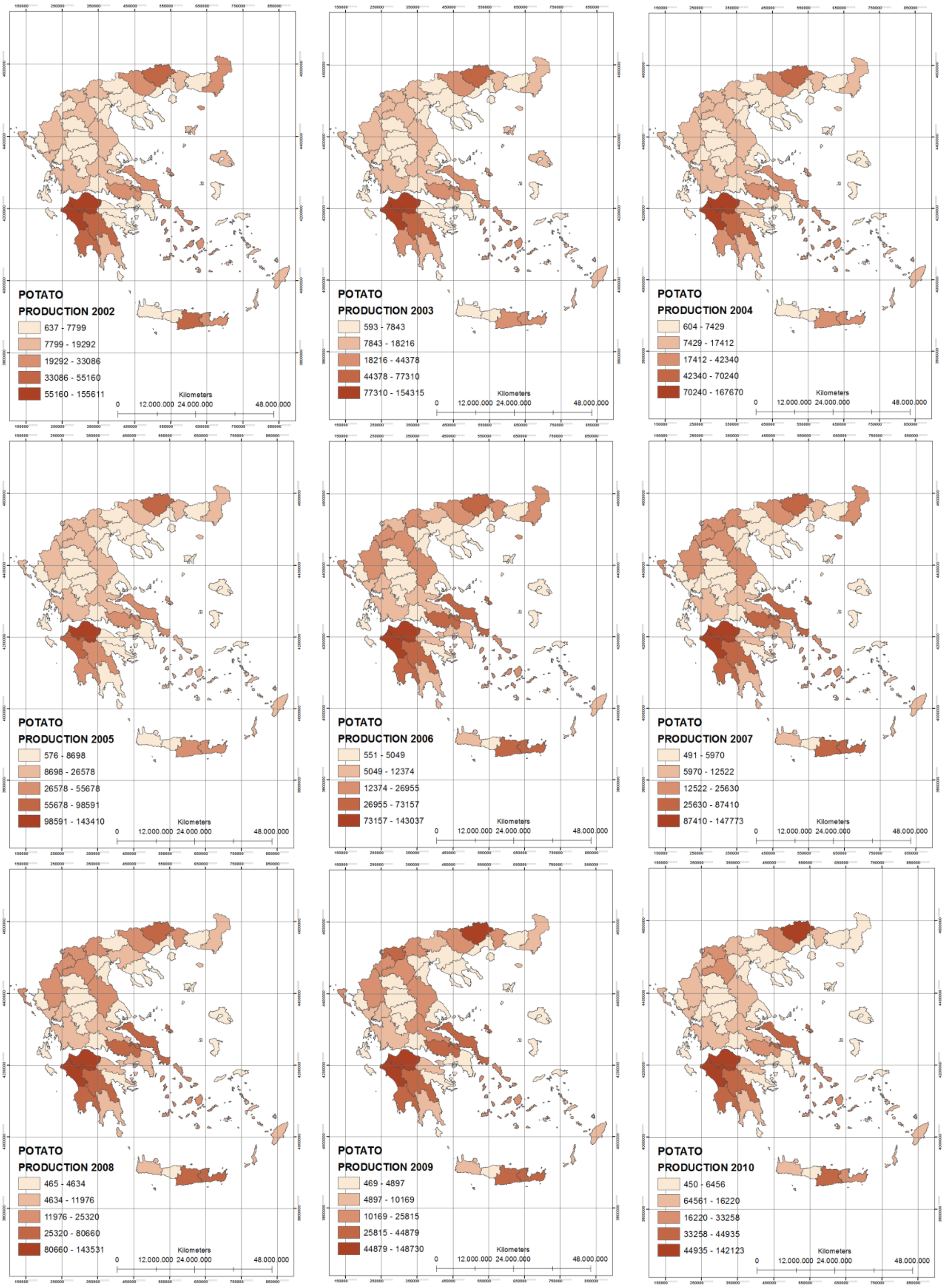




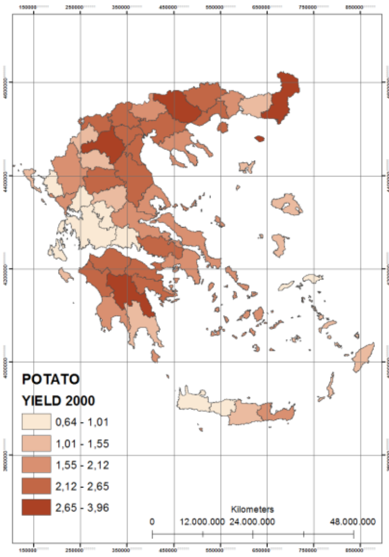
GIS maps for the production of ***Potato*** *from 2000 to 2010*

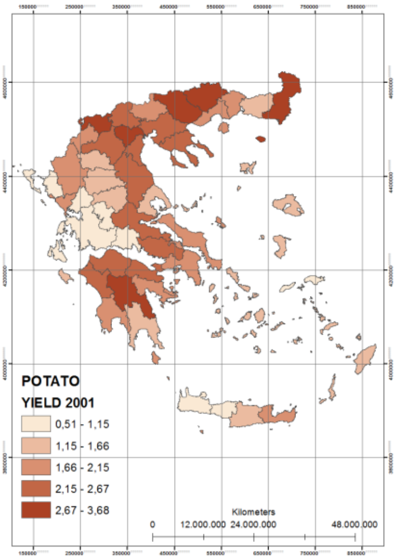


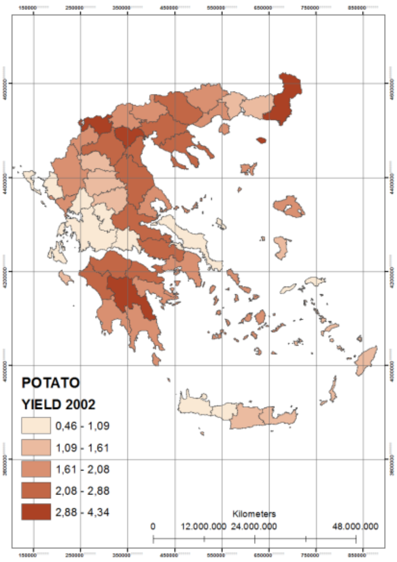


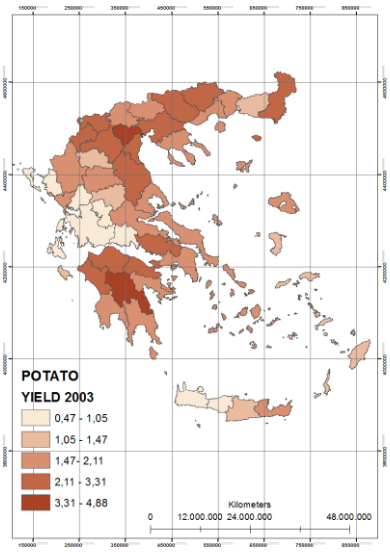

POTATO
PRODUCTION 2002
637 - 7799
7799 - 19292
19292 - 33086
33086 - 55160
55160 - 155611
POTATO
PRODUCTION 2003
593 - 7843
7843 - 18216
18216 - 44378
44378 - 77310
77310 - 154315
POTATO
PRODUCTION 2004
604 - 7429
7429 - 17412
17412 - 42340
42340 - 70240
70240 - 167670
POTATO
PRODUCTION 2005
576 - 8698
8698 - 26578
26578 - 55678
55678 - 98591
98591 - 143410
POTATO
PRODUCTION 2006
551 - 5049
5049 - 12374
12374 - 26955
26955 - 73157
73157 - 143037
POTATO
PRODUCTION 2007
491 - 5970
5970 - 12522
12522 - 25630
25630 - 87410
87410 - 147773
POTATO
PRODUCTION 2008
465 - 4634
4634 - 11976
11976 - 25320
25320 - 80660
80660 - 143531
POTATO
PRODUCTION 2009
469 - 4897
4897 - 10169
10169 - 25815
25815 - 44879
44879 - 148730
POTATO
PRODUCTION 2010
450 - 6456
64561 - 16220
16220 - 33258
33258 - 44935
44935 - 142123
Kilometers
0 12.000.000 24.000.000 48.000.000

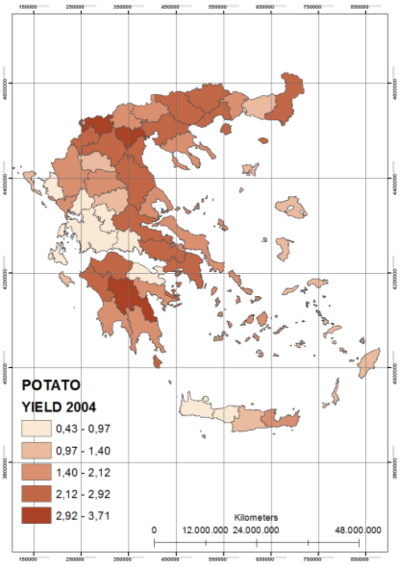
GIS maps for the yield of ***Potato*** *from 2000 to 2010*

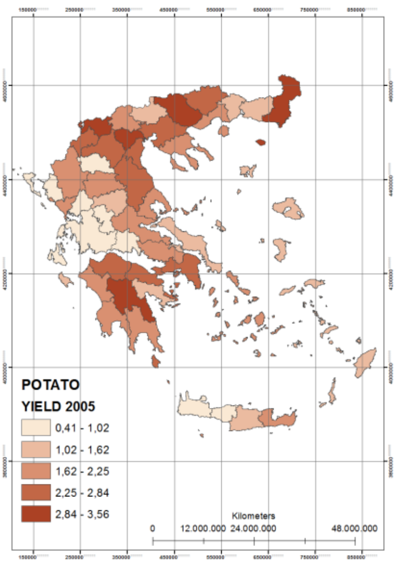


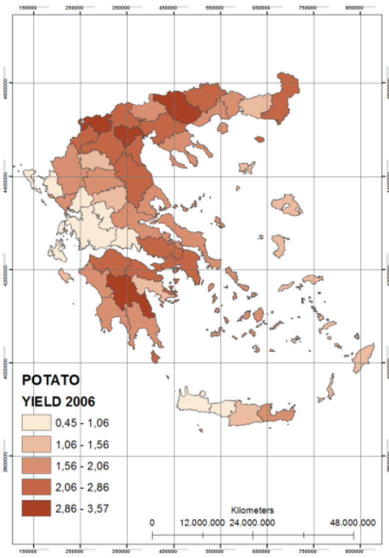


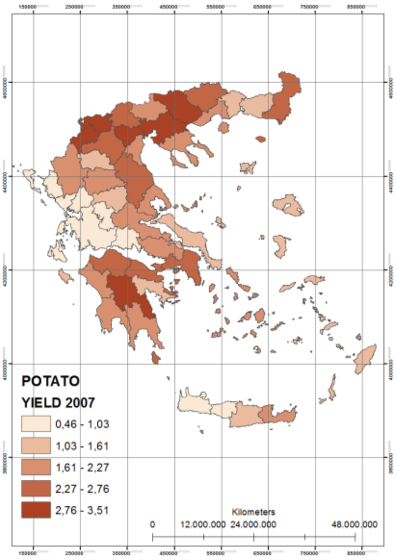


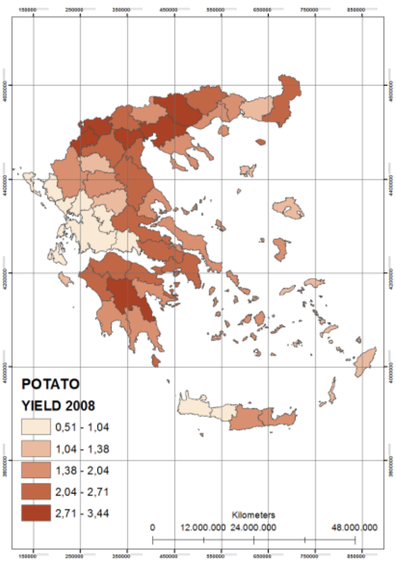


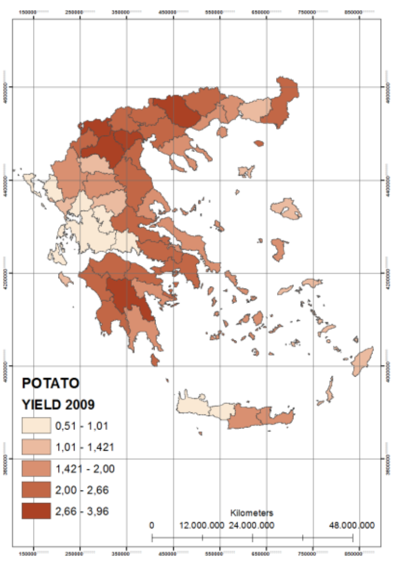


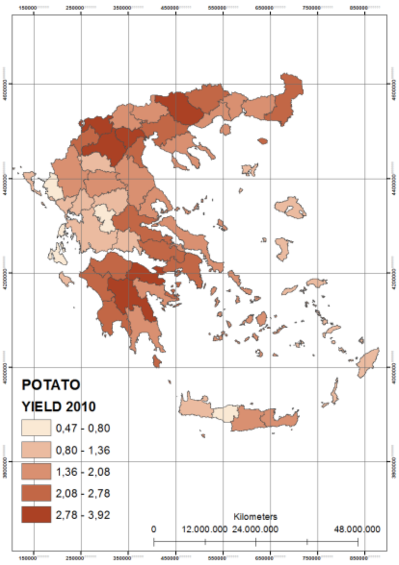




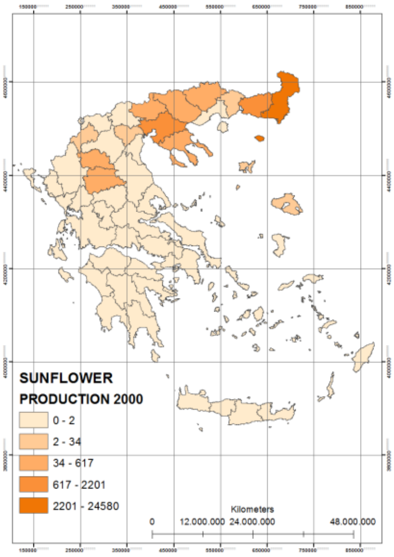


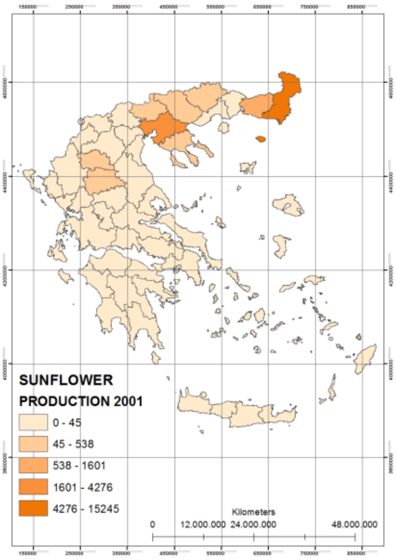


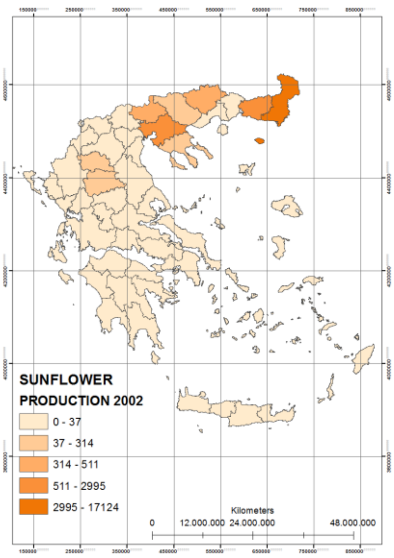


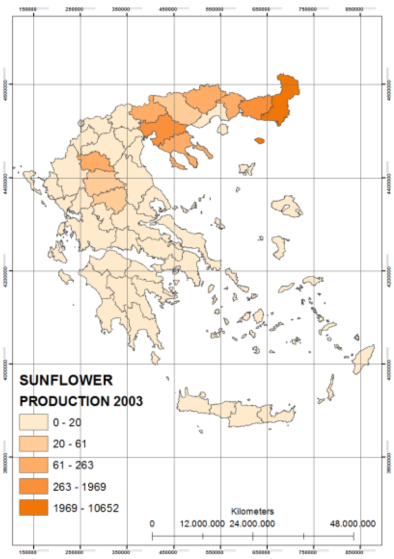


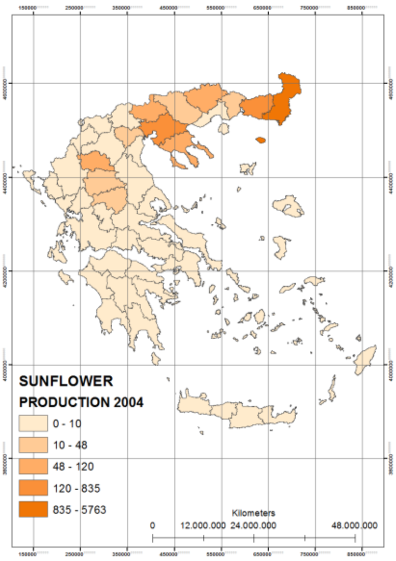
GIS maps for the production of ***Sunflower*** *from 2000 to 2010*

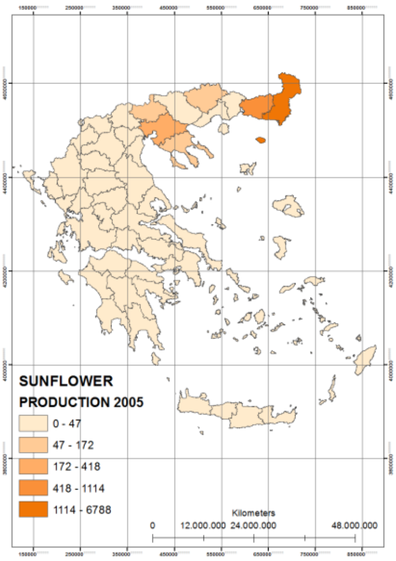


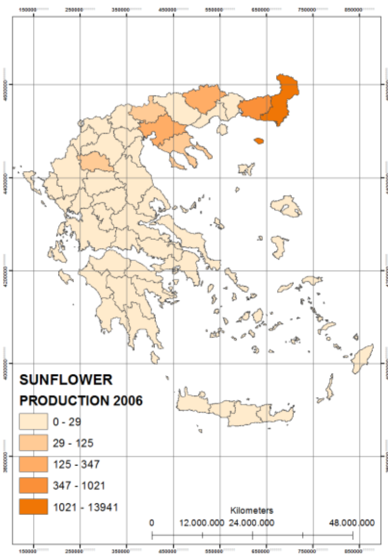


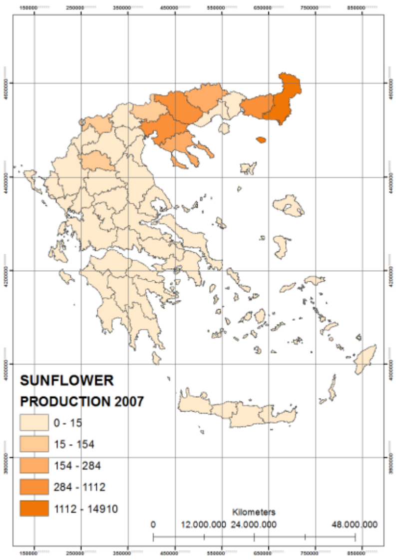


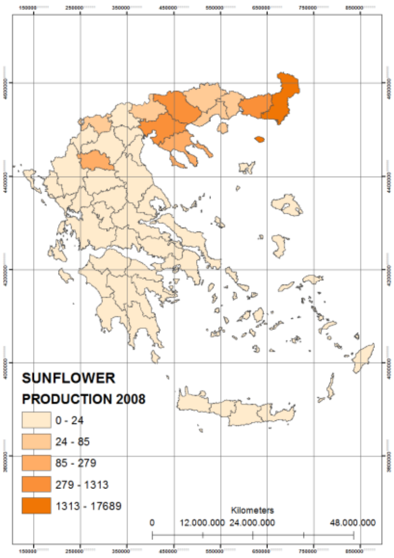


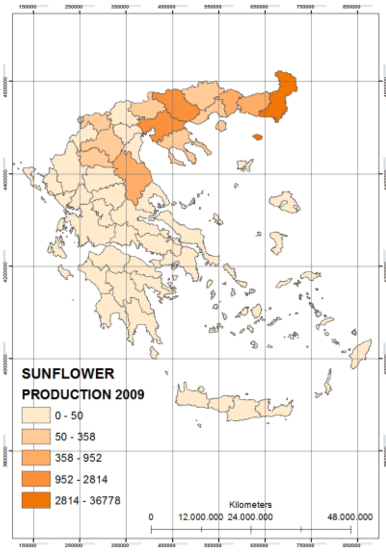


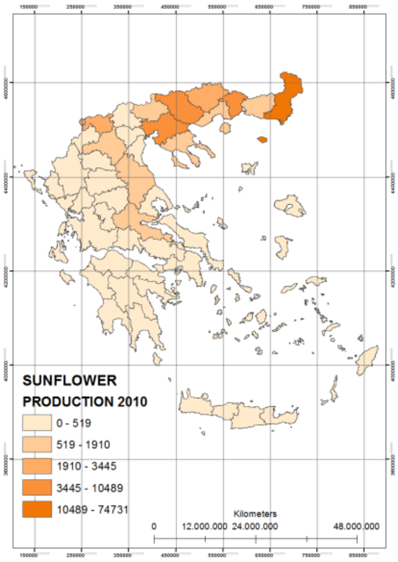




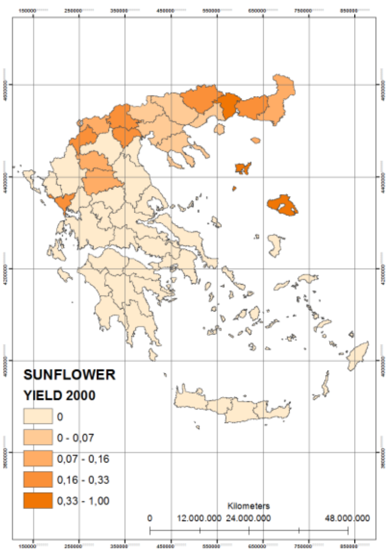


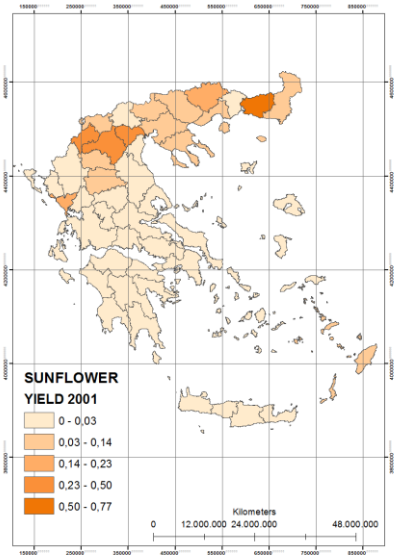


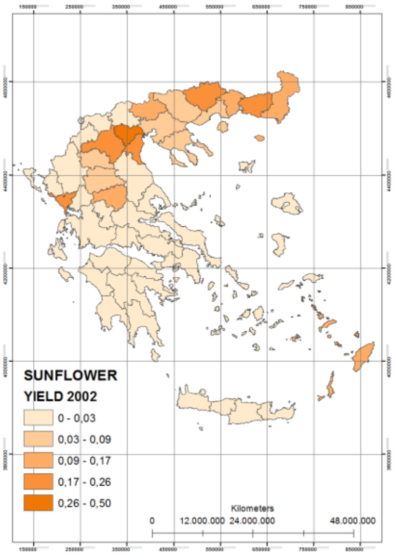


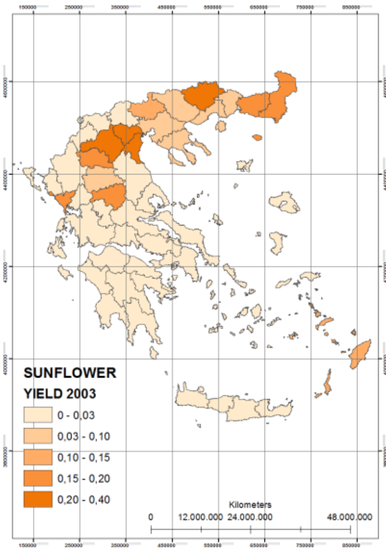


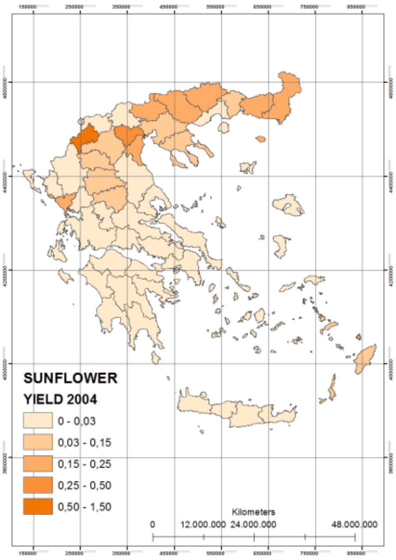
*GIS maps for the yield of **Sunflower** from 2000 to 2010*

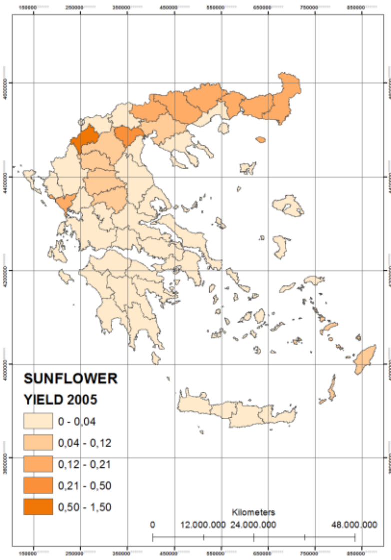


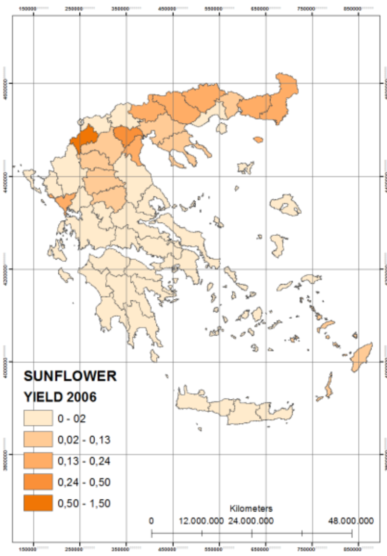


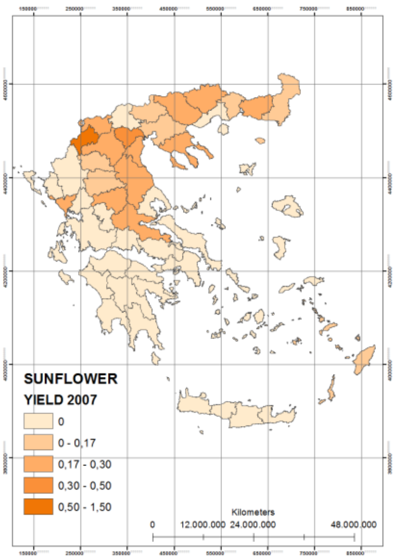

SUNFLOWER
YIELD 2002
0 - 0,03
0,03 - 0,09
0,09 - 0,17
0,17 - 0,26
0,26 - 0,50
Kilometers
0 12.000.000 24.000.000 48.000.000

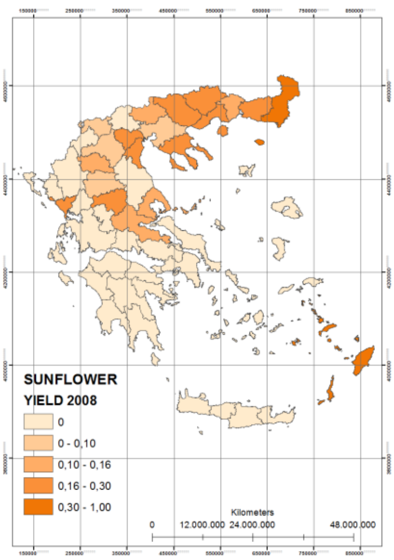

SUNFLOWER
YIELD 2003
0 - 0,03
0,03 - 0,10
0,10 - 0,15
0,15 - 0,20
0,20 - 0,40
Kilometers
0 12.000.000 24.000.000 48.000.000

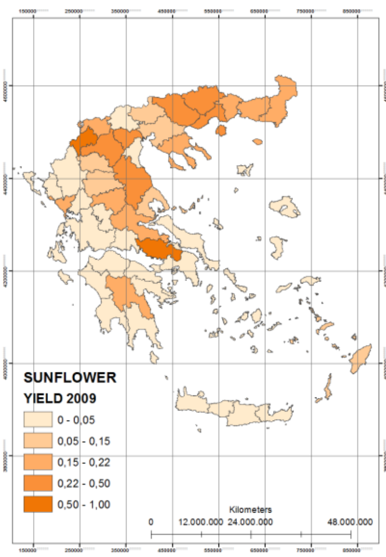

SUNFLOWER
YIELD 2004
0 - 0,03
0,03 - 0,15
0,15 - 0,25
0,25 - 0,50
0,50 - 1,50
Kilometers
0 12.000.000 24.000.000 48.000.000

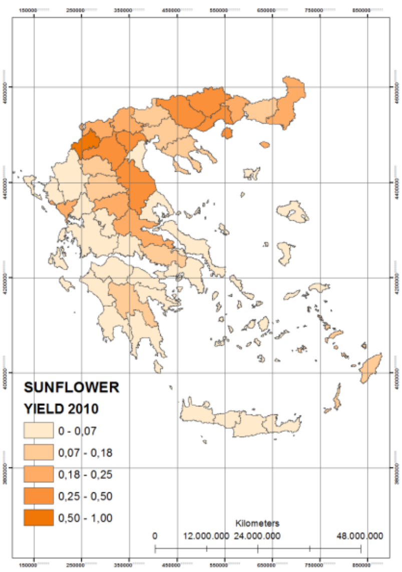

SUNFLOWER
YIELD 2005
0 - 0,04
0,04 - 0,12
0,12 - 0,21
0,21 - 0,50
0,50 - 1,50
Kilometers
0 12.000.000 24.000.000 48.000.000


SUNFLOWER
YIELD 2006
0 - 02
0,02 - 0,13
0,13 - 0,24
0,24 - 0,50
0,50 - 1,50
Kilometers
0 12.000.000 24.000.000 48.000.000

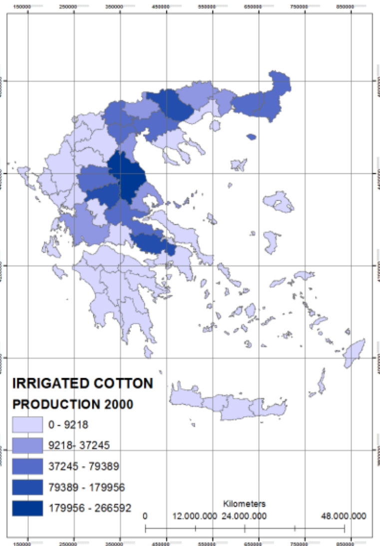

SUNFLOWER
YIELD 2007
0
0 - 0,17
0,17 - 0,30
0,30 - 0,50
0,50 - 1,50
Kilometers
0 12.000.000 24.000.000 48.000.000

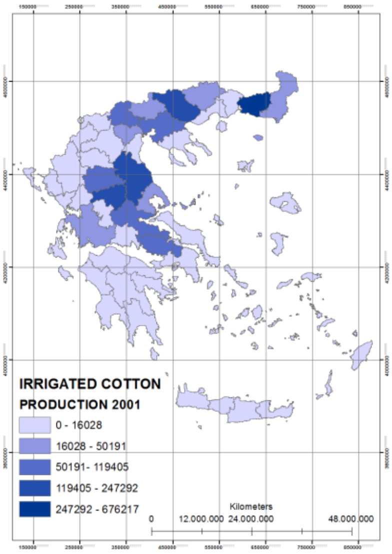

SUNFLOWER
YIELD 2008
0
0 - 0,10
0,10 - 0,16
0,16 - 0,30
0,30 - 1,00
Kilometers
0 12.000.000 24.000.000 48.000.000

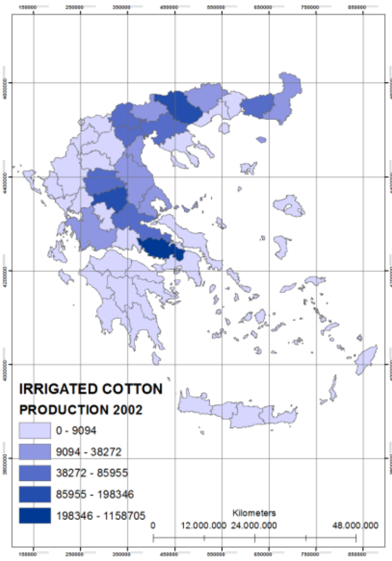

SUNFLOWER
YIELD 2009
0 - 0,05
0,05 - 0,15
0,15 - 0,22
0,22 - 0,50
0,50 - 1,00
Kilometers
0 12.000.000 24.000.000 48.000.000

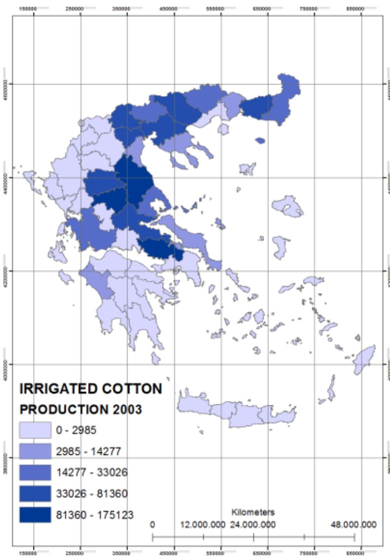

SUNFLOWER
YIELD 2010
0 - 0,07
0,07 - 0,18
0,18 - 0,25
0,25 - 0,50
0,50 - 1,00
Kilometers
0 12.000.000 24.000.000 48.000.000

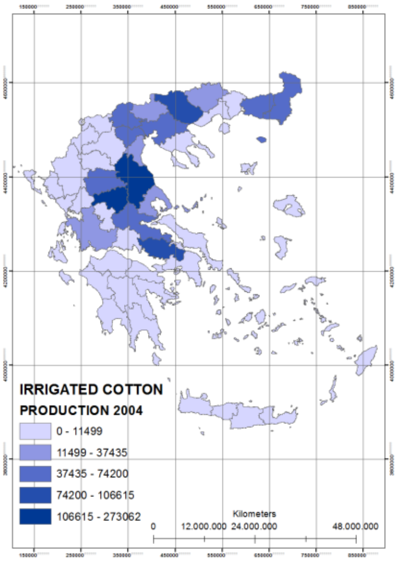
*GIS maps for the production of **Irrigated Cotton** from 2000 to 2010*

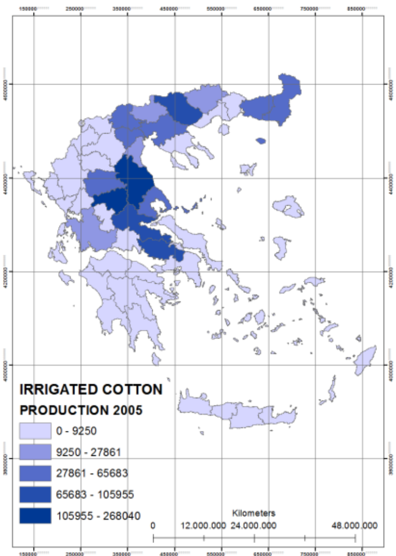


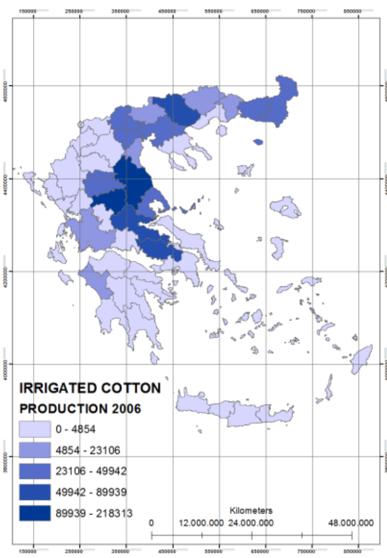


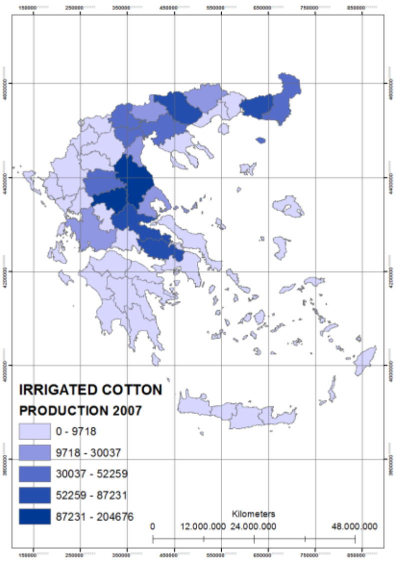


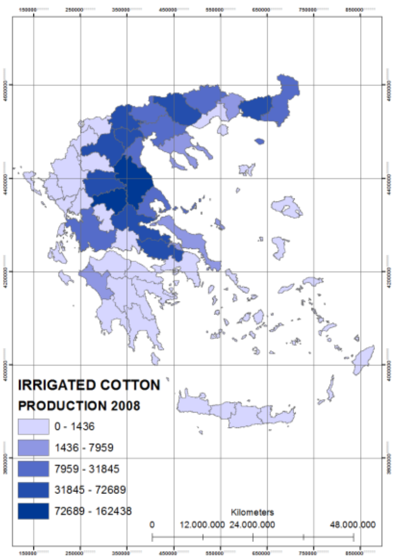


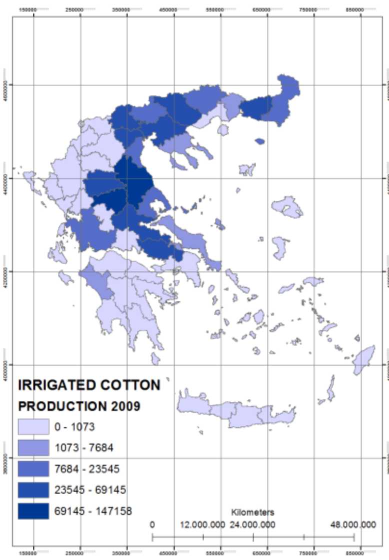


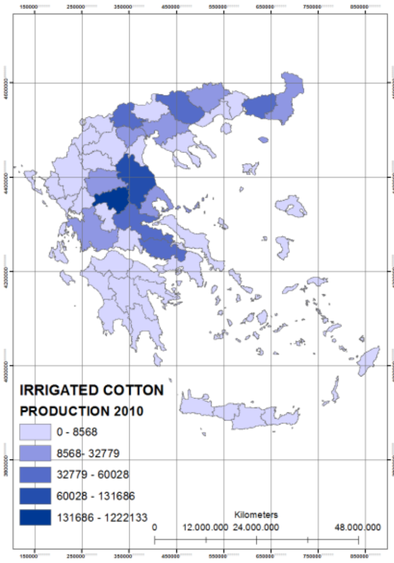




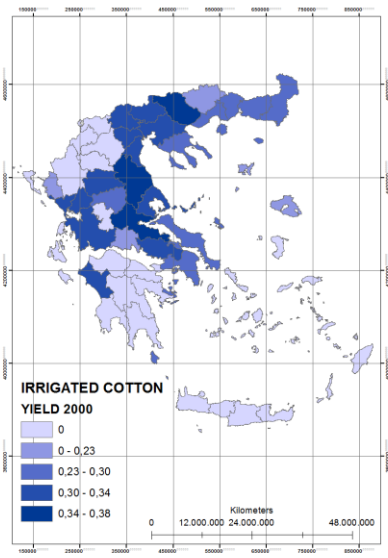


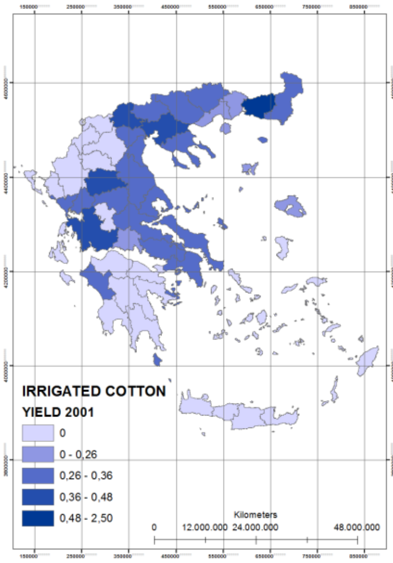


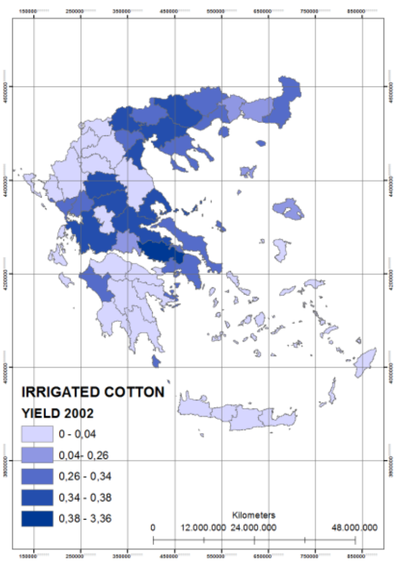


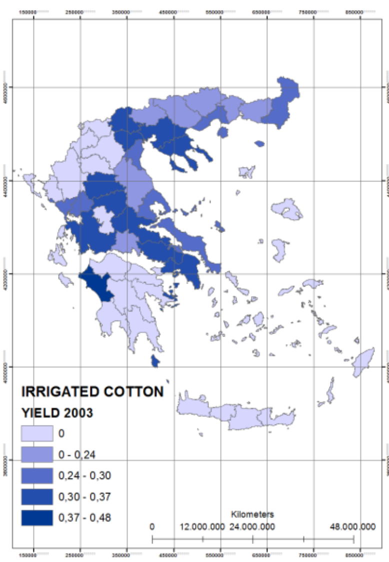


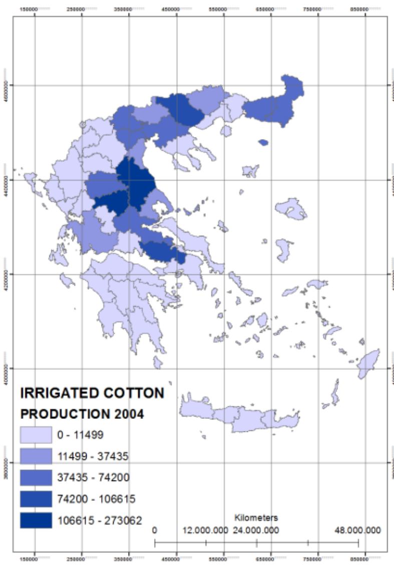
GIS maps for the yield of ***Irrigated Cotton*** *from 2000 to 2010*

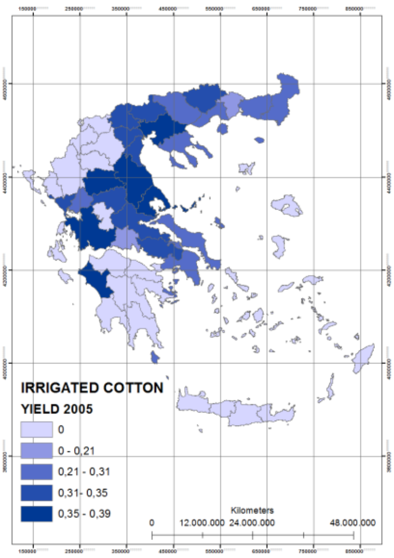


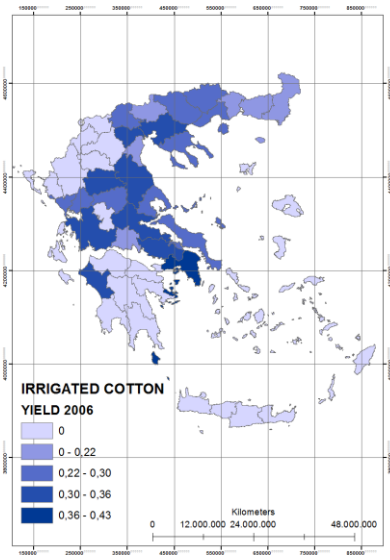


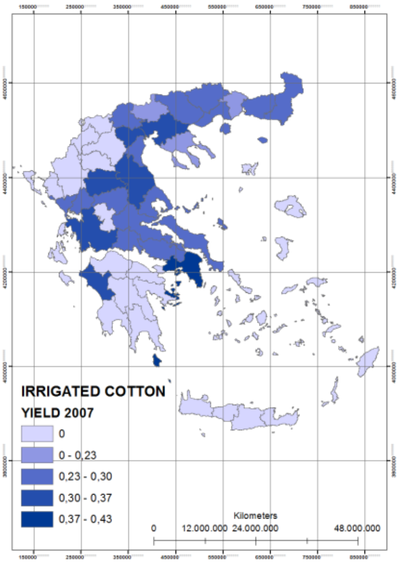


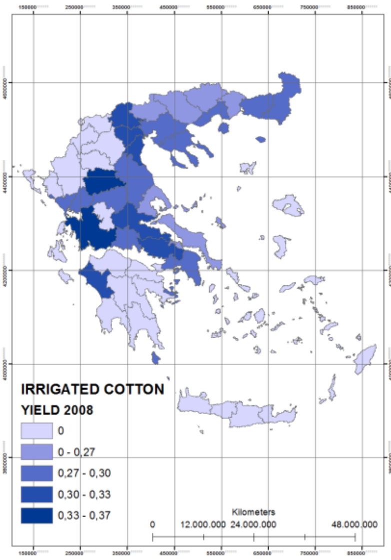


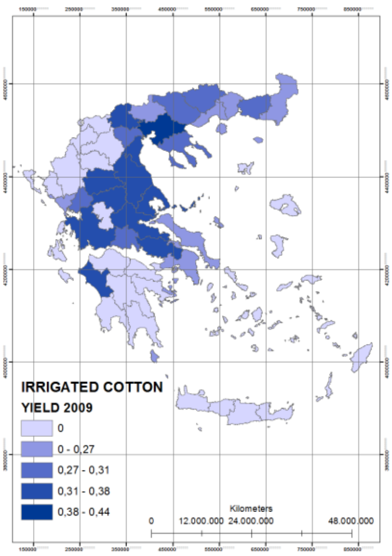


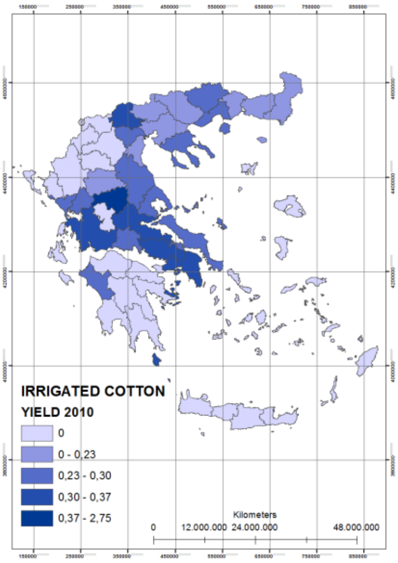




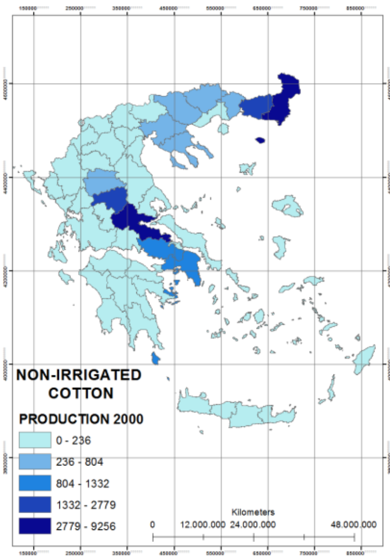


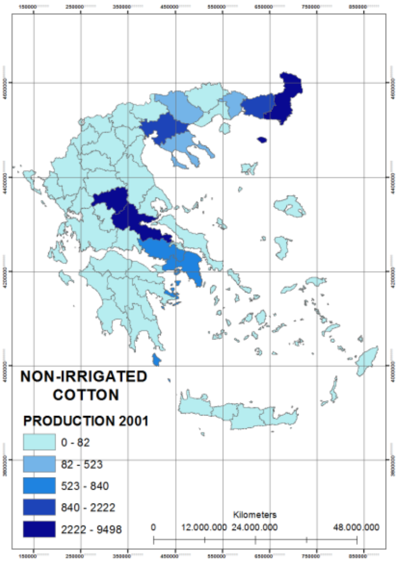


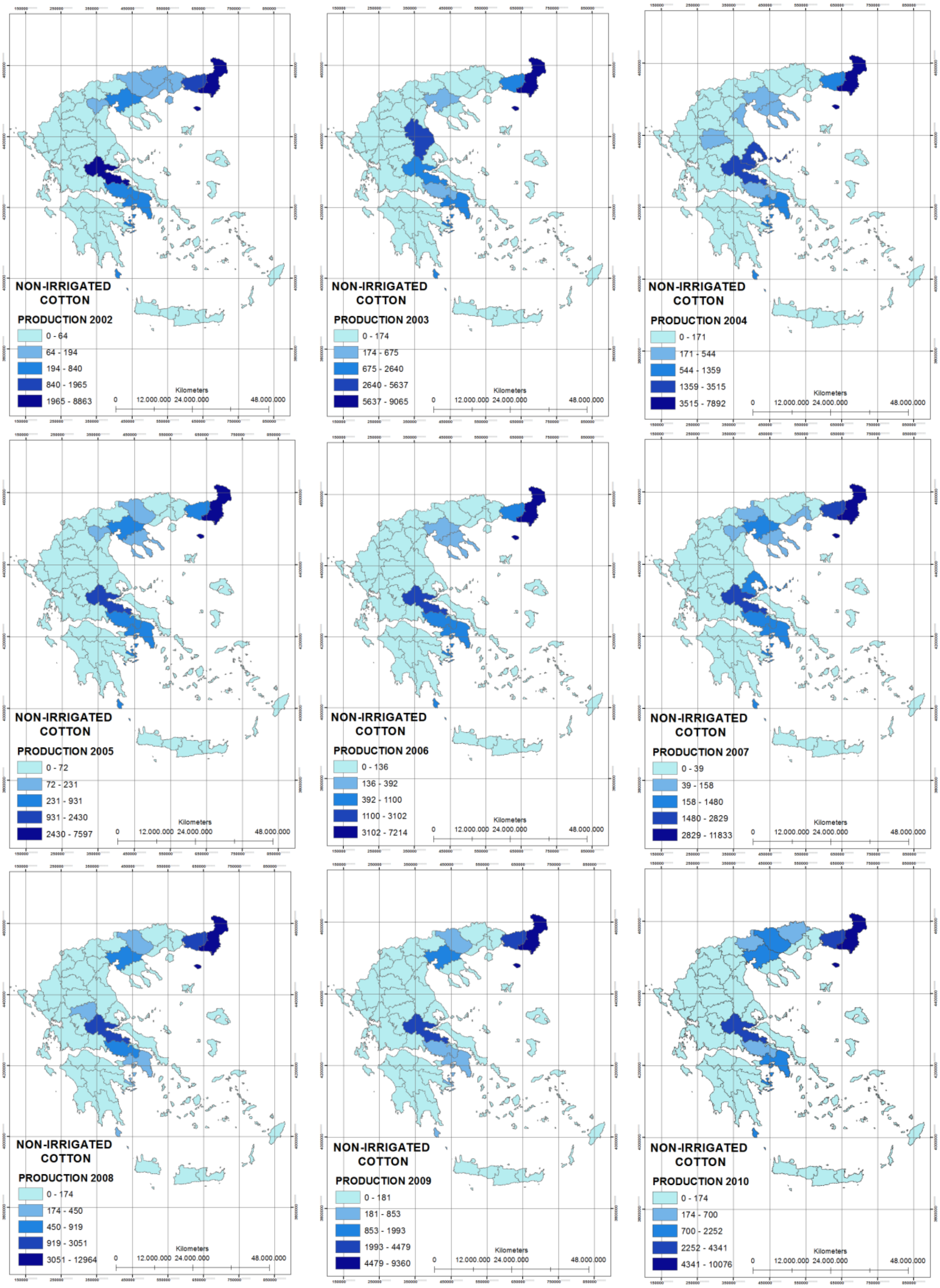


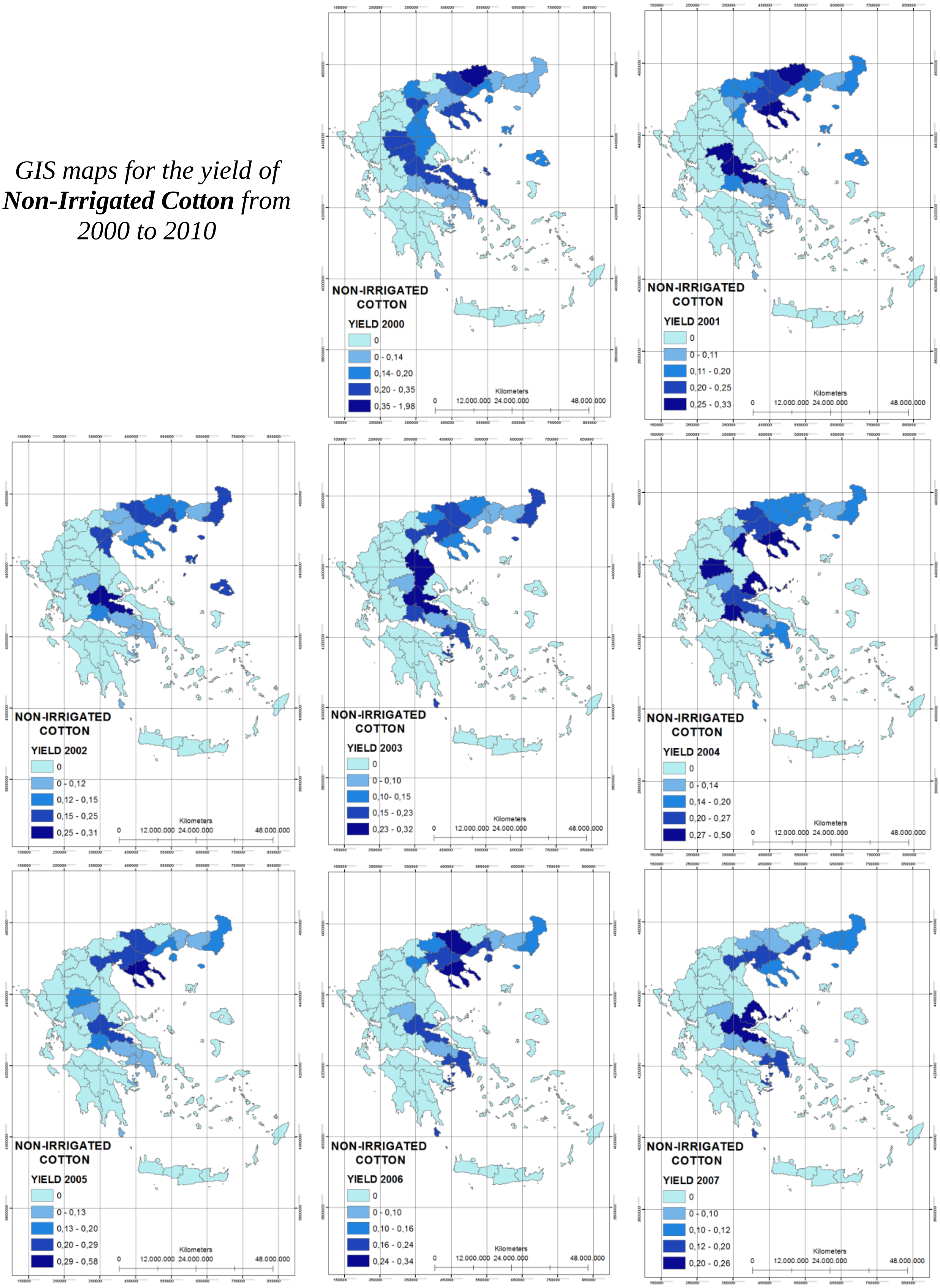


GIS maps for the production of ***Non-Irrigated Cotton*** *from 2000 to 2010*

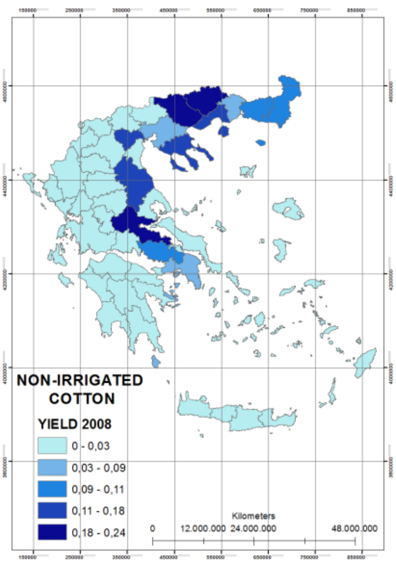


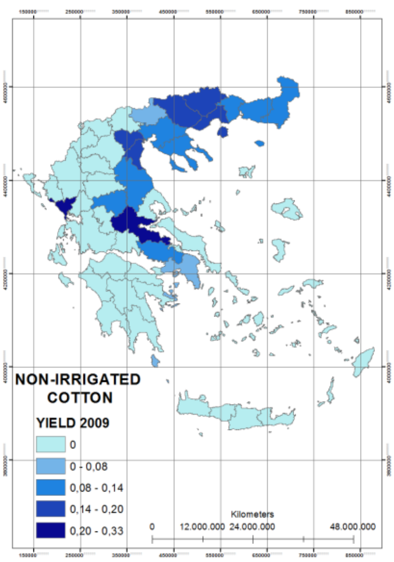


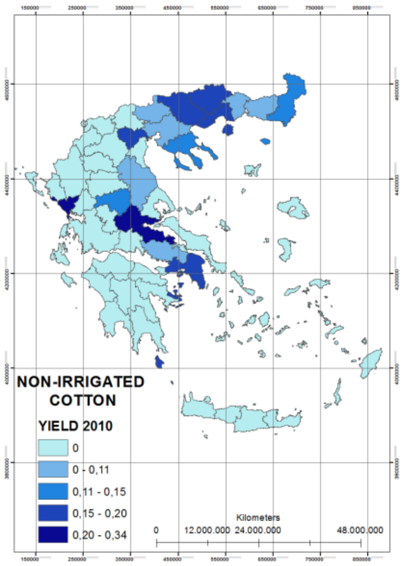

NON-IRRIGATED COTTON
PRODUCTION 2002
0 - 64
64 - 194
194 - 840
840 - 1965
1965 - 8863
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2003
0 - 174
174 - 675
675 - 2640
2640 - 5637
5637 - 9065
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2004
0 - 171
171 - 544
544 - 1359
1359 - 3515
3515 - 7892
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2005
0 - 72
72 - 231
231 - 931
931 - 2430
2430 - 7597
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2006
0 - 136
136 - 392
392 - 1100
1100 - 3102
3102 - 7214
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2007
0 - 39
39 - 158
158 - 1480
1480 - 2829
2829 - 11833
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2008
0 - 174
174 - 450
450 - 919
919 - 3051
3051 - 12964
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2009
0 - 181
181 - 853
853 - 1993
1993 - 4479
4479 - 9360
Kilometers
0 12.000.000 24.000.000 48.000.000
NON-IRRIGATED COTTON
PRODUCTION 2010
0 - 174
174 - 700
700 - 2252
2252 - 4341
4341 - 10076
Kilometers
0 12.000.000 24.000.000 48.000.000



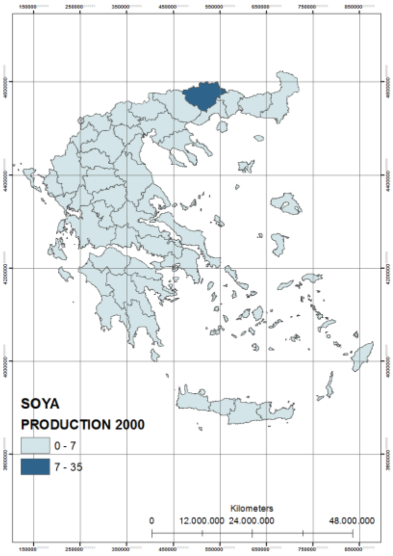
GIS maps for the yield of ***Non-Irrigated Cotton*** *from 2000 to 2010*

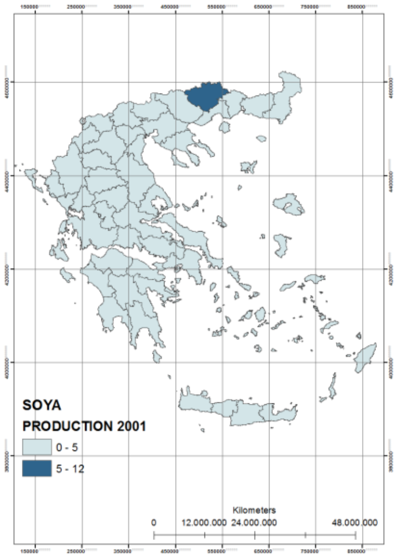


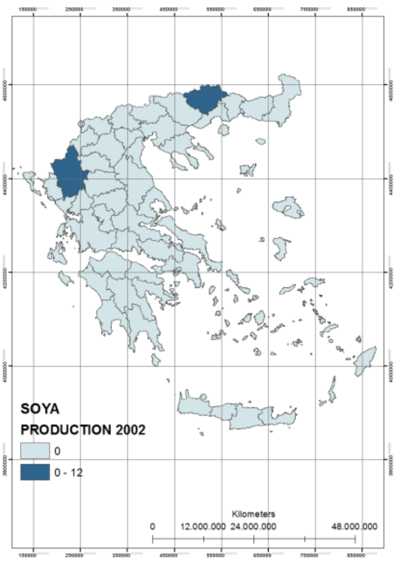


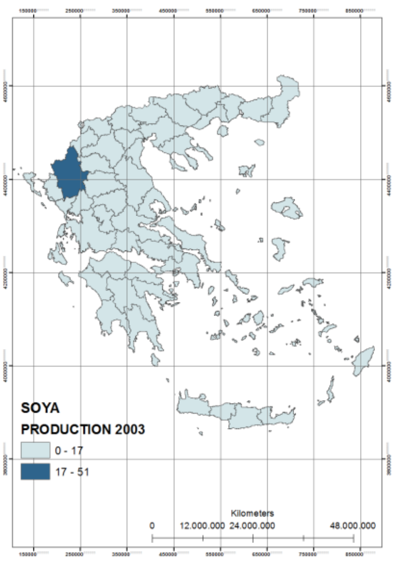


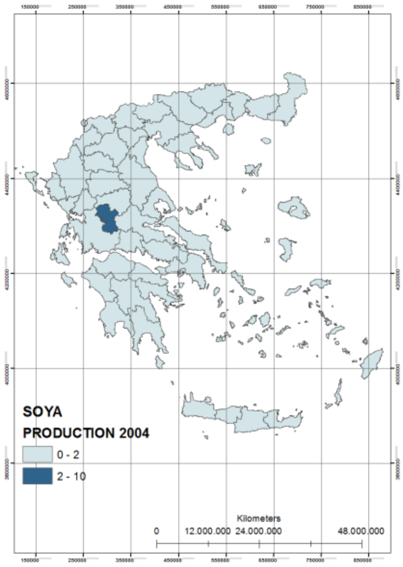
*GIS maps for the production of **Soya** from 2000 to 2010*

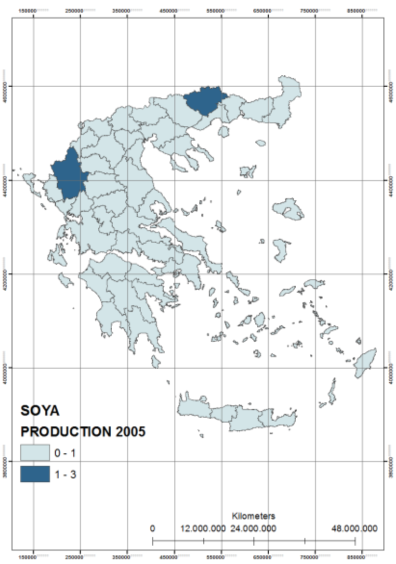


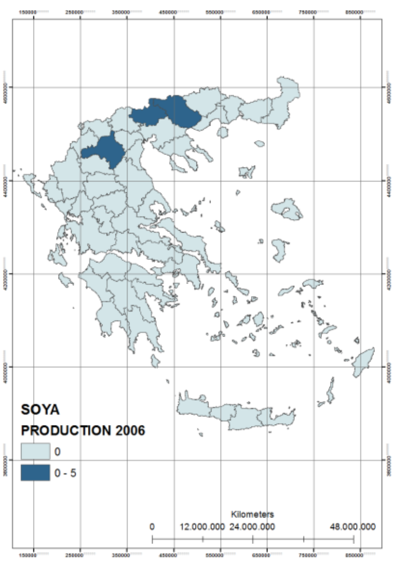


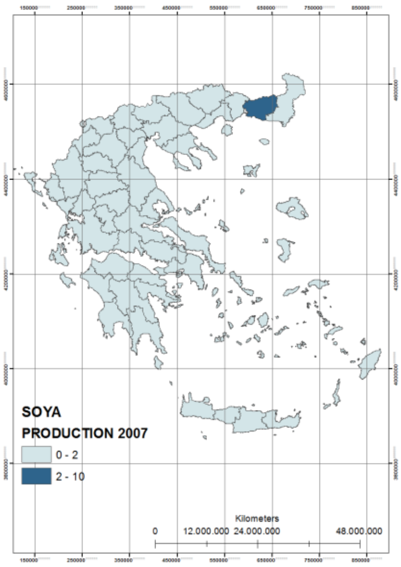


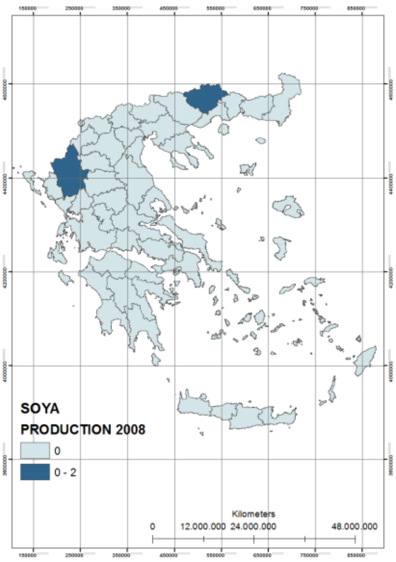


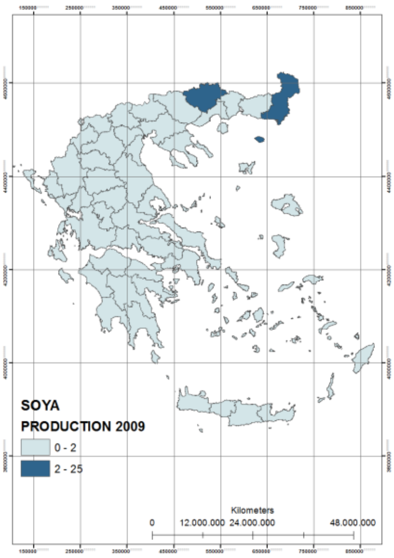


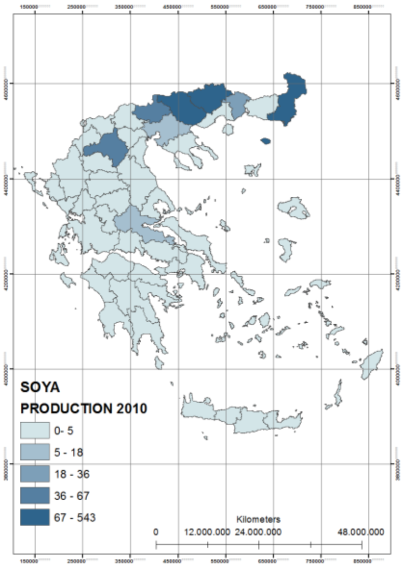




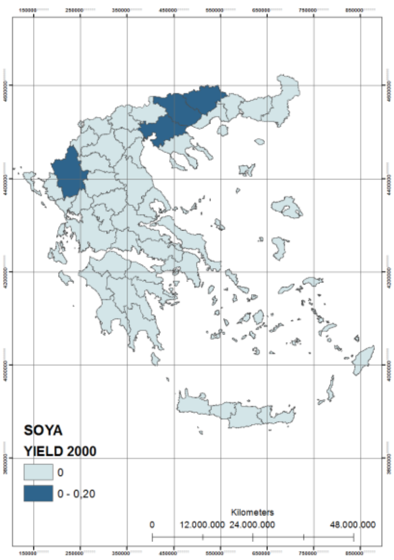


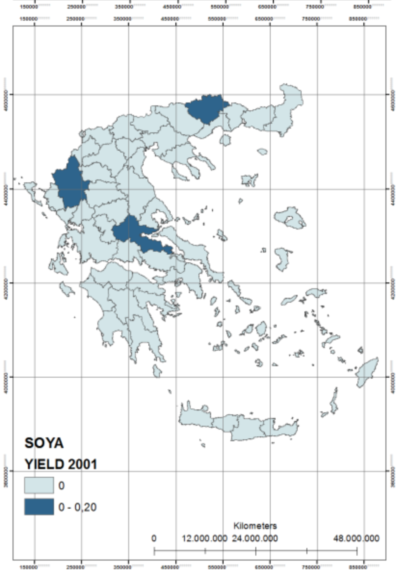


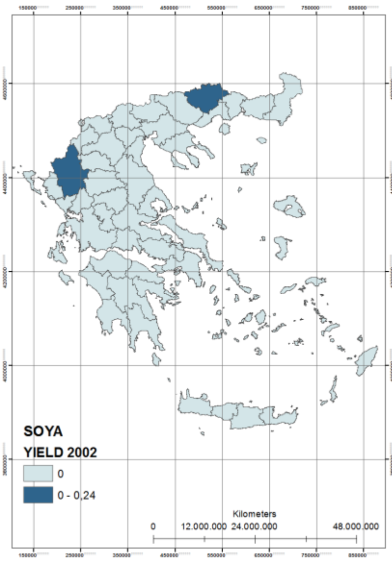


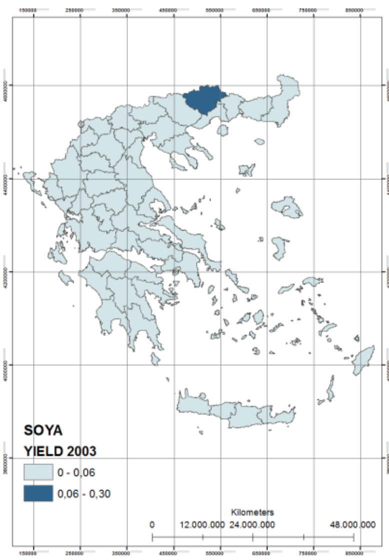


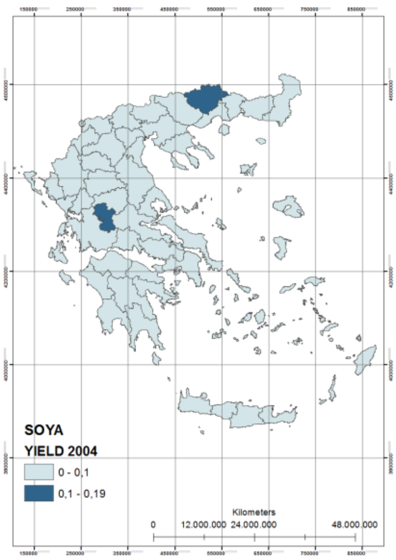
GIS maps for the yield of ***Soya*** *from 2000 to 2010*

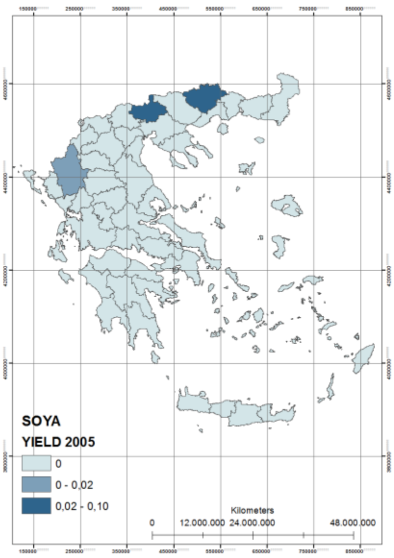


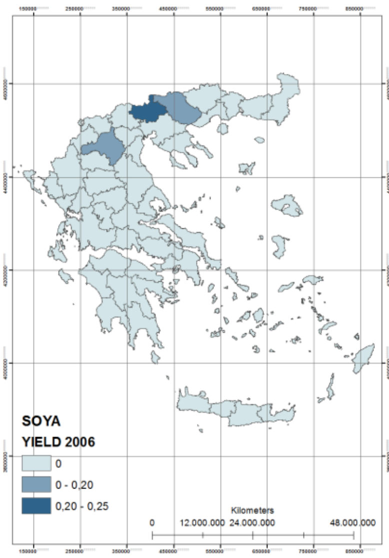


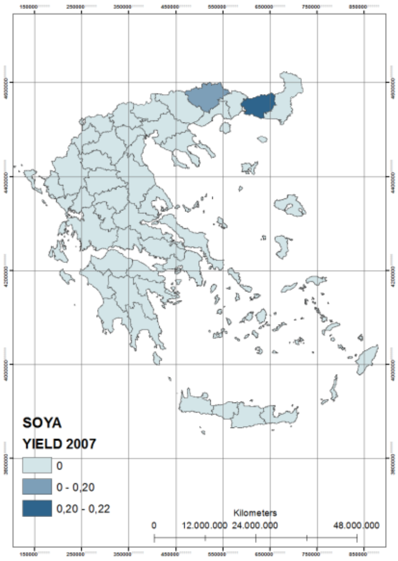

SOYA
YIELD 2002
0
0 - 0,24
Kilometers
0 12.000.000 24.000.000 48.000.000

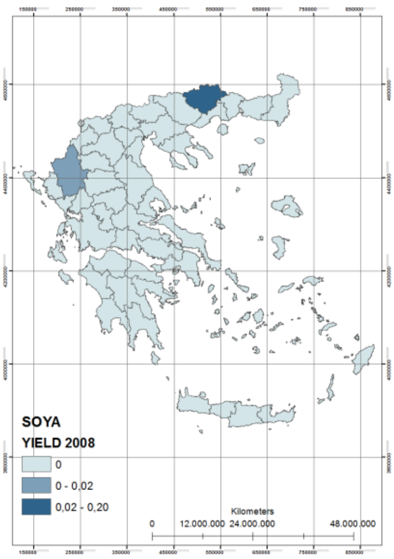

SOYA
YIELD 2003
0 - 0,06
0,06 - 0,30
Kilometers
0 12.000.000 24.000.000 48.000.000

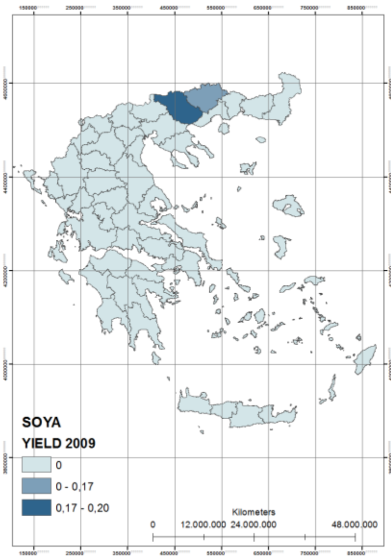

SOYA
YIELD 2004
0 - 0,1
0,1 - 0,19
Kilometers
0 12.000.000 24.000.000 48.000.000

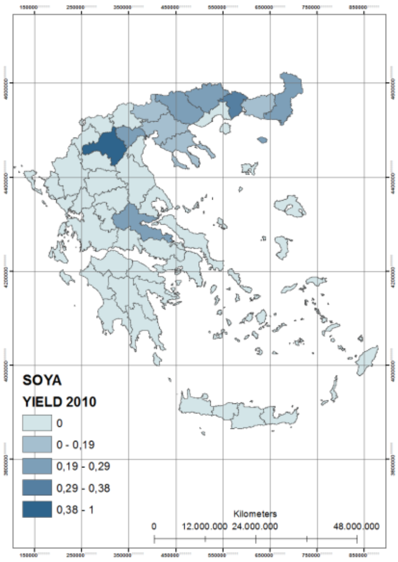

SOYA
YIELD 2005
0
0 - 0,02
0,02 - 0,10
Kilometers
0 12.000.000 24.000.000 48.000.000


SOYA
YIELD 2006
0
0 - 0,20
0,20 - 0,25
Kilometers
0 12.000.000 24.000.000 48.000.000

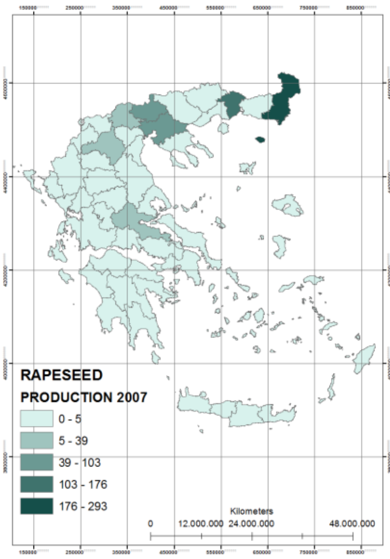

SOYA
YIELD 2007
0
0 - 0,20
0,20 - 0,22
Kilometers
0 12.000.000 24.000.000 48.000.000

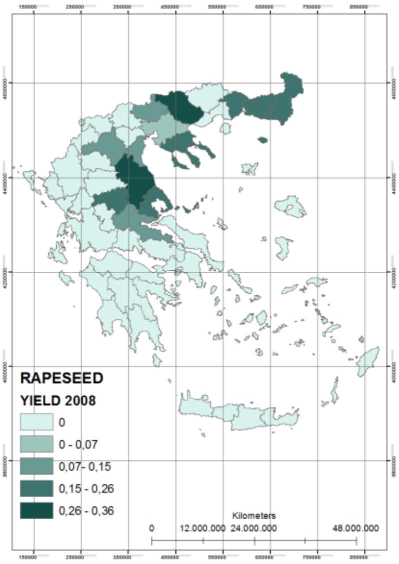

SOYA
YIELD 2008
0
0 - 0,02
0,02 - 0,20
Kilometers
0 12.000.000 24.000.000 48.000.000

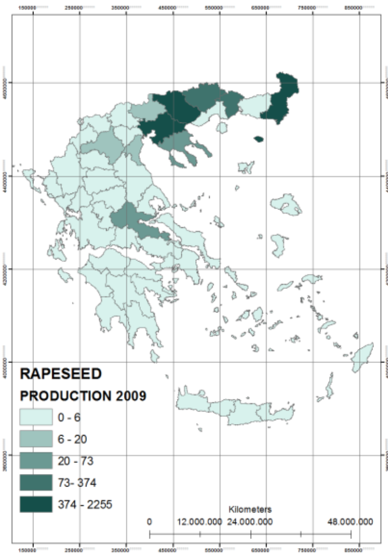

SOYA
YIELD 2009
0
0 - 0,17
0,17 - 0,20
Kilometers
0 12.000.000 24.000.000 48.000.000

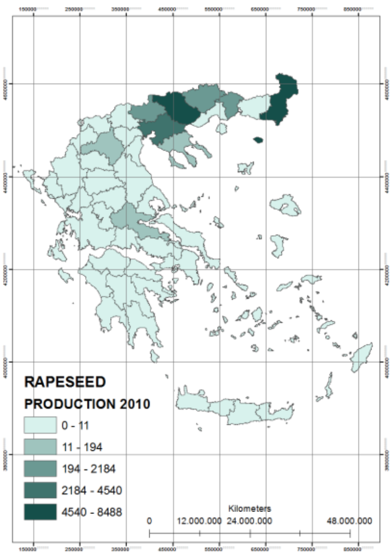

SOYA
YIELD 2010
0
0 - 0,19
0,19 - 0,29
0,29 - 0,38
0,38 - 1
Kilometers
0 12.000.000 24.000.000 48.000.000

*GIS maps for the production of **Rapeseed** from 2007 to 2010*

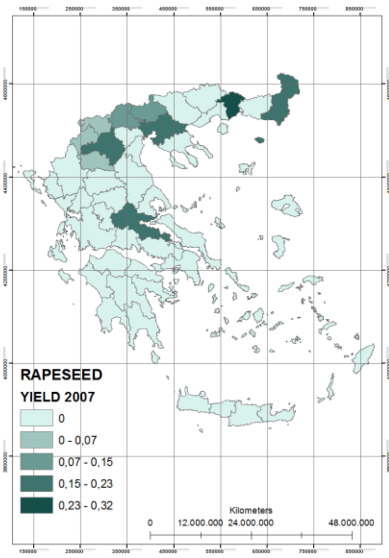


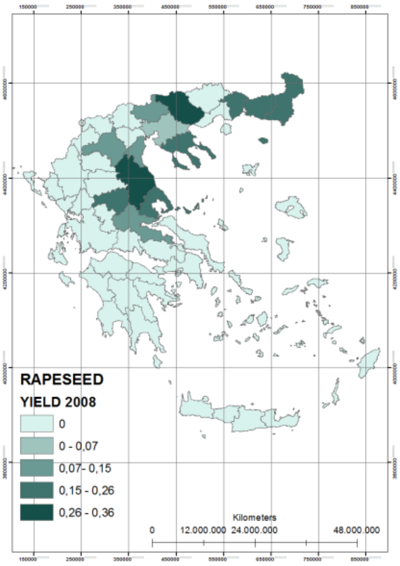


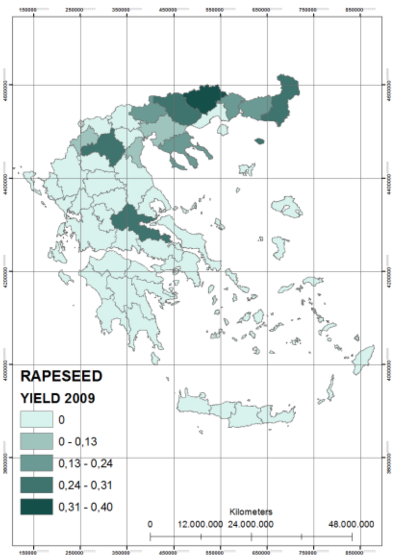


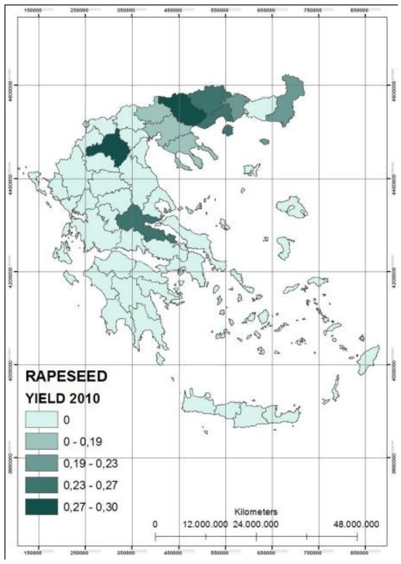


*GIS maps for the yield of **Rapeseed** from 2007 to 2010*









<u>Note</u>: Due to diminution of the maps for reasons of convenience, a slight divergence of the scale has emerged.