An Integrated Approach to Promote Precision Farming as a Measure Toward Reduced-Input Agriculture in Northern Greece Using a Spatial Decision Support System

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An integrated approach to promote precision farming as a measure towards reduced-input agriculture in northern Greece using a spatial decision support system

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Abstract

Although precision farming has matured enough to provide off-the-shelf solutions, the level of penetration in southeast European agricultural production is low. The aim of this work was to identify the locations with highest potential for adopting precision farming in the Region of Central Macedonia (Greece) and promote the adoption of precision farming clusters, as a measure towards reduce input agriculture. This was achieved through spatial multi-criteria decision analysis on several geographic layers, and the identification of the appropriate weights for the criteria through the analytic hierarchy process. A Geographic Information System was incorporated to perform the analysis of numerous layers that describe the environmental, social and economic relevant data of the study area. Five locations were selected because of their potentially high benefit on an environmental and socio-economic dimension if they were to replace the conventional farming techniques and adopt precision farming. Educational and information sessions were set up within the selected locations, and questionnaires were used to collect the farmers' perceptions. The formation of precision farming clusters was promoted as a sustainable solution to the attendees, and questionnaires were used to collect their opinion. To form an integrated approach towards precision farming adoption, additional recommendations were provided to support pilot actions that will act as showcases of success stories.

Keywords: multi-criteria, analytic hierarchy process, precision agriculture, reduced-input agriculture, clusters

1. Introduction

Precision farming covers all activities that investigate within farm variability in the temporal and spatial domains, in order to improve its management as a means of reduced-input agriculture. It uses sensors carried by tractors, UAVs or satellites to map this variability, and after creating a comprehensive knowledge of the farm, it is able to provide smart recommendations for reduced inputs that minimise farmers' costs and prevent environmental deterioration. Overall, it is one of the main instruments of reduced-input agriculture and share the common goal of optimizing the farm management in order to achieve a balance between sustainability and profitability (Elbersen and Andersen, 2007; Zhang et al., 2002).

Adoption of precision farming in southeast Europe has been very low due to the small size of farms, infrequent contact of farmers with new technology, no awareness of the precision agricultural practices, and the high cost of initial investment (Swinton and Lowenberg-Deboer, 2001). These reasons have prevented the dissemination and application of technologically-advanced practices, even though they could help improve the agricultural income and protect the environment. In addition to cost and farm size, other factors reported to influence the adoption of precision farming in USA, Australia and Europe are socio-economic factors (farmers' age and education level, and cost of labour, land and capital), agro-ecological factors (soil quality, land ownership), institutional factors (pressure for sustainability), informational factors (hiring consultants), farmer perception (prospect of increased profit) and technological factors (use of IT) (Adrian et al., 2005; Edwards-Jones, 2006; Swinton and Lowenberg-Deboer, 2001; Tey and Brindal, 2012). The continuous development and improvement of precision farming technologies, the associated time and cost for continuous update, and the ineffective educational programs have been limiting its uptake in USA (Kitchen et al., 2002). Another major factor reported as an impediment in the uptake of precision farming is the lack of co-operation and horizontal integration on its adoption, such as joint investment, agricultural contracting and data outsourcing (Kutter et al., 2011).

The potential of an area to adopt precision farming has been assessed at a regional EU level (NUTS2) using five indicators: cropland over total area, farms with cropland over all farms, cropland over farms with cropland, large farms over all farms, and farmland per worker (Blackmore and Apostolidi, 2011). Their results show high potential in central parts of western Europe, while predominantly medium and low potential on the Atlantic coast, in the Balkans and the Mediterranean, with a few exceptions in the new Member States of central and eastern Europe. Nevertheless, the adoption level in northern European countries is still low (Pedersen et al., 2004; Sylvester-Bradley et al., 1999). In another study, it was suggested that adoption should be faster in areas with abundant undeveloped land, where human force and financial capital are available, and the use of labour and variable inputs is already quite efficient (Swinton and

Lowenberg-Deboer, 2001). This is not the case in Bulgaria, where no precision farming projects have been reported yet, and in Greece, where notably few exploratory actions have been reported to test the applicability of the new technology in olive groves, cotton fields, apple orchards and vineyards (Davis et al., 2007; Tagarakis et al., 2013). Thus, their impact on the farmers' practices was low and the penetration level negligible (Alexandridis et al., 2015).

Determining proposed locations for a particular use, such as the identification of the most favourable land for future implementation of precision farming, is a complex process involving integration of data from various domains and sources, from soil science to social science, meteorology to environmental science and requiring multiple decisions that may relate to many different priorities or objectives. Most decision makers are unable to solve such a problem unaided, and usually resolve to intuitive heuristic approaches that try to simplify the complexity in order for the problem to become more manageable. However, this simplification process involves also reducing detailed information, discarding multiple points of view, and ignoring elements of uncertainty. Thus, it is expected that unassisted individuals (either lay or expert) will find it difficult to take firm choices in a complex decision-making environment (McDaniels, 1999).

Decision making, to be effective, requires a specific structure for taking into consideration all the involved environmental, ecological, technological, economic, and social factors that are related, and to evaluate and select among management alternatives. In order to align this heterogeneous information with the decision makers' aspirations and technical applications, there is a demand for a systematic and comprehensive framework, offered by a Geographical Information System (GIS) (Linkov et al., 2004). Moreover, the increasing volume of complex information, generated from various origins and scales to support such decisions and the limited capacity of a single individual to integrate and process that information, emphasizes the need for developing tractable methods for aggregating the information in a manner consistent with the values of the targets set (Linkov et al., 2004).

Worldwide, MCDA methods applied in a GIS have been used to solve spatial problems. The main benefit provided are the list of techniques and procedures to structure decision problems, and to evaluate them through the use of selected criteria (Malczewski, 2006). GIS is considered as a decision support system integrating spatially data analysis with analytical modeling capabilities (Densham and Goodchild, 1989). The combination of these two fields can aid in large variety of spatial decision making applications. In the last decades a substantial increase in the number of GIS-based MCDA implementations has been observed (Malczewski, 2004).

This fact is highly correlated with the rapid developments and evolution in the GIS science (Goodchild, 2009). According to Malczewski (2006) the rapid increase in the integrated use of GIS and MCDA can be attributed to a number of factors such as the wider recognition of decision analysis and support methods, as an essential element of GIScience, the availability of low-cost and easy-to-use MCDA software and finally the availability of MCDA modules in widely used GIS software.

Targeting the correct audience has been a leading strategy presented in several studies as an appropriate action for the promotion of precision farming. In an attempt to attract cotton growers in southeastern USA, a profile of the farmer who will most likely adopt the precision farming technologies was drawn up and targeted (Roberts et al., 2004). Other promotion strategies include the identification of the appropriate communication channels (Kutter et al., 2011), involving farmers in the process of developing precision farming applications (Pedersen et al., 2004) and reducing the IT complexity such as development of a more friendly user interface of the precision farming technology (Cox, 2002). Further research has clearly shown that farmers' education, through seminars, is an essential prerequisite for the adoption of precision farming in several countries (Kitchen et al., 2002).

'Clusters' is a relatively new business model within the agricultural sector, but with great potential for small enterprises in disadvantaged and remote rural areas. For instance, several agri-food product line activities (e.g. fruit, sugar, wine, salmon, milk) in Latin American countries have expanded and attained higher level of competitiveness due to the organization of these product lines in clusters or networks, as has happened also in Asia and Africa (Gálvez-Nogales, 2010). The main advantage offered by farmers' clusters is the elimination of the size disadvantage. Moreover, due to the regional character of clusters, agri-business companies in collaboration with various institutions can secure access to suppliers, assure sales volumes and take advantage of research and development possibilities provided by institutions (Matopoulos et al., 2005).

Two projects (AgroLess and ClusterPoliSEE) have been running over the last two years with the combined aim of demonstrating precision farming technology and promoting its adoption in Greece and Bulgaria through farmers' clusters. The AgroLess project (http://agrolessproject.eu) "Joint reference strategies for rural activities of reduced inputs" was set up to introduce and develop precision farming protocols on irrigation, fertilization and crop protection for important crops in Greece and Bulgaria, in order to achieve reduced-input agriculture. Within this project, several experiments have been designed to define the spatial and temporal distribution of pesticides, fertilizer and irrigation water to a variety of Mediterranean crops: maize, vine, kiwi, asparagus and pomegranate. ClusterPoliSEE (http://www.precisionfarmingcluster.org) "Smarter Cluster Policies for South East Europe" was aimed at preparing the path for the establishment of farmers' cooperatives (clusters) to facilitate the use of precision farming technology in the Region of Central Macedonia, Greece.

The aim of this work is to combine the findings of these two projects and provide an integrated framework for the promotion of precision farming in the Region of Central Macedonia, Greece based on geographic analysis. Specific objectives include the identification of locations with high potential for adopting precision farming, and the evaluation of promoting precision farming clusters through information and educational sessions to the farmers.

2. Materials and methods

2.1. Description of test site

The test site covers the whole territory of the Region of Central Macedonia, a total area of 18,811 sq. km. which consists of seven Regional Units, (former Prefectures): Imathia, Thessaloniki, Kilkis, Pella, Pieria, Serres and Chalkidiki. The location of the study area is shown in Figure 1.

Agriculture plays an important role in the region's economy. The primary sector accounts for approximately 5,2 % of the region's gross value added (GVA) and employs around 12% of the region's labor force (ELSTAT, 2012). The total agricultural land is 7220 km^2 (almost 19,5 % of the country's arable land) and occupies nearly 39% of the region's area. The regional sector's structure is characterised by high percentages of arable and irrigated crops, high production of cereals, fruits and industrial plants, better structure (size) of holdings in comparison to the country's average, relatively high degree of mechanization and business organization. Nevertheless holdings' size is still small compared to EU and international standards and collaborative bonds, that could facilitate groups and clusters, are generally weak among producers. The region's agriculture is characterised by the dominance of traditional sectors of low specialization and a high dependence on subsidies.

In terms of connection with other sectors, the processing of primary products constitutes one of the most dynamic fields of the secondary sector within the Region. The relevant infrastructure is mostly concentrated in the RUs of Thessaloniki, Imathia, Pella and Serres. The products that are mainly processed are peaches, cotton, tobacco, grapes, tomato, olives, corn and sugar beets. Still there is significant lack of infrastructure (irrigation, transport, secondary units) and of adequate educational and technical support.

In terms of R&D, there is an adequate concentration of research institutes and academic bodies related to the agricultural sector within the region's territory, especially in Thessaloniki which acts as a transport, business and innovation hub for the whole region, but the level of connection between primary production and research is low. The use of new technologies is limited, the educational level is low and the age of the active population is high.

In environmental terms, the region is rich in ecosystems and protected areas with a high biodiversity level. The pressures from agriculture upon the environment are numerous and mainly concern the nitrification of soils, the quantitative and qualitative deterioration of the water resources and the resulting threats on the flora and fauna of the affected areas. In most cases, current agricultural practices are non-sustainable with overexploitation of water resources and excessive use of agricultural inputs (chemicals, fertilizers)

Overall, the primary sector is characterised by a low entrepreneurship and innovative spirit and a low level of certification, brand naming, marketing and product promotion which consequently results in products of low competitiveness and low added value.

The unprecedented period of economic recession that has struck the country the past years has taken a toll on the primary sector and rural areas with high unemployment, increasing burden from taxation, reduced subsidies and limited availability of resources. The present economic climate has not favoured, so far, the transition to a more competitive agricultural productive system although it has been clearly set as a primary objective within the regional strategic framework of the upcoming programming period.

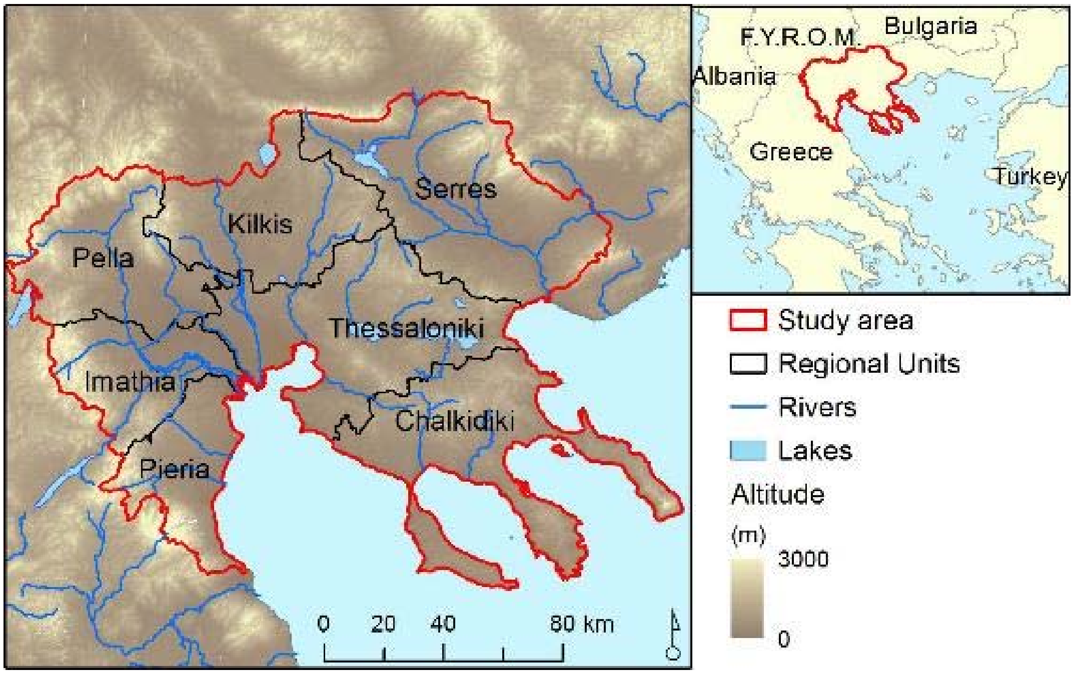

Figure 1: Location of study area.

2.2. Data sources

In order to carry out the spatial analysis a large quantity of spatial information was required. The research has focused on the collection of spatial data and information from numerous different sources.

Wherever spatial data have not been readily available (as in the case of most social criteria) descriptive and statistical data have been converted to spatial ones. In every occasion the smallest possible spatial unit was preferred so as to incorporate into the analysis the maximum possible spatial variability.

The types of primary data that were deemed essential and which were subsequently collected by the various sources listed above are presented in Table 1.

Table 1: Data required for spatial analysis of precision farming implementation within the Region of Central Macedonia

Required spatial data	Type of data	Source of data
Spatial units – Infrastructure - Demography		
Boundaries of Region of Central Macedonia Boundaries of Regional Units Boundaries of Municipalities Boundaries of Municipal Districts Settlements (cities, villages, etc) Road network Primary processing units Demographic data	Vector (polygon) Vector (polygon) Vector (polygon) Vector (polygon) Vector (point) Vector (polyline) Vector (point) Attribute	geodata.gov.gr geodata.gov.gr geodata.gov.gr geodata.gov.gr Digitizing 1:50k topo maps Digitizing 1:50k topo maps ELSTAT ELSTAT
Terrain		
Terrain surface Land cover (CORINE)	DEM (raster) Vector (polygon)	Digitizing 1:50k topo maps CORINE
Hydrology		
Boundaries of water districts Boundaries of river basins Boundaries of water bodies sub-basins Lakes Rivers Transitional waters Coastal waters Groundwater systems Geological formations	Vector (polygon) Vector (polygon) Vector (polygon) Vector (polygon) Vector (polyline) Vector (polygon) Vector (polygon) Vector (polygon) Vector (polygon)	RCM Water Directorate RCM Water Directorate RCM Water Directorate RCM Water Directorate RCM Water Directorate RCM Water Directorate RCM Water Directorate RCM Water Directorate Digitizing 1:50k topo maps
Protected areas		
<u>Waters used for the abstraction of drinking water</u> Groundwater systems Drilling Surface water bodies <u>Areas designated to protect economically significant aquatic species</u> Aquacultures Fishing areas - coastal, lakes, rivers	 Vector (polygon) Vector (point) Vector (polygon) Vector (polygon) Vector (polygon,	 EOINET RCM Water Directorate EOINET EOINET EOINET

	polyline)	EOINET
<u>Nutrient Sensitive Areas</u>		
Nitrate vulnerable zones	Vector (polygon)	EOINET
Organic substance vulnerable zones	Vector (polygon)	EOINET
Recreational Waters (bathing waters)	Vector (point)	EOINET
<u>Areas designated for the protection of habitats or species</u>		
Natura 2000 sites (SCI and SPA)	Vector (polygon)	EOINET
Wildlife reserves	Vector (polygon)	EOINET
National parks	Vector (polygon)	EOINET
Agricultural activity		
Crops (detailed)	Vector (polygon)	OPEKEPE
Meteorology		
Evapotranspiration	Raster	MOD16
Soil		
Soil map	Vector (polygon)	OPEKEPE
Socioeconomic		
Income per capita	Attribute	ELSTAT
Local contribution to regional primary sector	Attribute	ELSTAT
Unemployment rate	Attribute	Consultation document, 2015
Producer motivation for precision farming adoption	Attribute	Koudios, 2014

Where:

- ELSTAT is the Greek Statistical Agency (www.statistics.gr)
- OPEKEPE is the Greek Payment Authority of Common Agricultural Policy Aid Schemes (http://www.opekepe.gr)
- EIONET is the European Environment Information and Observation Network (https://www.eionet.europa.eu)

2.3. Geographic analyses

2.3.1. Multi criteria decision analysis (MCDA)

Planning and decision making process in MCDA is executed in three major phases, intelligence, design and choice or decision (Sharifi et al., 2002) (Figure 2). In the intelligence phase, which is also called problem formulation phase, the situation is analysed for the problem and prospects. The design phase involves problem understanding, generating alternatives, selecting criteria and establishing relationships among them. The choice/decision phase involves the evaluation of the alternatives using the set criteria to achieve the objective.

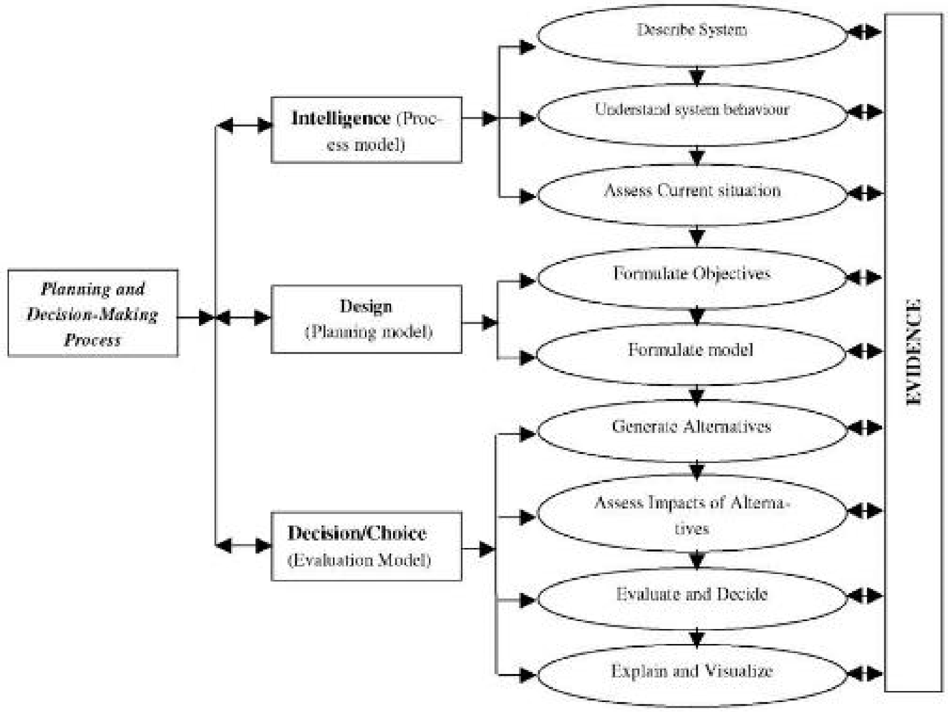

Figure 2: Framework for planning and decision making process (after Sharifi et al. (2002)).

Multicriteria decision analysis (MCDA) offers the methodological framework of decision-analytics that is useful for agricultural land suitability, including one for application of precision farming. MCDA has been used not only to find out one correct decision, but to improve the understanding of the problems in ways that makes possible a decision-making process that involves risk, multiple criteria, and conflicting interests. This process facilitates the decision maker (ranging from technical personnel to stakeholders), to systematically take into account and apply value judgments to select the most favourable among various management alternatives. The MCDA also promotes a participatory element in the decision making process because multiple stakeholder values are gathered and explicitly incorporated (Linkov and Ramadan, 2004).

It is not uncommon that opposing criteria and complex trade-offs should be incorporated into the process of decision making. For instance, the traditional approach to land suitability decision making includes the cross-examination of multiple criteria after transforming them into a common unit, usually monetary, and then execution of standard mathematical optimization procedures. Nonetheless, several weaknesses of the approach have been reported, and new methods for rigorous analysis of MCDA have been developed (Belton and Stewart, 2002).

In MCDA, the analyst establishes preferences between pairs of options having in mind a set of objectives identified by the decision maker. Measurable criteria are used to assess the level of accomplishment of the objectives. In simple cases, even the process of listing the objectives and criteria may support decision makers with adequate insight into the problem. However, MCDA offers additional ways of combining the data on individual criteria and estimate indicators of the overall performance of alternatives. An important characteristic of MCDA is that during the definition of the objectives and criteria, it highlights the opinion of the decision maker, and allows the estimation of weights that show their relative importance. Although the process incorporates objective numeric data and measurements, the subjectivity of the decision maker that is inserted in the definition of weights has been a matter of concern.

MCDA has many advantages over informal judgment unsupported by analysis (Dodgson et al., 2009):

- it is an open process and allows explicit analysis of the data,
- it allows flexibility in the choice of objectives and criteria if the decision maker judges them as inappropriate,

- the standard techniques are used for the definition of explicit scores and weights. They can also be connected to alternative sources of information, and easily be updated using relative values,
- it is a multi-disciplinary approach amenable to capturing the complexity of natural systems, the plurality of values associated with environmental goods and varying perceptions of sustainable development (Toman, 1998).
- a large variety of criteria can be considered, whether quantitative or qualitative, independent of the measurement scale. Hence, it can include all aspects of sustainability rather than being restricted to marketed goods or monetized costs and benefits (Omann, 2000).

2.3.2. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) has been developed by Saaty (1988) and is one of the best known and most widely used MCDA approaches. It allows users to assess the relative weight of multiple criteria or multiple options against given criteria in an intuitive manner. In case quantitative ratings are not available, decision makers can still recognize whether one criterion is more important than another. Saaty (1988) established a consistent way of converting such pair wise comparisons (X is more important than Y) into a set of numbers representing the relative priority of each of the criteria (http://www.liaise-kit.eu/content/analytic-hierarchy-process).

The AHP is used to break down complex problems into a hierarchy of sub-problems which can be evaluated more easily. Numerical values are derived from the subjective evaluations of the decision maker, and then are processed to place each alternative in an order of importance.

The methodology of the AHP is described in the following steps (Bhushan and Rai, 2007):

Step 1: The problem is broken down into a hierarchical array of a goal, criteria, sub-criteria and alternatives. This part is considered or high importance to the decision-making process. The hierarchy is fundamental, as it indicates a relationship between elements across levels, with the relationship assuring an interconnection of all elements, at least in an indirect manner. A hierarchy is a more orderly form of a network. An inverted tree structure is similar to a hierarchy. Saaty (1988) suggests that a useful way to structure the hierarchy is to work down from the goal as far as one can and then work up from the alternatives until the levels of the two processes are linked in such a way as to make comparisons possible. Figure 3 shows a generic hierarchic structure.

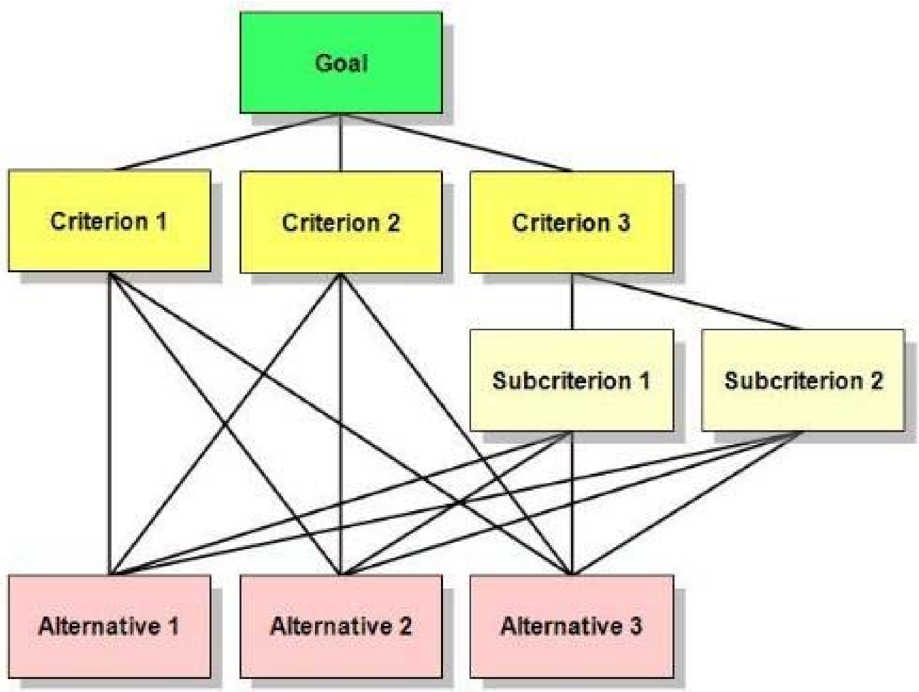

Figure 3: A generic hierarchic structure (adapted from wikipedia.org).

The root of the hierarchy includes the goal or objective of the problem to be solved. The leaves of the inverted tree structure are the alternatives to be compared for selection. In between the root and the leaf levels are various levels of criteria and sub-criteria. A powerful advantage of the AHP is that the decision-maker has just to form comparisons among elements of lower-level to those connected to the upper-level.

Step 2: The next step in the AHP process is pair-wise comparison of alternatives, i.e., for each criterion the decision maker compares all the alternatives pair-wise. The decision maker can make numerical or verbal judgments. In the verbal mode, statements are selected varying from 'equally preferred' to 'greatly preferred'. In the numerical method, the decision maker selects a score on a scale of one to nine. For example, the score three indicate that one alternative is three times as preferable to the other alternative.

Step 3: A square matrix is organised that contains the pair-wise comparisons of various criteria from step 2.. The criteria are ranked in the matrix according to their relative importance. The diagonal elements of the matrix are 1, and the (*j, i*) element of the matrix is the reciprocal of the (*i, j*) element.

Step 4: The comparison matrix produces the normalised right eigenvector and the principal eigenvalue which corresponds to the relative importance of the various criteria being compared. The elements of the normalised eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

Step 5: The consistency index (CI) is used to evaluate the matrix.

The consistency index, CI, is calculated as

$$CI = (\lambda_{max} - n)/(n - 1)$$

where λ_{max} is the maximum eigenvalue of the judgement matrix and n is the order of the matrix. This CI can be compared with that of a random matrix, RI. The ratio derived, CI/RI, is termed the consistency ratio, CR. Saaty suggests the value of CR should be less than 0.1. If CI fails, then answers to comparisons may be re-examined.

Step 6: The weight of each sub-criterion is multiplied by the rating of each alternative and then summed up to calculate local ratings for each criterion. The weights of the local criterion is then multiplied by the local ratings and further summed up to calculate global ratings. Finally, the AHP produces weight values for each of the alternatives, based on the ranking of the importance between pairs of them, for each criterion.

By the prior discussion on AHP, it becomes apparent that AHP is based on three basic principles:

- *Decomposition*: the structuring of a complex problem into different clusters at various hierarchies
- *Pairwise Comparisons*: the creation of Pairwise Comparison Matrices (PCMs) for all the elements or criteria under evaluation to derive the weights or the preferences, and
- *Hierarchical composition*: the aggregation these local comparisons over the hierarchy to arrive at the final evaluation

and three simple axioms, which are

- *Reciprocal axiom*: if the pair wise comparison between two elements a and b with respect to an element c is Pc(xab), then the comparison between b and c must be 1/ Pc(xab).
- *Homogeneity axiom*: elements clustered and arranged under a hierarchy must be homogeneous i.e. they must be comparable with an order of magnitude. It means that elements within a cluster should preferably be compared within the AHP scale, 1 to 9.
- *Independency of judgment at each level*: judgment at one level of hierarchy should be independent of the elements under it. One should carefully consider this axiom while making decisions, as the human tendency force one to look at the elements under the hierarchy during evaluation

- One should make sure that their ideas are adequately represented in or incorporated into process of decision making so that the results match their expectations

2.4. Survey for precision farming cluster

Six information and training sessions and a concluding event were held in the regional units of the Region of Central Macedonia, Greece, during 2014-2015. The sessions aimed at informing farmers on issues related to the application of precision farming, the detection of existing interest regarding their willingness to participate in a precision farming cluster, and present the list of requirements and conditions for their formation.

During the sessions, the following issues were discussed:

- The needs of farmers in relation to the current situation of agriculture in their areas.

- Their goals for the near future.

- Their positions on the establishment of a rural cluster in the region with regard to the following characteristics:

  - Structure of the cluster.

  - Innovative features on the comparative advantages of each region.

  - Targeting and meeting the needs of farmers through a precision farming cluster.

  - Members' specific issues to be addressed.

During the sessions, questionnaires were distributed to attendees, with 10 questions regarding their willingness to take up precision farming practices, with attachments for expressions of interest to participate in a precision farming cluster (Memorandum of Agreement).

Furthermore, the farmers were asked to prepare a relevant document, as feedback material, and were invited to present these to the final concluding event. The final step in preparation for creating a cluster took place at the concluding event where, the farmers willing to adopt the precision farming methodologies and form a cluster, participated.

The final selection of the proposed members to participate in the formation of the cluster was based on the degree of motivation among the farmers.

A consultation between the interested farmers and the working group of the project was held at the end of the concluding event in order to analyse the following issues:

- How to draw up the structure of a precision farming cluster

- What the potential future actions are, to further specify the characteristics of those clusters within each region.

The selected farmers then proceeded to the signature of the Memorandum of Agreement with the working group of the ClusterPoliSEE project, declaring their willingness to be involved in a precision farming cluster in their individual areas.

3. Application of multi-criteria decision analysis in the study area

The first step in the geographic analysis was to set the overall goal, which was the identification of the agricultural areas within the Region of Central Macedonia with the maximum potential for precision farming implementation. Higher potential refers to the attributes that favour the implementation of precision farming. It also encompasses the concept of **maximum induced** benefit, which refers to the areas that best fulfil the requirements for precision farming application and, at the same time, have the potential to benefit most from a conversion of the existing conventional agricultural practices to reduced input ones.

Within this context, the factors that affect the magnitude of the induced benefits and precision farming application efficiency were determined, through the definition of criteria and sub-criteria of the spatial analysis. This was performed taking into account the strategic framework and the respective strategic objectives set for the primary sector on a regional level, which are expressed with the three elemental priorities: (i) "sustainable" rural development, i.e. reducing the impact on the environment from agricultural activity and increasing the sustainable management of natural resources, (ii) "smart" rural development, i.e. increasing the potency and competitiveness of the regional agricultural economy through the use of new technology and innovation, and (iii) "inclusive" rural development, i.e. promoting employment, social cohesion and balanced development in rural areas.

The criteria used in the spatial analysis and the respective induced benefits are grouped in the following three main categories: (i) environmental, (ii) economic, and (iii) social criteria. Each major group of criteria was further “populated” with sub-criteria and parameters that affect the magnitude of the induced benefit type and which can be used to build the environmental, economic and social spatial indices for the required evaluation. A large number and diversity of criteria was sought to ensure an integrated evaluation.

3.1. Definition of criteria

3.1.1. Environmental criteria

The environmental criteria concern the parameters and spatial attributes that affect the magnitude of the environmental results, i.e. the environmental benefit that derives from the conversion of existing conventional practices to reduced input ones. Taking in mind the legal environmental framework, the impact of agricultural activity on the environment and the present environmental state of the region, the environmental criteria are divided into the following 2nd tier categories: (i) impact on water bodies, (ii) impact on protected areas, (iii) impact on soil, and (iv) impact on natural resources.

Impact on water bodies

The impact of farming on water is one of the major environmental issues of agricultural activity. This impact can be summarized in the following key points:

- *Impact on water quantity*: agriculture is the major user of water resources by far, exploiting 80-90 per cent of the region's water availability every year. The supply and demand of water is not homogeneous across the region, but varies from basin to sub-basin as *water exploitation indexes* indicate, and so non-stressed and stressed intra-regional areas both exist. Over pumping through uncontrolled drilling is common practice leading to depletion of groundwater aquifers.
- *Impact on water quality*: water quality may be negatively affected by the presence of pesticide residues, nutrients from fertilisers, or sediments from soil erosion. The impact of agriculture on the quality of both surface and groundwater bodies occurs through the processes of runoff and leaching respectively and is more intense in areas where excessive use of inputs (water, fertilizers and agrochemicals) is used.

The selected criteria assess the benefit from the potential application of precision farming on the water bodies that are located in proximity of the agricultural areas. They also incorporate the spatial dimension in order to identify the spatial variability in the magnitude of the induced benefit and are therefore governed by the following two basic principles:

- Induced benefit on surface water bodies is proportional to distance of agricultural holdings undergoing conversion from traditional practices to reduced input ones.
- Induced benefit on groundwater bodies is dependent on location of agricultural holdings that lie on top.

The **types of water bodies** that were included in the analysis consist of surface water bodies (lakes, rivers, transitional and coastal) and groundwater systems.

The available spatial data regarding the water bodies of the region have been collected from various sources (see section 2.1). The distribution of surface water bodies is shown in Figure 4 while that of groundwater systems in Figure 5.

Figure 4: Surface water bodies (transitional waters with pink color)

Figure 5: Groundwater systems' boundaries

On the basis of the first principle mentioned above it follows that the induced benefit from the application of precision farming maximizes the closer we get to a given water body and therefore the agricultural holdings that are closest will be attributed higher scores in respect to that specific criterion. This basic concept is used repeatedly within the spatial analysis whenever distance is the decisive factor that determines the magnitude of the criterion's intensity.

On the other hand in the case of groundwater systems the spatial relationship is that of location, i.e. the agricultural holdings inherit the "qualities" of the groundwater system beneath them and the spatial variability is determined by those qualities which differ from one system to another. Such a quality is the permeability level of the geological formations of the groundwater systems that affects the level of infiltration and recharge of the latter. Also the quantitative and qualitative characteristics of the groundwater systems' state which are discussed further below.

In order to shape the criterion layer of the permeability attribute, the geological formations have been grouped into permeability categories according to the available data (IGME 2008) that determine the magnitude of the impact on the groundwater system under examination on the basis of the simple principle: higher permeability level results into more severe impact, as a result of more direct communication between the overlying layer and the water table and of more unobstructed transport of pollutants and nutrients from surface agricultural activity.

Attributes regarding the water body's quantity and quality state have also been included (information collected from recent River Basin Management Plans of the Region's Water Districts according to the Water Framework Directive). The presence of the quality and quantity characteristic allow for the integration of two more criteria layers, namely those that regard sensitive water bodies and degraded water bodies. These were designated as sensitive under the Urban Waste Water Treatment Directive (91/271/EEC) and the Water Framework Directive.

In all the criteria layers above concerning surface water bodies the spatial relationship is defined by the distance factor of the agricultural holdings while in the cases of the groundwater systems the relationship is defined by the presence (or absence) of degraded bodies underneath the agricultural areas (presence adds "points" in induced environmental benefit).

Impact on protected areas

The protected areas examined here are those suggested by the European Water Framework Directive (2000/60/EC) to be included in the relevant national register. These are drinking water protected areas, areas designated for the protection of economically significant freshwater fish and shellfish, recreational bodies of water and bathing waters, nutrient-sensitive areas including nitrate vulnerable zones according to the Nitrates Directive, areas designated as sensitive under Urban Waste Water Treatment Directive, and Natura 2000 sites in which the status of water is an important factor for the protection of their habitats or species.

The WFD states that whenever overlapping occurs, the most stringent objective always applies so that one regulation does not undermine the requirements of another. In this work the overlapping of areas is treated in a cumulative manner, i.e. a water body that is also specified as a protected area receives extra score in respect of the overall induced benefit and therefore two (or more) layers can exist for any individual water body.

In the case or the drinking water protected areas the spatial relationship used in the current analysis follows the pattern already described previously i.e. for the surface water bodies the spatial parameter determining intensity value is distance while for the groundwater bodies is presence of pumping activity. The water bodies, both surface and groundwater, which are used for drinking purposes within RCM are shown in Figure 6.

Figure 6: Protected areas used for abstraction of water for human consumption (Water Framework Directive, Article 7)

Another protected areas category concerns those for the **protection of economically significant aquatic species**, namely freshwater fish and shellfish, which are considered very important for the local rural and coastal communities as there is significant fishing and aquaculture activity occurring across the regional territory. Good water quality is important for the production of high quality fish and shellfish. Water bodies can be impacted by pollution from various sources, such as run-off from agricultural land or discharges from sewage treatment works. The areas of the Region designated to protect economically significant aquatic species are shown in Figure 7.

Figure 7: Protected areas designated to protect economically significant aquatic species – shellfish (left), fish (right)

In the case of the bathing waters, as before, the corresponding criterion layer utilizes the parameter of linear distance in order to assess the intensity of the induced impact (and corresponding benefit) that the agricultural activity imposes on the nearby bathing water bodies. The protected areas of the Region designated as recreational waters are presented in Figure 8.

Figure 8: Protected areas designated as recreational waters

The last protected areas' category concerns areas designated for the protection of **habitats or species** under and the Habitats Directive (92/43/EEC) and the Birds Directive (79/409/EEC).

The impact of farming on ecosystems is more difficult to quantify than that imposed on water bodies. The relationship is even more complex and may also include positive impacts. For this reason, the Common Agricultural Policy of the EU (CAP) has been trying to target aid at rural development measures promoting environmentally sustainable farming practices, like agri-environment schemes. Within such a context a transformation of the existing agricultural practices towards a more environmentally friendly model (with less chemicals and harmful substances) such as the reduced input one, will almost definitely benefit the conservation of habitats and species existing within the boundaries or in proximity of the transformed agricultural areas.

Following the distance principle, as in the case of the water bodies, the criterion layer that describes the spatial relationship of the impact on the ecosystems grades higher values to those agricultural holdings that are closer to the boundaries of areas with protected status. The areas of the RCM that are designated as important for the protection of habitats or species are shown in Figure 9.

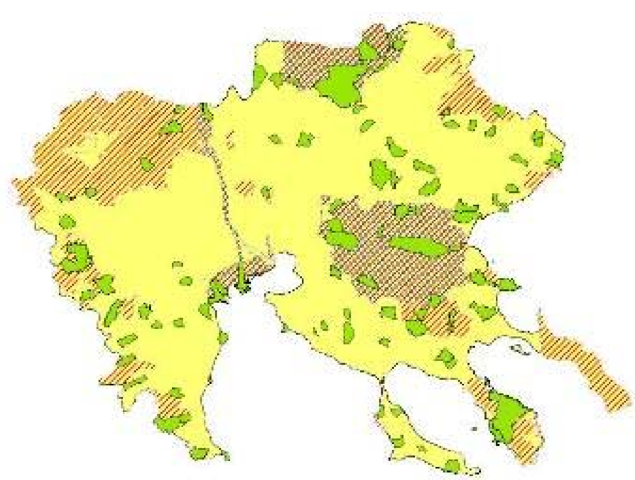

Figure 9: Areas designated for the protection of habitats or species (Natura 2000 sites – red striped, national parks – blue striped, wildlife reserves – green)

As it can be seen in Figure 9 the different types of protected areas may overlap. Again, whenever this occurs, the end effect, in terms of spatial analysis, is a cumulative score for the areas that are characterized by more than one protection status.

Impact on soil

Intensive farming can have severe impact on soil such as acidification, nitrification, desertification, decline in organic matter in soil, soil contamination (e.g. by heavy metals and agrochemicals), soil compaction and erosion. Such degradation can result from inappropriate farming practices such as excessive fertilization, improper use of pesticides, and the use of heavy machinery.

In order to assess the impact on soil, and the induced benefit from a conversion to precision farming practices, two important soil attributes are being used in the present analysis as sub-criteria layers of the soil criterion hierarchy tree: nitrification and $CaCO_3$ concentration.

Nitrification is one of the major environmental issues associated with agricultural activity. Agricultural intensification and pushing towards higher land productivity during much of the past fifty years was usually accompanied with large applications of inorganic nitrogen and phosphorous fertilisers. This led to high concentrations of nitrates and phosphates in soils and waters and subsequently to high eutrophication levels in downstream water bodies. The problem has led to the adoption of the Nitrates Directive (91/676/EEC) with the aim to protect water quality across Europe by promoting the use of good farming practices in order to reduce nitrates from agricultural sources to pollute water bodies.

The Nitrates Directive is incorporated in the Water Framework Directive and is one of the key mechanisms for the protection of waters against agricultural pressures. Within the WFD’s framework Member States are required to designate "Nitrate Vulnerable Zones" (NVZs) of areas of land which drain into polluted waters or waters at risk of pollution and which contribute to nitrate pollution, or Member States may choose to apply measures to the whole territory (instead of designating NVZs). The areas that have been designated NVZs in line with the EU legislation in RCM are shown in

Figure 10, where it is obvious that the largest part of the region has been characterized as vulnerable to nitrates and includes entirely the plain areas of the major rivers.

Figure 10: Areas designated as Nitrate Vulnerable Zones (brown color)

The **$CaCO_3$ concentration** parameter used in the current analysis is an indicator of good soil quality against acidity and degradation. High concentrations of $CaCO_3$ indicate strong ability of soil to resist change through the property of *buffer capacity*. Soil buffering is the ability of the soil to stop nutrient or pH changes by absorption. A higher buffer capacity means that the soil can absorb more acid and/or alcaline without a significant change in pH and is therefore important because it helps to stabilize pH values in favour of soil fertility and plant growth.

The data that were used in the current analysis have been provided by the Greek Payment Authority of Common Agricultural Policy (OPEKEPE) and concern $CaCO_3$ measurement values from 2166 sampling points within the regional territory as shown in Figure 11 (left). Through surface interpolation methods a continuous surface layer representing spatial variability of $CaCO_3$ influence (inversely proportional to concentration) has been created from the sampled point values and is shown in Figure 11 (right). The map represents areas of $CaCO_3$ concentration values and is used in the spatial analysis as an environmental criterion layer that grades scores to agricultural areas according to their degradation status i.e. in an inversely proportional manner to their $CaCO_3$ concentration value (red to green).

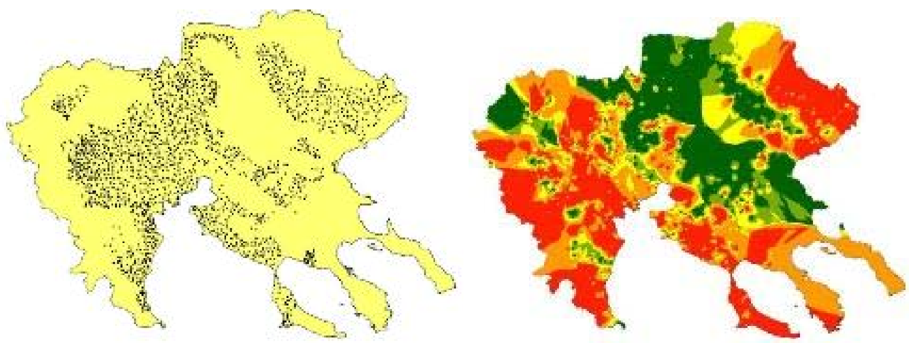

Figure 11: Sampling points (left) and influence of $CaCO_3$ concentration (red to green) (right)

Impact on resources

The last category of the environmental criteria concerns the impact of agriculture on resources and the associated benefit that would be produced from a transformation to precision farming practices.

For the assessment of the impact on resources a different approach is required in comparison with the methods used so far. The spatial relationships that arise in the cases of these criteria are regulated by "internal" attributes of the crop themselves and not by their location in respect to other layers. The final spatial variability maps are of course determined by the locations of the agricultural holdings but the intensity of the criterion layer is not governed by their location but by their attributes.

Those attributes that are of importance in the current analysis, and their corresponding associated environmental impacts are shown in Table 2.

Table 2: Crop attributes and corresponding environmental impacts

Crop attribute	Environmental impact

Irrigation needs	Water footprint
Fertilization needs	Water and soil pollution
Aggregation / Dispersion	Carbon footprint

The crop map for year 2014 was provided by the Greek Payment Authority of Common Agricultural Policy (OPEKEPE). The sixteen crops with the largest distribution have been selected for spatial analysis representing about 90 per cent of the total agricultural area. The crops representing the rest 10 per cent have been evaluated as insignificant for the purposes of this study. The main data for the sixteen types of crops are presented in Table 3 and their distribution is shown in Figure 12.

Table 3: Number of holdings and total surface area for most important crops of RCM

	Type of crop	Number of holdings	Total surface area (m²)
1	Fodder	79784	4957288
2	Corn	58157	4176889
3	Cotton	69302	6917179
4	Energy Crops[1]	39564	2482187
5	Fruit Trees[2]	135157	6202504
6	Hard Wheat	183489	11880132
7	Herbs	1778	121723
8	Legumes	6424	345611
9	Non Hard Wheat Cereals[3]	211470	11889086
10	Nut trees	3042	268008
11	Olive Trees	77932	3317809

12	Rice	22544	2289520
13	Sugarbeets	5551	314335
14	Tobacco[4]	14786	876002
15	Vegetables	16747	784454
16	Vines	10980	470161

1 – mainly sunflower
2 – mainly peaches, cherries, nectarines, apples and kiwis
3 - mainly soft wheat and barley
4 – mainly of eastern type

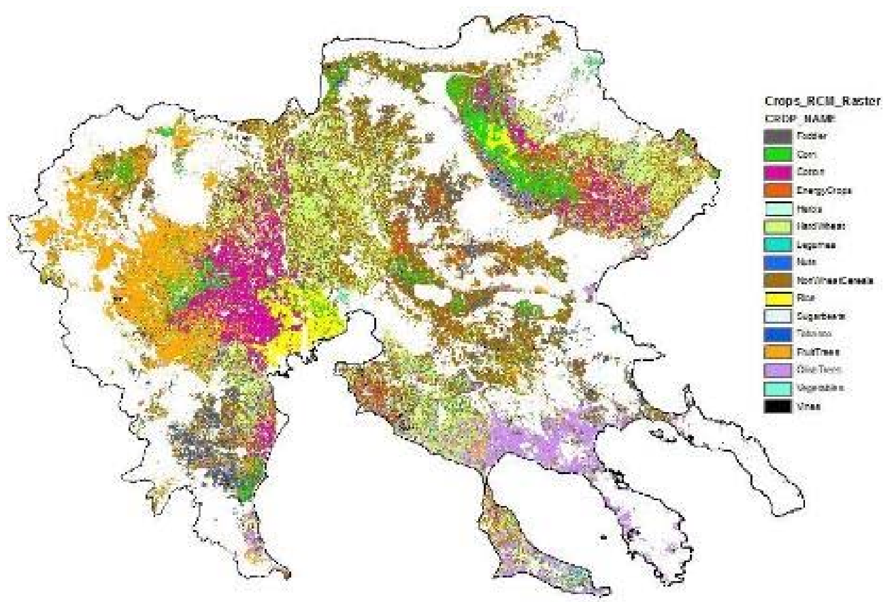

Figure 12: Spatial distribution of major crops 2014

The first attribute to be considered is that of **irrigation**. Agriculture, as already mentioned, is the primary water user in Mediterranean (up to 90 per cent of freshwater resources) and any reduction in the water demand, for instance through better irrigation practices, can make a huge difference in water saving. At the same time, a reduction in the quantity of consumed water entails additional environmental benefits through reduced leaching and runoff.

In order to assess the spatial variability of the impact on water resources the selected crops were categorized in classes according to their consumptive water use through **evapotranspiration (ET)**. ET can be used for the identification of water consuming areas and, in the present case, for the identification of agricultural areas with an apparently high irrigational activity. The average evapotranspiration values for the period 2000-2013 for the area of RCM are shown in Figure 13. The data have been collected by the MODIS Global Evapotranspiration Project (MOD16). The project is part of NASA/EOS project to estimate global terrestrial evapotranspiration from earth land surface by using satellite remote sensing data. The ET data derived from the MOD16 algorithm were available at 1-km spatial resolution at annual intervals.

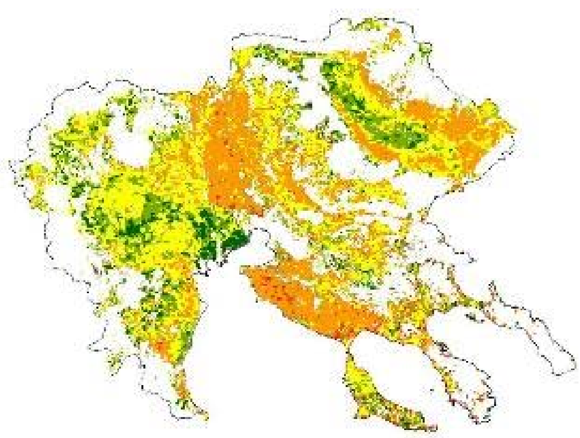

Figure 13: Evapotranspiration map (ascending ET values - red to green)

The next attribute to be considered is that of **fertilization**. The environmental impact of fertilization, as already described in the water bodies and soil sections, concerns two major environmental issues:

- The degradation of water through the processes of leaching and runoff that carries excessive fertilizer quantities to receiving surface and groundwater bodies and causes polluting incidents such nitrification and eutrophication.
- The degradation of soil, when excessive amounts of fertilizers alter the pH and mineral synthesis of the soil causing acidification and, as a consequence, reduced fertility and plant growth.

In order to examine the spatial variability of fertilization application and the corresponding induced benefit from fertilization reduction the crop types of Table 3 were classified into categories according to their fertilization requirements.

For the determination of the fertilization classes the relevant information from the River Basin Management Plans of the region's water districts was used. During the composition of the Management Plans, and for the requirements of the analysis of pressures of the river basins, the estimation of the agricultural loads was undertaken on the basis of:

- records of fertilization practices that have been published within the context of Article 4 of CMD 568/2004,
- reports of fertilization production companies and industries,
- data from input supplying enterprises,
- relevant studies and bibliography.

The estimated nitrogen and phosphorus requirements for the different types of crops per area and on a yearly basis as classified in fertilization classes are shown in Table 4, which in turn produce the spatial distribution map of the fertilization requirements depicted in Figure 14.

The spatial relationship that is produced between fertilization requirements and environmental benefits is proportional i.e. the higher the fertilization class an agricultural holding belongs to the bigger the benefit and therefore the higher the granted value from the spatial analysis.

Table 4: Fertilization requirements classes and types of crops

Fertilization class	Type of crop	N fertilization Kg/1000 m²	P_2O_5 fertilization Kg/1000 m²
I	fodder, herbs, legumes, tobacco	2-6	5-6
II	cereals, energy crops, rice	6-12	5-7
III	cotton, olive trees, sugar beets, vines	9-16	6-16
IV	fruit trees, nut trees, corn	18-24	8-15
V	vegetables	25	20

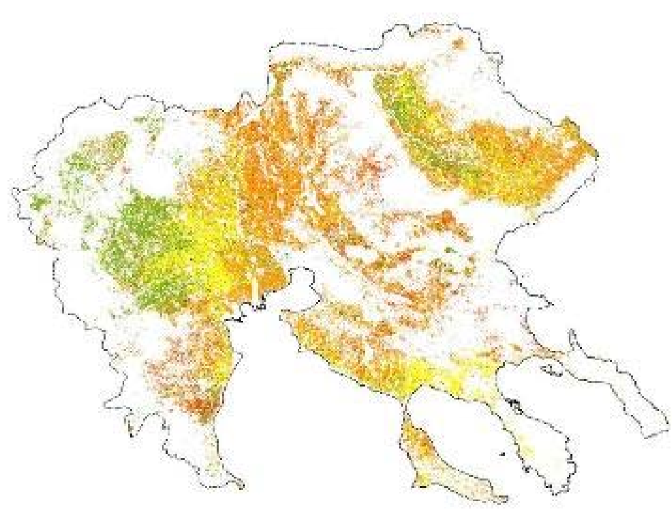

Figure 14: Spatial distribution of fertilization needs according to crop type (red to green)

The third, and final, attribute of the agricultural crops that is taken under consideration in the current analysis is the **spatial aggregation intensity** of the agricultural holdings, namely the degree of their proximity to fields of the same crop type.

This attribute is important as it provides an indicator of the distances between fields of the same crop type and therefore an indicator of the average transport (and time) requirements that would be needed in the case of a collective, large scale approach i.e. the type of approach that is considered desirable. Crops that present high spatial density and a high degree of local clustering require less transport, less fuel and are hence less demanding on resources than crops with a higher degree of internal dispersion. The overall environmental result is therefore a total carbon footprint of reduced intensity.

On the basis of the above, the criterion layer that concerns the impact on resources makes use of each crop's spatial aggregation intensity, on a regional level, and grants higher scores to the least dispersed ones.

In order to produce the layer mentioned above, the density pattern of each crop type was measured using the *average nearest neighbour* method. This method measures the distance between each field's centre and its nearest neighbour's centre location. It then averages all these nearest neighbour distances and returns the *observed mean distance* which represents the average distance between fields of the same crop. The lower the average distance the more clustered the agricultural holdings of the particular crop.

The application of the average nearest neighbour method has produced for each crop the observed mean distance values, which were classified into the five categories shown in Table 5, which in turn have produced the criterion layer of crop aggregation intensity depicted in Figure 15.

Table 5: Spatial aggregation intensity classes per type of crop

Aggregation intensity class	Type of crop	Mean observed distance (m)
I	herbs, legumes, nut trees	319-520
II	sugar beets, vegetables, vines	231-235
III	fodder, energy crops, tobacco	121-125

IV	corn, cotton, cereals, olive trees	87-97
V	Rice, fruit trees	61-74

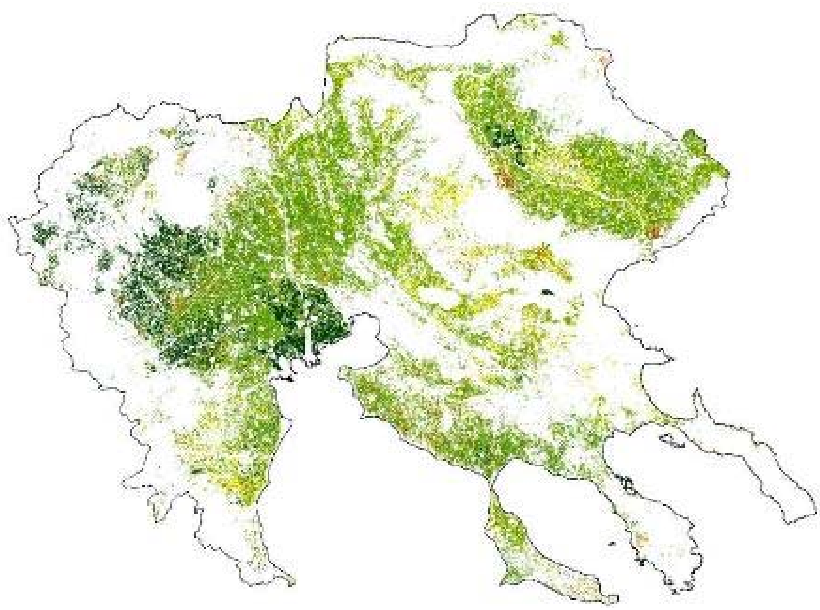

Figure 15: Crop aggregation intensity (density of agricultural holdings (from red to green)

3.1.2. Economic criteria

The economic criteria concern the parameters and spatial attributes that affect the magnitude of the economic results, i.e. the economic benefit that derives from the conversion of existing conventional practices to precision farming ones and the technical and economic factors that influence the degree of achievement. Taking in mind the economic strategic framework, the factors affecting the economic performance of reduced impact agriculture practices and the present state of the primary sector and regional infrastructure, the economic criteria are divided into the following 2nd tier categories: (i) reduction of inputs, (ii) crop value and (iii) available infrastructure.

Reduction of inputs

The economic criteria that concern the reduction of inputs attempt to measure the economic benefit that would be induced from the conversion of conventional agricultural practices to reduced impact ones on a field level. The inputs that are being examined are those of water (irrigation), nutrients (fertilization), and fuel and time (transport), which represent significant economic factors affecting production costs.

The first criterion, **irrigation**, concerns the savings from the reduction of irrigational water requirements and corresponding costs. The crops that are characterized by high irrigational needs also present a higher potential for significant savings, although this relationship is not absolutely linear. Nevertheless, it is safe to assume that the transition of water demanding crops from conventional to precision farming ones will produce a higher economic benefit in terms of water consumption than low demanding ones. The criterion layer of irrigation follows exactly the same principles as the corresponding environmental one (Figure 13).

As far as **fertilization** is concerned, it represents a significant cost in absolute figures and an important share of the inputs' total costs. Again, as previously, the criterion layer assumes that crops with high demands in fertilizers are expected to infer higher economic benefits from the application of reduced practices as there is more room for savings to be achieved than in crops with low fertilization requirements and low corresponding costs.

The criterion follows the same principles as before; crops are divided into classes representing fertilization requirements (Table 4) and produce a layer of varying fertilization intensity across the regional space (Figure 14). Agricultural holdings receive scores proportionally to their fertilization demands.

The final criterion, that of **fuel and time**, as already discussed in the relevant subsection, is associated with the spatial density of each crop's distribution and is based on the average distance among fields of the same crop type. The specific criterion is of major economic importance as it assesses the aggregate potential of existing crops and expresses in this way the concept of large scale agriculture. Agricultural areas of high density are in position to form large aggregations that can be treated as single entities that could overcome the domestic structural problem of small holdings' size and support economies of scale with substantial critical mass.

Moreover the profit/cost ratio that affects the precision farming practices is highly dependent on the spatial distribution of the crops and is technically favourable towards large areas in close proximity to one another. Furthermore, high field aggregation means reduced transport costs and also, very important, reduced personnel costs through savings in both time and labour.

The individual spatial densities of the various crops have already been calculated in the relevant environmental subsection (impact on resources) by using the average nearest neighbour method. The different classes of crop types have been categorized according to their mean observed distance values and are shown in Table 5 while the layer that is produced on the basis of these classes is shown in Figure 15. Same as before, the analysis grants values of higher magnitude to agricultural holdings of higher aggregation intensity class.

Crop value

The second group of economic criteria concern those that determine crop value by taking in consideration economic indicators on a crop type level. Two criteria concerning crop value are included: contribution to local and regional economy, and profitability.

The first sub-criterion of this category is associated with the contribution of the crop type to the **local and regional economy**.

Since the application of precision farming practices foresees, above all, the production of competitive products with an extrovert potential, the parameter that has been selected for the assessment of the crop type contribution to the regional economy is that of the export performance of each crop type.

Within this context, and on the basis of the available data provided from the Greek International Business Association (SEVE) for the year 2010, the selected crop types are categorized into classes of export intensity (Table 6) according to which the relevant criterion layer is structured (Figure 16).

Table 6: Contribution of crop type on regional exports

Contribution to regional exports (class)	Type of crop
I	fodder, legumes, energy crops
II	herbs, nuts
III	Olives, vines, cereals, rice, corn, sugar beets
IV	Vegetables, , tobacco, cotton
V	Fruit trees

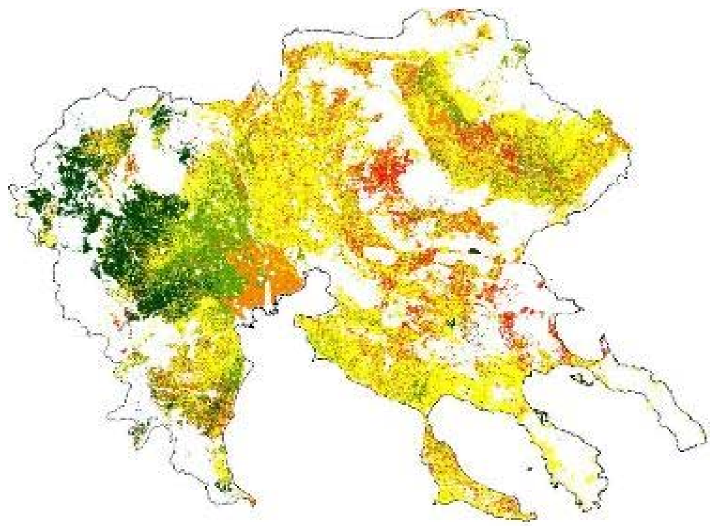

Figure 16: Crop type export intensity (red to green)

The second sub-criterion is the profitability measured by the **Internal rate of return** (IRR) indicator. IRR is a measure of the yield or efficiency of an investment. It is also known as the discounted cash flow rate of return (DCFROR) and is the yearly compounded return rate at which an investment delivers results. In other words, the IRR is the discount rate (DR), which makes the net present value (NPV) of the income stream from an investment equal to zero.

For the purposes of this study the IRR's of all sixteen crops have been estimated for both conventional and precision farming practices. In all cases the application of precision farming came out profitable (compared to the conventional one). According to the magnitude of this profit (or difference between conventional and precision farming) the crops have been categorized in five classes, as presented in Table 7. On the basis of this classification the layer shown in Figure 17 was produced expressing the spatial distribution of profitability intensity.

Table 7: Profitability classes and crop types

Profitability – IRR	Type of crop

(class)	
I	Olives, sugar beets
II	Herbs, nuts, legumes, cereals, vegetables
III	Cotton, vines
IV	Rice, energy crops
V	Fruit trees, corn, fodder, tobacco

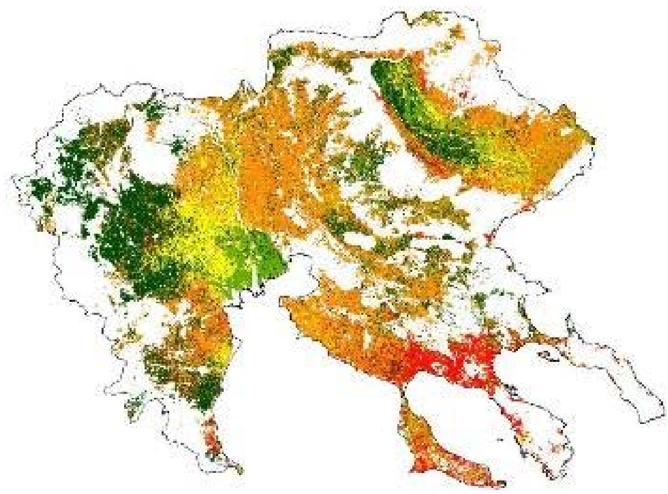

Figure 17: Profitability intensity (red to green)

Available infrastructure

The last set of economic criteria concern the local availability of infrastructure that can be associated, in some quantitative or qualitative way, with the service and promotion of the ongoing agricultural activity. The higher the existing availability of infrastructure the more likely an attempt for precision farming adoption is to be successful.

The economic criteria that fall into this category are the proximity to major urban centres, the accessibility to main road connections, and the existence of primary processing industries.

The first criterion, that of proximity to **urban centres,** is associated with the degree of isolation of the agricultural area under study from major hubs, especially in terms of innovation and new technology know-how availability.

Precision farming is a demanding field, in terms of required knowledge, incorporating the use of state of the art technologies and practices (GPS, GIS, remote sensing, UAV, VRT and others). Moreover, it involves the managing of the farm through a completely different approach that requires a shift in the established perception of the traditional way of farming towards a much more versatile, data intensive approach based on in-farm variability and whole farm plan development.

It is therefore considered certain that its application, as well as the associated training of the producers, will require some kind of support from specialists or, most probable, be provided as a complete service by specialists. As the presence of such specialists (universities, research institutes and private companies) is higher in major urban centres, it follows that agricultural areas in high proximity can benefit the most.

On the basis of the above the specific criterion layer makes use of the average distance of each point in the map, or agricultural holding, from the major urban centres of the region and calculates a value that increases with urban proximity.

All the capitals of the Regional Units have been included in the analysis along with the cities of Giannitsa, Naoussa and N. Moudania. Different weights have been applied to the various urban centres according to their population (Table 8) in order to produce the layer final criterion layer shown in Figure 18. As it can been seen, the city of Thessaloniki, due to its size, dominates the landscape in terms of urban influence, as expected, as it is the main pole of innovation and R&D in the regional territory.

Table 8: Major urban centers, populations (2011) and respective spatial weights

City	Population (2011)	Weight
Thessaloniki	892656	45
Serres	58287	10
Katerini	55997	10
Beroia	43158	10
Giannitsa	29789	5
Kilkis	22914	5
Naoussa	18882	5
Edessa	18229	5
N.Moudania	6475	3
Polygyros	5040	2

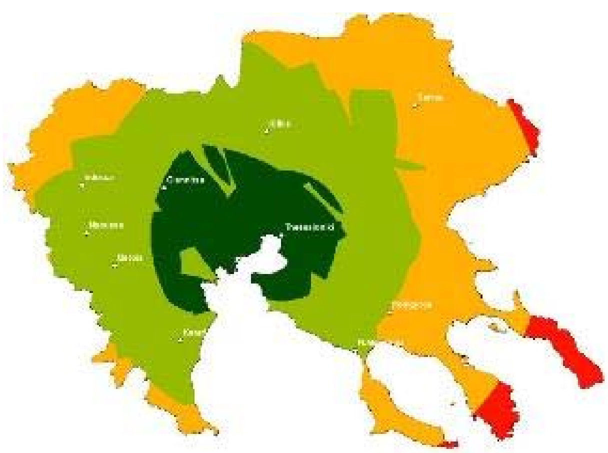

Figure 18: Urban centre influence (value from red to green)

The second economic criterion that concerns infrastructure availability is based on the existing **road network** and is associated with the proximity of the agricultural areas to major roads. The specific criterion layer expresses the degree of accessibility to and from the agricultural holdings. High connectivity and accessibility is important for everyday field working, transport and commuting, and connection with research and business centres. It is therefore natural that agricultural areas close to major roads to present an advantage, in that sense, over more remote ones.

Within this context the specific criterion layer assess the distance of each agricultural holding from major roads and grants value on an inversely proportional manner. The spatial variability map that is produced in that way is shown in Figure 19.

Figure 19: Road network influence (from red to green)

The last economic criterion of the infrastructure category concerns the spatial distribution of primary processing industries within the regional territory. The specific criterion is significant because it expresses the local potential for processing of agricultural goods which constitutes a crucial element of the viability equation. Linkages between the primary and the secondary sector are sought after as they entail upgrading of the agricultural goods to products with added value and synergies among sectors for vertical chain structuring should always be encouraged.

Within this context the analysis integrates information concerning the distribution of primary processing units across the region to produce a layer of varying intensity according to their number and density. The relevant data have been collected by Greek

Statistics Agency and refer to the primary processing units included within the relevant business registry for the year 2010. The data are available on a municipal level. The criterion layer that has been produced is shown in Figure 20, and makes use of the above data to grant scores to the agricultural areas proportionally to the magnitude of processing unit's intensity.

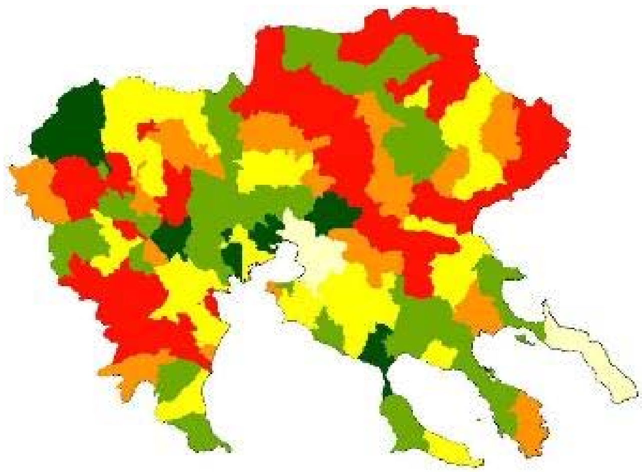

Figure 20: Primary processing industries density (from red to green)

3.1.3. Social criteria

The social criteria concern the parameters and spatial attributes that affect the magnitude of the social results, i.e. the social factors that influence the degree of attainment of the precision farming practices application in the targeted rural areas and the social benefit that will be induced from such a conversion.

Thus, taking into consideration the strategic framework concerning 'inclusive' growth, the contribution of the primary sector on the local economy, and the present socio-economic state of the region, the social criteria are divided into the following 2nd tier categories: (i) impact on unemployment, (ii) impact on per capita GDP, (iii) impact on local economy and (iv) adoption potential.

It should be mentioned that the analysis of the social criteria that affect the application of precision farming practices is not straightforward as there is not a direct pathway linking the two concepts. Their connection is rather built on the notion that a potential transformation of the current state of the targeted agricultural area will boost local development in multiple ways that will also include a positive impact on socio-economic indicators such as local unemployment and per capita GDP.

The existence of a successful example of large scale precision farming can induce further aggregation of economic activity as related companies, customers, suppliers etc. are attracted by the high inner-sectoral concentration within the specific agricultural area.

On another matter, the expected benefits on a social level may also include the induced changes on the mentality and entrepreneurial perception of the local society. The strengthening of social and other informal links, the incubation of innovation and the release of the local creative forces can lead to the birth of new ideas and the creation of new business activities.

Within this context the first three criteria make use of the assumption that the conversion of the existing conventional practices into precision farming ones on any given agricultural territory, along with the associated positive changes that will take place within the wider local business environment, will also have a positive effect on the individual criterion under examination.

Impact on unemployment

Following the logic described above regarding the effect of precision farming on the various social indicators, the impact on unemployment is assumed to be positive on a local scale through the increased expected business activity in both the primary sector and associated secondary and tertiary ones.

In order to assess the spatial differentiation of this effect, the analysis makes use of the unemployment percentage rates, on a municipal level and grants scores proportionally i.e. areas with higher unemployment rates receive higher scores expressing in this way a higher induced social benefit.

The criterion layer derived this way represents spatial variability of unemployment intensity and is shown in Figure 21.

Figure 21: Unemployment influence (red to green)

Impact on per capita GDP

The Gross Domestic Product (GDP) per capita constitutes a crucial common factor, used to measure the growth and prosperity level in a region or regional unit, while its comparison with the average GDP per capita of the European Union is the very basic parameter in assessing the economic and social convergence.

Again, as in the case of the unemployment criterion, the effect of precision farming on per capita GDP is assumed to be positive on a local scale through the relevant expected boost in the development of the targeted rural area.

In order to assess the spatial differentiation of the induced benefit, the analysis makes use of the relevant data provided by Eurostat for the year 2014, on a Regional Unit level, and grants scores on an inversely proportional manner i.e. areas with lower GDP per capita figures receive higher scores expressing in this way a higher induced social benefit. The criterion layer derived this way represents spatial variability of GDP per capita intensity and is shown in Figure 22.

Figure 22: GDP per capita influence (red to green)

Impact on local economy

In order to assess the impact on local economy the Gross Value Added (GVA) indicator of the primary sector is used, namely the share of the primary sector on the total GVA of each Regional Unit. The more a local economy is dependent on the primary sector the bigger the induced benefit. Similarly, as in the previous cases, the effect of precision farming on the local economy, and in this particular case on the primary GVA, is assumed to be positive.

Within this context, and on the basis of the data provided by Eurostat for the year 2014, the specific criterion layer which is produced grants higher scores to areas with larger GVA percentages, and is depicted in Figure 23.

Figure 23: Primary sector GVA influence (red to green)

Adoption potential

The final social criterion is different in character than the three previous ones in that it does not represent a type of induced benefit but a prerequisite for the successful application of precision farming practices. This specific criterion concerns the potential for adoption of precision farming practices on a producer level.

In order to assess the adoption potential on an intra-regional level, the data from an extensive local survey on a sample of 492 young farmers across the whole regional territory were used (Koudios, 2014). The data were collected by means of a structured questionnaire which focused on innovation adoption in agriculture and especially on adoption of precision farming and information and communication technologies. The study is the only available extensive region-specific source of available data concerning the intention of farmers for adoption of precision farming technologies and practices.

On the basis of the findings of the study, the farmers of each Regional Unit can be characterized by their apparent interest and motivation for new technologies and innovation adoption and hence for their suitability to adopt and support the application of precision farming.

According to the evidence from the specific study, the RUs are categorized in classes which are used by the criterion layer of adoption potential to grant scores to each one of the RU areas as depicted in Figure 24.

Figure 24: Adoption potential intensity (red to green)

After having set and examined the goal, objectives, criteria and sub-criteria in detail, the hierarchy tree of the analysis can be structured as shown in Figure 25.

Alexandridis, T.K., Andrianopoulos, A., Galanis, G., Kalopesa, E., Dimitrakos, A., Katsogiannos, F., & Zalidis, G. (2017). An integrated approach to promote precision farming as a measure towards reduced-input agriculture in northern Greece using a spatial decision support system. In B. Huang (Ed.), Comprehensive Geographic Information Systems (pp. 315–352). Oxford: Elsevier

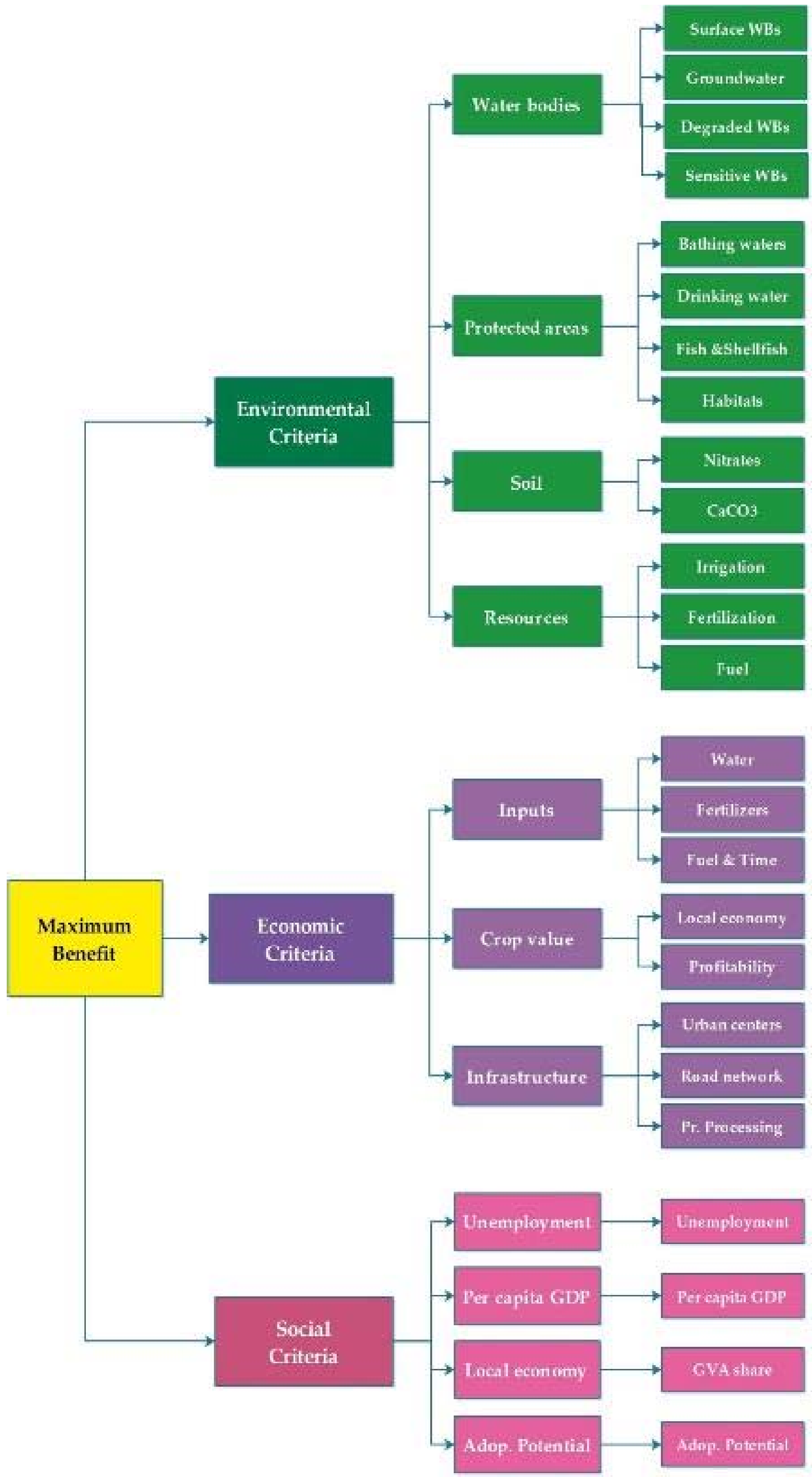

Figure 25: Hierarchy tree of multi criteria analysis

3.2. Spatial layers

The next step of the multicriteria analysis is the production of the layers that represent the spatial relationships described above for every criterion.

The layers were prepared in a GIS environment (ArcGIS 10.2) by using both the methods and tools that are integrated into the system and others that were imported from external sources such as:

- The Weighted Raster Overlay Service Tools, provided by ESRI
- The CRWR MODIS Toolbox, provided by the Center for Research in Water Resources at the University of Texas – Austin
- The Patch Analyst extension developed under the Spatial Ecology Program (Centre for Northern Forest Ecosystem Research)

The complete list of criteria, spatial layers and respective spatial relationships are summarized in Table 9, while in the complete hierarchy tree of the analysis is shown after the incorporation of the spatial layers' level.

All produced layers are rasters. This simplifies their combination (overlay) to produce composite rasters representing new, more complex spatial layers.

Table 9: Criteria, spatial layers and spatial relationships of multi-criteria analysis

Criteria	Sub-criteria	Spatial layer	Spatial relationship	Weight
Environmental criteria				**46**
Water bodies				13.8
	Surface water bodies	Distance from water bodies	Shorter distance → greater benefit	2.9
	- Rivers			0.7
	- Lakes			0.87
	- Transitional waters			0.87
	- Coastal waters			0.46
	Groundwater	Permeability of	Greater permeability →	2.9

		underlying geological formations	greater benefit	
	Degraded water bodies - Rivers - Lakes - Transitional waters	Distance from degraded water bodies	Shorter distance → greater benefit	4.42 0.71 0.93 0.93
	Degraded water bodies - Groundwater quality - Groundwater quantity	Presence of degraded groundwater body	Presence → greater benefit	4.42 0.93 0.93
	Sensitive water bodies - Lakes - Rivers - Coastal	Distance from sensitive water bodies	Shorter distance → greater benefit	3.59 1.61 1.22 0.75
Protected areas	Bathing waters	Distance from bathing waters	Shorter distance → greater benefit	9.2 1.48
	Drinking water areas - Rivers - Lakes	Distance from drinking water areas	Shorter distance → greater benefit	3.77 0.91 1.43
	Drinking water areas - Groundwater	Presence of groundwater body	Presence → greater benefit	3.77 1.43
	Fish & shellfish areas - Rivers - Lakes - Coastal waters	Distance from water bodies	Shorter distance → greater benefit	1.56 0.19 0.28 0.42
	Habitats - Natura 2000 sites - National parks - Wildlife reserves	Distance from water bodies	Shorter distance → greater benefit	3.13 1.63 1.13 0.38
Soil				9.2

	Nitrates	Distance from Nitrate Vulnerable Zones	Shorter distance → greater benefit	1.84
	$CaCO_3$	Concentration of $CaCO_3$	Lower concentration → greater benefit	7.36
Resources				13.8
	Water	Irrigation requirements of crop type	Higher requirements → greater benefit	6.49
	Fertilizers	Fertilization requirements of crop type	Higher requirements → greater benefit	5.66
	Fuel	Aggregation intensity of crop type	Higher aggregation → greater benefit	1.66
Economic criteria				**40**
Inputs				16.8
	Irrigation	Irrigation requirements of crop type	Higher requirements → greater benefit	6.72
	Fertilization	Fertilization requirements of crop type	Higher requirements → greater benefit	5.88
	Fuel & time	Aggregation intensity of crop type	Higher aggregation → greater benefit	4.2
Crop value				14
	Local economy	Regional exports share of crop type	Higher share → greater benefit	9.1
	Profitability	IRR value of crop type	Higher value → greater benefit	4.9
Infrastructure				9.2
	Urban centres	Distance to major urban centres	Shorter distance → greater benefit	2.94

	Road network	Distance to major road network	Shorter distance → greater benefit	2.3
	Primary processing industries	Distance to primary processing units	Shorter distance → greater benefit	3.96
Social criteria				**14**
Unemployment	Unemployment	Unemployment rates per municipality	Higher rates → greater benefit	8.4
Per capita GDP	Per capita GDP	Per capita GDP per RU	Lower GDP → greater benefit	8.4
Local economy	Local economy	Share of primary sector on total GVA of RU	Higher share → greater benefit	14.28
Adoption potential	Adoption Potential	Adoption potential of precision farming practices and new technologies	Higher potential → greater benefit	10.92
Total				**100**

3.3. Assignment of weights with AHP

The next step of the multicriteria analysis is the calculation of weights for the various criteria and sub-criteria.

The different criteria were characterised by different importance levels which were included into the evaluation, by assigning a weight to each criterion. The process involved the pair-wise comparison of the criteria, i.e., for each criterion all the alternative pairs were compared using a common judgment scale from 1 to 9.

The free web based AHP software by Klaus D. Goepel (http://bpmsg.com/) was used for the calculation of all the criteria weights.

Setting the weights

Beginning from the first level of the hierarchy tree the relative priorities of the three main criteria groups, namely the environmental, economic and social, were set. The assignment of the individual weights, although based on the priorities deriving from the corresponding targets set by the strategic framework, is a rather subjective issue. According to the framework set by the Europe 2020 Strategy, emphasis should be given to all three pillars mentioned above, i.e. economy, environment and society through the simultaneous attainment of smart, sustainable and inclusive growth, and the respective national and regional strategic frameworks also seem to converge to the same point. However, no absolute data exist and no objective scale can be used for such a purpose and therefore is up to the decision makers to assign the weights that are most suitable for the occasion. For the purposes of the current analysis, the priorities are assigned on a descending order from environmental criteria to economic criteria to social criteria, on the basis of the following arguments:

- The environmental benefits from the application of precision farming practices are the least debatable according to literature. Even in those cases where the economic benefit is under question, the environmental effect is always positive in comparison to conventional methods.
- The expectation of economic benefits seem to constitute the primary type of incentives on a producer and business level, while on a developmental policy level, both economic and environmental targets seem to be equally important. On an institutional and legal policy level, the environmental requirements are the ones comprising the limiting factor.
- The social benefits, both within the strategic framework and within the analysis logic, are in fact derivatives of the economic, and to a lesser degree, of the environmental ones i.e. the economic and environmental dimensions of development are usually prerequisites of the social one.

In line with the above, the use of Saaty's linear pair wise comparison method produces the matrix shown in the following figure.

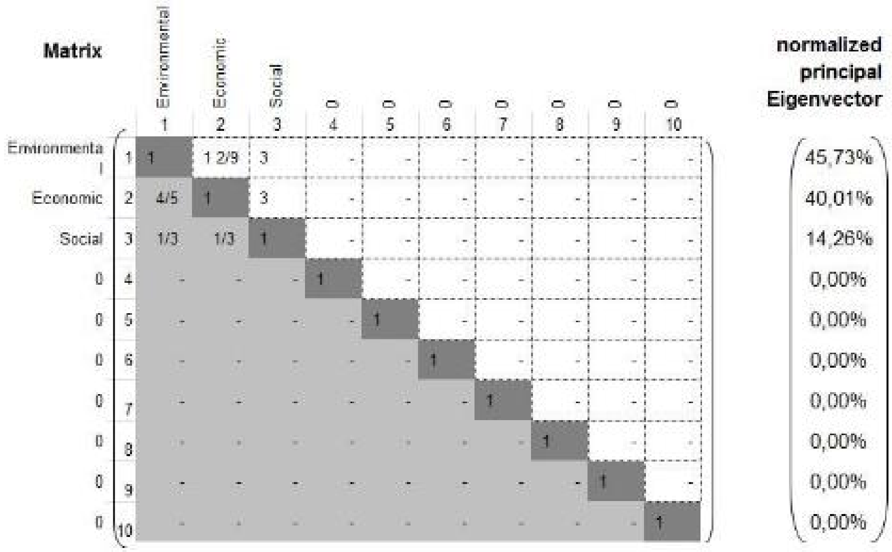

Figure 26: Comparison matrix of main criteria

In accordance with section 2.3.2, the matrix above indicates that for the criteria under examination, the environmental are considered very strongly more important than the social and slightly more important than the economic ones, and the economic are considered strongly more important than the social ones. The relative weights are distributed as follows:

- Environmental criteria = 46%
- Economic criteria = 40%
- Social criteria = 14%

The pair wise comparison process described above for the main criteria was repeated for all the rest criteria and sub-criteria of the hierarchy tree shown in Figure 25. In this way, fifteen more comparison matrices were produced (not shown).

As a summary of this process, Table 9 shows the distribution of the assigned weights (coefficients) to each criterion and sub-criterion of the analysis.

4. Results

4.1. Locations with high potential for precision farming

By implementing the weighted overlay method in the current analysis, using the spatial criteria layers listed in Figure 25, the following composite output layers were produced. In all layers the same colour map was used, from red to green, representing ascending intensity of expected impact.

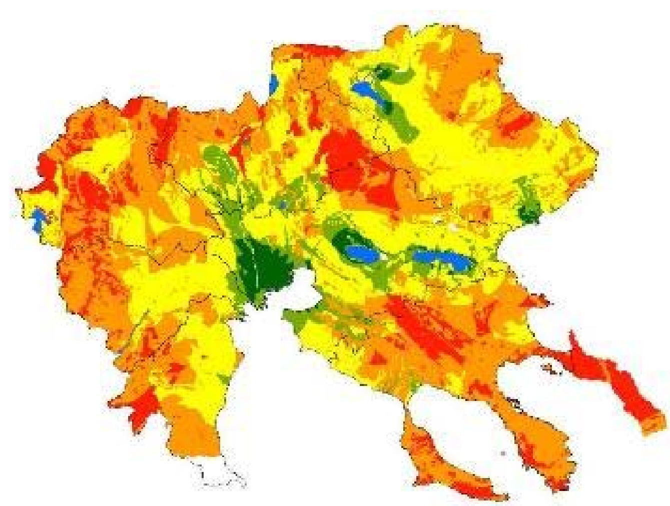

Figure 27: Layer of impact on water bodies (ascending intensity: red to green)

From the figure above it becomes apparent that the impact on water bodies is dominated by the presence of the most important ones, as expected, mainly the flood plain of rivers Axios-Loudias-Aliakmonas, the agricultural land around lakes Volvi, Koronia and Kerkini. Secondary water bodies with significant influence are the Aggelochori and Epanomi lagoons and the estuary of Strymonas river.

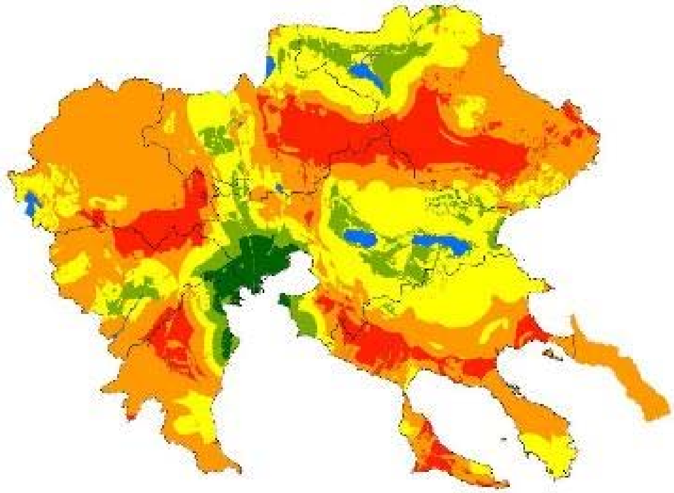

Figure 28: Layer of impact on protected areas (ascending intensity: red to green)

Due to the fact that the most important areas under protection happen to be water bodies, a similar to the previous pattern appears in the case of the protected areas (Figure 28). Apart from the water bodies mentioned above, lake Polyfytou also presents strong impact within this layer because of its role as a drinking source.

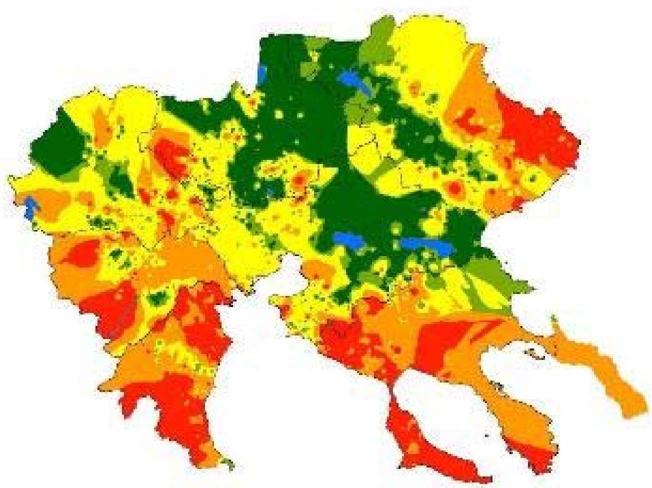

Figure 29: Layer of impact on soils (ascending intensity: red to green)

When concerning soils, the layer (Figure 29) is apparently dominated by the layer of $CaCO_3$ concentration that has been assigned a very high relative weight of 80% compared to the nitrates layer, which has very limited spatial variability.

The next layer, that of impact on resources (Figure 30), reflects the cumulative influence of irrigation, fertilization and field aggregation of the different crop types on resources saving. The layer has been based primarily on irrigation and fertilization as the environmental impact of fuel consumption, apart from being very difficult to quantify, is considered of secondary importance. The water consuming crops score higher in this layer, especially those with high fertilization needs. As a result rice, trees, cotton and corn dominate the landscape. Other demanding crops like vegetables, although they score high, do not have substantial size and density to become notable.

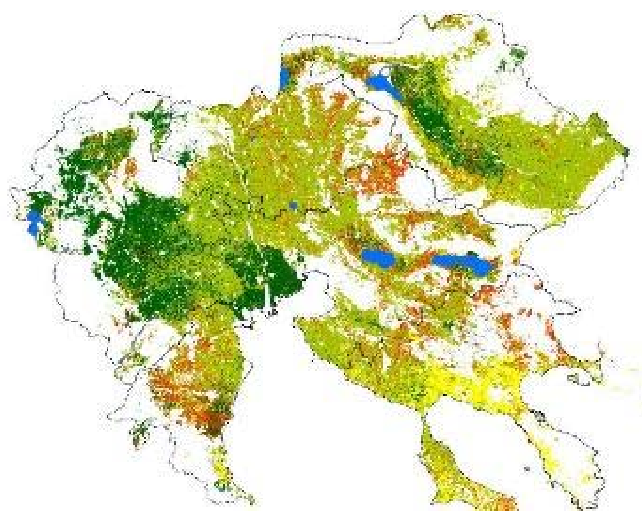

Figure 30: Layer of impact on resources (ascending intensity: red to green)

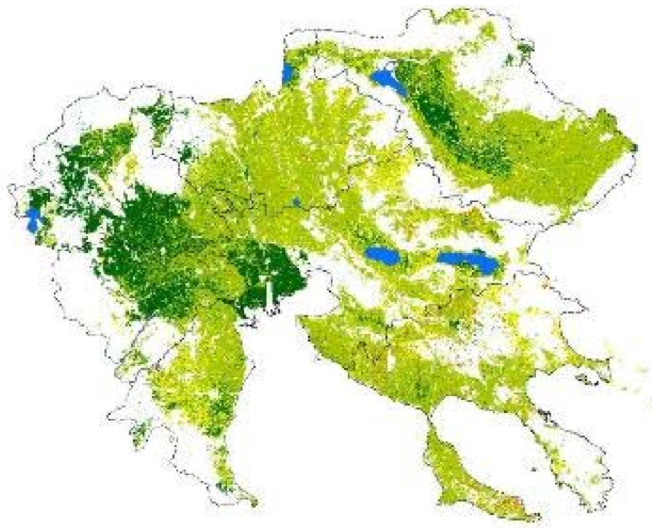

Figure 31: Layer of input intensity (ascending intensity: red to green)

Similarly, the layer of inputs (Figure 31) takes under consideration the same crop attributes to produce a slightly different influence distribution map where fertilization is assigned a slightly higher weight than irrigation (representing a higher cost) and where the relative importance of fuel and time has increased, as their economic dimension is a lot more significant than the environmental one.

The next layer (Figure 32) is that of crop value which has been composed by the synthesis of the profitability sub-criterion, expressed by the internal return rate indicator, and the exports sub-criterion expressing the share of the different crop types in regional exports. The later layer has been granted much higher importance (65%) because the export character of the precision farming products is one of the non-negotiable requirements for their success and because the specific layer is based on indisputable data (internal return rate is an estimation and as such it may deviate from real circumstances).

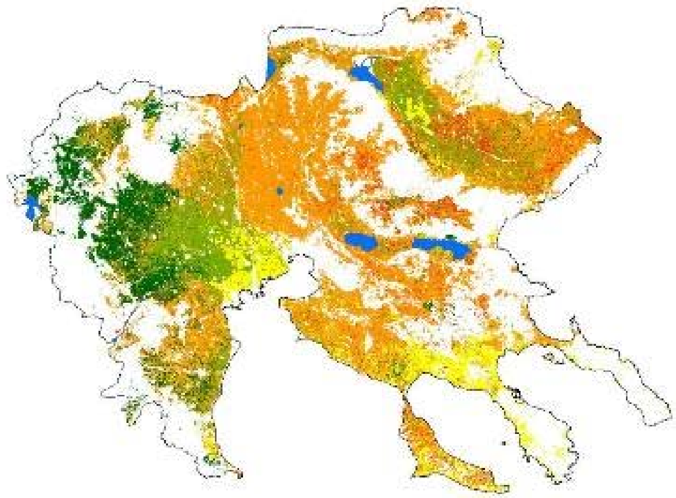

Figure 32: Layer of crop value intensity (ascending intensity: red to green)

The layer of infrastructure influence (Figure 33) is primarily affected by the presence of processing units, their contribution is considered essential, followed by that of urban centres, reflecting connectivity of the agricultural areas with business and research centres, and finally roads where the spatial variability is not that significant and where only the most isolated areas receive a high scoring penalty.

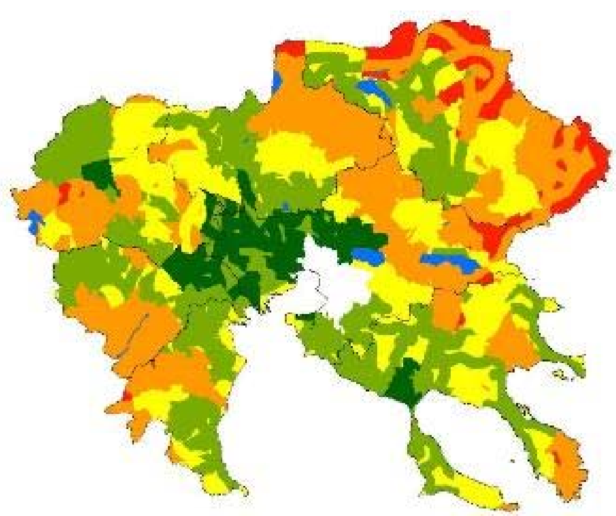

Figure 33: Layer of infrastructure influence (ascending intensity: red to green)

The next three layers represent the **composite effects of the criteria** and sub-criteria on an environmental, economic and social level respectively.

The first composite layer, that of overall environmental benefit, is shown in Figure 34, and is a composite map of all the environmental criteria, namely those of water bodies, protected areas, soil and resources. Areas that scored high in all of these levels show a high respective total environmental benefit. The highest induced benefits was found in areas where resource demanding crops were cultivated in proximity with water bodies and Natura sites, especially if there was a recorded environmental degradation due to agricultural activities. As a result, the areas of the Axios Delta (rice) and plains (corn and cereals), lakes Volvi and Koroneia (corn and cereals), lake Kerkini (rice and corn) along with the area of lake Doirani (corn), showed the highest intensity as far as environmental impact was concerned.

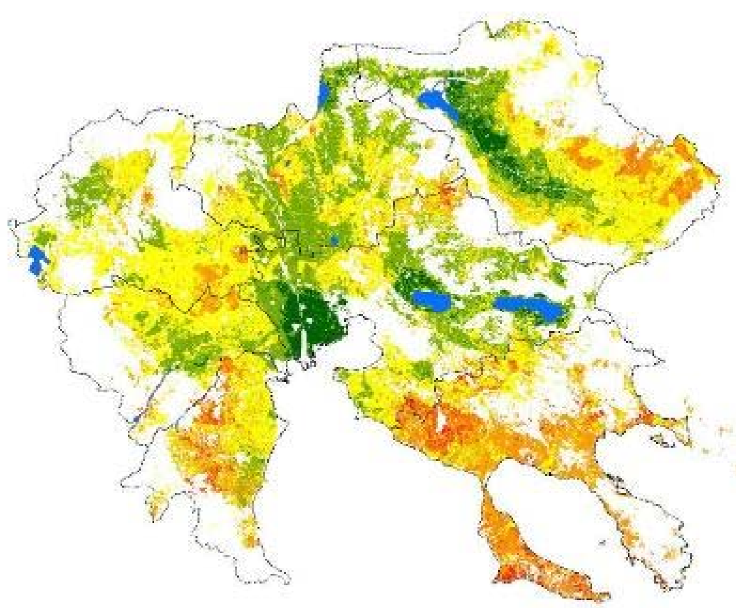

Figure 34: Layer of total environmental benefit intensity (ascending intensity: red to green)

The second composite layer, shown in Figure 35, represents the total economic benefit and is a synthesis of the input, crop value and infrastructure economic sub-criteria.

The areas that scored high were located primarily in the big plains of the Region i.e. the plain of the big central rivers Axios, Loudias and Aliakmonas and the plain of Strymon in Serres. Small pockets of high economic intensity were also found in the area near Lake Koronia, in the plain, coastal areas of Pieria and in Chalkidiki near the urban centre of N. Moudania probably because of the high concentration of primary processing units. Concerning types of crops, the ones that presented the higher overall economic intensity were fruit trees, cotton, rice and corn.

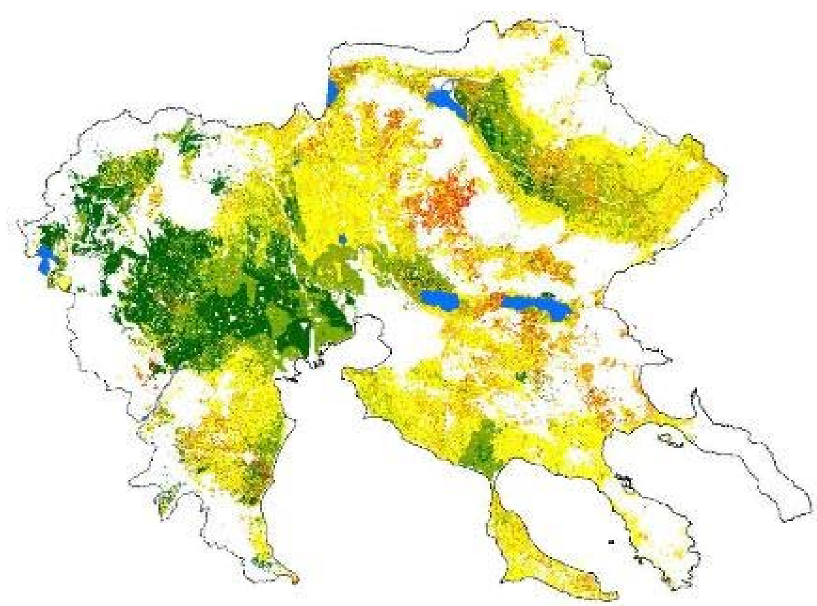

Figure 35: Layer of total economic benefit intensity (ascending intensity: red to green)

The third composite layer represents the total social expected benefit and is the result of the synthesis of the sub-criteria layers of unemployment, per capita GDP, GVA share and adoption potential. As it can be seen in Figure 36, the spatial variation is limited, as in three out of four sub-criteria the spatial unit of analysis was that of the Regional Unit, leaving little room for a detailed spatial investigation.

In any case, on the basis of the selected sub-criteria, the induced social benefit was highest in the RUs of Pella, Imathia and partly of Serres, mainly because the rest of the RUs were less dependent on the primary sector (especially Thessaloniki and

Chalkidiki) and because the rural character of the RUs were assigned the highest weight among the different social sub-criteria.

Figure 36: Layer of total social benefit intensity (ascending intensity: red to green)

The final layer-map of the MCDA analysis is that of the **total overall benefit** and is map reflecting the analysis overall goal, i.e. the identification of the agricultural areas within the Region of Central Macedonia with the maximum potential for precision farming implementation (Figure 37).

The map is a result of the overlay of the environmental, economic and social layers and is the layer on the basis of which the five locations were selected for further examination, and specification of potential for intra-regional precision farming implementation. The questionnaires were focused on the farmers of these areas.

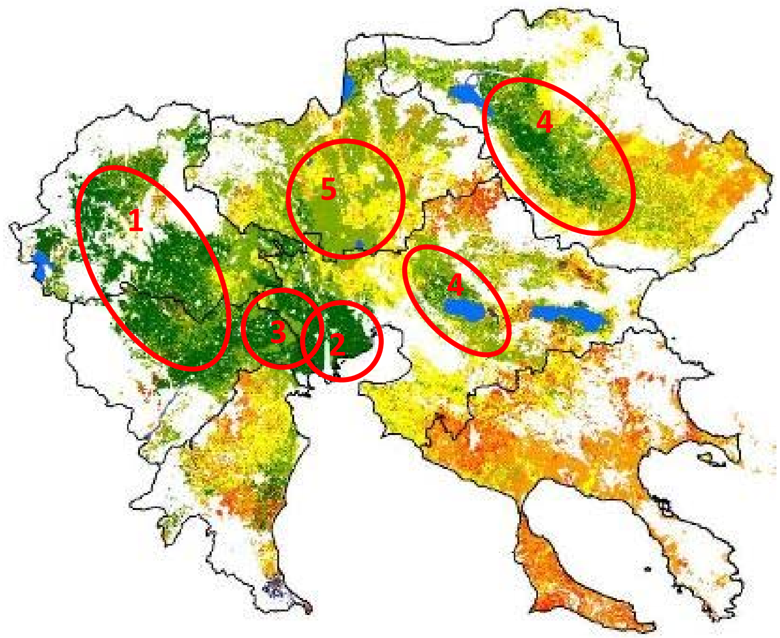

Figure 37: Layer of overall benefit intensity (ascending intensity: red to green)

According to the figure above, representing the distribution of overall benefit intensity, the five areas, and respective crops, that show the highest potential for precision farming implementation are:

1. The fruit tree crops in Imathia and Pella
2. The rice crops in the Axios Delta area
3. The cotton crops in the plains of Axios, Loudias and Aliakmonas
4. The corn crops in the Strymon plain (and Mygdonia sub-basin)
5. The cereal crops (mainly hard wheat) in the plain between Gallikos and Axios (Kilkis)

4.2. Results from analysis of questionnaires

From a total of 202 farmers that attended the sessions, 102 questionnaires were completed while 62 farmers declared interest and signed the relative documents for participation in the precision farming cluster. The following results are derived from the analysis of the participants' responses:

- More than half of the farmers (59%) said they already knew the terms "cluster" and "precision farming" and what they refer to.

- Almost all farmers (94%) felt that these sessions have helped to understand the concepts "cluster" and "precision farming" and thus, at least with regard to informative character, the sessions accomplished their purpose.

- The majority of farmers (68%) said they would use precision farming on their crops and about the same percentage (66%) said they would be prepared to change their crop in order to apply precision farming. In addition, the majority of farmers (73%) expressed their interest in participating in educational programs to be further informed about precision farming. Overall, the above percentages are considered to be promising regarding the acceptance of the practice of precision farming by farmers and to further promote its adoption by the farmers of the region.

- Almost all farmers (91%) indicated their willingness to purchase precision farming services within a relevant cluster. The majority of farmers (60%) said that their decision to buy such services would depend on the price, however a notable proportion (31%) responded positively regardless of the price.

- The majority of farmers (66%) said they would like to participate in a precision farming cluster, while most of them (61%) have signed the documents for expression of interest (Memorandum of Agreement).

Some additional findings derived from the questionnaires' comments and discussions with the farmers during the sessions were:

- There was a general willingness from the farmers to adopt new farming methods and a desire to cooperate with research centers, expecting both the transfer of knowledge as well as technical support and guidance in their choice of crop and end products.

- The farmers expressed their considerations concerning (i) the fragmentation of land as an obstacle to the creation of large-scale economies, (ii) the lack of cooperation between farmers and (iii) the absence of specific studies per sub-region for the formulation of targets and the quantification of requirements for the establishment of cluster-type formations.

- A view was expressed that the creation of a cluster may be a response to the current problems of the rural community.

5. Discussion

5.1. Advantages and disadvantages of proposed methodology

Several specialists in MCDA have listed the strengths and weaknesses of the AHP. The cited strengths include the flexibility of AHP over other multi criteria methods, ease of use by the decision makers and its ability to check inconsistencies and make corrections (Ramanathan, 2001). Additionally, through the decomposition of the decision problem and the hierarchies of criteria, the importance of each element is clarified (Macharis et al., 2004). AHP also helps reduce bias in decision making by providing a mechanism for checking consistencies of the evaluation measures and alternative. AHP also facilitates group decision-making through consensus by allowing to estimate the geometric mean of the individual pair-wise comparisons (Zahir, 1999). Finally, AHP helps evaluate various simulation scenarios for which measures ordinarily do not exist (Millet and Wedley, 2002).

Despite the advantages of the AHP, certain issues have caused the concern of many researchers. The first issue concerns cases in which ranking irregularities can occur using the AHP, such as a potential rank reversal when similarly looking options are added to the alternatives under evaluation. This may be caused by the interpretation of the criteria weights (Belton, 1986). Nevertheless, it has been proven that a multiplicative variant of the AHP can be used to avoid rank reversal (Triantaphyllou, 2001). Thus, the AHP and some of its variants are considered by many as the most reliable MCDA method. Another issue is that the AHP-method can be considered as a complete aggregation method of the additive type. The problem associated with such method is that good scores on some criteria and bad scores on others can be neutralized through compensation, thus losing detailed and important information. Also, during the decomposition of the problem into subsystems, a large number of pair-wise comparisons need to be evaluated (n (n-1)/2), and thus become a lengthy task (Macharis et al., 2004). Another disadvantage of the AHP method is the restriction to use the rather detailed 9-point scale, with which it may be difficult for the decision-maker to distinguish the importance between alternatives. Finally, the variable scale of available input layers could pose a problem, as it makes the assumption of homogeneity of large aerial units.

The methodology relies on the availability and quality of detailed geographical data to represent the multitude information layers. This may not be the case in southeast European countries, where sometimes basic information layers are outdated or missing. In case of missing data approximations were used, such as the fertilization requirements of the crops instead of the actual use of agrichemicals. In other cases, when appropriate detail was unavailable, generic data were used, such as the use of tree crops area instead of detailed tree type.

5.2. Evaluation of proposed locations

Fruit Trees in the Regional Units of Pella, Imathia and Pieria

The first area with the highest overall score is the extensive fruit orchards of the Regional Units of Pella and Imathia.. This wider area is shown in Figure 38.

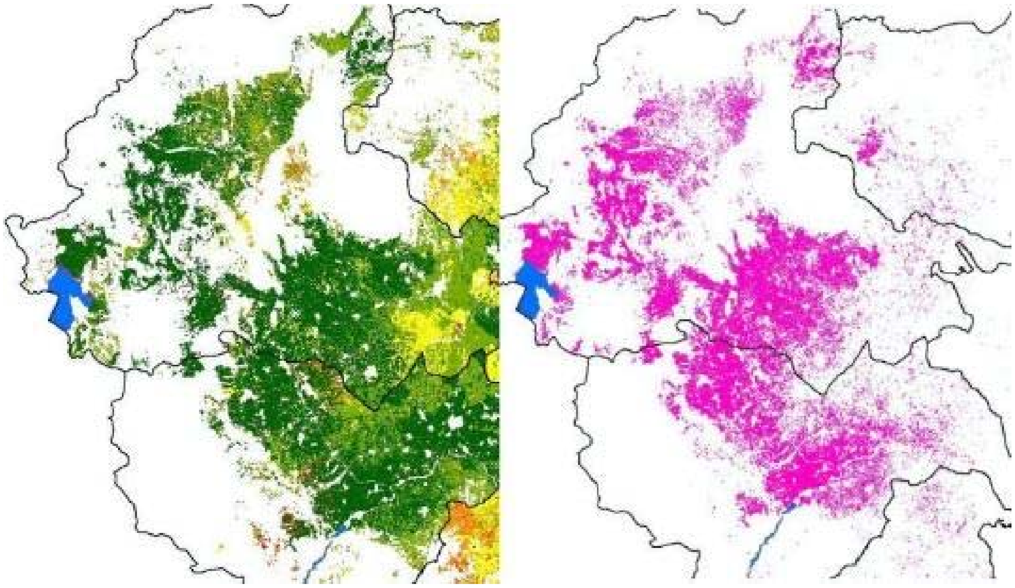

Figure 38: Area of fruit trees in Imathia and Pella (left: overall benefit map, right: fruit tree crops)

The fruits that are concerned are mainly peaches (Pella and Imathia) but also cherries (Pella), nectarines and apples (Pella and Imathia). Those areas have been collectively classified as fruit tree crops in the current study because spatial data with more detailed information on a sub-crop level (type of fruit) were not available. Nevertheless, the different fruit crops share common traits such as their perennial nature and their similar requirements in applied agricultural practices that allow for their similar treatment and their inclusion into a single class for the needs of the current analysis.

The basic characteristic of the fruit tree crops is their high **economic importance** on both a local and national level. Peaches, kiwis and cherries are the main exported fruits of RCM but also of the whole country as well. Their contribution to the local, regional and national economy is highly significant especially when considering the current economic recession and the low performance on a national level in terms of exported goods. Moreover, the size and total surface area of the specific crops, especially of the peaches, is substantial and already able to support a large scale economy approach. According to the 2014 data (OPEKEPE) approximately 120.000 holdings exist in the area under examination covering a total surface area of about 53000 ha (mean holding size of 0.4 ha).

Existing agricultural practices within this extensive, non-uniform area vary a lot from place to place and concern conventional methods and some localized organic ones. No precision farming applications exist within this territory, although, on a country level, there have been some attempts and pilot applications in tree crops that showed positive outcomes in productivity and yield (Gemtos et al., 2005).

Rice in the Axios Delta

The second of the two areas with the highest score is the wider area of the Axios Delta, and more specifically the area where the rice crops are located (Figure 39).

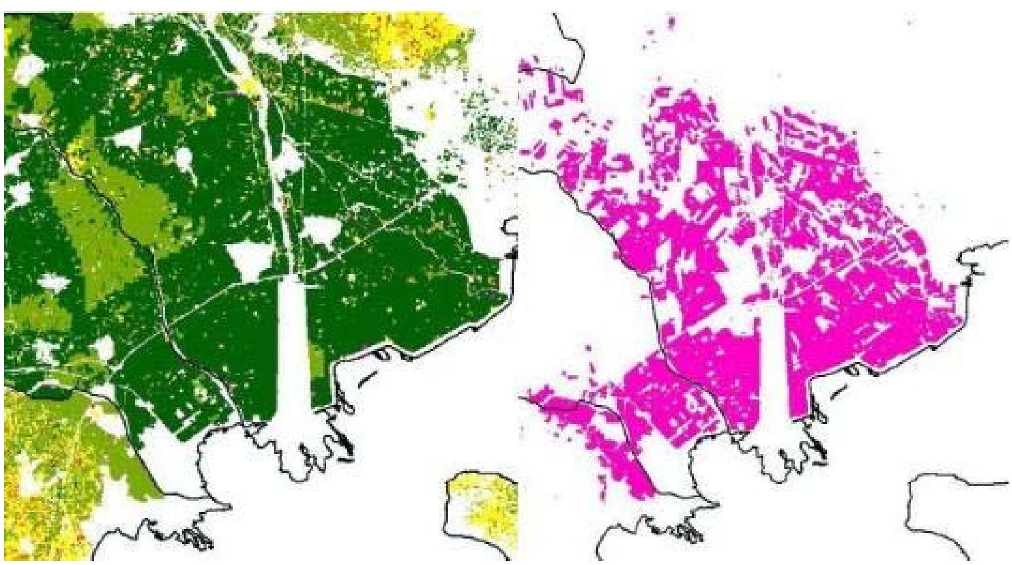

Figure 39: Area of rice crops in Axios Delta (left: overall benefit map, right: rice crops)

The crops are found within the protected area of the Axios, Loudias, Aliakmonas Delta, a protected area of international importance (Ramsar) and a national park, very rich in habitats and species diversity, especially of avifauna.

Rice farming begun in the area of Chalastra in 1949. Today around 60% of the national production takes place in the area of the Axios Delta and is very important for the local economy. Over the previous decade, many farmers have switched to rice instead of cotton or vegetables, because rice is very tolerant to weather conditions, rice seeds are relatively cheap, and harvest is much easier.

Today (2014 data – OPEKEPE) there are approximately 22.500 rice crop holdings forming a total farming area of about 23000 ha (mean holding size of 0.1 ha) of very high aggregation level (mean observed distance of 61,6 meters).

Irrigation takes place through an extensive, but rather out of date, network constructed during the 60s. The method of irrigation is that of flooding and occurs during the summer months with water extracted from the Axios River. The method is preferred by local farmers due to the familiarity with the specific method, the low cost of tools and infrastructure needed, and the low demand in time and labour. However, the disadvantages of this method are the losses of large quantities of water, the non-uniform distribution of water, and the long periods of water-logging conditions beyond the plants tolerating levels, which are favourable conditions for pest growth.

The farming community is the largest consumer of the Axios R. water and the demand for irrigational water is the highest during the dry period resulting in an intense competition for water among agricultural needs and the wetland ecosystem's ones. On the other hand, the rice paddies form a seasonal artificial network of small wetlands supporting wildlife, especially that of migrating birds, and playing their own role as ecosystems during the dry, summer season.

The sustenance of the existing agricultural activity is therefore important on an economic level but also compatible from an environmental aspect. However, the specific agricultural practices taking place could be significantly improved in terms of efficiency and economy. As already stated, the existing methods cause great losses of water and fertilizers and their environmental footprint is very high.

There seems to be a lot of room for improvement on that level and for the potential application of precision farming practices. In that respect there is quite an extensive international experience concerning application of precision farming in rice paddies, mainly in Australia and Asia (no applications exist for Greece).

The various studies and applications highlight the importance of spatial and temporal variability in terms of the timing and amount needed for specific crop growth for increasing farm productivity and profits. In rice production, for example, correct fertilizer application is the most important factor for determining the final yield of rice: it affects directly grain yield, and indirectly crop establishment, panicle and grain formation, and pest and weed occurrence. Use of a chlorophyll meter and leaf colour chart for field-specific N management (as tested by IRRI – International Rice Research institute – and national research centres) has helped farmers in nitrogen fertilizer application in a number of Asian developing countries (Thind and Gupta, 2010).

Cotton in the Loudias, Aliakmonas and Axios plains

The third area with the highest overall score is that of cotton fields in the plains of the three major rivers Axios, Loudias and Aliakmonas, an area that belongs mainly to the Regional Unit of Imathia but also, in smaller parts in descending order, to the RUs of Pella, Thessaloniki, Pieria and Kilkis as shown in the figure below.

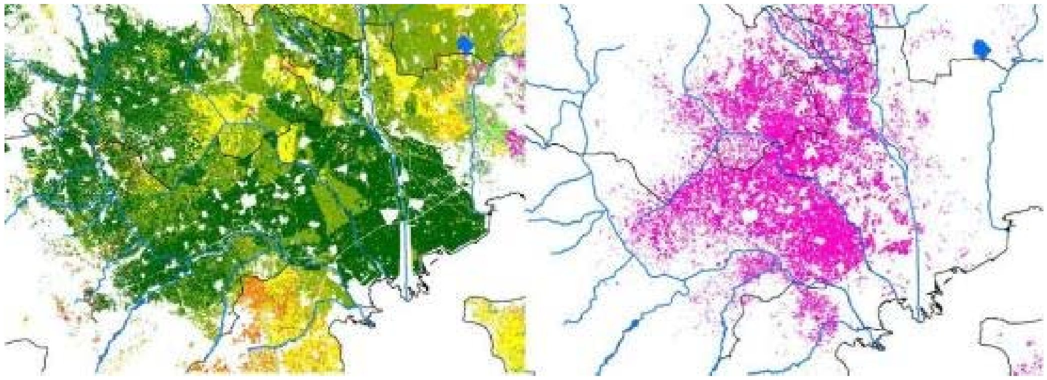

Figure 40: Area of cotton crops in the Axios, Loudias and Aliakmonas plains (left: overall benefit map, right: cotton crops)

The area represents the largest and most concentrated cotton production territory within the Region. The total surface area of this wider territory is around 43300 ha with a total number of about 42.000 holdings (mean holding size of approximately 0.1 ha) and a high aggregation level (mean observed distance of 74,5 meters).

Cotton is a very important product for the Region and its fate has been so far directly related to the country's relation to EU policy. *Cotton aid* was introduced in 1981, with the accession of Greece to the Community. During the following two decades cotton production in Greece (mainly Thessaly and Northern Greece) followed a constantly increasing trend thanks to arable land expansion, cultivation improvement (mechanization, irrigation), new tolerant crop varieties and use of agrochemicals.

Corn in the Strymon plain (and in the Mygdonia sub-basin)

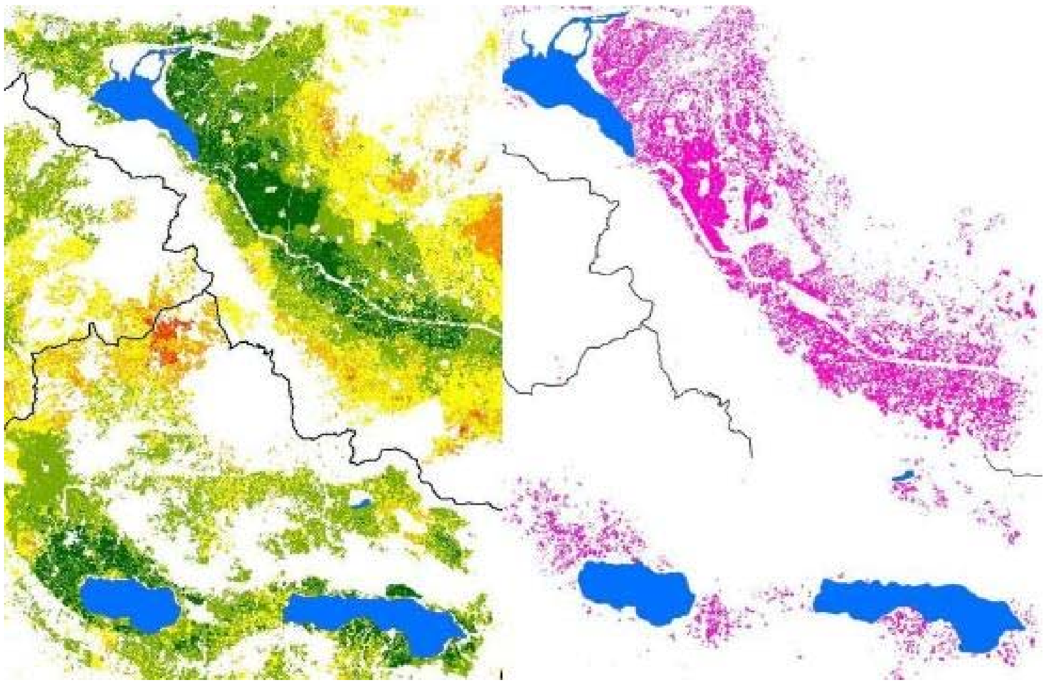

Figure 41: Area of corn crops in Strymon plain and Mygdonia sub-basin (left: overall benefit map, right: corn crops)

The fourth area (Figure 41), or better areas, to be examined are those in the plain of Strymon, especially near Lake Kerkini, and those around Lake Koronia and to a lesser degree Lake Volvi . Although limited in terms of surface area the agricultural zone around Lake Doirani could also be included in this group of areas, as it possesses similar characteristics.

In terms of number of crop holdings in the Strymon plain area there are about 20.000 with another 1.800 in Lake Doirani, 3.100 in Lake Koroneia and about 1000 in Lake Volvi, while in terms of total surface area the figures are approximately 10200, 1460, 1950 and 920 ha, respectively, corresponding mean holding size of about 0.5, 0.7, 0.6 and 0.9 ha, respectively.

In all forementioned areas the dominant crop is corn and in all areas there is a very high **environmental factor** associated with:

a. the presence of water bodies/protected areas of very high ecological value that face high pressure from agricultural activity. Regarding sites of special interest, the lakes of Kerkini, Doirani and especially of Koronia suffer from existing human activities in varying degrees, from the water shortage and eutrophication incidents of the first two to the total degradation state of the third one. All lakes have a high protection status on multiple levels (Natura 2000 sites, national parks, Ramsar sites, areas of economic importance – fishing areas). Lakes Kerkini, Koronia and Volvi are all characterized as degraded, in terms of chemical quality, while the two later are also characterized as sensitive to organic substances, according to EU Council Directive 91/271/EEC. Lastly, the groundwater system of the Mygdonia sub-basin is also characterized as degraded, in terms of quantity, as there is a direct connection between the Lakes and the water table beneath them.
b. the degradation of the soil from agricultural activities resulting in high soil acidity (as shown in the soil map of) and nitrification phenomena (the area belongs to the Nitrate Vulnerable Zone of the Region).
c. the high input requirements of corn for water and fertilization and the out of date irrigational practices being applied.

From the above it follows that the application of precision farming practices in those areas could produce, if implemented successfully, a very significant environmental benefit in both levels of natural environment protection and natural resources management. Indeed, the current international experience concerning precision farming practices on corn is wide and could prove helpful for such a task.

On an international level, plenty of bibliography exists on the use of tools and methods for application of precision techniques in corn fields with useful outcomes and recommendations to improve yield and productivity although their economic assessment usually concerns holdings of very large size (mainly in the U.S.) compared to the respective domestic numbers mentioned above. Nevertheless, the high aggregation of the holdings favours the undertaking of a collective treatment that could be either carried out be an agricultural cooperative or an external service provider.

Cereals in the plain between Axios and Gallikos (Kilkis)

The area with the fifth highest score, and final area under examination, is the area of the plain between the rivers Axios and Gallikos, from the urban centre of Thessaloniki up North to the Lake of Doirani, located mainly within the RU of Kilkis (Figure 42). The area is covered with cereals, mainly hard wheat and also some soft wheat and barley.

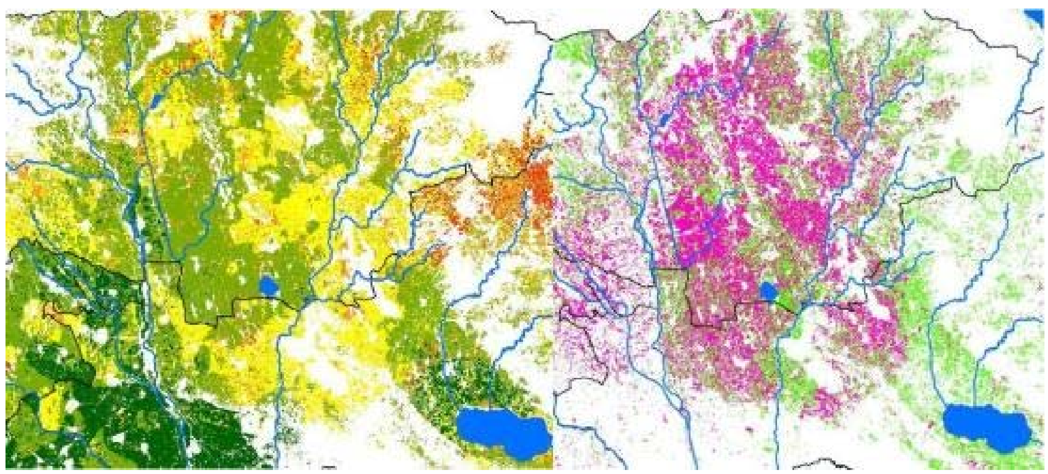

Figure 42: Area of cereal crops in the plain between Axios and Gallikos rivers (left: overall benefit map, right: cereal crops: pink – hard wheat, green – soft wheat and a little barley)

According to data of 2014 (OPEKEPE) the number of holdings with hard wheat in this really extensive area is about 40.000 covering a total farm area of 35700 ha (mean holding size of approximately 0.9 ha), while the rest of cereals sum up to a total number of about 2900 ha and a total surface area of 22500 ha (mean holding size approximately 0.8 ha).

From an environmental point of view the area scores relatively high due to the presence of the two rivers and of the respective groundwater systems (G1000030 Axios and GR1000050 Gallikos) which are characterised by quality and quantity degradation and also due to the existing soil conditions (below average state). There are no significant protected areas for habitats and species in close proximity.

In economic terms, the inputs and crop value are moderate and infrastructure is good, mainly due to the proximity of Thessaloniki while from a social point of view the area scores right on average.

Perhaps the most important feature of this area, that causes it to stand out in respect to the remaining areas not examined, is its large size. Combined, the two classes of crop types (hard wheat and other cereals) in the particular area come up to about 50000 ha. The area presents a particularly high concentration of those classes, but cereals are abundant in the rest of the region as well. They are by far the most populous crops within the Region occupying a total area of about 237000 ha and many farmers cultivate them in rotation to other crops.

The extensive farming of cereals makes these crops serious contestants for the application of precision farming practices. The benefit that would be induced from a conversion of existing practices to precision farming ones in such a large scale would be very high. For cereals, as for corn, there has been extensive application of precision farming techniques and the international experience offers plentiful case studies, although the majority of these concern farms of large sizes (mostly in the US and Australia). Nevertheless, as in the case of corn (and most crops actually) an approach that would take in mind the spatial distribution of holdings and treat them collectively could overcome the limitations of farm size. In that terms, the high aggregation of farms in the specific area examined is considered highly favourable in that direction.

5.3. Potential of adoption through farmers' opinions

Having identified the potentially optimum locations for having a benefit and thus accepting more easily precision farming, the two strategic projects adopted, as a sustainability factor, the formation and function of clusters of farmers for creating the needed critical mass concerning land area use and capital availability.

The questionnaires given to the farmers of the optimum locations focused on the possibility of adopting precision farming in their workflow, as well as participating in a precision farming cluster. More than half of the farmers that participated in the information and education sessions were already aware of the concept of precision farming and clusters. More optimistically, Swinton and Lowenberg-Deboer (2001) and Winstead et al. (2010) have reported a worldwide adoption of location determination by GPS and its consequent use in yield monitoring and variable rate applicators. The educational value of the sessions was satisfactory for almost all of the farmers, despite the fact that a smaller fraction were aware of the concept. Custom-tailored and narrowly specialized educational programs have been requested by advanced farmers as precision farming continues to mature (Kitchen et al., 2002). The investment cost of the new technology has been reported as a barrier by several participants, which can nevertheless be overcome with the proposed clusters, and the incorporation of service providers (Winstead et al., 2010). Another barrier that can be overcome with the formation of clusters, is the fragmentation of land, as the critical area for profitable investment can be reached (Godwin et al., 2003; Zarco-Tejada et al., 2014). Cluster-based policies have also been used to support SMEs and smallholder farmers in other places (Gálvez-Nogales, 2010).

The potential of the Region of Central Macedonia for agricultural cluster formation is significant according to evidence from relevant studies. Looijen and Heijman (2013) have attempted to measure agricultural cluster potential through a competitiveness analysis based on their widely used method of Location Quotient (LQ), a computation tool for measuring the economic strength of a firm or industry in a region. The tool is used to identify specializations in a local economy. Based on local and regional employment statistics in various industrial sectors provided by the European Cluster Observatory and Eurostat for the year 2007, they conducted a cluster analysis for NUTS-1 regions in Europe. Northern Greece scored 3,124 on their rating system occupying the 5th place (Central Greece came 3rd) among all measured NUTS-1 areas for agriculture based on Gross Added Value.

The same findings are supported by the study «Smart specialization in Europe: European specialization data by region Centre for Strategy and Competitiveness» of the Stockholm School of Economics (April 2011), which show that the agri-food sector displays the highest relative regional specialization within the RCM and is therefore a sector with high dynamic and high potential production of value added products and increased competitiveness. Also the evaluation of the European Cluster Observatory comes to the same conclusion and the agriculture and livestock Central Macedonia with three stars yielding the highest score possible within that system evaluation.

The existing farming groups in northern Greece do not have the infrastructure to support the adoption of precision farming. Through the formation of precision farming clusters, the farming community has the chance to develop the missing components of innovation, specialization, technical support, product certification, promotion, and regionalization. The clusters include the participation of farmers, private service providers and research organizations for the customization of the services in the local conditions. The formation of clusters gives individual farmers the opportunity to belong to a group that has the advantage of using high-tech machinery and specialized methods for delivering a product with increased quality and a certified path of production while protecting natural resources (soil, water). More importantly, being a bottom-up approach, it ensures sustainability. Several difficulties were encountered during the projects' implementation concerning the maturity of the farmers; accepting new, modern techniques instead of the traditional ones, limited experience of ICT tools, unwillingness to cooperate with neighbours and reluctance to adopt new techniques without being ensured of their economic benefits.

Clusters offer a new model that can help the primary sector to overcome some of the structural deficiencies, such as large production costs, small average holding size and limited use of technologies, through cooperation, through support form R&D bodies and through a collective approach in: a) the treatment of farming land area where agricultural practices are carried out centrally or even by an external service provider, b) the promotion and distribution of agricultural goods where aggregation and size creates the necessary mass for negotiation and marketing.

The undertaking of initiatives concerning actions to support clusters are considered essential and should focus on:

- promotion of collaboration among related groups of producers and actors of the vertical chain by creating conditions for alliances,
- the identification of stakeholders with high potential for precision farming adoption and cluster formation in order to build up a regional 'pool' of motivated actors,
- education and training of stakeholders in order to build capacity for the adoption of new ideas and technologies,
- diffusion of knowhow on precision farming practices and of new advancements in agricultural practices and methodologies.

On a similar level, some of the recommendations proposed by the RIS3 review concerning cluster development are (DG Regio, 2013):

- the use of recent cluster mapping data and techniques to identify regional competences and assets;
- the creation of a cluster secretariat;
- the strengthening of cooperation of existing clusters to make connections to local, national and global value chains;
- the facilitation of cross-clustering and the identification of innovation opportunities at the interface between different clusters;
- the creation of specialised one-stop-shops for the regional specialisations and competences, preferably within existing structures to support mainly SMEs;

- the development of further, incubators and accelerators that provide wide range of services including training, business angel networks, etc;
- the assurance that support in rural areas is directed to young people through support for business start-ups in the agro-food/forestry sector.

5.4. Towards an integrated approach for promoting precision farming

With an average farm size of 0.7 ha (the lowest in the EU), the small and fragmented agricultural holdings in Greece lead to increase in production costs and reduction in competitiveness (http://ec.europa.eu/eurostat). The same situation applies to small farms in Bulgaria, emphasizing the need for modernization, increase of productivity and capital input and output. At the same time, the few precision farming projects in Greece (and none in Bulgaria) did not have a significant impact on the farming community.

The presented integrated methodological approach takes take into account the acting legislation (CAP, EU directives, local legislation), the current environmental conditions of the study area, the socio-economic situation of the farmers' and other connected communities to identify the optimum locations. Direct contact with the farmers through the training and information sessions, as well as through the questionnaires, is a method to validate the proposed locations.

Except for agricultural clusters, some additional policies and actions, on a regional level, that could be undertaken for the enhancement of the business environment for the adoption of precision farming practices and for the magnification of the benefits induced by its implementation are considered to be the following.

Pilot applications and studies

Pilot applications and studies should be conducted at various growers' locations by involving farmers in all stages of precision farcing application. The projects should attempt to cover the grower's needs, emphasize on the operational implementation of technology and on the complete analysis of the costs and savings involved. Documentation of the results would aid in the evaluation of the operational weaknesses and identification of counter-measures. The projects should also focus on the training of innovative farmers and early adopters, familiarize non-participating farmers to new technologies and demonstrate the usefulness of PA application through tangible outcomes.

Results from pilot studies will provide valuable insight on all the practical and technical aspects and specific requirements needed for their wider application. Also, their successful implementation will encourage more farmers and stakeholders to undertake initiatives of precision farming application building up, in this way, the domestic experience in that field.

Pilot studies are advocated to focus on an unbiased enumeration of potential benefits (especially concerning the environmental ones) and using these as examples to increase farmers' awareness, particularly to extend their use to a wider range of types and size of farms. Studies identifying typology of farms should be made, showing where and in which conditions precision farming could be potentially implemented with benefits for the farm competitiveness and/or environmental stewardship. Research and studies are necessary to improve the knowledge and cost-benefit aspects of precision farming, especially concerning the environmental impact. Case studies must go beyond farm- and field-specific measures and consider the wider environmental footprint.

Public training initiatives should be undertaken to improve awareness, and knowledge of farmers and agribusinesses. Focus should be given on the improvement of their agronomic knowledge and skills, computer and information management skills, and the recognition and development of precision farming as a management system for increasing knowledge. Within each of these dimensions, educational efforts should emphasize the specific needs of the significant players interested and/or potentially involved in precision farming.

Public services concerned with Rural Development can play an important role, providing support and advice to farmers regarding technology and precision farming methods as an independent body not linked with commercial companies.

Access should be ensured to free and accurate data products for precision farming applications. In particular, suitable services from GNSS developments (Galileo) are a priority, but also more easily available data from remote sensing programmes (Copernicus) can be a stimulant to improving precision farming applications. On a similar level, emphasis should be given for the collection of data and detailed documentation of agricultural practices from all possible sources. A detailed database could greatly facilitate the implementation of a MCDA and enhance its precision in the spatial dimension.

Rural development

Besides initiatives for precision farming promotion and cluster development, other actions that could improve the current state in terms of rural development could be considered the following:

- The promotion of precision farming in contract farming, within the context of agricultural associations (including cooperatives), through the intermediation of major primary producing companies that could function as major contractors and as integrators for the better enforcement of those practices on the basis of Corporate social responsibility.
- The strengthening of the enforcement of the environmental legislation regarding protection of the natural environment and management of natural resources, especially water, to urge rural communities to take up environmentally friendly

habits and practices, and the rewarding of early-adopters, through the implementation of relevant agri-environment measures, to support and envisage further encouragement.

- Finally, the undertaking of infrastructure projects in the countryside, not only of those which are directly related to production (reclamation projects, resolution of irrigation problems, exploitation of geothermal energy, enhancement of access to the Region, connection of the Region to large centres and markets abroad and improvement of the attractiveness of investments, etc.) but also of measures related to enhancement of the attractiveness of rural areas through the improvement of quality of life in the countryside. These measures will increase the attractiveness of the countryside which is a necessary requirement for the engagement of young people in agricultural activities (e.g. improvement of infrastructures such as road networks, health infrastructures, improvement of access to new information and communication technologies, etc).

6. Conclusions

This work has presented an integrated approach to promote precision farming as a measure towards reduced-input agriculture in northern Greece, through identifying the optimum locations for adoption, and the formation of precision farming clusters as a sustainable solution. The analytic hierarchy process was incorporated in a multi criteria decision analysis GIS environment to overcome a complex spatial problem. Five locations show high benefit on an environmental and socio-economic dimension if they were to replace the conventional farming techniques and adopt precision farming. These are mainly intensively cultivated flood plains of substantial dimensions and economic importance, located adjacent to environmentally sensitive ecosystems and near high-tech urban centres.

Educational and information sessions were set up within the selected locations, and questionnaires were used to collect the farmers' perceptions. The farmers responded positively to the potential adoption of precision farming in their farms, and were satisfied with the level of information received during the sessions. Most importantly, the majority signed the document for committing their participation to the formation of precision farming clusters in their regions.

To form an integrated approach towards precision farming adoption, additional recommendations were provided to promote rural development, and pilot actions need to be supported to act as showcases of success stories.

Acknowledgements

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