ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
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ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

A GIS-BASED ANALYTICAL HIERARCHY PROCESS (AHP) APPROACH FOR THE SUSTAINABLE SITING OF RENEWABLE ENERGY INSTALLATIONS:
THE CASE STUDY OF THE REGIONAL UNIT OF RETHYMNO

ΜΕΤΑΠΤΥΧΙΑΚΗ ΔΙΑΤΡΙΒΗ

ΤΗΣ ΓΙΑΜΑΛΑΚΗ ΜΑΡΙΝΑΣ

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ΤΡΙΜΕΛΗΣ ΕΠΙΤΡΟΠΗ:
Καθηγητής ΘΕΟΧΑΡΗΣ ΤΣΟΥΤΣΟΣ
(ΕΠΙΒΛΕΠΩΝ)
Αν. Καθηγήτρια ΔΙΟΝΥΣΙΑ ΚΟΛΟΚΟΤΣΑ
Επ. Καθηγήτρια ΑΝΔΡΟΝΙΚΗ ΤΣΟΥΧΛΑΡΑΚΗ

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
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ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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Η ΜΕΛΕΤΗ ΠΕΡΙΠΤΩΣΗΣ ΤΗΣ ΠΕΡΙΦΕΡΕΙΑΚΗΣ ΕΝΟΤΗΤΑΣ ΡΕΘΥΜΝΗΣ

Μαρίνα Γιαμαλάκη

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Ευχαριστίες

Σε αυτό το σημείο θα ήθελα να ευχαριστήσω θερμά τον επιβλέποντα καθηγητή κ. Θεοχάρη Τσούτσο, για τον χρόνο που αφιέρωσε, τις πολύτιμες συμβουλές του και για τη συνεχή καθοδήγηση καθ' όλη τη διάρκεια εκπόνησης της μεταπτυχιακής μου διατριβής.

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Μαρίνα Γιαμαλάκη

ABSTRACT

As the effects of the climate change become more pronounced and the energy demand is increasing, the interest for renewable energy investments is growing globally. However, the exploitation of the renewable energy resources has to be implemented in a rational and sustainable way, taking into account both the maximization of the renewable energy potential, but also the social and environmental implications accruing.

This study aims to develop a useful methodology for clarifying and prioritizing at a regional level, the most suitable locations for siting wind and solar farms, as well as biomass and biogas plants. By employing Geographical Information Systems (GIS) and the Analytical Hierarchy Process (AHP), the sustainable siting areas for renewable energy installations siting are identified, applying a spatial multi-criteria decision-making (MCDM) approach.

The adopted methodology identifies the available siting areas for each Renewable Energy System (RES), based on exclusion criteria derived from the Specific Framework for the Spatial Planning and Sustainable Development for the Renewable Energy Sources (SFSPSD-RES) and related legislation. Furthermore, the available siting areas for each renewable energy technology are evaluated through a multicriteria analysis, based on evaluation criteria derived from the literature. Moreover, the sustainable locations for each renewable energy technology are derived, considering also the relative importance of the selected criteria, through the AHP implementation and the criteria pair-wise comparisons performed by involved energy-related groups.

Therefore, the main result of this study is the development of a strategic planning methodology for the sustainable siting of RES, which was applied for the case study of the Regional Unit of Rethymno. The developed methodology employs different types of criteria, such as techno-economic and socio-environmental, it takes into account the distinct opinions of different stakeholders and it enables the evaluation of different scenarios.

Key words: RES siting, exclusion and evaluation siting criteria, spatial multicriteria analysis, sustainable siting areas, GIS, AHP

ΠΕΡΙΛΗΨΗ

Καθώς τα αποτελέσματα της κλιματικής αλλαγής γίνονται όλο και πιο φανερά και οι ενεργειακές ανάγκες αυξάνονται, το ενδιαφέρον για επενδύσεις σε Ανανεώσιμες Πηγές Ενέργειας (ΑΠΕ) αυξάνεται παγκοσμίως. Βέβαια, η εκμετάλλευση των ανανεώσιμων πόρων πρέπει να γίνεται με τρόπο ορθολογικό και βιώσιμο, λαμβάνοντας υπόψη τόσο τη μέγιστη δυνατή εκμετάλλευση του δυναμικού ΑΠΕ, αλλά και τις κοινωνικές και περιβαλλοντικές επιπτώσεις που μπορεί να προκύψουν.

Ο σκοπός της παρούσας μελέτης είναι η δημιουργία μίας χρήσιμης μεθοδολογίας για την προτεραιοποίηση σε τοπικό επίπεδο, των πιο κατάλληλων θέσεων για τη χωροθέτηση αιολικών και ηλιακών εγκαταστάσεων, καθώς και μονάδων εκμετάλλευσης βιομάζας και βιοαερίου. Μη τη χρησιμοποίηση Γεωγραφικών Συστημάτων Πληροφοριών (ΓΣΠ) και της Μεθόδου Αναλυτικής Ιεράρχησης, αναγνωρίζονται οι βιώσιμες περιοχές χωροθέτησης κάθε συστήματος ΑΠΕ, με την εφαρμογή μία χωρικής πολύ-κριτηριακής ανάλυσης.

Με την παρούσα μεθοδολογία αναγνωρίζονται οι διαθέσιμες περιοχές χωροθέτησης κάθε συστήματος ΑΠΕ, με βάση κριτήρια αποκλεισμού από το Ειδικό Πλαίσιο Χωροταξικού Σχεδιασμού και Αειφόρου Ανάπτυξης για τις ΑΠΕ και τη σχετική νομοθεσία. Επίσης, οι διαθέσιμες περιοχές χωροθέτησης κάθε συστήματος ΑΠΕ αξιολογούνται με την εφαρμογή πολύ-κριτηριακής ανάλυσης, με βάση κριτήρια αξιολόγησης από τη βιβλιογραφία. Έτσι, προκύπτουν οι βιώσιμες περιοχές χωροθέτησης, λαμβάνοντας παράλληλα υπόψη τη σχετική σημαντικότητα των επιλεγμένων κριτηρίων, με την εφαρμογή της Μεθόδου Αναλυτικής Ιεράρχησης και την πραγματοποίηση των κατά ζεύγη συγκρίσεων των κριτήριων από εμπλεκόμενους φορείς.

Επομένως, το κύριο αποτέλεσμα της παρούσας μελέτης είναι η ανάπτυξη μίας μεθοδολογίας για τον στρατηγικό σχεδιασμό και τη βιώσιμη χωροθέτηση μονάδων ΑΠΕ, η οποία εφαρμόστηκε για την μελέτη περίπτωσης της Περιφερειακής Ενότητας Ρεθύμνης. Η μεθοδολογία αυτή λαμβάνει υπόψη διαφορετικούς τύπους κριτηρίων, όπως τεχνοοικονομικά, κοινωνικά και περιβαλλοντικά κριτήρια, καθώς και τις διαφορετικές απόψεις εμπλεκόμενων φορέων και επιτρέπει την αξιολόγηση εναλλακτικών σεναρίων.

Λέξεις Κλειδιά: χωροθέτηση συστημάτων ΑΠΕ, κριτήρια αποκλεισμού και αξιολόγησης, χωρική πολύ-κριτηριακή ανάλυση, βιώσιμες περιοχές χωροθέτησης, ΓΣΠ, Μέθοδος Αναλυτικής Ιεράρχησης

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Abbreviations List

MCDM: Multicriteria Decision Making

GIS: Geographic Information Systems

RES: Renewable Energy Sources

SFSPSD-RES: Specific Framework for Spatial Planning and Sustainable Development for the Renewable Energy Sources

WLC: Weighted Linear Combination

AHP: Analytical Hierarchy Process

OWA: Ordered Weighted Averaging

CSP: Concentrated Solar Power

PV: Photovoltaic

GHI: Global Horizontal Irradiance

DNI: Direct Normal Irradiance

DHI: Diffuse Horizontal Irradiation

JRC: Joint Research Centre

DEM: Digital Elevation Map

TIN: Triangular Irregular Network

SCIs: Sites of Community Importance

SPAs: Special Protection Areas

TCD: Tree Cover Density

WWTP: Waste Water Treatment Plants

CI: Consistency Index

CR: Consistency Ratio

RI: Random Index

AIP: Aggregation of Individual Priorities

OPI: Overall Priority Index

LHV: Lower Heating Value

1 Introduction

It is a common knowledge nowadays that, climate change is one of the biggest problems that the humanity has to address, in association with the ever-growing energy needs and the excessive natural resources consumption. Therefore, as the effects of the climate change become more pronounced, the need to increase the penetration of renewable energy sources in the energy mix is growing globally. The European Union (EU), in the light of the climate change, energy supply security and reduction of its dependence on imported fossil fuels has fostered the diffusion of renewable energy technologies, for a more sustainable energy production.

The EU's Renewable Energy Directive [89] has established an overall policy for the production and promotion of renewable energy in the EU. It requires the EU to fulfill at least 20% of its total energy needs with renewable energy by 2020. To achieve this, EU countries have committed to reaching their own national targets, taking into account their starting point and renewable energy potential, ranging from 10% for Malta to 49% for Sweden [90]. For Greece, the national targets concern a 4% reduction of greenhouse gases from the 2005 levels, as well as an 18% penetration of renewable energy in the gross final energy consumption by 2020 (expected amount of energy from renewable sources 4,341 ktoe) [38]. However, the Greek government, with the adoption of new environmental policies, with the Law 3851/2010 has increased its national target to 20%, concerning a 40% contribution of RES to electricity production, 20% for heating and cooling energy needs and 10% for transport [101].

However, renewables will continue to play a key role for the EU to meet its energy needs beyond 2020, as EU countries have already agreed to a new renewable energy target for 2030 [91]. These new targets concern a 40% cut in greenhouse gas emissions compared to 1990 levels and at least a 27% share of renewable energy consumption in the EU as a whole by 2030 [15]. Therefore, the growing concern for environmental issues and more specifically for the environmental impacts of the conventional electricity generation systems, has opened up the dialogue for the renewable energy sources exploitation in a rational and sustainable way.

The energy sector in Crete has unique characteristics, due to Crete's island nature, sensitive ecosystems and distance from the mainland. Furthermore, Crete has an autonomous electricity production system, where the supply of conventional energy resources occurs only via sea transportation [74]. Finally, the increasing energy demands, especially in the tourist season, and the European and national targets for renewable energy promotion have led to an increasing interest for renewable energy investments.

In addition, the region of Crete, due to its position and Mediterranean climate can effectively accommodate the installation of renewable energy systems. The strong Mediterranean winds encourage the siting of wind farms, the solar potential is ideal for installations exploiting the solar radiation and the developed agricultural sector, due to Crete's mild climatic conditions, can launch the production of energy from biomass from agriculture residues. However, for the sustainable siting of renewable energy installations, together with the greatest possible exploitation of renewable energy resources, the social and environmental implications accruing must be taken into consideration, such as conflicts of land use, preservation of the natural environment and sensitive ecosystems and social reactions.

The aforementioned points demonstrate the need for the development of a methodology for the sustainable siting of renewable energy installations at a regional level. Therefore, this study aims to develop a dynamic methodology for the complete prioritization of the available locations for siting solar and wind farms, as well as biomass and biogas plants, at a regional level, based on a wide selection of evaluation criteria. In addition, this methodology enables the sustainable siting areas identification, for each renewable energy technology studied, by employing Geographical Information Systems (GIS) and a Multi-Criteria Decision-Making (MCDM) technique.

With a GIS, all the required information for siting renewable energy systems can be incorporated, allowing the analysis of spatial data and the production of dynamic maps. The Analytical Hierarchy Process (AHP) is a widespread MCDM technique, which allows the combination of different evaluation criteria. In addition, AHP allows the participation of different stakeholders of energy-related fields, by the implementation of pair-wise comparisons of the evaluation criteria, for their relative importance determination. The aforementioned capabilities reinforce the developed RES sustainable siting methodology, for the minimization of the socio-environmental impacts and the maximization of the techno-economic potential.

The adopted methodology was applied in the Regional Unit of Rethymno, while in the next Sections all the stages for the renewable energy potential and sustainable siting areas identification of the study area will be presented. More specifically:

Section 2 presents an overview of the literature, with regard to finding the optimal locations for siting RES, presenting the different approaches and methodologies employed in the literature for the site selection problems of wind and solar energy installations, as well as biomass and biogas plants.

Section 3 describes the main steps of the adopted methodology, providing also an overview of the current situation of the study area. In addition, a detailed description of the exclusion criteria, derived mainly from the legislation is conducted, for the available siting areas identification for each renewable energy technology studied. In addition, for each RES, the evaluation criteria of the available siting areas, derived mainly from the literature review, are described. Finally, this *Section* provides also a description of the classification of each criterion to the five-classes priority scale selected.

In *Section 4*, a detailed presentation of the Analytical Hierarchy Process is implemented, presenting also its application in this study. In addition, the methodology for the priority maps production and the sustainable siting areas identification, for each renewable energy technology studied is presented. Finally, in this *Section*, the results in terms of each municipality's coverage, by the sustainable siting areas are provided, for each RES.

Section 5 presents the results of the sensitivity analysis implemented, for each RES studied, by employing equal-weighted, techno-economic, socio-environmental and safety scenarios. In addition, a comparison of the results from the AHP and the adopted sensitivity analysis scenarios is conducted, for checking the sensitivity of the developed methodology's results.

Section 6 provides a summary of this study and of the conclusions that are accruing. In addition, in *Section 7* further research that can be implemented is also discussed.

Finally, in the *Annexes*, the literature review implemented can be found, providing an overview of the evaluation and exclusion criteria selected in the literature, as well as of the evaluation criteria classification and constraints adopted by different RES site selection studies. In addition, the questionnaire sent to the different participants, for the AHP implementation is presented. Finally, the *Map Annex* presents the main maps produced for the Regional Unit of Rethymno, for the RES siting investigated.

2 State of the art on the Renewable Energy Systems siting problem

The selection of suitable sites to host renewable energy installations is a quite complex problem, as it requires evaluating different criteria, e.g. renewable energy potential, the existence of infrastructure etc. In the literature, the problem of defining suitable locations for siting RES is a common one, where researchers usually employ Multi-Criteria Decision-Making techniques (MCDM) and Geographic Information System tools to optimally combine the different evaluation and exclusion criteria. However, studies vary widely with respect to the energy technologies considered, the methodologies applied and the spatial scale of the area taken into consideration. In this Section, an overview of different studies with regard to finding the optimal locations for siting RES is provided.

2.1 Siting of wind energy installations

GIS-based MCDM approaches for wind power plant site selection are the most common in the literature, as wind installations are usually connected with several potential environmental impacts, such as electromagnetic interferences, noise, visual impact, bird impacts etc. [73]. Therefore, the first step for defining the optimal locations for siting wind farms is to exclude the areas, where these impacts may occur. After defining the appropriate constraints and buffer safety distances, the evaluation criteria of the available locations are chosen. In Annex A, the constraints and evaluation criteria, from the studies found in the literature are presented.

Tsoutsos et al. [60] developed a methodology for the comprehensive evaluation and prioritization of available areas for siting wind farms and applied it in the island of Crete, by employing the Specific Framework for Spatial Planning and Sustainable Development for Renewable Energy (SFSPSD-RES), Geographic Information Systems and multicriteria analysis. Based on the SFSPSD-RES [85] the legally available areas for wind farms siting were determined and they were evaluated based on selected criteria, such as distances from national parks, airports, main roads etc. The criteria were classified into five scales of priority and were synthesized by summing the values of the area at all the criteria. The total priority of each area was further analyzed taking into account the criterion of wind potential and the carrying capacity of the sustainable siting areas was determined. Voivontas et al. [64] also studied the renewable energy potential in Crete, using a GIS decision support system and evaluated the economic potential of wind energy projects.

In another study about the island of Crete, Kokologos et al., [30] developed a methodology for the assessment of the visual impacts of wind parks and applied it in a wind park in the Regional Unit of Chania. The developed methodology allowed for the evaluation and reduction of the visual impacts, by combining quantitative indicators for the visual impacts quantification and 3D simulation of the study area. In addition, a multi-criteria methodology was also employed for the sustainable energy planning of the island of Crete, by Tsoutsos et al., [61], with the implementation of the MCDM PROMETHEE model. The authors employed a set of energy planning alternatives, based on different technology solutions for the sustainable energy supply of Crete and evaluated them against economic, technical, social and environmental criteria, identified by the stakeholders involved in the island's energy planning.

Atici et al. [4] dealt with the site selection problem for wind power plants in Western Turkey, with a two-stage methodology, employing a GIS tool. In the first stage, they eliminated infeasible sites based on selected elimination criteria and constraints and then they used ELECTRE methods to rank the available areas, based on identified evaluation criteria. The ELECTRE-TRI methodology was also employed by Sanchez-Lozano et al. [47], in order to rank the optimal sites for onshore wind farms on the coast of the Region of Murcia, in Spain.

The most commonly used MCDM technique in the literature for renewable energy site assessment is the Analytical Hierarchy Process (AHP). In general, AHP is in the broader category of pair-wise comparison MCDM techniques, where the attributes' relative importance is assessed by ranking them against each other [59]. Bennui et al. [8] applied a GIS-based AHP model to select the optimal sites for wind farms in five provinces in Thailand. A similar model was applied by Tegou et al. [59], where a set of constraints were applied and then different criteria were defined for wind farms site selection in Lesvos, Greece. Finally, Szurek et al. [57] also employed an AHP approach for the definition of the evaluation criteria weights for wind farms siting in Lower Silesia, Poland. They used a five scale suitability classification of each criterion and then they employed a weighted linear combination (WLC) based on the occurring weights from the AHP process. However, these studies do not give sufficient explanation about who assigns the criteria weights. Therefore, it is not clear, if they accrue based on the authors' expertise or if a group of experts is assigned to conduct the necessary pair-wise comparisons.

Baban and Parry [6] also applied the same model, where constraint layers were created and scores were assigned to the selected criteria, after consulting local council bodies and wind companies in UK. Therefore, an equal-weighted aggregation, as well as a pair-wise comparison of the selected criteria was applied. However, the weights are not directly assigned to the criteria, but instead four groups of factors are pair-wise compared, in order to derive the relative importance of each factor. Latinopoulos and Kechagia [31] applied an AHP approach for the suitability assessment of future, as well as already licensed wind farms in the Regional Unit of Kozani, Greece. The evaluation criteria were represented as fuzzy sets, where the membership functions were used to estimate the satisfaction degree of each factor, for each grid cell of the study area. In addition, the authors developed three different scenarios to assess the suitability of each potential siting area (a scenario of equal-importance factors, a scenario focusing on the environmental and social suitability and a scenario focusing on the technical and economic feasibility) and the importance of the criteria was defined based on the authors expertise.

A comprehensive GIS-based AHP approach was applied by Watson and Hudson [66] for the suitability assessment of wind and solar farms developments in southern England. The authors constructed a set of constraint layers and consulted seven experts to evaluate the relative importance of the selected evaluation criteria. A similar approach was also applied by Hofer et al. [26] for wind farms siting at Aachen, Germany. The authors present a comprehensive literature review for the identification of the most important aspects, influencing the suitability of the siting areas for wind energy installations and assigned value scores to each criterion in order to allow a spatial rating of the potential locations. In addition, 22 local wind power experts, from different wind- related power groups, such as business, science, administration, environmental and local public initiatives were asked to perform pair-wise comparisons of the selected criteria, in order to determine their relative importance. Finally, the authors emphasize that the experts were selected in such a way that their different opinions reflect the complexity of the RES siting problem and that finding the areas that are most acceptable by most stakeholders is of greatest importance.

Gorsevski et al. [20] and Hansen [24] used weighted linear combination (WLC) techniques and GIS functionality for wind farm site selection in Northwest Ohio, USA and Northern Jutland, Denmark respectively. In these studies, the selected criteria were represented using fuzzy membership equations and a direct assignment of the criteria weights was performed. Gorsevski et al. [20] asked 30 university students to assign weights to the selected criteria, without performing pair-wise comparisons and Hansen [24] directly assigned the criteria weights, based on his common sense. In addition, Janke [29] studied the wind and solar potential of Colorado, USA and the suitable locations for wind and solar energy projects, by incorporating a GIS-based methodology with direct assignment of the criteria weights, based on his expertise. Finally, Noorollahi et al. [39] dealt with the wind farms siting problem in Markazi province, Iran, by employing restrictive and classifying analytical methods. They divided the study area into suitable and unsuitable based on exclusion criteria using the Boolean logic and classified the suitable locations based on three classifying criteria (wind speed, distance from electric power lines, highways and roads) with different weight influence, using the Weighted Index Overlay method.

Van Haaren and Fthenakis [22] presented a method for site selection for wind turbine farms in New York State, based on a spatial cost-revenue optimization. The authors, after excluding infeasible sites for wind turbine farms, they evaluated the feasible locations based on the expected net present value from four cost and revenue categories (revenue from electricity production, costs from access to roads, power lines and land clearings) and the potential impacts on bird habitats. A similar approach was also adopted by Schallenberg-Rodriguez and Notario-del Pino [50] for wind potential evaluation in the Canary Islands, taking into account territorial and techno-economic constraints and performing a cost analysis based on the net present value.

Rodman and Meentemeyer [43] developed a rule-based GIS model to predict suitable locations for large and small-scale wind energy projects in the Greater San Francisco Area, USA. They created three models: a physical, an environmental and a human impact model, where each model consists of different layers (e.g. wind speed layer in the physical suitability model) and each layer is subdivided into multiple classes, where each class gets values scores according to its suitability. Moreover, the weights of the different layers where directly assigned, with no explanation about who assigns them and the three models where combined to produce the total suitability of the potential siting locations. Aydin et al. [5] identified the environmental objectives associated with energy generation from wind turbines in Western Turkey, which are quantified with certain criteria. They used fuzzy membership equations for six environmental objectives (e.g. acceptable in terms of natural reserves), generated using associated criteria (e.g. distances from ecologically sensitive areas, water bodies and areas of ecologic value). The generated membership equations are used to compute individual satisfaction degree for each potential location and objective. Finally, aggregation operators were used, such as ‘and’ and ‘or’, as well as ‘ordered weighted averaging (OWA)’ to indicate satisfaction of all, any or most environmental objectives respectively.

Sliz-Szkliniarz and Vogt [53] evaluated the wind energy potential in a region of Poland. They determined the available locations for wind installations siting based on the spatial and ecological policy. In addition, they performed horizontal and vertical interpolation of measured wind speed datasets from weather stations to derive the continuous surface of wind speed to rotor blade heights. They defined the vertical profiles of wind changes and performed geo-statistical methods, such as Ordinary Kriging, Ordinary Cokriging, Inverse Distance Weighting (IDW) and Polynomial Interpolation Methods (PIM) in a GIS environment, using the corresponding geo-statistical tools.

2.2 Siting of solar energy installations

In this Section, an overview of the literature review for the solar installations siting problem is presented. Photovoltaic Installations (PV) are usually connected with small environmental impacts, as they harness a natural renewable energy source, the sun, allowing the direct conversion of solar radiation to electricity and they do not cause atmospheric emissions [73]. However, large-scale PV systems may cause some environmental impacts, due to the large area required for their operation, causing visual impacts, the potential occupation of arable land and disturbance of the local ecosystem (flora and fauna) [73]. In addition, concentrated solar power (CSP) systems generate solar power by using mirrors or lenses that transform solar energy into heat, which is then converted to electricity by means of steam turbines [68]. CSP systems are usually selected for their higher efficiency, but they require large areas for their operation, special cooling systems (large water quantities), causing visual impacts, noise, impacts to the water bodies and disturbance of the local ecosystem [73]. Therefore, the problem of finding suitable locations for these installations is crucial and quite common in the literature, where GIS-based approaches and multicriteria methods are usually employed by the researchers. Finally, in Annex B, the most common evaluation criteria and restrictions from the literature review are presented.

Aly et al. [2] used MCDM methodology for the identification and prioritization of the suitable locations for siting PV and CSP installations in Tanzania. They incorporated a GIS tool for the exclusion of unsuitable locations and the production of suitability maps. For the definition of the relative importance of the selected criteria, the authors employed the AHP methodology, but due to lack of regional experts, they performed an extensive literature review for the implementation of the necessary pair-wise comparisons. Finally, suitability maps were produced using the weighted linear model and performing sensitivity analysis. A similar approach was also employed by Asakereh et al. [3] for identifying suitable PV sites in the study area of Khuzestan province, Iran, but instead of assigning value scores to the classes of each selected criterion, they used fuzzy membership equations to represent the selected criteria. Finally, an AHP approach was also used by Al Garni and Awasthi [10] for PV power plant site selection in Saudi Arabia, where the pair-wise comparisons were based on the authors' expertise and the literature, while the suitability index of each potential location accrued by the employment of the weighted overlay tool in ArcGIS.

As it was mentioned before, AHP methodology is quite common in the literature for defining the relative importance of the selected criteria for the selection of suitable sites of solar installations. Carrion et al. [11] and Uyan [62] implemented a GIS-assisted two-staged AHP methodology for a region in Andalusia, Spain and the Karapinar region, Turkey respectively. Georgiou and Skarlatos [21] used satellite images and image classification techniques for the production of land use, built-up areas and surface waters classes and employed AHP process for acquiring the PV siting criteria weights in Limassol, Cyprus. Sadeghi and Karimi [46] and Merrouni et al. [35] also approached with AHP methodology the solar farms site selection problem, in Iran and Marocco respectively. Finally, Yushchenko et al. [68] evaluated the geographical and technical potential for solar electricity generation, from PV and CSP plants, in rural areas of West Africa, producing two different scenarios for the implementation of the criteria pair-wise comparisons (the first concerning the solar irradiance as the main criterion and the second concerning the minimization of potential investment costs). However, in these studies, the pair-wise comparisons are conducted by the authors and different scenarios are examined through a sensitivity analysis, not directly taking into account the stakeholders inputs.

Besides AHP methodology, in the literature, other MCDM techniques can be found for approaching the PV and CSP site selection problem. Sanchez-Lozano et al. [49] used the ELECTRE-TRI method for the solar farms site selection in the region of Murcia, Spain. They applied a set of restrictions for defining the feasible siting areas and then they evaluated 20 alternative sites, based on 10 selected criteria. In addition, they consulted an expert in solar photovoltaic facilities, who provided based on his expertise the lower and upper reference profiles of the criteria, as well as the indifference, preference and veto thresholds. Tavana et al. [58] introduced a fuzzy multi-criteria methodology for solar farm site selection, where GIS and MATLAB's fuzzy logic toolbox were employed. The authors consulted several experts for the definition of the evaluation criteria and the crisp input data of each criterion were converted into a membership degree of participation into linguistic subsets (low, medium, high). In addition, 37 if-then rules incorporating the criteria weights accruing from an AHP process were considered, producing that way the final priority maps of two Iranian regions for PV installation. Finally, Mondino et al. [36] produced a synthetic index representing ground-mounted PV plants carrying capability in North Italy, incorporating quantitative and qualitative criteria (restricted areas), with assigned weights produced by means of an Artificial Neutral Network (ANN) analysis.

Sindhu et al. [52] and Sanchez-Lozano et al. [48] applied a hybrid AHP-TOPSIS methodology for the evaluation of solar farms siting locations in India and Cartagena, Spain respectively. AHP process was used for the criteria weights definition and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methodology was applied for the assessment of the alternatives based on the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). In addition, the Boolean overlay was applied by Hott et al. [28] and Merrouni et al. [34] with no assignment of criteria weights in the case studies of Wyoming, USA and Eastern Morocco respectively. Moreover, Charabi and Gastli [12] performed a fuzzy multi-criteria analysis in GIS-environment for PV site suitability analysis in Oman, using OWA and AHP methodology, where all objectives were selected to be met simultaneously. Finally, Sun et al. [56] performed a technical and economical potential analysis of solar PV generation in Fujian Province, China, based on the geographical potential analysis, which identified the suitable land areas for constructing PV plants, taking into account geographical constraints.

2.3 Estimation of the solar resource

As it can be seen from the Tables in Annex B, the solar potential is a critical criterion for the suitability assessment of an area for PV or CSP installation. In many studies, a value of 1,800kWh/m^2 for the average yearly solar irradiance on the ground level is taken as a lower limit for characterizing an area of having a good solar potential for siting solar installations ([35], [2], [68]).

As the solar radiation goes through the atmosphere it suffers different processes of absorption, dispersion or scattering that result in lower levels of radiation being received at the Earth's surface. The main source of attenuation is the cloud cover, but other atmosphere components, such as O_3 or CO_2, liquid and solid particles in suspension (aerosols, water vapor) can affect differently the wavelengths of solar radiation, causing the spectral distribution of the solar radiation at ground level to be different from the extraterrestrial one. The solar radiation received at ground level, known as global horizontal irradiance (GHI) is the sum of three components: the direct normal irradiance (DNI), the diffuse horizontal irradiation (DHI) and the ground-reflected irradiation. DNI is the fraction of the solar radiation that reaches the ground level, without being attenuated by the atmosphere and the DHI is the solar radiation that reaches the ground after being reflected or scattered by the atmosphere. Finally, the third component, which is not always taken into consideration, is the reflected radiation from the ground surface or nearby obstacles [92].

Many authors stress that PV technology works in the presence of both DNI and DHI solar irradiation, unlike CSP technology which works only by using the DNI ([10], [28], [68]). In the context of the solar potential estimation, in the literature, there are different methodologies employed, as presented in Table 2.1. Some authors employ geostatistical methods, such as Kriging interpolation, for the solar potential estimation from surface meteorological stations' measurements ([3], [34]), while others incorporate the AREA SOLAR RADIATION extension of the ArcGIS Spatial Analyst toolbox. In general, this ArcGIS tool results in the calculation of the insolation (Wh/m^2) across an entire landscape introduced as a DEM file in the tool. The routine can be run for a maximum time interval of 1 year, but options are also available for a month or a day intervals, while both the GHI and DNI raster files can be produced. However, the tool requires the determination of some solar radiation parameters, such as the diffusing part of the GHI (diffuse proportion), as well as the fraction of the radiation that passes through the atmosphere, in relation to the extraterrestrial radiation (transmissivity) [94]. In this study, the Area Solar Radiation tool was used for the calculation of the GHI and DNI for the Regional Unit of Rethymno, while the solar parameters determination is described in detail in Section 3.

Table 2.1 Overview of the methods for the assessment of the solar potential from the literature review

Authors	Solar potential determination
Asakereh et al., [3]	Kriging interpolation in ArcGIS of the monthly and yearly average data from 20 meteorological stations
Al Garni and Awasthi, [10]	Area Solar Radiation extension in ArcGIS: Transmissivity= 0.65, Diffuse proportion=0.36
Sun et al., [56]	Area Solar Radiation extension in ArcGIS: Transmissivity= 0.63
Charabi and Gasli, [12]	Area Solar Radiation extension in ArcGIS: Transmissivity= 0.65
Merrouni et al., [35]	High accuracy GHI solar map of Eastern Morocco from the IRESEN's server map portal
Sindhu et al., [52]	NASA Surface meteorology and Solar Energy (SSE) database
Hott et al., [28]	GHI and DHI raster files from the National Renewable Energy Laboratory (NREL)
Watson and Hudson, [66]	Area Solar Radiation extension in ArcGIS
Janke, [29]	DHI raster files from the National Renewable Energy Laboratory (NREL)

Table 2.1 Overview of the methods for the assessment of the solar potential from the literature review

Authors	Solar potential determination
Sadeghi and Karimi, [46]	Area Solar Radiation extension in ArcGIS
Mondino et al., [36]	Area Solar Radiation extension in ArcGIS-customization of input data from JRC's PVGIS utility
Merrouni et al., [34]	Kriging Interpolation in ArcGIS of the monthly and yearly average data from 10 meteorological stations

2.4 Biomass potential

The achievement of the European Union's challenging goal of 27% final energy consumption from renewable sources by 2030 [91] requires the consideration of the potential contributions that every type of renewable energy source can make. Biomass constitutes a key renewable energy source and calls for its energy-generating potential to be estimated. Therefore, the estimation of the energy-generating potential from forest and agricultural biomass, as well as from animal manure, municipal wastes and other biogas sources has piqued the interest of the scientific community.

Biomass is a clean, environmentally friendly and inexhaustible energy source, which is considered not to contribute to the increase of the greenhouse gases, as the CO_2 quantities produced during the biomass combustion are considered to be employed during its production by the photosynthetic process. However, energy production from biomass is usually connected with some environmental impacts, as emissions and particularly smell and noise emissions cannot be avoided [13]. In addition, the wood biomass and biogas feedstock transportation is considered the source of major environmental impacts, in terms of visual, audio impacts and atmospheric emissions [73]. Therefore, apart from the energy potential estimation of biomass resources based on statistical data and land uses maps (e.g. Corine databases), the suitable locations for biomass power plants and the biomass logistics and transport optimization are also a common study area in the literature.

The main sources of wood biomass residues in Crete originate from olive trees, fruit trees and vineyards [63]. Voivontas et al. [65] assessed the available biomass potential from agricultural wastes in Crete, taking into account statistical data, alternative uses of the agricultural residues and the efficiency of the residues collection process. In addition, they evaluated the technological and economical biomass potential, taking into account the characteristics of the energy production technologies and the alternative energy sources. Finally, the authors conclude that the island of Crete has a significant biomass potential that can be economically and competitively harvested.

Lourinho and Brito [33] assessed the biomass energy potential from agroforestry residues in a region of Portugal, using land cover maps and estimating the area capable of generating biomass residues. However, for the quantification of the area effectively occupied by each biomass species, the effective area of each land cover polygon was defined from the product of the total polygon area by the vegetation cover percentage and the occupation rate of each species. Moreover, they considered a set o restrictions for the collection of the resource by excluding areas with a slope greater than 20% and areas not easily accessible (distance 3km from the road network). Finally, the annual quantities of agroforestry biomass and the corresponding energy potential were defined taking into account the residue productivity of each species, the fraction of residues that can be effectively used for energy purposes and the efficiency of the resource to energy conversion technology. Similar restrictions, concerning the slope and access of an area, were adopted by Lopez-Rodriguez et al. [32] for the spatial assessment of the bioenergy potential from forest residues in Caceres province, Spain. Fernandes and Costa [16] also assessed the biomass potential from agricultural and forestry residues in a region of Portugal and illustrated the biomass potential for energy utilization, analyzing the heating system of a hotel located in the region.

Land cover maps were also employed by Gomez et al. [19], in order to assess the energy contents of agricultural and forestry residues in Spain and their associated electricity generation potential. They applied a set of physical, geographical (exclusion of protected areas, where forest management is not permitted) and technical restrictions (exclusion of areas with a slope greater than 20%) and performed an economic analysis considering three transformation technologies. Beccali et al. [7] used CORINE land cover maps in order to assess the technical and economic potential of biomass exploitation in Sicily, Italy. In addition, the adopted methodology incorporated agricultural, economic, climatic and infrastructural data for the definition of collection points of the agricultural residues and the assessment of the biodiesel production potential, supposing the cultivation of rapeseed in arable crop areas.

However, with the employment of land cover maps, the pruning wood productivity coefficients have to be determined, for each species, for scaling up the biomass quantities when multiplied by the area of a specific crop. Table 2.2 presents different values for these coefficients for agricultural crops, found in the literature, from different biomass potential assessment studies in different Mediterranean areas.

Table 2.2 Pruning wood productivity coefficients from the literature review for agricultural crops

Annual Pruning wood productivity coefficients			Source
Olive Trees	**Fruit Trees**	**Vineyards**	
1.5 t/ha	2 t/ha	7 t/ha	Lourinho and Brito, [33], Fernandes and Costa, [16] (Portugal)
2.82 t/ha	[1]16.92 - 5.11 t/ha	4.97 t/ha	Voinontas et al., [65] (Crete)
180 t/km^2	200 t/km^2	200 t/km^2	Beccali et al., [7] (Italy)
1.61 t/ha	3.91 t/ha	3.65 t/ha	Gomez et al., [19] (Spain)

[1]Depending on the fruit trees type (e.g. apricot, orange tree)

Haase et al. [23] used both digital map and statistical data (e.g. arable areas, crop yields etc.), in order to assess the amount and spatial distribution of cereal straw, root crop and oil plant residues for five European regions, considering the residues to product ratios (RPRs) and environmental sustainability issues, such as soil erodibility, protected areas and organic carbon content in topsoil. Hohn et al. [27] studied the spatial distribution of the biomass feedstock for biomethane production, as well as the optimal locations, sizes and number of biogas plants in southern Finland. In addition, the authors employed a GIS based methodology for the biomass transport optimization, using the Network Analyst tool in ArcGIS and considering the existing road network and the spatial distribution of the biomass feedstock. Brahma et al. [9] investigated the electricity power generation potential of a biomethanation plant in Assam, India and also used the Network Analyst tool for the optimal biomass collection and transportation network design.

2.5 Siting of biomass plants

In this study, apart from estimating the biomass potential in the Regional Unit of Rethymno, the suitable sites for biomass/biogas plants are also investigated, according to the methodology presenting in detail in Section 3. In the literature, the problem of finding the suitable locations for siting biomass plants is usually approached with a GIS-based methodology, similar to the siting problem of solar and wind installations.

Perpina et al. [41] applied a GIS-based methodology for the assessment of suitable sites for biomass plants in Valencia, Spain. The relative importance of the selected criteria was defined after conducting pair-wise comparisons in two levels: in the first level weights were assigned to three groups of factors (environmental, economic and social) and in the second levels weights were assigned to subcategories of the aforementioned factors (e.g. visual impact, accessibility by road etc.). Finally, the best alternatives were obtained after applying WLC and IPM (Ideal Point Method) approaches and conducting a sensitivity analysis of the set of factors and their associated weights. Perpina et al. [40] also developed and applied a GIS-based methodology focused on logistics and transport strategies of the available biomass potential to the potential bioenergy plants, considering technical, economic, environmental and social constraints. The proposed methodology was applied to the Valencian Community and consists of two stages: identification and quantification of the spatial distribution of the biomass potential in the study area and evaluation of the times, routes and transport costs of the biomass for its transport from the original location to the biomass plant, performing a network analysis.

Franco et al. [17] used a fuzzy approach for the identification of the most suitable sites for biogas plants in a Danish municipality, using GIS and an AHP approach for the weights assignment. Rodriguez et al. [44] also employed a GIS-based fuzzy AHP approach for defining the suitable sites for bioenergy plants, using cocoa residues in a region of Columbia. Silva et al. [51] applied the ELECTRE-TRI method for the determination of suitable sites for biogas plants using dairy manure as feedstock in a region of Portugal by setting a set of constraints and factors and exploiting the capabilities of GIS. Sliz-Szkliniarz and Vogt [54] developed a GIS model to determine the optimal sites for installing anaerobic digesters in a region of Poland, exploiting animal manure and crop silage as feedstock and performed a cost-benefit analysis for the assessment of the investments' viability. Finally, GIS-based AHP approaches were employed by Wu et al. [67] and Herrera-Seara et al. [25] for the criteria weights assignment, after defining the hierarchical structure of the problem and conducting pair-wise comparisons of the associated criteria, for biomass-based biofuel plants and biomass plants site selection, in Virginia, USA and Grenada, Spain respectively.

3 Methodology

This study aims to develop a useful methodology for clarifying and prioritizing at a regional level, the most suitable locations for siting solar and wind farms, as well as biomass and biogas plants. By employing geographical information systems and multicriteria analysis process, all the required information for siting renewable energy systems can be incorporated, for the minimization of the impacts on the natural and human environment and the maximization of the economic and technical potential.

The adopted methodology incorporates the same steps for the prioritization of the available locations, for each renewable energy technology studied. The first step constitutes of analyzing the current situation of the area investigated, locating all the required data that can affect the siting of renewable energy installations, such as: settlements, areas of environmental interest, areas and elements of cultural heritage, the main road network, the electricity transmission networks, the hydrographic network, land cover etc.

The next step constitutes of identifying the exclusion zones, where the siting of each of the renewable energy technologies studied is not permitted, based on the Specific Framework for the Spatial Planning and Sustainable Development for the Renewable Energy Sources [85] and related legislation. After the identification of the exclusion zones and minimum allowable distances from neighboring uses or activities (settlements, archaeological sites, monuments, areas of environmental interest etc.) according to the national legislation plan, the legally available areas for siting renewable energy installations are derived. Moreover, a stricter socio-environmental scenario is also evaluated, taking into account the specific environmental characteristics of Crete.

Furthermore, the legally available areas and the available areas of the socio-environmental scenario for each renewable energy technology are evaluated through a multicriteria analysis process, based on criteria derived from the national legislation or the literature, such as wind, solar, biomass potential, slope, elevation, distances from main roads, the electricity transmission and hydrographic network, the areas of environmental interest and the visibility from most visited areas etc. Especially for minimum distances not specifically determined in the national legislation, a comprehensive literature review is performed, for the construction of the criteria scale, as it is shown in Table 3.1.

Table 3.1 Criteria Suitability Scale

Priority scale	Score
Not Suitable	4
Less Suitable	3
Moderately Suitable	2
Suitable	1
Particularly Suitable	0

The final step consists of presenting the sustainable locations, accruing from the multicriteria analysis process, concerning the available siting areas of the socio-environmental scenario, with a high percentage of priority (greater than 60%), for each renewable energy technology studied. In addition, the maximum capacity and power of each technology, in each municipality is calculated, in order to guarantee the sustainable development of the region. The relative importance of the criteria considered, for each of the renewable technologies studied, is evaluated through pair-wise comparison performed by involved groups (e.g. environmental groups, policy makers, academic community etc.) and the implementation of an Analytical Hierarchy Process (AHP). Finally, a sensitivity analysis is performed, considering alternative scenarios for the criteria weights, for checking the sensitivity of the methodology's results.

The steps described above are presented in Figure 3.1 and were applied for the identification of the sustainable RES siting areas in the Regional Unit of Rethymno, as presented in Figure 3.2. The analysis is performed by the employment of a Geographic Information System (GIS), as it is the most suitable tool for solving spatial problems. GIS has the ability to combine the advantages of data bases and a realistic visualization of the registered spatial information can be performed. In this study, ESRI's ArcGIS 10.3 was used, which offers multiple geoprocessing tools and is enriched with the extensions of the Spatial, 3D, Geostatistical and Network analyst for data management, conversion and spatial modeling [76]. In addition, ArcGIS is compatible with vector and raster data and offers the ability to geocode data in terms of images and access databases. Finally, it uses the Python programming language and the users can create their own scripts for additional capabilities and functions.

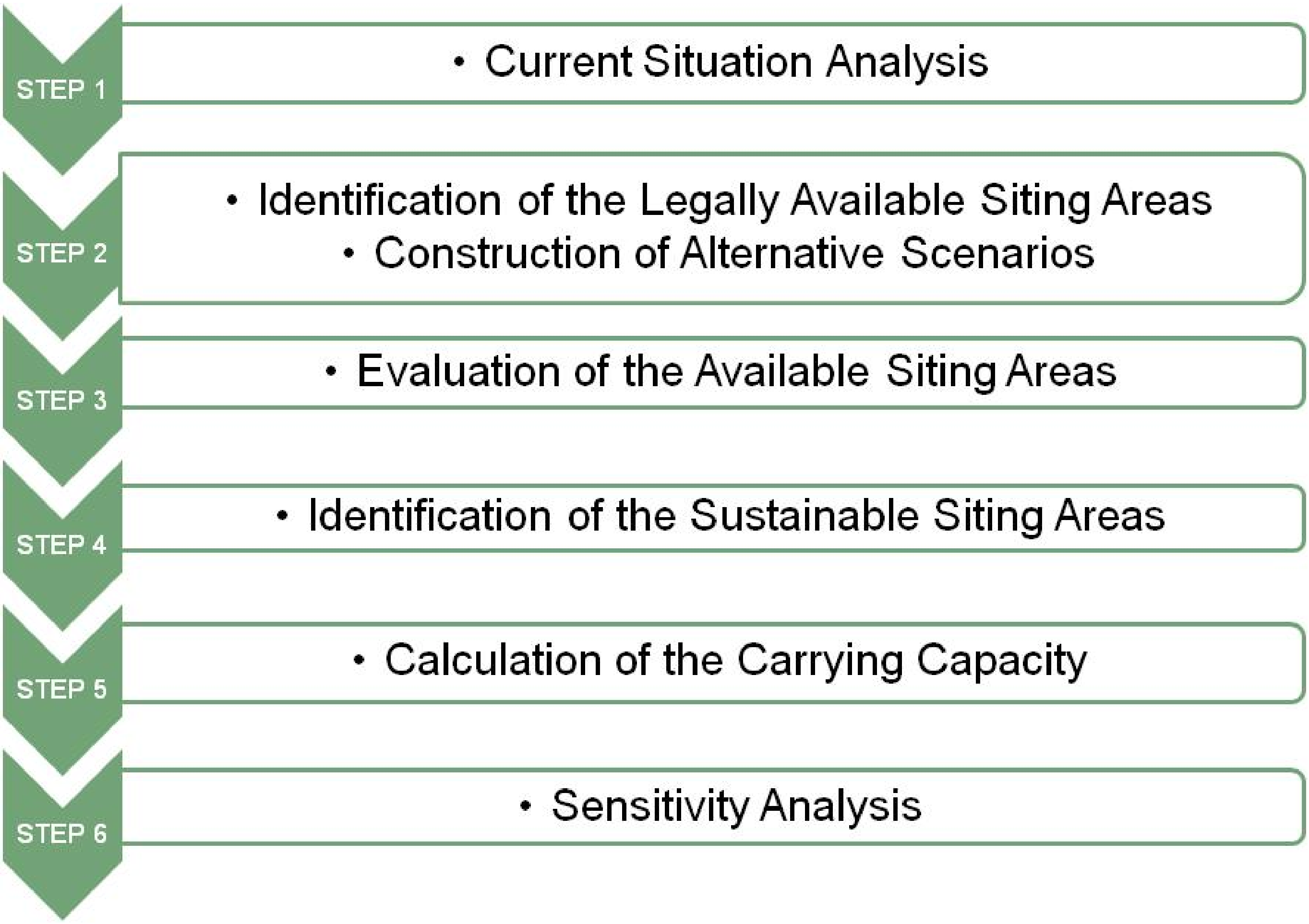


Figure 3.1 Steps of the adopted methodology

In the following Sections, the detailed methodology for each RES technology studied is presented, describing the exclusion and evaluation criteria, the alternative scenarios employed, as well as the sustainable siting areas accruing.

SUSTAINABLE SITING AREAS IDENTIFICATION METHODOLOGY FOR:
WIND AND SOLAR ENERGY INSTALLATIONS, AS WELL AS FOR BIOMASS AND BIOGAS PLANTS

CURRENT SITUATION ANALYSIS OF THE REGIONAL UNIT OF RETHYMNO:
Collection of all the required spatial data that can affect the siting of RES

EXCLUSION CRITERIA DETERMINATION BASED ON THE LEGISLATION:
Exclusion areas and minimum allowable distances from neighboring uses based on:

The Specific Framework for the Spatial Planning and the Sustainable Development for the Renewable Energy Sources (Official Government Gazette 2464/2008)
Law 3851/2010

IDENTIFICATION OF THE LEGALLY AVAILABLE SITING AREAS

ADDITIONAL EXCLUSION FOR WIND ENERGY INSTALLATIONS OF:

- The Sites of Community Importance (SCIs) of the NATURA 2000 network
- The rocky islets surrounding the Regional Unit of Rethymno

ADDITIONAL EXCLUSION FOR LARGE-SCALE PV AND CSP FARMS OF:

- The SCIs of the NATURA 2000 network
- The forests
- The rocky islets surrounding the Regional Unit of Rethymno
- The aesthetically and scientifically highly valued geotopes (500m buffer distance)
- Settlements and traditional settlements

ADDITIONAL EXCLUSION FOR BIOMASS AND BIOGAS PLANTS OF:

- The SCIs of the NATURA 2000 network
- The rocky islets surrounding the Regional Unit of Rethymno
- The aesthetically and scientifically highly valued geotopes (500m buffer distance)
- The coastline (50m buffer distance)

IDENTIFICATION OF THE AVAILABLE AREAS OF THE SOCIO-ENVIROMENTAL

EVALUATION CRITERIA DETERMINATION FOR WIND ENERGY INSTALLATIONS SITING:

Distance from the NATURA 2000 sites
Distance from water bodies
Distance from archaeological sites and monuments
Distance from antennas
Distance from national defense installations
Distance from the high voltage lines
Distance from the road network
Slope
Altitude
Visibility from most visited sites
Wind potential

EVALUATION CRITERIA DETERMINATION FOR SOLAR ENERGY INSTALLATIONS SITING:

Distance from water bodies
Distance from the coastline
Land cover
Aspects
Distance from the electricity transmission lines
Distance from the road network
Slope
Elevation
Visibility from most-visited sites
Solar potential:
Annual GHI for PVs
Annual DNI for CSPs

EVALUATION CRITERIA DETERMINATION FOR BIOMASS OF BIOGAS PLANTS SITING:

Distance from water bodies
Distance from SCIs of the NATURA 2000 network
Distance from archaeological sites, monuments and monasteries
Distance from the electricity transmission lines
Distance from the road network
Slope
Visibility from most visited areas
Biomass/Biogas potential:
Annual pruning wood biomass potential
OR
Distance from large biogas sources

CLASSIFICATION OF EACH CRITERION TO A FIVE CLASS PRIORITY SCALE BASED ON A RIGOROUS LITERATURE REVIEW:

Each cell of the study area has a score between 0 (particularly suitable) and 4 (unsuitable), for each criterion

CRITERIA WEIGHTS ASSIGNMENT BASED ON AN ANALYTICAL HIERARCHY PROCESS (AHP):

Criteria pair-wise comparisons by involved groups, for each RES:
A member from the policy makers, the power supplier, the academia and of an environmental group, as well as two engineers
Aggregation of the individual priorities based on the geometric mean method

PRIORITY MAPS PRODUCTION FOR EACH RES:
Weighted Sum Aggregation of the criteria for each RES
Each cell of the study area, for each RES, has a score between 0 and 4, where 0 corresponds to 100% priority and 4 corresponds to 0% priority

SUSTAINABLE SITING AREAS IDENTIFICATION:
The available areas of the socio-environmental scenarios with a priority percentage greater than 60%
Additional area constraints for the solar energy installations
Calculation of the municipalities' potential RES coverage

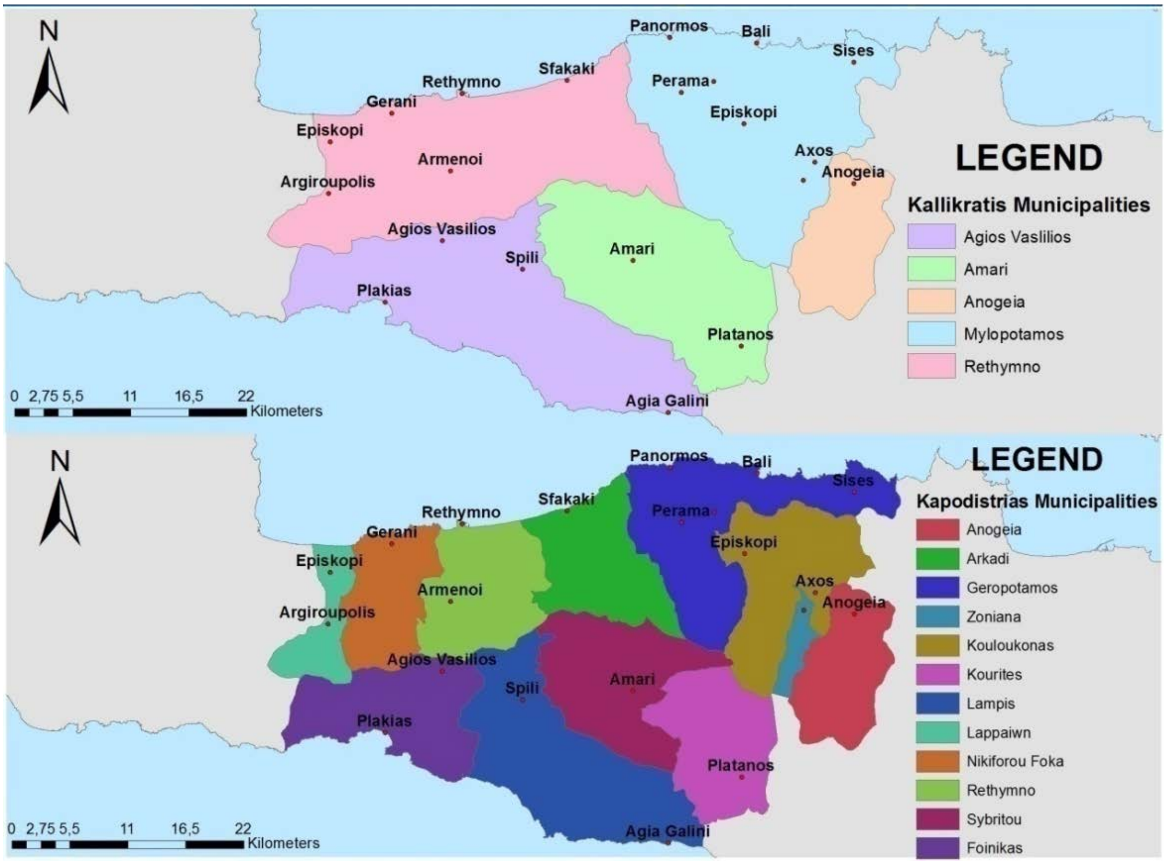
CARRYING CAPACITY PER MUNICIPALITY CALCULATION:
Calculation of the potential maximum power (wind and solar energy installations) or energy potential (biomass and biogas plants) per municipality, taking into account legislation constraints or the highest priority areas

SENSITIVITY ANALYSIS IMPLEMENTATION:
Implementation of alternative scenarios for the criteria weights
Scenarios: Equal-weighted, Techno-economic, Socio-environmental, Safety

Figure 3.2 Description of the methodology implementation for the case study of the Regional Unit of Rethymno

3.1 The case study of the Regional Unit of Rethymno

The Regional Unit of Rethymno is one of the four Regional Units of Crete, including five municipalities. As part of the 2011 Kallikratis government reform, the Rethymno Regional Unit was created out of the former prefecture, with the same territory and reorganization of the older municipalities to the five municipalities [110] presenting in Table 3.2 and Map 3.1. Rethymno Regional Unit has a mountainous terrain, especially in its eastern part, where the Psyloritis Mountain is located and flat lands can be found to the northern and southern coastal areas. Maps R.2 to R.4 (Map Annex) present the terrain of the Regional Unit of Rethymno and specifically the elevations, slopes and aspects of the study area. In addition, the climate is mild Mediterranean, with mild winters and hot summers, while in the mountainous areas, it can be slightly continental. Finally, in Maps R.5 to R.9 (Map Annex), the wind, solar, biomass and biogas potential of the study area can be found.



Map 3.1 Municipalities administrative boundaries of the Regional Unit of Rethymno, according to Kapodistrias and Kallikratis government reform

As it was mentioned before, the adopted methodology, for each of the RES technologies investigated, starts with the analysis of the Regional Unit's current situation. Map R.1 presents all the data that can affect the siting of RES installations, while the data sources are presented in Table 3.3. In addition, the locations of national parks, radars, airports and aesthetic forests can also affect the siting of RES installations, but there are no such areas in the Regional Unit of Rethymno.

Table 3.2 Information about the Regional Unit of Rethymno

[1]Municipality	Area (km^2)	[2]Population	[3]Electric power consumption (GWh/y)
Agios Vasilios	359.435	7,427	37.6
Amari	277.421	5,915	29.9
Anogeia	112.61	2,379	12
Mylopotamos	352.823	14,363	72.7
Rethymno	393.835	55,525	281.1

[1] According to Kallikratis government reform [110]
[2] Population census of 2011 [98]
[3] Annual Electric power consumption per capita for 2014 in Greece, 5063 kWh/capita [97]

Table 3.3 Data and sources

Data	Details	Source
Coasts	Bathing Beaches, included in the monitoring program of water quality, coordinated by the Decentralized Administration of Crete	[99]
Lakes	Lake and transitional water bodies, according to the River Basin Management Plan of the Water Department of Crete	[99] [69]
SCIs and SPAs	Sites of community importance (SCI) and Special Protection Areas (SPA) from the NATURA 2000 network, according to the Ministry of Environment, Energy and Climate change	[100]
CORINE 2012	CORINE 2012 land cover maps, according to the National Cadastre and Mapping Agency	[102]
Tourist Accommodations	Geocoding of 5,4 and 3 stars tourist accommodations sites from the Hellenic Chamber of Hotels and the Hotel Owners Club of the Regional Unit of Rethymno	[104] [103]

Table 3.3 Data and sources

Data	Details	Source
Urban Control Zone Georgioupolis-Episkopi	Geocoding of area 3, where it is forbidden any construction, according to Law 211Δ/1990	[80]
Geotopes	Point locations of geotopes sites in Crete	[75]
Municipalities' Boundaries of the Rethymno Regional Unit	Formation of the Boundaries from the former communities' boundaries, following the changes occurred from the Kapodistrias and Kallikratis government reform	[105] [110]
Ports-Marinas	Ports and Marinas position	[74]
Traditional settlements	Declared Traditional Settlements	
Settlements	Approved settlements' boundaries	
Monasteries	Declared Monasteries	
Camps	Organized Camp Sites	
Antennas	Antennas with installation permit	
Monuments	Declared cultural monuments and historical sites	
Archaeological sites	Absolute protection zone (Zone A) of archaeological sites	
National Defense Installations	Sites of military facilities	
Quarries	Operating mining zones	
Road Network	National, provincial and community roads	
Electricity Distribution Lines	High voltage lines	
Important places for bird's priority species	Breeding areas, colonies and feeding areas of priority species	
Specific Management Plans and Specific Environmental Studies	Areas of special environmental studies	
Rivers	Streaming rivers	
Wind potential	Average annual wind speed	
Elevation	Triangular irregular network (TIN) of the surface of Crete (Production of the Digital Elevation Map (DEM) of the Regional Unit of Rethymno, with 50x50m cell size)	
Slopes	Produced in ArcGIS 10.3 from the DEM of	

Table 3.3 Data and sources

Data	Details	Source
Aspects	the Regional Unit of Rethymno, by employing the associated tools of Spatial Analyst's extension. (cell size 50x50m)	
Visibility	Produced in ArcGIS 10.3 from the DEM of the Regional Unit of Rethymno and several observer points, by employing the VIEWSHED tool of the Spatial Analyst's extension (cell size 50x50m)	
Solar Potential	Produced in ArcGIS 10.3 from the AREA SOLAR RADIATION tool of Spatial Analyst's extension with a 50x50m cell size (Section 3.3.2)	
Biomass and Biogas Potential	Produced in ArcGIS 10.3 (Section 3.4.2)	

3.2 Wind energy installations site selection evaluation and exclusion criteria

In this Section, the detailed methodology for defining the exclusion and evaluation criteria for wind energy installations is presented. Following Figure 3.2, the exclusion and evaluation criteria are described, as well as the alternative scenarios employed. The selected evaluation criteria are derived from a rigorous literature review (Annex A) and are converted to the priority scale presented in Table 3.1. Finally, the priority scales adopted by studies found in the literature, concerning the wind farms siting problem, are presented in Annex C.

3.2.1 Exclusion criteria for wind energy installations site selection

As Figure 3.1 presents, the next step after analyzing the current situation of the study area is to determine exclusion areas, where the siting of wind installations is not permitted, according to the legislation. SFSPSD-RES [85] was coordinated by the Hellenic Ministry of the Environment, Physical Planning and Public Works and identifies criteria and guidelines for the siting of RES projects. According to SFSPSD-RES [85], the siting of wind installations is not permitted inside:

1) World heritage areas, archaeological monuments and historical places of high importance, as well as in archaeological sites of zone A
2) Areas of absolute protection of nature, according to Specific Management Plans and Specific Environmental Studies
3) Wetlands RAMSAR
4) Centre of national forests, nature monuments, aesthetic forests
5) Sites of Community Importance (SCIs) of NATURA 2000 network
6) Inside urban plans and settlement boundaries
7) Areas of integrated touristic development and organized productive activities of the tertiary sector, thematic parks and touristic ports
8) Bathing Beaches, included in the monitoring program of water quality
9) Mining zones and activities
10) Other areas or zones currently falling under a special land-use regime, according to which the siting of wind installations is not permitted as long as they are in force

However, points 5 and 10 are modified by the subsequent Law 3851/2010 [86], which states in Article 8, that the siting of RES installations is permitted inside SCIs, as a means for the climate change mitigation. In addition, this law states in Article 9 that for siting RES installations, only spatial, urban and regulatory land-use plans, that are in agreement with the SFSPSD-RES [85] are taken into consideration. In the Regional Unit of Rethymno, such plans are approved for:

- the former Lampis Municipality [81]
- the former Lappaion Municipality [82], [83]
- the Rethymno Municipality [84]
- the area of Georgioupolis-Episkopi [80]

From the aforementioned plans, only the area 3 of the Urban Control Zone of Georgioupolis-Episkopi is taken into consideration, which contains the biotope’s centre, where any construction is forbidden. As for the rest of the plans, they do not mention RES technologies, so they are not taken into consideration. With the identification of the aforementioned exclusion zones, Map W.1 (Map Annex) is constructed, where rivers and lakes are also excluded due to physical constraints. In addition, military facilities are also excluded for the same reason that aviation facilities and activities must be protected from electromagnetic interferences.

In addition, to the aforementioned exclusion zones, SFSPSD-RES [85] sets minimum distances from neighboring uses, for siting wind installations. These safety distances are presented in Table 3.4, concerning the minimum allowable distances from areas of environmental interest (Map W.2), cultural interest (Map W.3), urban activities (Map W.4), technical infrastructure (Map W.5) and productive activities (Map W.6).

Table 3.4 Minimum allowable distances from wind energy installations, according to SFSPSD-RES [85]

Area	Minimum distances
Areas of environmental interest	
Areas of absolute protection of nature	According to the approved specific environmental study or the relevant Presidential Decree
Centers of national forests, nature monuments, aesthetic forests, wetlands RAMSAR and SCIs of the NATURA 2000 network	Within the frame of the environmental terms and conditions approval
Beaches	1,500m
SPAs of bird habitat	Within the frame of the environmental terms and conditions approval, after conducting a special bird study [2]3,000m from important places of priority bird species
Areas of cultural heritage	
World heritage monuments, archaeological sites and historical places of high importance	3,000m
Zone A of the rest of the archaeological sites	At least 500m
Cultural monuments and historical sites	

Table 3.4 Minimum allowable distances from wind energy installations, according to SFSPSD-RES [85]

Area	Minimum distances
Urban activities	
Towns and settlements with population >2,000 inhabitants, characterized as dynamic, touristic or remarkable	1,000m from the element's boundary
Traditional settlements	1,500m from the element's boundaries
The rest of the settlements	500m from the element's boundaries
Monasteries	500m from the monastery's boundaries
Technical infrastructure and special uses	
Main roads, road network	Safety distance 1.5d=127.5m, where d is the rotor's diameter of a typical wind turbine
High voltage lines	
Antennas, radars	Per case after the approval of the relevant public body
Aviation facilities and activities	
Zones or facilities of production activities	
[1]Rural land of high productivity, land consolidation areas, irrigated agricultural areas	Safety distance 1.5d=127.5m, where d is the rotor's diameter of a typical wind turbine
Aquaculture	
Livestock plants	
Mining zones and activities	500m
Areas of integrated touristic development and organized productive activities of the tertiary sector, thematic parks, touristic ports and institutionalized tourist areas, tourist accommodation and special tourist infrastructures	1,000m from the boundaries of the zone/area

[1] According to Law 3851/2010 (Article 9), in parcels that the competent authority has identified as rural land of high productivity, it is forbidden to exercise any other activity except the agricultural exploitation and the electricity generation from RES. Provided that Law 3851/2010 is subsequent to the official government gazette 2464/2008 (SFSPSD-RES), this minimum allowable distance is not taken into consideration.

[2] According to a specialized bird study, presented from Tsoutsos et al., [74], from the important places of bird priority species, it is recommended a minimum distance of 3,000m to be kept, as birds are recorded to taking avoiding actions between 100-3,000m from turbines in daylight, whereas at night the distances are likely to be closer [14]

With the identification of the aforementioned exclusion zones and buffer distances, the legally available areas for siting wind energy installations are emerging (Map W.7). In addition, a second environmental scenario is also examined, where to the exclusion zones are added:

- The Sites of Community Importance (SCIs) of the NATURA 2000 network, which according to Law 3851/2010 [86] are available for siting RES installations. However, due to the environmental interest and sensitive ecosystems of these sites, they are excluded in this scenario
- The rocky islets surrounding Crete, which administratively belong to the Regional Unit of Rethymno, as these islets are usually habitats of sensitive flora and fauna species

Finally, with the identification of the additional exclusion zones, the available areas, emerging by the application of the environmental scenario are presented in Map W.8.

3.2.2 Evaluation criteria for wind energy installations site selection

The legally available siting areas and the available siting areas of the environmental scenario are evaluated based on selected criteria presenting in Table 3.5. In addition, the available sites are ranked based on the five-class priority scale, presented in Table 3.1. The distance criteria are produced by the EUCLIDEAN DISTANCE tool and the score assignment is performed by employing the RECLASSIFY tool, in ArcGIS 10.3. An example of a map, accruing from this procedure is presented in the Map Annex, concerning the distance from the NATURA 2000 sites (Map W.9). Finally, the classification of each criterion is based on the literature review presenting in Annex C.

Table 3.5 Evaluation criteria of the available areas for wind energy installations siting

Criterion	Criterion type	Goal
Distance from the NATURA 2000 sites	Environmental	Maximization
Distance from water bodies	Environmental	Maximization
Distance from	Aesthetic	Maximization

Table 3.5 Evaluation criteria of the available areas for wind energy installations siting

Criterion	Criterion type	Goal
archaeological sites and monuments		
Distance from antennas	Technical/Safety	Maximization
Distance from national defense installations	Technical/Safety	Maximization
Distance from the high voltage lines	Techno-economic	Minimization
Distance from the road network	Techno-economic	Minimization
Slope	Techno-economic	Minimization
Elevation	Techno-economic /Environmental	Minimization
Visibility from most visited sites	Aesthetic	Minimization
Wind potential	Techno-economic	Maximization

1) *Criterion: Distance from NATURA 2000 sites*

This criterion is purely environmental and includes the distance from Sites of Community Importance (SCI) and Special Protection Areas (SPA) of the NATURA 2000 network. SFSPSD-RES [85] states that wind energy installations are permitted to be sited in SPAs, after conducting a specialized bird study. In this study, a buffer distance of 3,000m was applied from important areas of bird priority species, following a specialized bird study, presented by Tsoutsos et al., [74]. However, the total area of NATURA's 2000 SPAs of bird species cannot be excluded and therefore they are included along with the SCIs in this environmental criterion.

Table 3.6 Distance from the NATURA 2000 sites criterion classification for wind energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	0-200
Less Suitable	3	200-400
Moderately Suitable	2	400-600
Suitable	1	600-800
Particularly Suitable	0	>800

Table 3.1 presents the priority scale of this criterion, consulting the relative scales and buffer distances presented in Annex C, concerning the distances from areas of environmental interest. The prevailing distance in the literature is 1,000m from areas of environmental interest. However, Hofer et al., [26], as well as Sliz-Szkliniarz and Vogt, [53] consider a distance of 500m from areas without sensitive bird species and NATURA sites respectively. Considering an average value of 800m as a threshold for the particularly suitable zone, the criterion classification presented in Table 3.6 is constructed, similar to the relative scale presented by Tsoutsos et al, [74] for wind energy installations site selection in Crete. Finally, it is noted that the aesthetic forest of Vai and the national forest of Samaria are located in a distance a lot longer than 800m from the boundaries of the Regional Unit of Rethymno, so they are not influencing the analysis. Map W.9 presents an evaluation of the available siting areas of the environmental scenario employed, based on this criterion's priority scale.

2) Criterion: Distance from water bodies

This criterion is also environmental, as the natural characteristics of the small rivers and lakes encountered in the study area have to be preserved. Bennui et al., [8], Tsoutsos et al., [74] and Sliz-Szkliniarz and Vogt, [53] consider a distance of 200m as the upper boundary of the unsuitable zone. Table 3.7 present the criterion classification for this study, similar to the classification of the criterion of the distance from areas of environmental interest.

Table 3.7 Distance from water bodies criterion classification for wind energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	0-200
Less Suitable	3	200-400
Moderately Suitable	2	400-600
Suitable	1	600-800
Particularly Suitable	0	>800

3) Criterion: Distance from areas of cultural interest

SFSPSD-RES [85] sets a distance of 500m from archaeological sites and monuments, but it does not define an optimum distance from these sites. In this study, a 500m range on every priority class was defined, producing the criterion classification, presenting in Table 3.8. In Annex C, the scales and buffer distances from areas of cultural interest from the literature can be found. The suitable class of this criterion begins from 2,000m, similar to the buffer distance applied by Voivontas et al., [64].

Table 3.8 Distance from areas of cultural interest criterion classification for wind energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	500-1,000
Less Suitable	3	1,000-1,500
Moderately Suitable	2	1,500-2,000
Suitable	1	2,000-2,500
Particularly Suitable	0	>2,500

4) Criterion: Distance from antennas

Wind turbines may cause interferences to a wide spectrum of electromagnetic signals of the contemporary electromagnetic systems. SFSPSD-RES [85] states that the minimum distance from antennas is defined per case by the competent authority. In this study, the criterion classification presenting in Table 3.9 was based on the literature review conducted. Szurek et al., [57], and Tsoutsos et al., [74] set the upper boundary of the unsuitable zone to 200m, while Hansen, [24] defines a distance longer than 1,500m for an area to be highly suitable for wind turbines installation. Finally, it is noted that in the Regional Unit of Rethymno, radars have not been installed and the radars installed in the other Regional Units are in a distance longer than 1,800m.

Table 3.9 Distance from antennas criterion classification for wind energy installations siting

Priority scale	Score	Distance (m)
Unsuitable	4	0-200
Less Suitable	3	200-600
Moderately Suitable	2	600-1,200
Suitable	1	1,200-1,800
Particularly Suitable	0	>1,800

5) *Criterion: Distance from national defense installations*

This criterion is also associated with the electromagnetic interferences, which may cause problems to signal transmission and communications in airports and national defense installations. In the Regional Unit of Rethymno, an airport has not been established, but there are national defense installations, which have to be protected. In the literature, a distance shorter than 3,000m from airports is considered unsuitable for wind turbines siting [8], [31], [53], [74]. The criterion classification in this study is presented in Table 3.10, taking into account the scale of Bennui et al., [8] and Tsoutsos et al., [74].

Table 3.10 Distance from national defense installations criterion classification for wind energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	0-3,000
Less Suitable	3	3,000-6,000
Moderately Suitable	2	6,000-9,000
Suitable	1	9,000-12,000
Particularly Suitable	0	>12,000

6) *Criterion: Distance from the high voltage lines*

SFSPSD-RES [85] defines a minimum distance of 127.5m from high voltage lines and states that the maximum distances from the electricity transmission lines are defined by the competent authority. This criterion is an important techno-economic criterion, as the shorter the distance from the transmission lines, the less interference to the physical environment will be needed to connect the wind energy installations to the electricity network.

Baban and Parry, [6] set a maximum distance of 10,000m, Hofer et al., [26] consider less suitable the areas in a distance of 9,000m, Noorollahi et al., [39] in a distance of 10,000m and Sanchez-Lozano et al., [47] in a distance of 5,000m from the wind turbines. In this study, the areas that are further than 8,000m from the wind energy installations are considered unsuitable and the criterion classification is presented in Table 3.11.

Table 3.11 Distance from high voltage lines criterion classification for wind energy installations siting

Priority scale	Score	Distance (m)
Unsuitable	4	>8,000
Less Suitable	3	6,000-8,000
Moderately Suitable	2	4,000-6,000
Suitable	1	2,000-4,000
Particularly Suitable	0	127.5-2,000

7) Criterion: Distance from the road network

This criterion is similar to the distance from the electricity transmission lines, as the closer, the wind turbines are sited to the road network, the less the interference for road construction. SFSPSD-RES [85] defines a minimum distance of 127.5m for safety reasons and a maximum of 10,000m from the road network for wind turbines siting in islands. Based on these minimum and maximum distances, the priority scale presenting in Table 3.12 is produced. In Annex C, the relative minimum and maximum distances from the literature review can be found.

Table 3.12 Distance from the road network criterion classification for wind energy installations siting

Priority Scale	Score	Distance (m)
Forbidden		<127.5 και >10,000
Unsuitable	4	8,000-10,000
Less Suitable	3	6,000-8,000
Moderately Suitable	2	4,000-6,000
Suitable	1	2,000-4,000
Particularly Suitable	0	127.5-2,000

8) Criterion: Slope

SFSPSD-RES [85] does not define a maximum slope for siting wind energy installations. However, in the literature, this criterion is quite common, as it can be seen from Table A.2. Steep slopes require extensive earthworks for slope smoothing, which can be an additional burden to the natural environment. In this study, a value of 30% was defined as the lower limit of the unsuitable class, as Hofer et al. [26] defined in their study. In addition, the upper limit of the particularly suitable class was set to 15%, which is one of the prevailing values in the literature (Annex C). The detailed criterion classification is presented in Table 3.13.

Table 3.13 Slope criterion classification for wind energy installations siting

Priority Scale	Score	Slope (%)
Unsuitable	4	>30
Less Suitable	3	30-25
Moderately Suitable	2	25-20
Suitable	1	20-15
Particularly Suitable	0	0-15

9) Criterion: Elevation

This criterion is of both environmental and techno-economic significance, as in high altitude, rare flora and fauna species are encountered and the road and electricity transmission network is sparse. In addition, as the altitude is increasing, the air density is decreasing, which can, in turn, abate the energy efficiency of the wind turbines. However, wind speed is known to increase with altitude, which can offset the decreased air density problem [50]. In this study, the criterion classification was based on the literature review and is presented in Table 3.14.

Table 3.14 Elevation criterion classification for wind energy installations siting

Priority Scale	Score	Elevation (m)
Unsuitable	4	>1,500
Less Suitable	3	1,100-1,500
Moderately Suitable	2	700-1,100
Suitable	1	300-700
Particularly Suitable	0	0-300

10) Criterion: Visibility from most-visited sites

The siting of wind turbines sometimes causes social reactions, due to visual impacts, they may cause to settlements, archaeological sites and areas of tourist activities. Therefore, the visibility criterion was defined, which takes into account the visibility from: settlements, traditional settlements, archaeological sites, monuments, beaches, ports, marinas, camps and tourist accommodations. The visibility analysis was conducted in ArcGIS 10.3, by employing the VIEWSHED analysis tool of the Spatial Analyst toolbox. After, defining the visible and invisible areas for each of the aforementioned sites, the criterion classification was produced, as described in Table 3.15, taking into account the classification produced by Tsoutsos et al., [75]. Finally, a visual representation of this criterion classification can be found in Map W.10 (Map Annex).

Table 3.15 Visibility criterion classification for wind energy installations siting

Priority Scale	Score	Visibility
Unsuitable	4	Areas visible from most-visited sites
Less Suitable	3	Invisible areas from archeological sites
Moderately Suitable	2	Invisible areas from archeological sites and traditional settlements
Suitable	1	Invisible areas from archeological sites, traditional settlements, monuments, beaches, ports-marinas, camps and tourist accommodations
Particularly Suitable	0	Invisible areas

11) Criterion: Wind potential

Wind speed is an important factor for wind energy installations siting, as it defines the efficiency and the selection of the appropriate nominal power of wind turbines. In this study, the upper limit of the unsuitable zone was set to 4m/s, as the constraint applied by Tegou et al.,[59] and the upper limit of the suitable zone was defined as 8m/s, which according to Tsoutsos et al.,[74] is the threshold for an area to be characterized as having a good wind potential. The classes of the wind potential criterion expressed as wind speed are presented in Table 3.16.

Table 3.16 Wind potential criterion classification for wind energy installations siting

Priority Scale	Score	Wind speed (m/s)
Unsuitable	4	0-4
Less Suitable	3	4-6
Moderately Suitable	2	6-8
Suitable	1	8-10
Particularly Suitable	0	>10

3.3 Solar energy installations site selection evaluation and exclusion criteria

In the previous Section, the exclusion and evaluation criteria for wind farms siting were presented. Similarly, in this Section, the exclusion zones and evaluation criteria of the available siting areas for PV and CSP installations are presented. The adopted methodology is the same one presented in Figure 3.2 and the evaluation areas are derived from applying the exclusion zones from the legislation and the exclusion zones of a stricter environmental scenario. Finally, the weights assigned from the AHP, as well as the sustainable siting areas accruing are presented in detail in Section 4.

3.3.1 Exclusion criteria for solar energy installations site selection

After analyzing the current situation of the Regional Unit of Rethymno, the exclusion criteria are presented in this Section, following the relative legislation. SFSPSD-RES [85] states that solar energy installations are not permitted to be installed in:

1) World heritage areas, archaeological monuments and historical places of high importance, as well as in archaeological sites of zone A
2) Areas of absolute protection of nature, according to Specific Management Plans and Specific Environmental Studies
3) Centre of national forests, nature monuments, aesthetic forests
4) Sites of Community Importance (SCIs) of NATURA 2000 network
5) Forests and high productivity agricultural areas

6) Other areas or zones currently falling under a special land-use regime, according to which siting of wind installations is not permitted as long as they are in force

As it was mentioned in Section 3.2.1, RES installations siting is permitted inside SCIs, as a means for the climate change mitigation, according to the subsequent Law 3851/2010 [86] and therefore point 4 is annulled. In addition, only the area 3 of the Urban Control Zone of Georgioupolis-Episkopi is taken into consideration concerning point 6, as the other spatial, urban and regulatory land-use plans, presented in Section 3.2.1 do not mention RES technologies, and therefore they are not in agreement with the SFSPSD-RES [85]. Moreover, Law 3851/2010 [86] states in Article 9, paragraph 6 that, in parcels that the competent authority has identified as rural land of high productivity, it is forbidden to exercise any other activity except the agricultural exploitation and the electricity generation from RES. Specifically for PV installations, this article states that it is permitted to be installed in parcels characterized as high productivity agricultural land. Finally, based on Law 3851/2010 [86] point 5, from the aforementioned exclusion zones is annulled.

After the clarification of the aforementioned points (Map S.1), considering which of them are still in force, Map S.2 (Map Annex) is constructed from the legally exclusion zones, where rivers, lakes and the road network are also excluded due to the physical constraints they evoke. However, a second socio-environmental scenario is also considered where to the exclusion areas are added (Map S.3):

- The Sites of Community Importance of the NATURA 2000 network
- The forests (the corresponding CORINE 2012 codes were considered, as the forest authority has not yet issued the forest maps of the Regional Unit of Rethymno)
- The aesthetically and scientifically highly valued geotopes (the corresponding data are point features and therefore an additional 500m distance was considered for their exclusion)

- The rocky islets surrounding Crete, which administratively belong to the Regional Unit of Rethymno, as these islets are usually habitats of sensitive flora and fauna species
- The settlements and traditional settlements are also excluded, as the studied large-scale installations require a large surface area to be occupied and therefore the visual impacts can be significant, in addition to the noise impacts they cause

With the definition of the additional exclusion zones, Map S.4 (Map Annex) is produced, presenting the available areas for siting PV and CSP installations in the Rethymno Regional Unit of the socio-environmental scenario.

3.3.2 Evaluation criteria for solar energy installations site selection

The available siting areas of the two adopted scenarios are evaluated based on the criteria presenting in Table 3.17. In this Section, a detailed description of the selected criteria is conducted, constructing the classification of each criterion, based on the suitability scale displayed in Table 3.1. In addition, in Annex D, the literature review concerning the selected criteria and the adopted suitability scale of each study can be found.

Table 3.17 Evaluation criteria of the available areas for solar energy installations siting

Criterion	Criterion type	Goal
Distance from water bodies	Environmental	Maximization
Distance from the coastline	Aesthetic/ Technical	Maximization
Land cover	Environmental/ Aesthetic	Barren and low productivity areas, with low aesthetic value
Aspects	Techno-economic	SE-SW
Distance from the electricity transmission lines	Techno-economic	Minimization
Distance from the road network	Techno-economic	Minimization
Slope	Techno-economic	Minimization

Table 3.17 Evaluation criteria of the available areas for solar energy installations siting

Criterion	Criterion type	Goal
Elevation	Techno-economic/Environmental	Minimization
Visibility from most-visited sites	Aesthetic	Minimization
Solar potential	Techno-economic	Maximization

1) *Criterion: Distance from the road network*

This criterion can significantly influence the construction and maintenance costs of solar energy installations. A buffer distance of 100m is frequently found in the literature for aesthetic and safety reasons ([3], [35], [62], [46]). In addition, for the maximum distance from the road network, Carrion et al., [11] set a 3,000m distance, whereas Uyan, [62] and Yushchenko et al., [68] set a distance of 5,000m. In this study, the criterion classification is presented in Table 3.18, taking into account the related suitability scale of Tsoutsos et al., [75] for large-scale solar energy installations siting in Crete.

Table 3.18 Distance from the road network criterion classification for solar energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	<100 and >4,000
Less suitable	3	3,000-4,000
Moderately suitable	2	2,000-3,000
Suitable	1	1,000-2,000
Particularly suitable	0	100-1,000

2) *Criterion: Distance from the high voltage lines*

For large scale solar energy installations siting, as the ones investigating in this study, the proximity to the electricity transmission lines is an important criterion for the installation's connection and reduction of the associated costs. Due to lack of spatial data for the medium voltage lines of the Regional Unit of Rethymno, this criterion was limited to the evaluation of the distance from the high voltage lines, whose spatial representation was available.

From the literature review presenting in Annex D, the most frequent upper bound adopted for the highly suitable class is of 1km distance from the electricity transmission lines ([35], [11], [68]), while for the unsuitable class is a 10km distance ([35], [11], [62]). Based on the literature review, the priority scale of this criterion was constructed, as presented in Table 3.19.

Table 3.19 Distance from the high voltage lines criterion classification for solar energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	>10,000
Less Suitable	3	7,000-10,000
Moderately Suitable	2	4,000-7,000
Suitable	1	1,000-4,000
Particularly Suitable	0	<1,000

3) Criterion: Slope

The Regional Unit of Rethymno, as it can be seen from Map R.4, presents a rough terrain with steep slopes, which incommodes the siting of large-scale solar energy installations. Therefore, extensive earthworks may be required for slope smoothing, as steep slopes make more difficult the right siting (with the optimum angle) of the PV panels. Carrion et al., [11] set the upper bound of the unsuitable slopes to 30%, Hott et al., [28] consider a constraint of 27%, Mondino et al., [36] of 15% and Sun et al., [56] of 7%. For this study, the priority scale is presented in Table 3.20, where the unsuitable class begins from 28%.

Table 3.20 Slope criterion classification for solar energy installations siting

Priority Scale	Score	Slope (%)
Unsuitable	4	>28
Less Suitable	3	21-28
Moderately Suitable	2	14-21
Suitable	1	7-14
Particularly Suitable	0	0-7

4) Criterion: Elevation

This criterion, as it was mentioned in Section 3.2.2, is both environmental and techno-economic. The reason for its selection is the same as for the study of wind energy installations siting. In high altitudes, rare flora and fauna species can be found and the road and electricity transmission network is sparse. Therefore, the criterion classification was considered the same as in the study for wind energy installations siting, presented in Table 3.14.

5) Criterion: Aspects

As for the slope criterion, the criterion of aspects is quite important for the efficiency of solar energy installations. Map R.5 presents the facing directions of the slopes in the Regional Unit of Rethymno, where the intense slope variation leads to a great fluctuation of these directions. From the literature review accrues that the most suitable aspect is the south-facing [10], so that the PV panels can receive the greatest amount of solar energy during the daytime. In addition, most studies consider suitable, the aspects between 112.5^o and 247.5^o, namely the southeastern to southwestern aspects ([28], [66], [21]). Based on the aforementioned points, this criterion's priority scale was constructed, as it is shown in Table 3.21 and Map S.5 (Map Annex).

Table 3.21 Aspects criterion classification for solar energy installations siting

Priority Scale	Score	Aspects
Unsuitable	4	Northern
Less Suitable	3	Northeastern and Northwestern
Moderately Suitable	2	Eastern and Western
Suitable	1	Southeastern and Southwestern
Particularly Suitable	0	Southern

6) Criterion: Land cover

The land cover criterion is quite common in the literature because of the large areas that solar energy installations require for their siting. Most reviewed studies consider the agricultural areas as unsuitable for the preservation of the agricultural production. In addition, it is usually suggested solar energy installations to be sited in low vegetated areas, as forest areas have to be preserved and the dense vegetation can reduce the efficiency of the installed systems [3]. SFSPSD-RES [85] suggests as priority areas for siting solar energy installations the barren and low productivity areas. Moreover, Tsoutsos et al., [75] suggest as suitable siting areas some urban land uses (inactive quarries, military areas, hospitals, industrial areas), with low aesthetic value and high energy needs. Based on these points, Table 3.22 is constructed, presenting the adopted criterion classification (Map S.6).

Table 3.22 Land cover criterion classification for solar energy installations siting

Priority Scale	Score	Land cover
Unsuitable	4	Permanent crops and forests
Less Suitable	3	Other agricultural areas
Moderately Suitable	2	Low vegetation lands
Suitable	1	Urban areas and other land uses
Particularly Suitable	0	Barren areas with little or no vegetation

7) Criterion: Visibility from most-visited sites

The criterion concerning the distance from residential areas is quite common in the literature, as it can be seen from Table B.1. However, this criterion can be ambiguous for siting PV installations, as, from a technical point of view, siting near residential areas can reduce energy losses and connection costs. On the other hand, SFSPSD-RES [85] states that solar energy installations should preferably be invisible from most-visited areas. Therefore, it is suggested to investigate the visual impacts in residential areas and sites of cultural interest, for which buffer distances were not taken into consideration. Instead, a viewshed analysis was conducted, as in the study for wind energy installations siting, studying the visibility from settlements, traditional settlements, archaeological sites, monuments, beaches, ports, marinas, camps and tourist accommodations. The criterion classification is the same as for the wind energy installations siting and was presented in Table 3.15.

8) *Criterion: Distance from the coastline*

The reasoning behind selecting this evaluation criterion has multiple aspects, as technical, environmental and aesthetic reasons require its selection. According to Law 2971/2001 [87], the main purpose of the seashore, including a 50m distance from the coast, is the free access to them. In addition, siting solar energy installations in proximity to the shoreline can cause visual impacts to tourist activities and saltiness can reduce the efficiency and life span of solar energy systems. Finally, reasons for preservation of the marine ecosystems from pollution incidents are also taken into account. Georgiou and Skarlatos, [21] set a buffer distance of 200m from the coastline and Tsoutsos et al., [75] define as particularly suitable, the areas located more than 200m far from the seashore. For this study, the criterion classification is presented in Table 3.23.

Table 3.23 Distance from the coastline criterion classification for solar energy installations siting

Priority Scale	Score	Distance (m)
Unsuitable	4	<50
Less Suitable	3	50-100
Moderately Suitable	2	100-150
Suitable	1	150-200
Particularly Suitable	0	>200

9) Criterion: Distance from water bodies

Proportionally to the previous criterion, water bodies have to be protected, as they constitute sensitive ecosystems, where some materials of the PV systems can contaminate the aquifer, in case of abandonment [3]. However, Merrouni et al., [35] consider the need of proximity to water bodies, for cleaning purposes of the PV panels, especially in barren dusty areas, such as Saudi Arabia and cooling purposes of the CSP systems [2]. In this study, this criterion was set to be maximized, as the thermal contamination of the water bodies, in cases where water is used for cooling purposes of the CSP systems is also a serious environmental impact. The priority scale of this criterion is presented in Table 3.24 and the classification concerns both the CSPs and PVs siting.

Table 3.24 Distance from water bodies criterion classification for solar energy installations siting

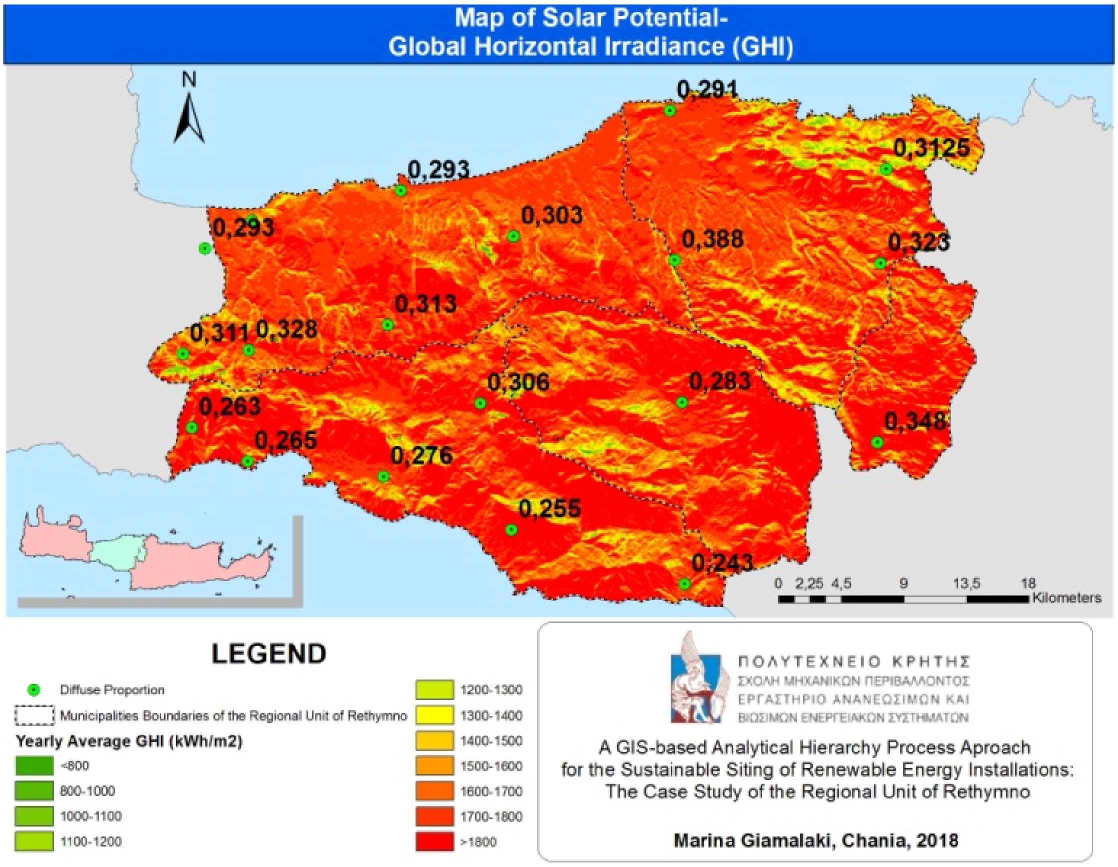
Priority Scale	Score	Distance (m)
Unsuitable	4	<100
Less Suitable	3	100-200
Moderately Suitable	2	200-300
Suitable	1	300-400
Particularly Suitable	0	>400

10) Criterion: Solar potential

The solar potential criterion is a very important one, as it can individually exclude areas, where the solar potential is not adequate for siting solar energy installations. From the literature review, a value of 1,800 kWh/m^2 for the yearly average solar irradiance at ground level is considered ideal for solar energy installations siting [35], [2], [68]. However, as it was mentioned in Section 2.3, PV technology works in the presence of both DNI and DHI solar irradiation, unlike CSP technology which works only by using the DNI. Therefore, two different maps were constructed, concerning the yearly average Global Horizontal and Direct Normal Irradiance for the Regional Unit of Rethymno, as it shown in Maps R.6 and R.7 (Map Annex). For the construction of the aforementioned maps with 50x50m cell size, the AREA SOLAR RADIATION tool of the Spatial Analyst extension in ArcGIS 10.3 was employed

For the required parameters determination, described in Section 2.3, data from the interactive maps of JRC's Photovoltaic Geographical Information System (PVGIS) utility [93] were used. By employing the PVGIS utility, it is possible to estimate different parameters of the solar irradiance, for different latitudes and longitudes. Therefore, the coordinates of the point features presenting in Map 3.2 were given and the diffuse proportion of the solar irradiance was determined. An average value of 0.30 was then introduced to ArcGIS's AREA SOLAR RADIATION tool for the ratio of diffuse to global radiation parameter definition. In addition, NASA's Surface Meteorology and Solar Energy utility [95] was also employed, for the transmissivity parameter determination. Therefore, the aforementioned point features coordinates were introduced to NASA's utility and an average value for the Insolation Clearness Index was determined. As this utility mentions, this index represents the fraction of insolation at the top of the atmosphere which reaches the surface of the earth [96].

After the construction of the solar potential maps of the Regional Unit of Rethymno, the criterion's priority scale was produced, as shown in Table 3.25. The suitable areas were defined as the ones with GHI and DNI greater than 1,400 kWh/m^2, as Tsoutsos et al., [75] defined in their study for large-scale solar energy installations siting in Crete.



Map 3.2 Feature points for the solar irradiance parameters determination

Table 3.25 Solar potential criterion classification for solar energy installations siting

Priority Scale	**Score**	**Solar potential (kWh/m^2/year)**
Unsuitable	4	<1,000
Less Suitable	3	1,000-1,200
Moderately Suitable	2	1,200-1,400
Suitable	1	1,400-1,800
Particularly Suitable	0	>1,800

3.4 Biomass/ Biogas plants site selection evaluation and exclusion criteria

Finally, in this Section, a detailed presentation of the exclusion and evaluation criteria, for biomass and biogas plants site selection is conducted.

The exclusion criteria are derived from the legislation, examining also a stricter environmental scenario, while the evaluation criteria are derived from the literature review presenting in Annex E.

3.4.1 Exclusion criteria for biomass/biogas plants site selection

As it is shown in Figure 3.1, exclusion criteria have to be adopted, in order to exclude infeasible siting areas of biomass/biogas plants, according to the related legislation. Therefore, according to SFSPSD-RES [85], biomass/biogas plants are not permitted to be installed inside:

1) World heritage areas, archaeological monuments and historical places of high importance, as well as in archaeological sites of zone A
2) Areas of absolute protection of nature, according to Specific Management Plans and Specific Environmental Studies
3) Wetlands RAMSAR
4) Centre of national forests, nature monuments, aesthetic forests
5) Sites of Community Importance (SCIs) of NATURA 2000 network
6) Inside urban plans and settlement boundaries
7) Areas of integrated touristic development and organized productive activities of the tertiary sector, thematic parks and touristic ports
8) Bathing Beaches, included in the monitoring program of water quality
9) Mining zones and activities
10) Other areas or zones currently falling under a special land-use regime, according to which siting of wind installations is not permitted as long as they are in force

However, points 5 and 10 are modified by the subsequent Law 3851/2010 [86], as described in Section 3.2.1. In addition, SFSPSD-RES [85] also defines minimum allowable distances from neighboring land uses, for siting biomass/biogas plants, as shown in Table 3.26.

Table 3.26 Minimum allowable distances from biomass/biogas plants according to SFSPSD-RES [85]

Area	Minimum distances
Areas of environmental interest	
Areas of absolute protection of nature	According to the approved specific environmental study or the relevant Presidential Decree
Centers of national forests, nature monuments, aesthetic forests and SCIs of the NATURA 2000 network	Within the frame of the environmental terms and conditions approval
Beaches	1,000m
SPAs of bird habitat	200m
Areas of cultural heritage	
World heritage monuments, archaeological sites and historical places of high importance	Within the frame of the environmental terms and conditions approval, after the Ministry's of Culture assessment
Zone A of the rest of the archaeological sites	
Cultural monuments and historical sites	
[1]Urban activities	
Towns and settlements with population >2,000 inhabitants, characterized as dynamic, touristic or remarkable	For biomass plants up to 500 kWe, SFSPSD-RES [85] does not set any constraints For biomass plants with average impacts (>5 MW), SFSPSD-RES [85] defines that the minimum allowable distances from industrial plants have to be taken into consideration. Therefore, the Presidential Decree of 24-5-1985 [88] is taken into consideration
Traditional settlements	
The rest of the settlements	
Monasteries	
[2]Technical infrastructure and special uses	
Main roads, road network	Per case, within the frame of the environmental terms and conditions approval
High voltage lines	
Antennas, radars	
Aviation facilities and activities	
Port facilities and activities	
Zones or facilities of production activities	
Industrial and Business areas	Siting is permitted inside these zones
Mining zones and activities	500m
Areas of integrated touristic development and organized	500m from the boundaries of the zone/area

Table 3.26 Minimum allowable distances from biomass/biogas plants according to SFSPSD-RES [85]

Area	Minimum distances
productive activities of the tertiary sector, thematic parks, touristic ports and institutionalized tourist areas	
[3]Individual tourist accommodations	The minimum allowable distances from industrial plants

[1] According to the Presidential Decree of 24-5-1985 [88], a minimum distance of 500m has to be kept from settlements with a population less than 2,000 residents, 700m from settlements with a population between 2,000-10,000 residents and 1,000m from settlements with a population greater than 10,000 residents. These minimum distances were taken into consideration, while a 1,500m distance was kept from traditional settlements, in accordance with the wind energy installations siting [77]. Finally, for the distance from monasteries, a minimum distance has not been set, as this distance was taken into consideration in the evaluation criteria stage.

[2] For the antennas, a minimum distance of 200m was set, in accordance with the study of Silva et al., [51]. In addition, the distance from the road network and high voltage lines was examined in the criteria evaluation stage.

[3] For the individual tourist accommodations, a minimum distance of 500m is taken into consideration, proportionally with the tourist ports and camps.

After the exclusion of the aforementioned zones (Map B.1) and the application of the minimum allowable distances (Map B.2 to B.5), described in Table 3.26, the available areas for biomass/biogas plants are presented in Map B.6 (Map Annex). In addition, a second environmental scenario is also taken into consideration (Map B.7), where to the exclusion zones, are also added:

- The Sites of Community Importance of the NATURA 2000 network
- The aesthetically and scientifically highly valued geotopes (the corresponding data are point features and therefore an additional 500m distance was considered for their exclusion)
- The rocky islets surrounding Crete, which administratively belong to the Regional Unit of Rethymno
- The coastline, with an additional 50m buffer zone, to guarantee the free access to the shores, based on the Law 2971/2001 [87]

3.4.2 Evaluation criteria for biomass/biogas plants site selection

In accordance with the wind and solar energy installations, evaluation criteria are selected for the assessment of the available siting areas of biomass/biogas plants. The selected evaluation criteria are presented in Table 3.27, where the criteria types and goals can also be found. Finally, in this section, a detailed presentation of the selected criteria classification into the five-class priority scale, presented in Table 3.1, is conducted.

Table 3.27 Evaluation criteria of the available siting areas of biomass/biogas plants

Criterion	Criterion Type	Goal
Distance from water bodies	Environmental	Maximization
Distance from SCIs of the NATURA 2000 network	Environmental	Maximization
Distance from archaeological sites, monuments and monasteries	Aesthetic	Maximization
Distance from the electricity transmission lines	Techno-economic	Minimization
Distance from the road network	Techno-economic	Minimization
Slope	Techno-economic	Minimization
Visibility from most visited areas	Aesthetic	Minimization
Biomass/Biogas potential	Techno-economic	Maximization

1) Criterion: Distance from SCIs of the NATURA 2000 network

As it was mentioned before, according to Law 3851/2010 [86], it is permitted to site renewable energy installations inside NATURA 2000 sites, as a means for the climate change mitigation. However, the siting inside these sites is not always considered acceptable, due to conservation reasons of these sensitive ecosystems. Perpina et al., [40], [41] set a buffer distance of 500m from environmentally protected areas for siting biomass plants, while Wu et al., [67] Herrera-Seara et al., [25] and Sliz-Szkliniarz and Vogt, [54] exclude these sites from the available siting areas. In this study, the criterion classification was chosen to be the same as for the wind energy installations siting, presented in Table 3.6.

2) Criterion: Distance from water bodies

Table E.2 (Annex E) presents the literature review on the criterion of the distance from water bodies, concerning the adopted buffer distances employed in the literature from them. In this study, the criterion's classes are the same as for the wind energy installations siting, presented in Section 3.2.2 (Table 3.7).

3) Criterion: Distance from archaeological sites, monuments and monasteries

SFSPSD-RES [85] does not set the minimum allowable distances from archaeological sites and monuments, which are defined within the frame of the environmental terms and conditions approval, after the Ministry's of Culture assessment. Therefore, this criterion is adopted, considering, in addition, the distance from monasteries, which is also not exactly defined by SFSPSD-RES [85]. Table 3.28 and Map B.8 (Map Annex) present the classification of this criterion, concerning the distances from these sites of cultural interest.

Table 3.28 Distance from archaeological sites, monuments and monasteries criterion classification for biomass/biogas plants siting

Priority Scale	Score	Distance (m)
Unsuitable	4	0-500
Less Suitable	3	500-1,000
Moderately Suitable	2	1,000-1,500
Suitable	1	1,500-2,000
Particularly Suitable	0	>2,000

4) Criterion: Distance from the road network

The distance from the road network is a critical factor for biomass plants siting, as these plants have to be easily accessible by road for their supply of the biomass feedstock. As it was mentioned in Section 2.4, biomass logistics and transport optimization are a common study area in the literature. In this study, the threshold for the unsuitable area was set to 3,200m, in accordance with the upper bound of the acceptable range adopted from Wu et al., [67]. In addition, a safety distance of 70m was adopted, as the buffer distance set by

Silva et al., [51] and the criterion classes were constructed, as presented in Table 3.29.

Table 3.29 Distance from the road network criterion classification for biomass/biogas plants siting

Priority Scale	Score	Distance (m)
Unsuitable	4	<70 , >3,200
Less Suitable	3	2,400-3,200
Moderately Suitable	2	1,600-2,400
Suitable	1	800-1,600
Particularly Suitable	0	70-800

5) Criterion: Slope

Table E.5 (Annex E) presents the constraints and criteria classes adopted in the literature, concerning the slope criterion. Perpina et al., [40] and Silva et al., [51] set a constraint of a 15% for acceptable slopes for siting biomass plants. For this study, the criterion classes are presented in Table 3.13 and Map B.9 (Map Annex), taking into account the aforementioned constraint and the criterion classes for wind energy installations siting.

6) Criterion: Distance from the high voltage lines

As it was mentioned in Section 3.3.2, due to lack of spatial representation of the medium voltage lines in the Regional Unit of Rethymno, this criterion was limited to evaluating the distance only from the high voltage lines. Perpina et al., [40], [41] and Silva et al., [51] set a safety distance of 100m from the electricity transmission lines, while Sliz-Szkliniarz and Vogt, [54] consider distances less than 2,000m as suitable. Taking into account these constrains, Table 3.30 was formed, presenting the priority scale of this criterion for biomass/biogas plants siting.

Table 3.30 Distance from the high voltage lines criterion classification for biomass/biogas plants siting

Priority Scale	Score	Distance (m)
Unsuitable	4	<100, >8,000
Less Suitable	3	6,000-8,000
Moderately Suitable	2	4,000-6,000
Suitable	1	2,000-4,000
Particularly Suitable	0	100-2,000

7) Criterion: Visibility from most-visited sites

Proportionally to the solar and wind energy installations, the criterion of the visibility from most-visited areas has been set. As most-visited areas, the archaeological sites, monuments, settlements, traditional settlements, beaches, marinas, camps and hotels were defined and this criterion's priority scale is presented in Table 3.15.

8) Criterion: Biomass and Biogas potential

For the estimation of the biomass potential of the Regional unit of Rethymno, the theoretical biomass potential of pruning wood from olive trees, vineyards, fruit trees, coniferous and broadleaved forests was estimated. The adopted methodology is based on the CORINE 2012 database and the pruning wood productivity coefficients η^c presenting in Table 3.31.

Table 3.31 Pruning wood productivity coefficients of different forest and agricultural biomass sources

Biomass family	Residue productivity η^c
[1]Olive trees	280.5 dry pruning wood t/km^2
[1]Vineyards	100 dry pruning wood t/km^2
[1]Fruit trees	375 dry pruning wood t/km^2
[2]Coniferous trees	85 dry pruning wood t/km^2
[2]Broadleaved trees	48 dry pruning wood t/km^2

[1] These residue productivity coefficients are derived from data of the Renewable and Sustainable Energy Systems Laboratory (RESEL) of the University of Crete, accruing from the consultation of local producers.
[2] Residue productivity coefficients presented by Lourinho and Brito, [33] for pine and holm oak respectively

However, land cover maps do not always allow for a direct quantification of the theoretical biomass potential, as the total area of a polygon does not necessarily equal to the vegetation covered area. Therefore, the tree cover density was introduced, for the effective vegetated area quantification, as presented in Table 3.32. In addition, it must be noted that for the estimation of the theoretical biomass potential from vineyards pruning wood, the total area of the CORINE 2012 polygons was taken into consideration, due to the spatial uniformity of this cultivation type.

Table 3.32 Sources and methodology for the theoretical biomass potential estimation

<table>
<tr><th>Biomass family</th><th>Sources</th><th>Effective vegetated area A_{eff} (m^2)</th><th>Theoretical biomass potential B_{ol} (t)</th></tr>
<tr><td>Olive trees</td><td rowspan="2">Polygons from CORINE 2012 database with codes 223 and 222 for olive trees and fruit trees respectively [102]

Tree cover density maps (20m resolution) of the Copernicus, Land Cover Service [106]</td><td rowspan="4">$\boldsymbol{A_{eff} = A_{pixel} \times TCD}$,

A_{pixel}=20×20=400 m^2
TCD: tree cover density (0-100%)</td><td rowspan="4">$\boldsymbol{B_{ol}=A_{eff} \times \eta^c}$,

η^c: residue productivity coefficient (t/km^2)</td></tr>
<tr><td>Fruit trees</td></tr>
<tr><td>Coniferous trees</td><td>Pixels corresponding to coniferous forests from the Forest Type maps (20m resolution) of the Copernicus, Land Cover Service [107]

Tree cover density maps [106]</td></tr>
<tr><td>Broadleaved trees</td><td>Pixels corresponding to broadleaved forests from the Forest Type maps [107]

Pixels not belonging to broadleaved forest used for agricultural practices from the Forest Type maps of the Copernicus, Land Cover Service [107]

Tree cover density maps [106]</td></tr>
<tr><td>Vineyards</td><td>Polygons from CORINE 2012 database with code 221, corresponding to vineyards</td><td></td><td>$\boldsymbol{B_{ol}=A_c \times \eta^c}$,

A_c: CORINE's polygon area (m^2)</td></tr>
</table>

Following Figure 3.3, the estimation methodology for olive trees theoretical biomass potential can be seen. From the intersection of the olive trees CORINE polygons with the tree cover density maps; the theoretical biomass potential of olive trees’ pruning wood in the Regional Unit of Rethymno is derived, based on the equations presented in Table 3.32. In addition, a similar estimation methodology was also applied for the other cultivation types, investigated in this study.

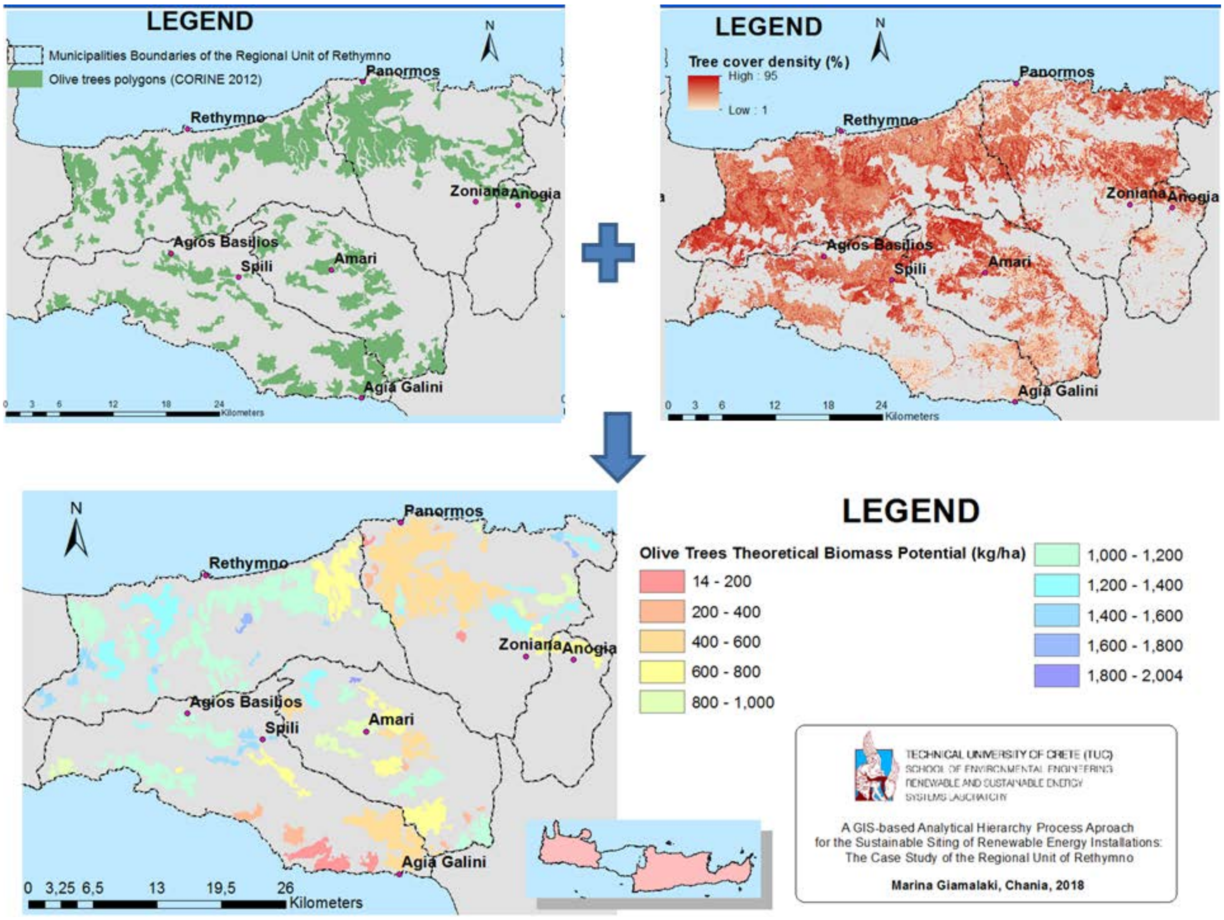


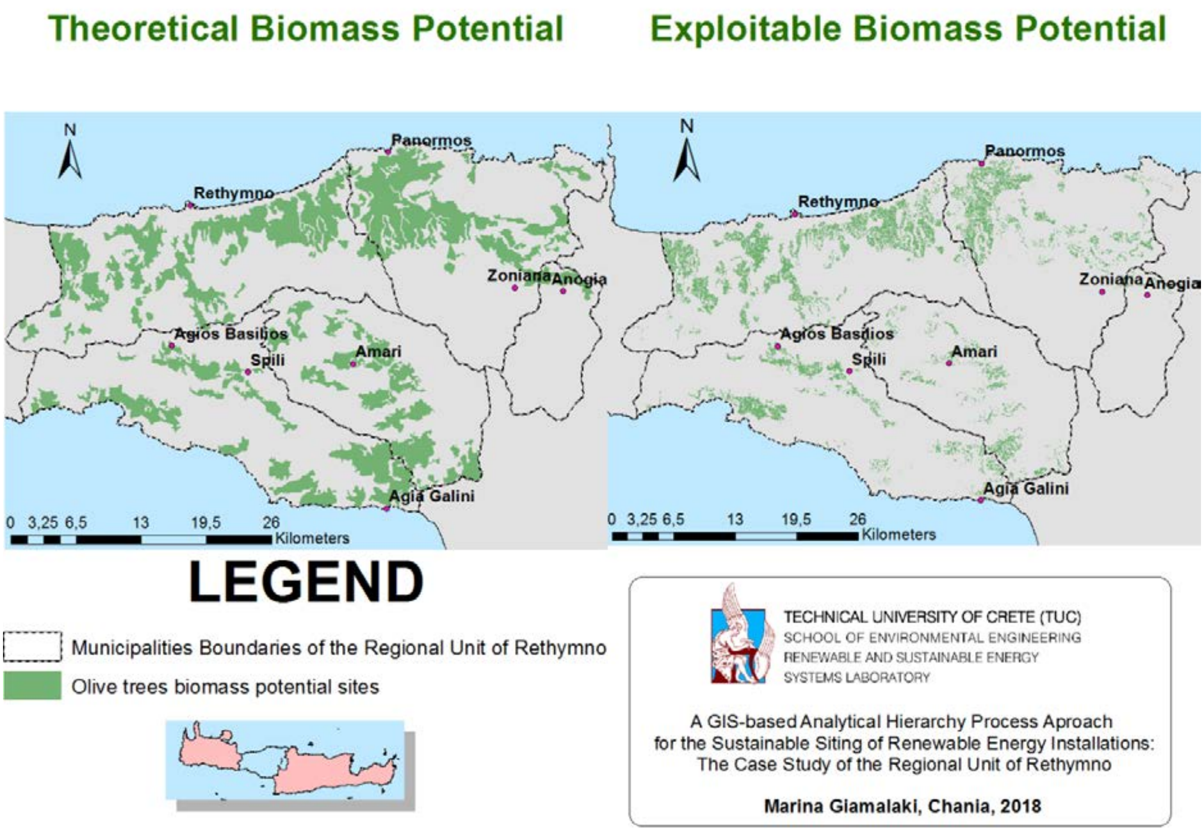
Figure 3.3 Olive trees theoretical biomass potential estimation methodology

Finally, after the calculation of the theoretical biomass potential for every cultivation type, some restrictions have been set, in order to derive the exploitable biomass potential in the Regional Unit of Rethymno. Specifically, only the biomass potential of areas with:

- A slope less than 20% was taken into consideration, as greater slopes may indicate difficult access, erosion and soil loss problems [33]

- A distance less than 3km from the road network, in order to ensure that these areas are easily accessible [33]

By establishing the aforementioned constraints, the exploitable biomass potential for every cultivation type is produced. Map 3.3 presents the sites occurring after the introduction of the constraints, for the olive trees biomass potential exploitation. Finally, Map R.8 (Map Annex) presents the total exploitable biomass potential of the Regional Unit of Rethymno, for all cultivation types considered.



Map 3.3 Olive trees theoretical and exploitable biomass sites

For the biogas potential estimation of the Regional Unit of Rethymno, the potential production from waste water treatment plants (WWTP), landfills and large livestock farms were taken into consideration. In the study area, the WWTP [108] presenting in Table 3.33 are found. Based on the permanent and peak population of the areas served by these plants and the assumption that every 1,000 residents produce 28m^3/d biogas [78], the maximum and minimum biogas quantities are derived, as presented in Table 3.33.

Table 3.33 Biogas quantities from sewage treatment plants in the Regional Unit of Rethymno

Location	Serving areas	Permanent population [98]	Peak population [108]	Minimum biogas quantity (m^3/d)	Maximum biogas quantity (m^3/d)	Average biogas quantity (m^3/y)
Anogia	Anogia	2,319	2,322	64.93	65.02	23,715.51
Bali	Bali, Vlichada	565	6,500	15.82	182	36,102.15
Panormos	Panormos, Roumeli, Achlades, Siripidiana	1,296	7,700	36.288	215.6	45,969.56
Rethymno	Rethymno	32,468	58,000	909.1	1,624	462,291.48

In addition to the waste water treatment plants, the biogas potential from a landfill located in the Regional Unit of Rethymno was estimated. Based on the annual solid wastes quantity and the assumption that the biogas quantity produced from solid wastes is between 120-400m^3/t [72], Table 3.34 was produced.

Table 3.34 Biogas quantities from a landfill in the Regional Unit of Rethymno

Location	Serving areas	Urban solid wastes (t/y)	Maximum biogas quantity (m^3/y)	Minimum biogas quantity (m^3/y)	Average biogas quantity (m^3/y)
Rethymno	Rethymno	42,000	16,800,000	5,040,000	10,920,000

Finally, the biogas potential from a pig farm located in the Regional Unit of Rethymno, with a capacity of 1,800 sows was estimated. Based on the issued environmental terms approval, the waste quantities produced by the plant were determined [79]. In addition to these quantities, an average value between 30 and 65 m^3/t biogas [109] from pig farm wastes was used. Finally, an average value of 0.35 m^3/kg COD [42] was employed for sizing the biogas potential from the slaughterhouse wastes. Based on the aforementioned points, Table 3.35 is produced, presenting the annual potential biogas yield of the pig farm.

Table 3.35 Biogas quantities from a livestock farm in the Regional Unit of Rethymno

Brand	Slaughterhouse waste production (kg COD/d)	Biogas quantity from the slaughterhouse (m^3/d)	Pig farm waste production (t/d)	Biogas quantity from the pig farm (m^3/d)	Total (m^3/y)
Creta Farms	1,395	488.25	24	1,140	594,311.3

After the estimation of the biomass and biogas potential of the Regional Unit of Rethymno, the criterion classification was constructed. For the criterion of the biomass potential, the produced classification is presented in Table 3.36. In addition, due to the fact that the biogas potential consists of point features, the criterion classification was constructed in terms of a distance from the biogas sources, described in the following Tables. Moreover, SFSPSD-RES [85] states that, the preferred locations for biogas plants siting are the ones, in close proximity to waste water treatment plants, landfills and large livestock farms, but it does not define a minimum distance. Therefore, the criterion classification presented in Table 3.37 was adopted.

Table 3.36 Biomass potential criterion classification for biomass plants siting

Priority Scale	Score	Biomass Potential (t/ha)
Unsuitable	4	0
Less Suitable	3	0 - 0.5
Moderately Suitable	2	0.5 - 1
Suitable	1	1 - 2
Particularly Suitable	0	2 - 3.5

Table 3.37 Biogas potential criterion classification for biogas plants siting

Priority Scale	Score	Distance (m)
Unsuitable	4	0-500
Less Suitable	3	500-1,000
Moderately Suitable	2	1,000-1,500
Suitable	1	1,500-2,000
Particularly Suitable	0	>2,000

4 Analytical Hierarchy Process (AHP) implementation and sustainable siting areas

In the previous Section, the exclusion and evaluation criteria for each renewable energy technology studied were presented. In addition, the evaluation criteria were classified to the priority scale presented in Table 3.1, so for each criterion, each cell of the study area has a score between 0 and 4. According to Figure 3.2, the next step constitutes of assigning weights to the selected criteria, applying an Analytical Hierarchy Process. In the next Sections, a detailed description of the Analytical Hierarchy Process and its application in this study, as well as the sustainable siting areas of each renewable energy technology studied are presented.

4.1 Multi-criteria decision making: the Analytical Hierarchy Process

Before proceeding to the individual steps of the adopted methodology, a brief representation of the Analytical Hierarchy Process (AHP) is conducted. AHP was developed by Saaty (1980) and is a structured technique for organizing and analyzing complex decision problems. In order to apply the AHP, the steps below must be followed [37]:

1) Definition of the problem and its goals
2) Structure of the problem's hierarchy, which constitutes the top level criteria, intermediate level subcriteria and lower level, which usually contains the list of alternatives (Figure 4.1)
3) Pair-wise comparisons of all criteria influencing the decision have to be conducted, based on Saaty's fundamental scale (Table 4.1)
4) The priority vector indicating the relative importance of different criteria is calculated and the consistency of the judgments have to be checked
5) Priorities of the alternatives with respect to each criterion separately are derived (pair-wise comparison of the alternatives with respect to each criterion) and the consistency is also checked and adjusted
6) All alternative priorities are combined as a weighted sum, to take into account the weight of each criterion

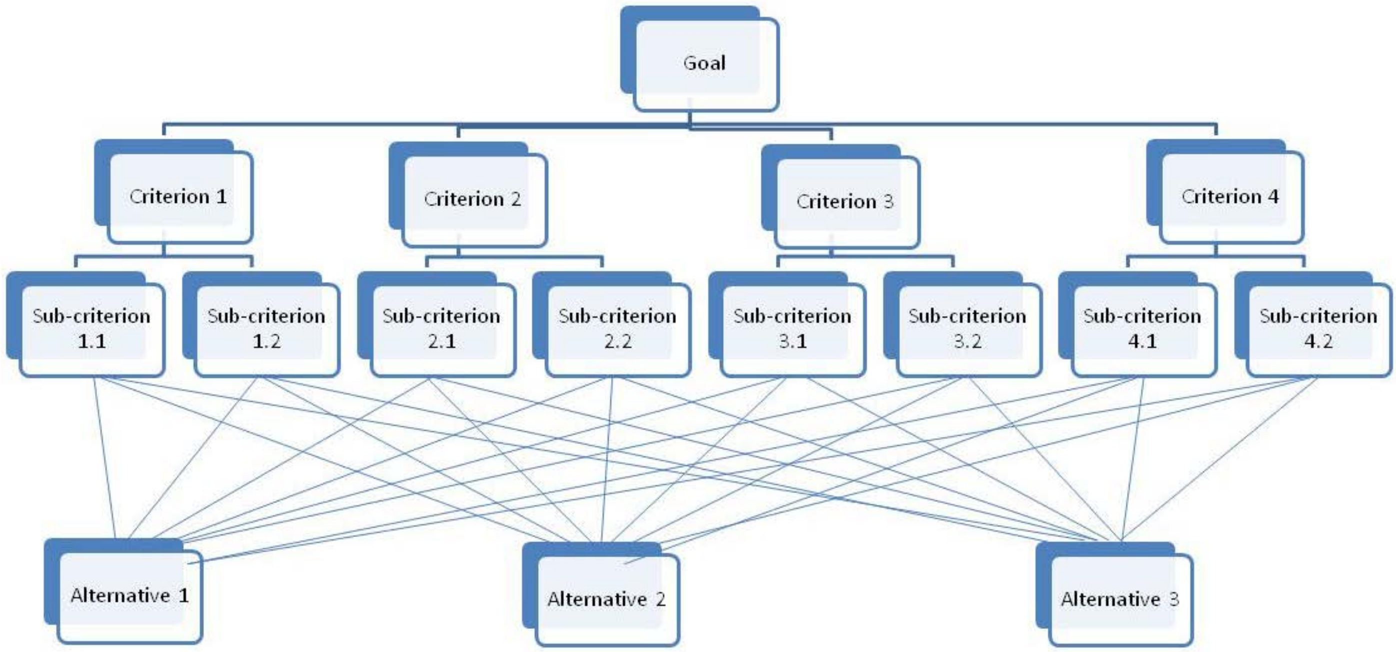


Figure 4.1 Hierarchical structure of the problem

The matrix of pair-wise comparisons A= [c_{ij}] represents the intensity of the expert's preference between individual criteria, that affect the selection of one of the available alternatives. The judgment matrix is given below (4.1), for n criteria, where c_{ij} is the relative importance of the criterion C_i over the criterion C_j.

$$A = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1(n-1)} & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2(n-1)} & c_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{n(n-1)} & c_{nn} \end{pmatrix} \tag{4.1}$$

According to the reciprocal judgment, if the importance of the criterion C_i over the criterion C_j is k, then the relative importance of the criterion C_j over the criterion C_i is 1/k, so in matrix A, $c_{ji}=1/c_{ij}$ $\forall$ $i \neq j$ and $c_{ii}=1$ for i,j=1,2,3…n. In addition, the number of judgments needed for such matrix is n(n-1)/2. The relative weights of criteria C_1, $C_2 \ldots C_n$ can be determined from matrix A, by normalizing it into a new matrix through dividing the elements of each column by the sum of the elements of the same column. The relative weights of the criteria are then computed by the row average of the new normalized matrix.

Table 4.1 The fundamental scale according to Saaty (1980) [45]

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

The advantage of this process is that it allows checking the consistency of the judgments made by the pair-wise comparisons. For a judgment to be consistent the following equation must be followed [18]:

$$c_{ij} = c_{ik} \times c_{kj} \ \forall \ i, j, k \tag{4.2}$$

However, Assumption (4.2) is often violated in empirical decision situations, but Saaty argues that a reasonable level of inconsistency is expected and tolerated. To measure the degree of inconsistency of comparison matrices, Saaty introduced the Consistency Index (CI), measured as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4.3}$$

In Equation (4.3), n is the size of the matrix (n x n) and λ_{max} is the maximum eigenvalue of the comparison matrix. By solving the eigenvalue problem and determining the principal eigenvalue λ_{max}, the Consistency Ratio (CR) can be defined by the Equation:

$$CR = \frac{CI}{RI} \tag{4.4}$$

In Equation (4.4), CI corresponds to the Consistency Index calculated based on the Equation (4.3) and RI corresponds to Random Index values, which vary with the matrix size. A random matrix is one where the judgments have been entered randomly based on the Saaty's scale and therefore it is highly inconsistent. More specifically, RI is the average CI of 500 randomly filled matrices provided by Saaty (1980), for different matrix sizes, as shown in Table 4.2.

Table 4.2 Saaty's Random Index Values (RI) [1]

Order of matrix	2	3	4	5	6	7	8	9	10	11
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Finally, as it was mentioned previously, a reasonable level of inconsistency is acceptable, therefore if CR<0.10, the degree of consistency is considered satisfactory. Otherwise, consistency adjustment procedures proposed by Saaty can be performed, based on a maximum deviation approach [18].

4.2 Analytical Hierarchy Process implementation

For the AHP implementation, a survey was conducted, where local experts from different involved renewable energy-related groups were asked to perform the necessary pair-wise comparisons of the selected criteria. These experts were selected in such a way, in order to evaluate the different preferences of the RES siting stakeholders, so that their distinct opinions reflect the complexity of the RES siting problem. For example, an environmental-focused expert may favor a site, which is far away from areas of environmental interest, while an expert focused in the techno-economic aspect of the problem, may favor a site close to the road network and the electricity transmission lines.

In this study, the selected participants represent different stakeholders, such as the policy makers, the power supplier, the academia, the environmental groups and the engineers. A special advisor for energy of the Region of Crete represents the policy makers group, the head of Crete's Dispatching Centre represents the power supplier group and a member of the Hellenic Ornithological Society represents the environmental group. In addition, two environmental engineers and a member of the educational personnel of the School of Environmental Engineering, of the Technical University of Crete complete the selected group of experts.

The participants were asked to perform the pair-wise comparisons of the selected criteria, by filling out the tables presenting in Annex F, defining the relative importance between the compared criteria, based on the scale presenting in Table 4.3.

Table 4.3 Scale for the Analytical Hierarchy Process implementation

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
3	Essential or strong importance	Experience and judgment strongly favor one activity over another
4	Very strong importance	An activity is favored very strongly and its dominance is demonstrated in practice
5	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Therefore, for each of the renewable energy systems studied, there are six completed judgment matrices. Subsequently, the participants' priority vectors for each RES were estimated, by applying the procedure described in Section 4.1. In addition, as for the engineers group, there are two participants, an average of the engineers' priority vectors was computed and then, an aggregation of the individual priorities (AIP) was applied. AIP of the five priority vectors of the different stakeholders is implemented by a geometric mean method, based on the Equation:

$$P_g(C_J) = \left(\prod_{i=1}^{n} P_i(C_J)\right)^{\frac{1}{n}} \tag{4.5}$$

In Equation (4.5), $P_g(C_j)$ is the priority of the group of experts for the criterion j, $P_i(C_j)$ is the priority vector of an individual expert i, for the criterion j and n is the number of experts questioned. AIP is used in cases, where each individual of a group acts on his/her own interest, with different value systems [26], as it is considered in this study. Finally, the priority vectors accruing from the geometric mean method are normalized in order to ensure that:

$$\sum_{j=1}^{n} P_g(C_J) = 1 \tag{4.6}$$

After the estimation of the aggregated priority vectors for each criterion j of each RES, the weighted sum aggregation is employed, in order to determine the Overall Priority Index (OPI) for each cell of the study area, based on the Equation:

$$OPI_i = \sum_{j=1}^{n} w_j s_{ij} \tag{4.7}$$

In Equation (4.7), OPI_i corresponds to the Overall Priority Index of the cell i, w_j is the relative importance of the criterion j, s_{ij} is the score of the cell i over the criterion j and n is the total number of criteria. With the employment of the weighted sum aggregation, the priority maps of each renewable energy technology are produced, based on the fact that after the aggregation, each cell of the study area has a score between 0 and 4, where 0 corresponds to 100% priority and 4 corresponds to 0% priority. Finally, the priority maps are produced with the assistance of the RASTER CALCULATOR tool in ArcGIS 10.3.

The production of the priority maps facilitates in identifying the sustainable siting location, which are considered to be the available areas of the stricter socio-environmental scenarios, which have a priority percentage greater than 60%. In the next Sections, the sustainable siting locations for each renewable energy system studied are presented, estimating the coverage of each municipality of the Regional Unit of Rethymno.

4.3 Sustainable siting areas for wind energy installations siting

As it was mentioned before, for the sustainable siting locations identification, the priority of the available areas of the environmental scenario for wind energy installations siting, have to be estimated. For this purpose, pair-wise comparisons of the selected criteria were conducted by experts from different renewable energy-related fields. Table 4.4 presents the judgment matrix from the expert of the policy makers group.

Table 4.4 Judgment matrix of the expert from the policy makers group

Criterion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Distance from the NATURA 2000 sites (1)	**1.00**	1.00	1.00	0.25	0.25	1.00	1.00	1.00	1.00	3.00	1.00
Distance from water bodies (2)	1.00	**1.00**	1.00	0.25	0.25	1.00	1.00	1.00	1.00	2.00	1.00
Distance from archaeological sites and monuments (3)	1.00	1.00	**1.00**	0.25	0.25	1.00	2.00	2.00	2.00	0.50	1.00
Distance from antennas (4)	4.00	4.00	4.00	**1.00**	1.00	4.00	4.00	4.00	4.00	3.00	4.00
Distance from national defense installations (5)	4.00	4.00	4.00	1.00	**1.00**	4.00	4.00	4.00	4.00	3.00	4.00
Distance from the high voltage lines (6)	1.00	1.00	1.00	0.25	0.25	**1.00**	1.00	1.00	0.50	0.25	2.00
Distance from the road network (7)	1.00	1.00	0.50	0.25	0.25	1.00	**1.00**	1.00	0.50	0.25	2.00
Slope (8)	1.00	1.00	0.50	0.25	0.25	1.00	1.00	**1.00**	1.00	0.33	2.00
Elevation (9)	1.00	1.00	0.50	0.25	0.25	2.00	2.00	1.00	**1.00**	0.33	2.00
Visibility from most visited sites (10)	0.33	0.50	2.00	0.33	0.33	4.00	4.00	3.00	3.00	**1.00**	3.00
Wind potential (11)	1.00	1.00	1.00	0.25	0.25	0.50	0.50	0.50	0.50	0.33	**1.00**

The relative weights of the above criteria can be determined from Table 4.4, by normalizing it into a new matrix through dividing the elements of each column by the sum of the elements of the same column. The relative weights of the criteria are then computed by the row average of the new normalized matrix. From the judgment matrix of the policy maker representative, presented in Table 4.4, the normalized new matrix is presented in Table 4.5.

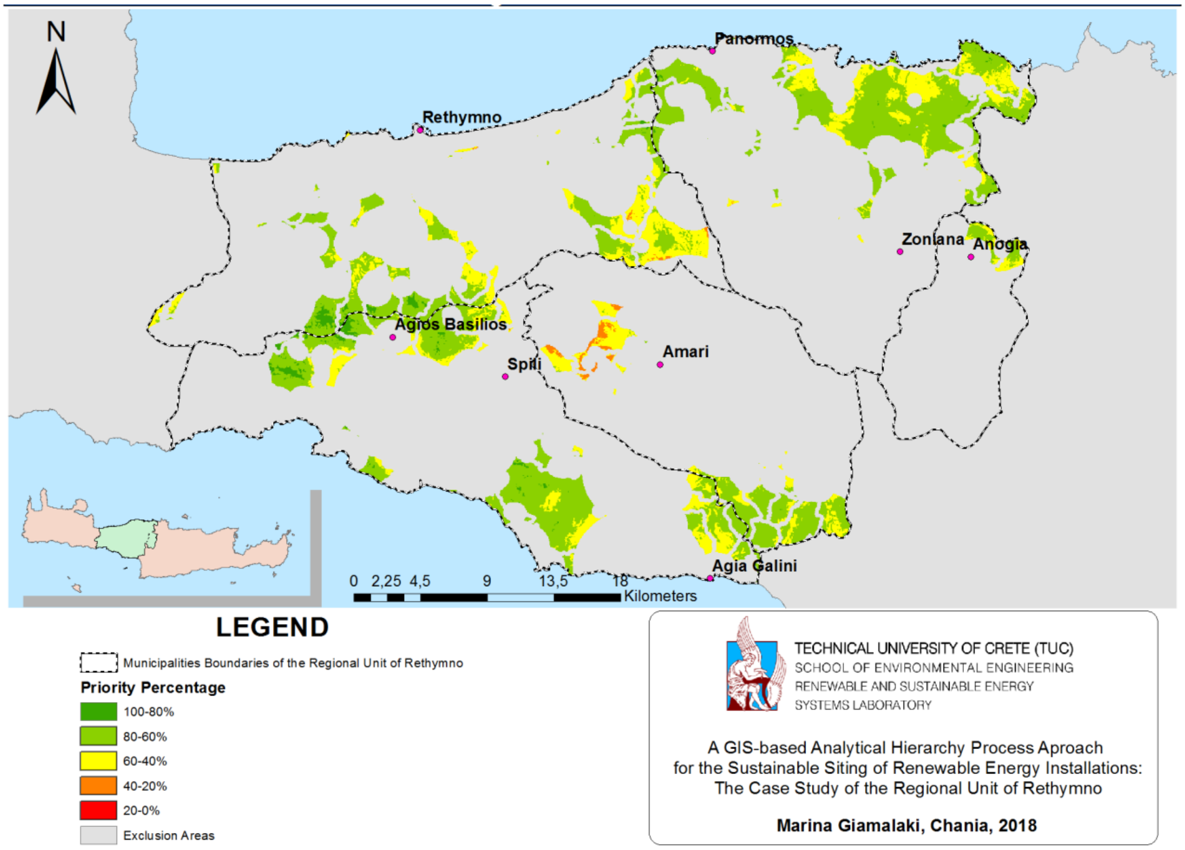
Based on the aforementioned procedure, the relative importance of the selected criteria from the different stakeholders, for wind energy installations siting is derived, as presented in Table 4.6. Finally, with an AIP of the five priority vectors of the different stakeholders, by a geometric mean method (Section 4.2), the criteria weights are derived. In addition, with the employment of the weighted sum aggregation, described in Section 4.2, the priority map for wind energy installations siting is produced, as presented in Map 4.1.

Table 4.5 Normalized matrix of the expert from the policy makers group

Criterion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Distance from the NATURA 2000 sites (1)	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.21	0.04
Distance from water bodies (2)	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.14	0.04
Distance from archaeological sites and monuments (3)	0.06	0.06	0.06	0.06	0.06	0.05	0.09	0.10	0.11	0.04	0.04
Distance from antennas (4)	0.24	0.24	0.24	0.23	0.23	0.20	0.19	0.21	0.22	0.21	0.17
Distance from national defense installations (5)	0.24	0.24	0.24	0.23	0.23	0.20	0.19	0.21	0.22	0.21	0.17
Distance from the high voltage lines (6)	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.03	0.02	0.09
Distance from the road network (7)	0.06	0.06	0.03	0.06	0.06	0.05	0.05	0.05	0.03	0.02	0.09
Slope (8)	0.06	0.06	0.03	0.06	0.06	0.05	0.05	0.05	0.05	0.02	0.09
Elevation (9)	0.06	0.06	0.03	0.06	0.06	0.10	0.09	0.05	0.05	0.02	0.09
Visibility from most visited sites (10)	0.02	0.03	0.12	0.08	0.08	0.20	0.19	0.15	0.16	0.07	0.13
Wind potential (11)	0.06	0.06	0.06	0.06	0.06	0.02	0.02	0.03	0.03	0.02	0.04

Table 4.6 The relative importance of the selected criteria, for wind energy installations siting, from the different stakeholders

Criterion	Policy Maker	Electricity power supplier	Academia	Environmental group	Engineers	Aggregation of individual priorities
Distance from the NATURA 2000 sites	0.07	0.22	0.16	0.19	0.17	**0.17**
Distance from water bodies	0.06	0.16	0.04	0.13	0.10	**0.10**
Distance from archaeological sites and monuments	0.07	0.14	0.05	0.17	0.13	**0.11**
Distance from antennas	0.22	0.06	0.14	0.05	0.08	**0.11**
Distance from national defense installations	0.22	0.11	0.11	0.10	0.11	**0.13**
Distance from the high voltage lines	0.05	0.04	0.08	0.03	0.10	**0.06**
Distance from the road network	0.05	0.04	0.04	0.03	0.09	**0.05**
Slope	0.05	0.04	0.04	0.11	0.04	**0.06**
Elevation	0.06	0.04	0.04	0.08	0.04	**0.06**
Visibility from most visited sites	0.11	0.09	0.10	0.06	0.02	**0.08**
Wind potential	0.04	0.05	0.21	0.03	0.11	**0.08**



Map 4.1 Priority map for wind energy installations siting based on the criteria weights derived from the AHP

With the production of the priority map for wind energy installations siting, the sustainable siting locations are identified, which are considered to be the available areas of the environmental scenario, where the SCIs of the NATURA 2000 network are also excluded, which also have a priority percentage greater than 60%. The municipalities' coverage by the different priority classes of the sustainable siting areas is presented in Table 4.7.

Table 4.7 Municipality coverage by the sustainable siting areas for wind energy installations siting

	Areas with priority 80-100%		Areas with priority 60-80%	
Municipality	**Area (km^2)**	**Municipality Coverage (%)**	**Area (km^2)**	**Municipality Coverage (%)**
Agios Vasilios	2.94	0.82	50.01	13.91
Amari	0.01	0.002	16.83	6.06
Anogia	-	-	2.78	2.71
Mylopotamos	0.50	0.14	59.30	16.33
Rethymno	2.35	0.60	32.79	8.33

Finally, by taking into account the constraint introduced by SFSPSD-RES [85], concerning the maximum land coverage from wind farms in the inhibited islands of the Aegean, the Ionian Sea and Crete, which cannot exceed 4% of the municipality area, Table 4.8 is produced. In Table 4.8, if municipality coverage by the sustainable siting areas exceeds the maximum coverage of 4%, then the 4% coverage is taken into account as the final municipality coverage from wind turbines. In addition, considering the standard wind turbine, with a rotor's diameter of 85m and an average power of 2MW [85], as well as a technical factor of 75.86 acres/MW [60], the maximum wind power from standard wind turbines is determined in Table 4.8.

Table 4.8 Calculation of carrying capacity per municipality for wind energy installations siting

Municipality	Maximum Coverage of 4% (km^2)	Sustainable Siting Areas (km^2)	Final Coverage (km^2)	Maximum Wind Power from Standard Wind Turbines (MW)
Agios Vasilios	14.38	52.95	14.38	190
Amari	11.10	16.83	11.10	146
Anogia	4.09	2.78	2.78	37
Mylopotamos	14.52	59.80	14.52	191
Rethymno	15.75	35.14	15.75	208

4.4 Sustainable siting areas for solar energy installations siting

The same procedure, as for wind energy installations priority map production, was also applied for the estimation of the relative importance of the selected evaluation criteria for solar energy installations siting. Table 4.9 presents the judgment matrix, produced by the criteria pair-wise comparisons performed by the participant from the academia group. By the normalization of the judgment matrixes of every participant, following the procedure presented in Section 4.2, the relative importance of the evaluation criteria for solar energy installations siting, for every participant, were estimated, as presented in Table 4.10.

Table 4.9 Judgment matrix of the expert from the academia group

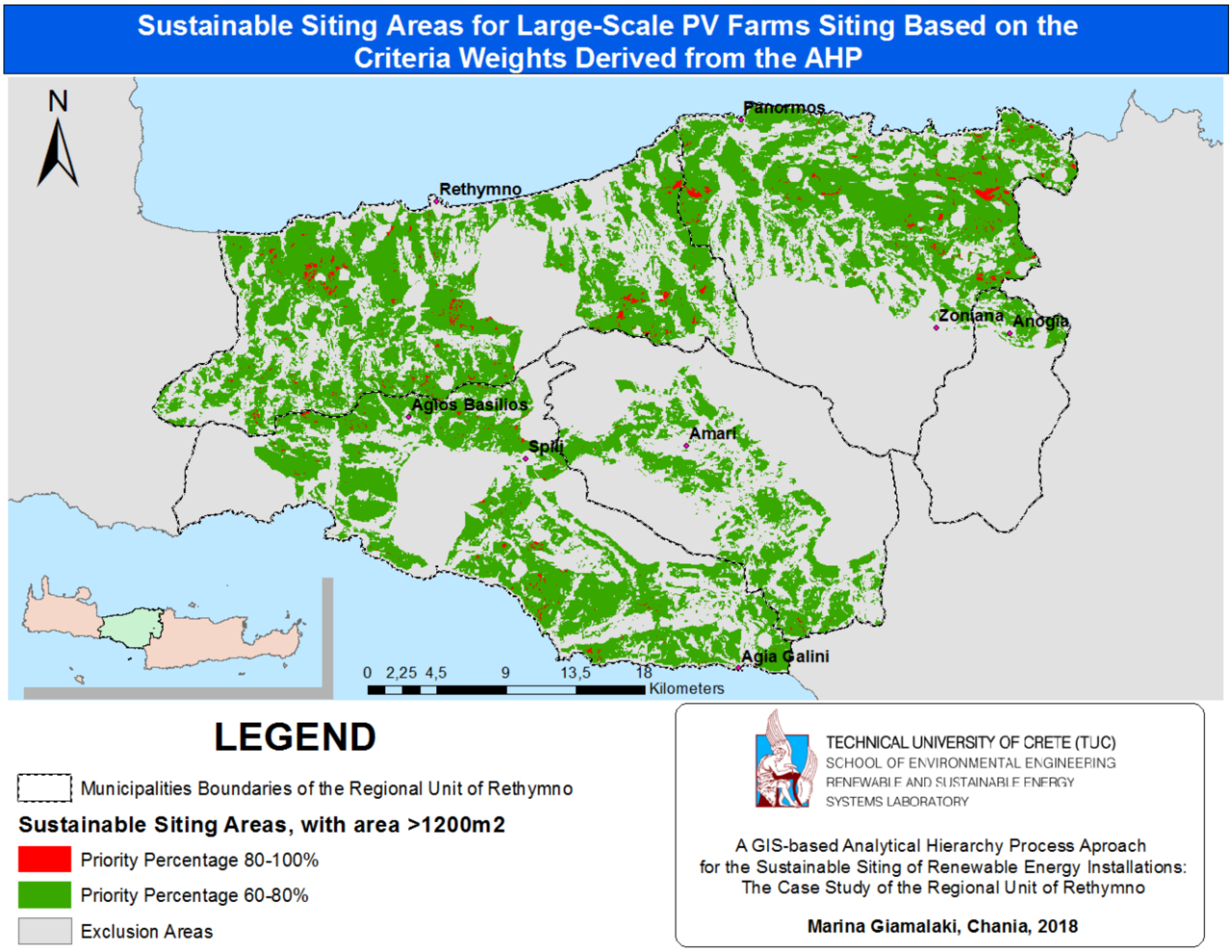
Criterion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Distance from the coastline (1)	**1.00**	3.00	3.00	3.00	2.00	0.33	2.00	2.00	2.00	0.50
Distance from water bodies (2)	0.33	**1.00**	1.00	1.00	2.00	0.25	2.00	2.00	1.00	0.33
Distance from the electricity transmission lines (3)	0.33	1.00	**1.00**	1.00	1.00	0.25	1.00	1.00	1.00	0.20
Distance from the road network (4)	0.33	1.00	1.00	**1.00**	2.00	0.25	2.00	1.00	0.50	0.25
Aspects (5)	0.50	0.50	1.00	0.50	**1.00**	0.50	3.00	4.00	3.00	1.00
Land cover (6)	3.00	4.00	4.00	4.00	2.00	**1.00**	4.00	4.00	4.00	1.00
Slope (7)	0.50	0.50	1.00	0.50	0.33	0.25	**1.00**	1.00	0.50	0.33
Elevation (8)	0.50	0.50	1.00	1.00	0.25	0.25	1.00	**1.00**	0.50	0.25
Visibility from most-visited sites (9)	0.50	1.00	1.00	2.00	0.33	0.25	2.00	2.00	**1.00**	0.50
Solar potential (10)	2.00	3.00	5.00	4.00	1.00	1.00	3.00	4.00	2.00	**1.00**

Table 4.10 The relative importance of the selected criteria, for wind energy installations siting, from the different stakeholders

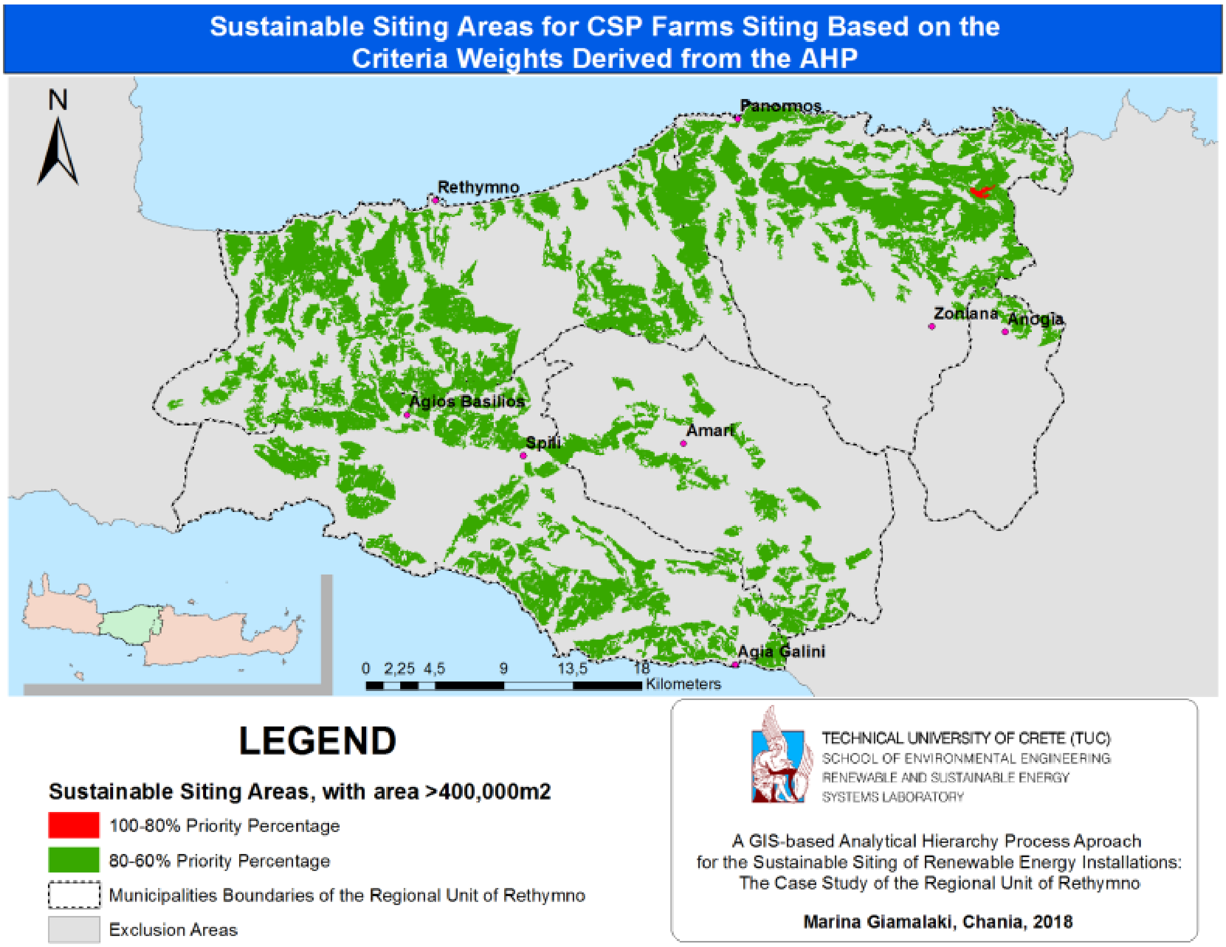
Criterion	Policy Maker	Electricity power supplier	Academia	Environmental group	Engineers	Aggregation of individual priorities
Distance from the coastline	0.15	0.25	0.13	0.12	0.10	**0.16**
Distance from water bodies	0.15	0.12	0.07	0.09	0.13	**0.12**
Distance from the electricity transmission lines	0.07	0.06	0.05	0.04	0.13	**0.07**
Distance from the road network	0.07	0.12	0.07	0.05	0.07	**0.08**
Aspects	0.06	0.07	0.11	0.10	0.15	**0.10**
Land cover	0.03	0.10	0.22	0.13	0.16	**0.12**
Slope	0.06	0.06	0.04	0.22	0.06	**0.08**
Elevation	0.15	0.06	0.04	0.17	0.04	**0.09**
Visibility from most-visited sites	0.21	0.11	0.07	0.05	0.03	**0.09**
Solar potential	0.03	0.05	0.19	0.04	0.12	**0.07**

By taking into account the available siting areas of the socio-environmental scenario, for solar energy installations siting, as described in Section 3.3.1 and the relative importance of the selected criteria from the AIP of the selected participants (Table 4.10), two different priorities maps are produced, for large-scale PV and CSP farms respectively. After the construction of the priority maps, the sustainable siting areas for each solar energy installations are emerging, corresponding to a priority percentage greater than 60%. An additional area constraint was also introduced for the sustainable siting areas identification, corresponding to an area greater than 1,200m^2 for the PVs (power of 60kW) and 400,000m^2 for CSPs (power of 20MW) [75]. Map 4.2 presents the sustainable siting areas for PV and CSP farms, based on the criteria relative importance derived from the AHP and Table 4.11 presents the municipality coverage by the sustainable siting areas for each solar energy technology.

a)



b)



Map 4.2 Sustainable siting areas for a) PV and b) CSP farms respectively, based on the criteria weights derived from the AHP

Table 4.11 Municipality coverage by the sustainable siting areas for solar energy installations siting

	Municipality Coverage (%)			
	Areas with priority 80-100%		**Areas with priority 60-80%**	
Municipality	**PV**	**CSP**	**PV**	**CSP**
Agios Vasilios	0.49	-	42.31	31.59
Amari	0.06	-	22.82	13.84
Anogia	0.05	-	7.88	4.92
Mylopotamos	1.08	0.17	41.16	32.49
Rethymno	1.19	-	48.86	38.42

SFSPSD-RES [85] does not state any constraint concerning the maximum coverage per municipality by solar energy installations. Therefore, taking into account only the highest priority siting areas, corresponding to 80-

100% priority, the potential maximum power, if the total of these areas is covered by solar energy installations, is estimated, as presented in Table 4.12. For the estimation of the potential maximum power, the technical factors taken into consideration are: 60kW/1,200m^2 for PVs and 20MW/400,000m^2 for CSPs [75].

Table 4.12 Calculation of the carrying capacity per municipality for solar energy installations siting, taking into account the highest priority areas

Municipality	Sustainable siting areas for PVs with priority percentage 80-100% (km^2)	Sustainable siting areas for CSPs with priority percentage 80-100% (km^2)	Potential maximum power from the 80-100% PVs priority areas (MW)	Potential maximum power from the 80-100% CSPs priority areas (MW)
Agios Vasilios	1.76	0	88	0
Amari	0.18	0	9	0
Anogia	0.05	0	3	0
Mylopotamos	3.93	0.6	197	30
Rethymno	4.68	0	234	0

4.5 Sustainable siting areas for biomass/biogas plants siting

Following the same procedure, as for the wind and solar energy installations siting, the relative importance of the selected evaluation criteria, for biomass or biogas plants siting is derived. Table 4.13 presents an example of a judgment matrix, completed by the expert from the power supplier group. In addition, Table 4.14 presents the criteria weights accrued from the judgment matrixes of the different stakeholder, as well as the aggregated weights, derived from a geometric mean method.

Table 4.13 Judgment matrix of the expert from the electricity power supplier group

Criterion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance from SCIs of the NATURA 2000 network (1)	**1.00**	5.00	2.00	5.00	5.00	5.00	2.00	5.00
Distance from water bodies (2)	0.20	**1.00**	1.00	5.00	4.00	4.00	1.00	2.00
Distance from archaeological sites, monuments and monasteries (3)	0.50	1.00	**1.00**	5.00	5.00	5.00	2.00	4.00
Distance from the electricity transmission lines (4)	0.20	0.20	0.20	**1.00**	1.00	1.00	1.00	1.00
Distance from the road network (5)	0.20	0.25	0.20	1.00	**1.00**	3.00	1.00	1.00
Slope (6)	0.20	0.25	0.20	1.00	0.33	**1.00**	1.00	1.00
Visibility from most visited areas (7)	0.50	1.00	0.50	1.00	1.00	1.00	**1.00**	1.00
Biomass/Biogas potential (8)	0.20	0.50	0.25	1.00	1.00	1.00	1.00	**1.00**

Table 4.14 The relative importance of the selected criteria, for biomass/biogas plants siting, from the different stakeholders

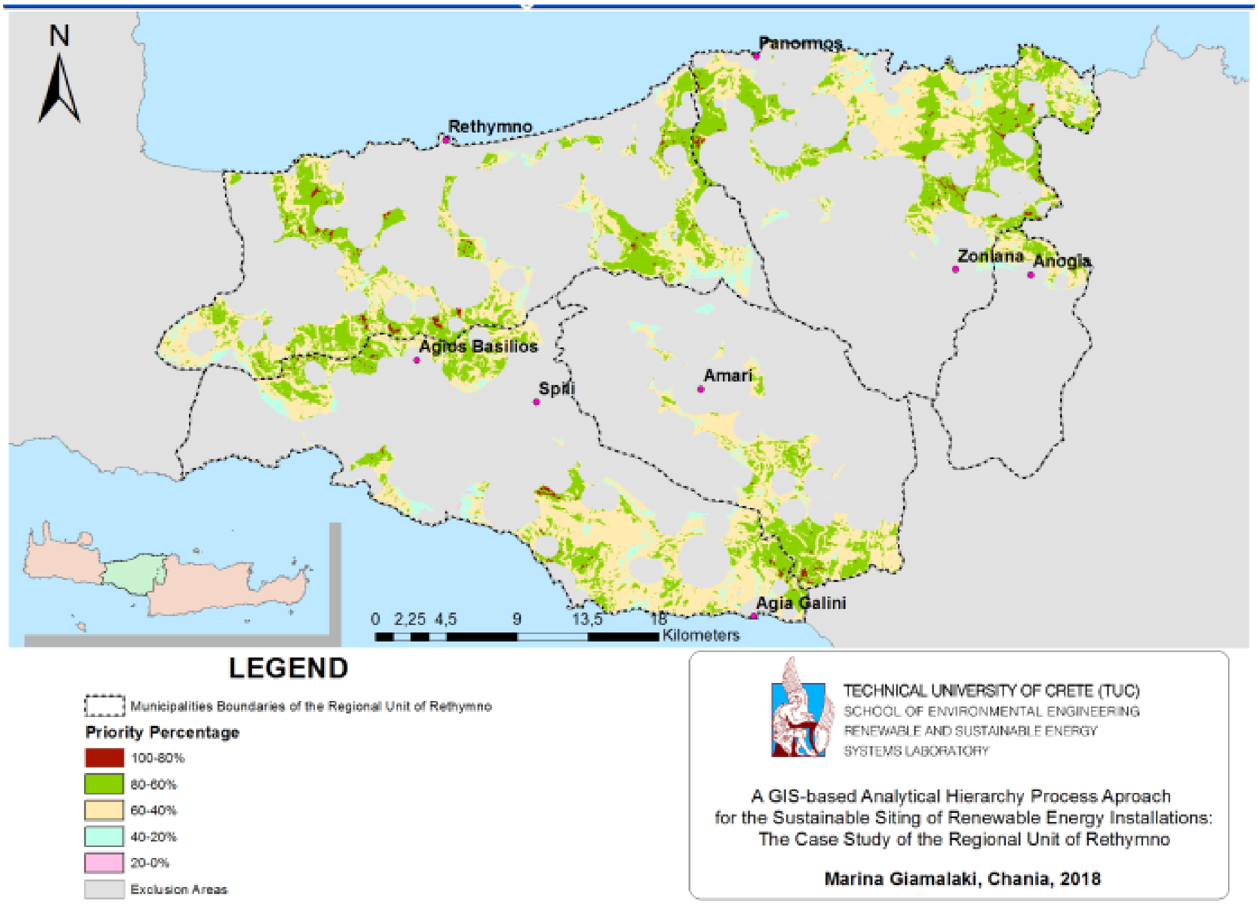
Criterion	Policy Maker	Electricity power supplier	Academia	Environmental group	Engineers	Aggregation of individual priorities
Distance from SCIs of the NATURA 2000 network	0.06	0.32	0.08	0.24	0.22	**0.18**
Distance from water bodies	0.07	0.16	0.08	0.14	0.12	**0.13**
Distance from archaeological sites, monuments and monasteries	0.06	0.21	0.11	0.21	0.09	**0.14**
Distance from the electricity transmission lines	0.12	0.06	0.06	0.06	0.11	**0.09**
Distance from the road network	0.15	0.07	0.23	0.05	0.12	**0.13**
Slope	0.25	0.05	0.05	0.17	0.05	**0.11**
Visibility from most visited areas	0.25	0.09	0.16	0.10	0.04	**0.13**
Biomass/Biogas potential	0.03	0.06	0.23	0.03	0.25	**0.10**

Map 4.3 presents the priority percentage of the available siting areas of the environmental scenario, for biomass plants siting, while in Table 4.15 the municipality coverage by the sustainable siting areas and the biomass

potential per municipality are presented. The energy potential from wood biomass per municipality is derived from the Equation:

$$B_{en} = \sum_{i=1}^{n} B_{av} \times LHV_i \times n_{eff} \tag{4.8}$$

In Equation (4.8), B_{en} is the energy potential of wood biomass (in GJ/y), B_{av} is the available wood biomass (in t/y), LHV is the lower heating value of the different wood biomass species i (14 GJ/t for vineyards, olive, fruit and broadleaved forest trees and 15 GJ/t for coniferous trees [33]) and n_{eff} is the efficiency of the biomass to electricity conversion technology (0.35 for combustion to electricity [55]).

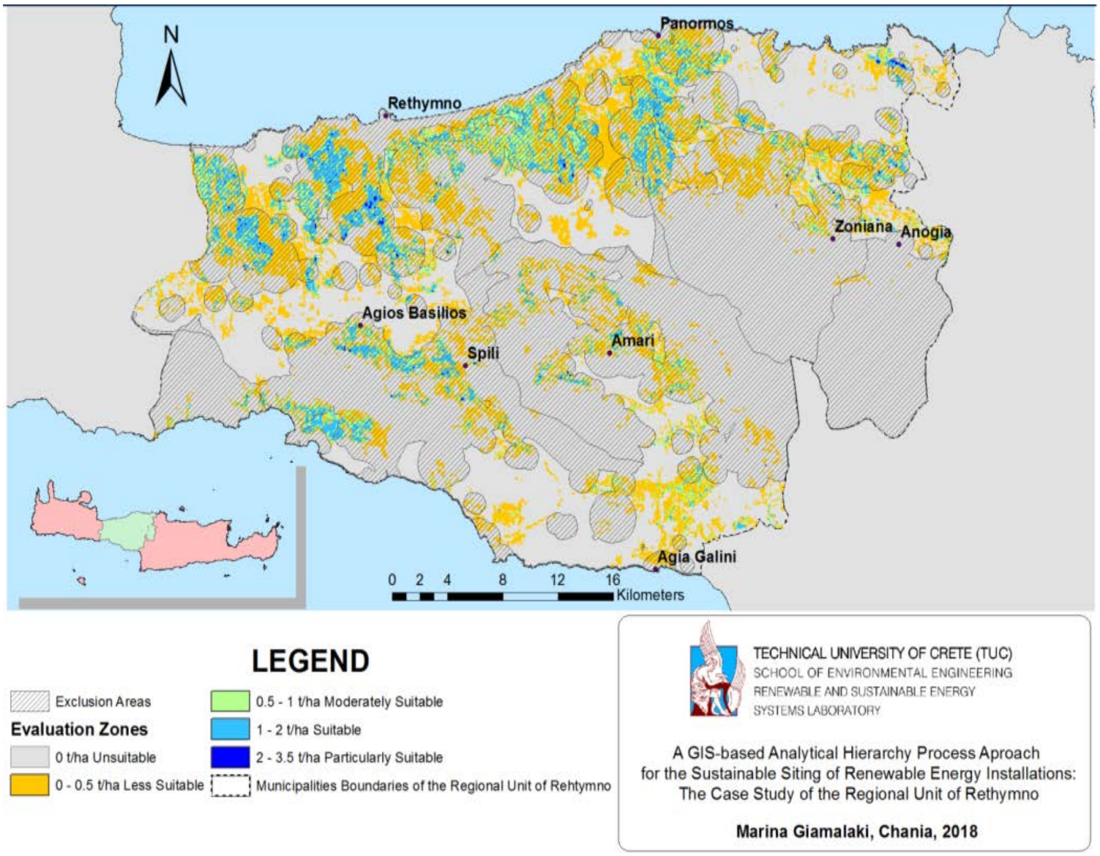


Map 4.3 Priority map for biomass plants siting based on the criteria weights derived from the AHP

Table 4.15 Biomass potential and the municipality coverage by the sustainable siting areas for biomass plants siting

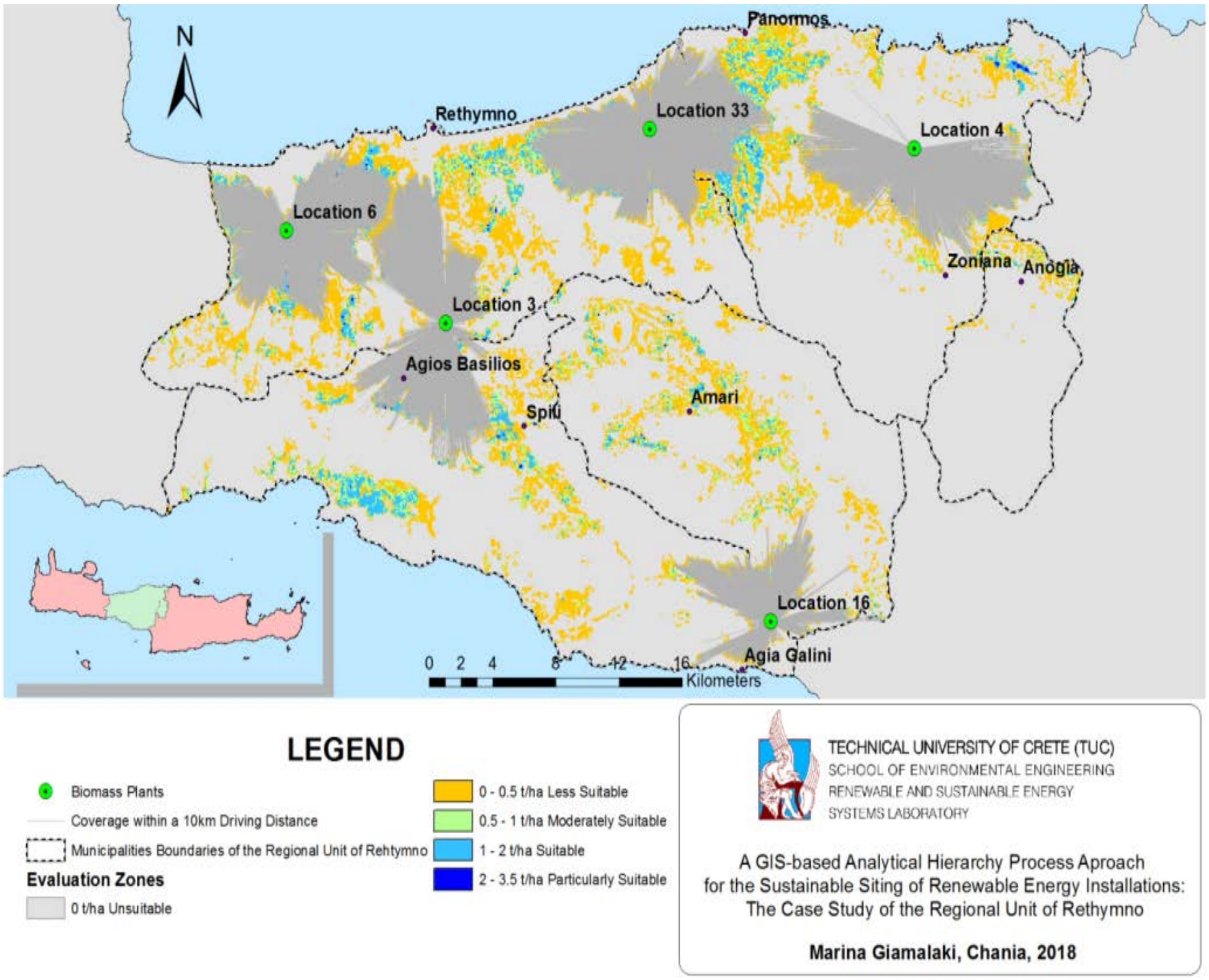
Municipality	Biomass Potential		Municipality Coverage (%) of the Sustainable Siting Areas	
	Biomass potential (t/y)	Energy Potential from Wood Biomass (GWh/y)	Areas with Priority 80-100%	Areas with Priority 60-80%
Agios Vasilios	3,626.18	4.94	0.29	10.54
Amari	2,335.13	3.18	0.16	6.86
Anogia	225.88	0.31	0.01	2.78
Mylopotamos	5,501.31	7.49	0.45	14.72
Rethymno	11,201.30	15.25	0.50	14.31
Total	**22,889.80**	**31.16**	**1.40**	**49.21**

However, for the sustainable biomass plants siting locations, an additional analysis was also performed, as many of the areas with the highest biomass potential are excluded based on the exclusion criteria adopted, as it can be seen in Map 4.4.



Map 4.4 The biomass potential of the Regional Unit of Rethymno and the exclusion areas for biomass plants siting

Therefore, after the combination of the selected criteria, based on the priorities derived by the AHP, the siting areas with the highest priority (80-100%) are derived. In these areas, hypothetical biomass plants were sited and with a location-allocation tool, in ArcGIS 10.3, five of them were chosen, which can allow the greatest coverage of the available biomass potential, within a 10km driving distance (Map 4.5). The available biomass potential for energy production (combustion to electricity efficiency 0.35 [55]) for each location is presented in Table 4.16, with the corresponding energy potential. As we can see, many high biomass potential areas are covered by these high priority siting areas, within a 10km driving distance.



Map 4.5 Allocation of the available biomass potential to five hypothetical biomass plants in high priority siting areas

Table 4.16 Available biomass and energy potential per high priority location

Location	Available Biomass (t/y)	Energy Potential of the Available Biomass (GWh/y)
3	2,527.59	3.44
4	1,496.77	2.04
6	3,793.74	5.16
16	757.26	1.03
33	3,875.55	5.28

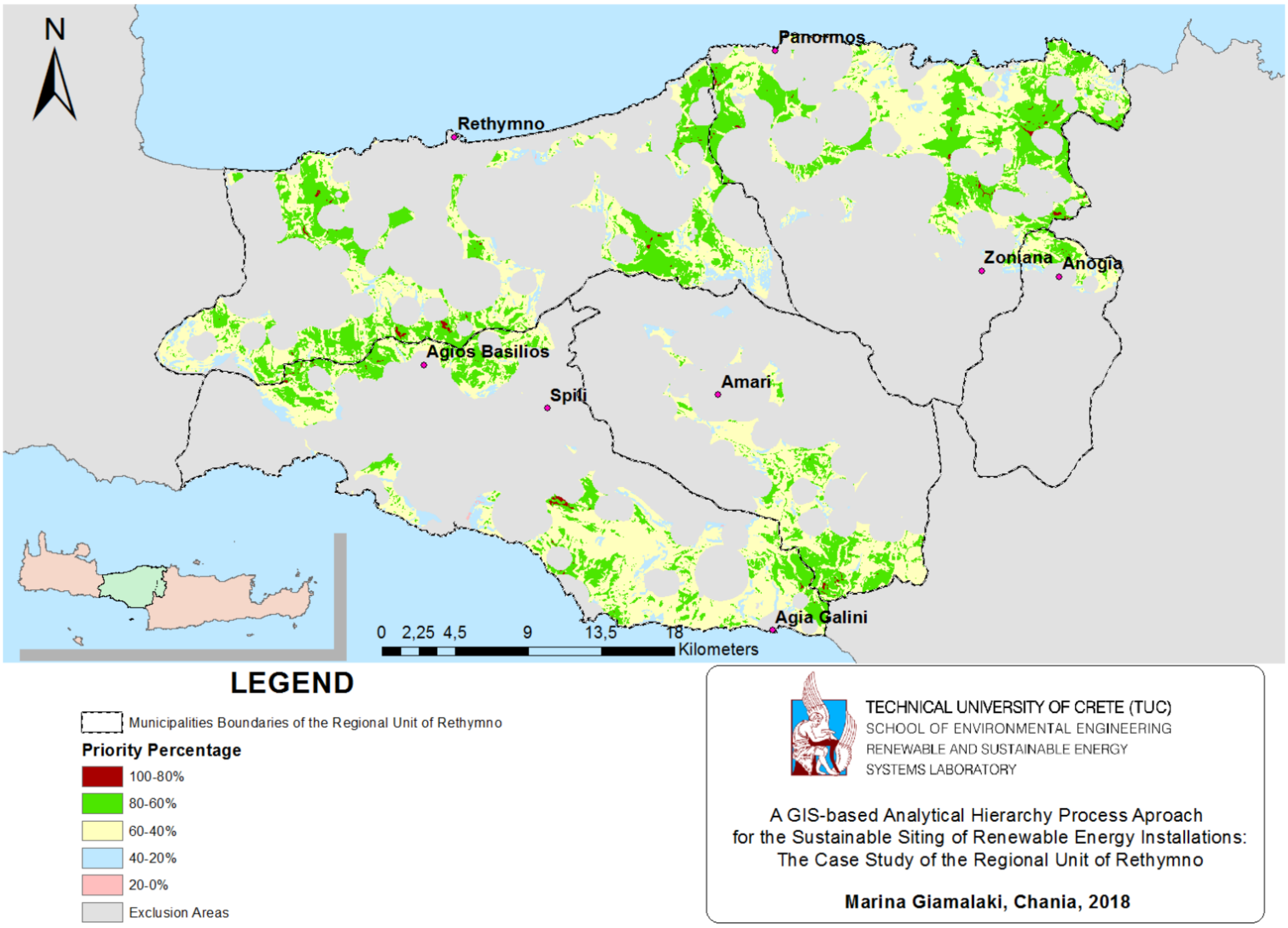
Finally, the selected criteria were also combined to produce the priority map for biogas plants siting, presenting in Map 4.6. In addition, the biogas potential per municipality and the coverage by the sustainable siting areas are presented in Table 4.17. For the energy biogas potential estimation, the Equation (4.9) was employed.

$$B_{enb} = B_b \times LHV_b \times n_{eff} \tag{4.9}$$

In Equation (4.9), B_{enb} corresponds to the energy potential of the available biogas quantities (in MJ/y), B_b is the annual average biogas potential per municipality (in m^3/y), LHV_b is the lower heating value of biogas (taken equal to 20 MJ/m^3 [70]) and n_{eff} is the efficiency of the conversion technology (taken equal to 0.85 for electricity and heat production [71]).

Table 4.17 Biogas potential and the municipality coverage by the sustainable siting areas for biogas plants siting

Municipality	Biogas Potential		Municipality Coverage (%) of the Sustainable Siting Areas	
	Biogas Potential (m^3/y)	Energy Potential from Biogas Sources (GWh/y)	Areas with Priority 80-100%	Areas with Priority 60-80%
Agios Vasilios	-	-	0.17	9.78
Amari	-	-	0.08	5.93
Anogia	23,715.51	0.11	0.01	3.00
Mylopotamos	82,071.71	0.39	0.23	13.94
Rethymno	11,976,602.78	56.92	0.20	13.56
Total	**12,082,390**	**57.42**	**0.69**	**46.21**



Map 4.6 Priority map for biogas plants siting based on the criteria weights derived from the AHP

5 Sensitivity analysis

In Section 4, the priority maps, for each of the renewable energy systems studied, were produced, based on the criteria weights derived from the implementation of an Analytical Hierarchy Process (AHP). The suitability assessment performed in the previous Section, was based on value scores assigned to each criterion and on their associated relative importance, determined by implementing a survey among local renewable energy stakeholders.

In this Section, in order to check the sensitivity of the assigned weights and the results obtained, a sensitivity analysis was carried out. For the sensitivity analysis implementation, different scenarios were employed, concerning the criteria weights. Apart from an equal-weighted scenario, techno-economic, socio-environmental and safety scenarios were employed. For example, in the techno-economic scenario, all techno-economic criteria were given equal weights and for the rest criteria, their relative importance was set to zero. In the next Sections, the different scenarios for the sensitivity analysis implementation and the associated results, for each of the renewable energy technologies studied are presented.

5.1 Sensitivity analysis implementation for wind energy installations siting

In this Section, the different scenarios, concerning the criteria relative importance for wind energy installations siting, for the sensitivity analysis implementation are presented. Table 5.1 presents the criteria weights derived from the AHP, as well as the criteria weights for the different scenarios employed, for the sensitivity analysis implementation. In the techno-economic, socio-environmental and safety scenarios, the criteria not falling under each category, were assigned a weight equal to zero, after consulting Table 3.5, describing the evaluation criteria type for wind energy installations siting.

Table 5.2 presents the results from the sensitivity analysis, in terms of the coverage percentage of the Regional Unit of Rethymno from the available siting area of the environmental scenario (Section 3.2.1), by the different priority classes. The greatest reduction of the sustainable siting areas, in relation to the coverage derived from the AHP, is encountered in the techno-economic scenario, while for the other employed scenarios, the coverage is not much different, in relation to the AHP scenario. In addition, it must be noted that the priority vectors derived from the AHP emphasize in the safety and socio-environmental criteria, giving them greater importance in relation to the techno-economic criteria, and therefore there is a great difference in the relative importance of these criteria between the AHP and the techno-economic scenario. The priority maps produced from the weights derived from the AHP and the different sensitivity analysis scenarios can be found in the Map Annex.

Table 5.1 Criteria relative importance in the different sensitivity analysis scenarios for wind energy installations siting

Evaluation Criteria	Criteria Relative Importance (%)				
	AHP	Equal - Weighted Scenario	Techno-economic Scenario	Socio-environmental Scenario	Safety Scenario
Distance from the NATURA 2000 sites	17	9	0	20	0
Distance from water bodies	10	9	0	20	0
Distance from archaeological sites and monuments	11	9	0	20	0
Distance from antennas	11	9	0	0	50
Distance from national defense installations	13	9	0	0	50
Distance from the high voltage lines	6	9	20	0	0
Distance from the road network	5	9	20	0	0
Slope	6	9	20	0	0
Elevation	6	9	20	20	0
Visibility from most visited sites	8	9	0	20	0
Wind potential	8	9	20	0	0

Table 5.2 The coverage of the Regional Unit of Rethymno in the different sensitivity analysis scenarios, for wind energy installations siting

Priority Percentage (%)	Coverage of the Regional Unit of Rethymno (%)				
	AHP	Equal-Weighted Scenario	Techno-Economic Scenario	Socio-Environmental Scenario	Safety Scenario
100-80	0.39	0.17	1.25	1.57	2.88
80-60	10.82	9.94	6.57	8.14	8.29
60-40	4.71	5.96	8.10	5.49	3.72
40-20	0.19	0.04	0.18	0.91	1.13
20-0	0.00	0.00	0.00	0.01	0.09
Sustainable Siting Areas	11.21	10.11	7.83	9.71	11.18

5.2 Sensitivity analysis implementation for solar energy installations siting

The equal-weighted, the socio-environmental and the techno-economic scenario were also employed for checking the sensitivity of the results obtained from the AHP, for solar energy installations siting. Therefore, Table 5.3 presents the criteria weights, in the different employed weight scenarios.

Table 5.3 Criteria relative importance in the different sensitivity analysis scenarios for solar energy installations siting

	Criteria Relative Importance (%)			
Evaluation Criteria	**AHP**	**Equal-Weighted Scenario**	**Techno-Economic Scenario**	**Socio-Environmental Scenario**
Distance from the coastline	16	10	0	20
Distance from water bodies	12	10	0	20
Distance from the electricity transmission lines	7	10	17	0
Distance from the road network	8	10	17	0
Aspects	10	10	17	0
Land cover	12	10	0	20
Slope	8	10	17	0
Elevation	9	10	17	20
Visibility from most-visited sites	9	10	0	20
Solar potential	7	10	17	0

In the Map Annex, the priority maps accrued from the different sensitivity analysis scenarios can be found, while in Table 5.4 the results, in terms of the Regional Unit's coverage by the different priority classes, for PVs and CSPs siting are presented. In addition, the results of the Table 5.4 concern the coverage of the Regional Unit of Rethymno by the available areas of the socio-environmental scenario, described in Section 3.3.1. As it can be seen from the Table, the greatest reduction in the sustainable areas coverage, in relation to the one from the AHP, accrues in the equal-weighted scenario, while a reduction is also observed in the techno-economic scenario for both PVs and CSPs siting. In addition, the results are about the same for the AHP and socio-environmental scenario.

Table 5.4 The coverage of the Regional Unit of Rethymno in the different sensitivity analysis scenarios, for solar energy installations siting

Priority Percentage (%)	Coverage of the Regional Unit of Rethymno (%)							
	PV Farms				CSP Farms			
	AHP	Equal-Weighted Scenario	Techno-Economic Scenario	Socio-Environmental Scenario	AHP	Equal-Weighted Scenario	Techno-Economic Scenario	Socio-Environmental Scenario
100-80	0.71	0.25	3.16	2.73	0.29	0.05	1.13	2.73
80-60	37.79	26.67	29.22	29.41	31.98	19.02	22.54	29.41
60-40	22.21	32.99	25.05	26.28	28.20	39.14	29.30	26.28
40-20	0.12	0.91	3.42	2.40	0.35	2.61	7.21	2.40
20-0	0.00	0.00	0.10	0.00	0.00	0.00	0.77	0.00
Sustainable Siting Areas	38.50	26.92	32.39	32.15	32.27	19.07	23.68	32.14

5.3 Sensitivity analysis implementation for biomass plants siting

Finally, the same sensitivity analysis procedure was conducted for the sensitivity checking of the AHP results, for biomass plants siting. Table 5.5 describes the criteria weights, in the different employed scenarios, while in the Map Annex the accruing priority maps can be found. In addition, Table 5.6 contains the coverage of the Regional Unit of Rethymno, by the environmental scenario's available areas (Section 3.4.1), in terms of its allocation in the different priority classes. In this case, it is also obvious the reduction of the sustainable siting areas in the techno-economic scenario and the socio-environmental oriented results from the AHP.

Table 5.5 Criteria relative importance in the different sensitivity analysis scenarios for biomass plants siting

Evaluation Criteria	AHP	Equal-Weighted Scenario	Techno-Economic Scenario	Socio-Environmental Scenario
Distance from SCIs of the NATURA 2000 network	18	12.5	0	25
Distance from water bodies	13	12.5	0	25
Distance from archaeological sites, monuments and monasteries	14	12.5	0	25
Distance from the electricity transmission lines	9	12.5	25	0
Distance from the road network	13	12.5	25	0
Slope	11	12.5	25	0
Visibility from most visited areas	13	12.5	0	25
Biomass potential	10	12.5	25	0

Table 5.6 The coverage of the Regional Unit of Rethymno in the different sensitivity analysis scenarios, for biomass plants siting

Priority Percentage (%)	Coverage of the Regional Unit of Rethymno (%)			
	AHP	Equal-Weighted Scenario	Techno-Economic Scenario	Socio-Environmental Scenario
100-80	0.34	0.16	1.39	5.00
80-60	11.34	7.17	4.09	13.75
60-40	16.62	19.78	9.27	9.12
40-20	2.04	3.21	12.12	2.30
20-0	0.02	0.04	3.49	0.18
Sustainable Siting Areas	11.68	7.33	5.48	18.76

6 Conclusions

The RES siting problem and more specifically the problem of finding suitable sites to host renewable energy installations is a common research area for scientific papers and other studies. The main characteristic of this problem is its complexity, as different and often contradictive criteria have to be taken into consideration, in order to find the most suitable siting areas. For example, an environmental criterion for wind energy installations siting, such as the distance from areas of environmental interest, whose aim is to be maximized, in some cases may contradict with the criterion of the distance from the road network, which is a techno-economic criterion aimed to be minimized. Therefore, the key objective of the RES site selection studies is to find the most suitable locations, for the minimization of the impacts on the natural and human environment and the maximization of the economic and technical potential.

This study dealt with the renewable energy installations siting problem, by employing Geographic Information Systems and the Analytical Hierarchy Process (AHP). Therefore, a dynamic methodology was developed, for finding the sustainable siting areas to host wind, PV and CSP farms, as well as biomass and biogas plants. The adopted methodology was applied in the case study of the Regional Unit of Rethymno and enabled:

- the identification of the legally available siting areas for each RES, after reviewing the related legislation
- the evaluation of the available siting locations, based on techno-economic, socio-environmental and safety criteria
- the classification of each evaluation criterion into a five-class priority scale, after a rigorous literature review
- the determination of the criteria relative importance, by implementing the AHP, where local experts from different involved renewable energy-related groups were asked to perform the necessary pair-wise comparisons of the selected criteria

- the identification of the sustainable siting areas for each RES, after the production of priority maps with a weighted sum aggregation of the selected criteria
- the sensitivity evaluation of the methodology's results, by employing different scenarios for the criteria weights

The results from the adopted methodology, for the Regional Unit of Rethymno, in terms of the coverage from the highest priority sustainable siting areas (80-100%) are: 1.55% for wind energy installations, 2.88% for PV farms, 0.17% for CSP farms, 1.40% for biomass plants and 0.69% for biogas plants. In addition, the results of the adopted methodology, in terms of the potential maximum power from the highest priority areas are: 76MW for wind energy installations, 530MW for PVs and 30MW for CSPs. Finally, the highest priority areas for biomass plants siting have the energy potential of 16.95GWh/y, for the collection of the available biomass in a 10km driving distance.

In addition, from the implemented sensitivity analysis, a reduction was observed in the sustainable siting areas of the techno-economic scenario, in relation to the coverage derived from the AHP, for every renewable energy technology studied. Moreover, it must be noted that the priority vectors derived from the AHP for each technology, emphasize in the safety and socio-environmental criteria, giving them greater importance in relation to the techno-economic criteria. Therefore, the main advantages of the adopted methodology are that:

- it takes into account the three spectrums of the sustainable development to ensure both the environmental and landscape preservation and the feasibility of the investment
- it takes into account the complexity of the renewable energy installations siting, by incorporating the distinct opinions of different renewable energy-related involved groups
- it enables the creation of alternative scenarios, for the exclusion criteria selection and the evaluation criteria importance and the visualization of the results for each scenario

7 Discussion and recommendations for further research

Further research can also be performed in the methodology development, for the RES sustainable siting areas identification and its application in the Regional Unit of Rethymno. More evaluation criteria can be incorporated, more stakeholders can participate in the survey for the criteria weights determination and more renewable energy technologies can be studied. Therefore, economic evaluation criteria can be employed for the economic potential determination and investors in the RES field can participate in the survey, for their input in the criteria relative importance.

In addition, for the AHP implementation, the criteria can be divided into categories, regarding their type (e.g. technical, economic, social, environmental, safety) and the hierarchical structure of the problem can include sub-criteria (e.g. the environmental criterion can include the distance from the NATURA 2000 sites and the distance from the water bodies sub-criteria). In this case, the selected stakeholders have to perform the necessary pair-wise comparisons for the criteria and the sub-criteria of each criterion separately.

Finally, the developed methodology is based on the quality and quantity of the available data for collection. In this study, a special effort was made for the collection of the necessary data from official authorities and scientific studies. However, as discussed in previous Sections, a spatial representation of the medium voltage lines of the Regional Unit of Rethymno was not available to us by the competent authority. In addition, forest maps and spatial data on the high productivity agricultural areas were not published yet for the Regional Unit of Rethymno. Therefore, data from the historical CORINE database were employed, concerning the forest and agricultural areas of the region. However, despite these limitations, the methodology developed is dynamic, allowing for the continuous update of the collected data, which can, in turn, lead to the employment of additional evaluation criteria.

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Annex A

In this Section the evaluation criteria (Crit.) and constraints (Con.) for siting wind energy projects, from the literature review are presented. Table A.1 and Table A.2 present the most common evaluation and exclusion criteria, while Table A.3 present the less used criteria and constraints, based on the literature review performed.

Table A.1 Overview of the evaluation criteria and constraints used in the literature for wind farms site selection

	Distance From:							
Authors	**Areas of environmental interest**	**Water bodies**	**Road network**	**Electricity transmission lines**	**Airports**	**Areas of cultural interest**	**Antennas/ telecom. infrastruc.**	**Residential areas**
Atici et al., [4]	Con.	Con.	Con. Crit.	Con. Crit.	Con.		Con.	Con.
Aydin et al., [5]	Con. Crit.	Con. Crit.			Con. Crit.			Con. Crit.
Baban and Parry, [6]	Con.	Con. Crit.	Con. Crit.	Con.		Con. Crit.		Con. Crit.
Bennui et al., [8]	Con. Crit.	Con. Crit.	Con. Crit.		Con. Crit.	Con. Crit.		Con. Crit.
Gorsevski et al., [20]	Crit.	Con.	Crit.	Crit.	Con.			Con.
Van Haaren and Fthenakis, [22]	Con.	Con.	Con. Crit.	Crit.		Con.		Con.
Hansen, [24]	Con.	Crit.	Crit.	Crit.	Crit.	Crit.	Crit.	Crit.
Hofer et al., [26]	Con. Crit.	Con. Crit.	Con. Crit.	Con. Crit.		Crit.		Con. Crit.
Janke, [29]	Crit.		Crit.	Crit.		Crit.		Crit.
Latinopoulos and Kechagia, [31]	Con. Crit.		Con. Crit.		Con.	Con. Crit.		Con.
Sanchez-Lozano et al., [47]	Con.	Con.	Con. Crit.	Crit.	Crit.	Con. Crit.	Crit.	Con. Crit.
Noorollahi et al., [39]	Con.	Con.	Con. Crit.	Con. Crit.	Con.	Con.		Con.
Rodman and Meentemeyer, [43]	Con.							Con.
Schallenberg-Rodriguez and Notario-del Pino, [50]	Con.	Con.	Con.	Con.	Con.			Con.
Sliz-Szkliniarz and Vogt, [53]	Con.	Con.	Con.	Con.	Con.	Con.		Con.
Szurek et al., [57]	Con.	Crit.	Crit.	Crit.			Crit.	Crit.
Tegou et al., [59]	Con.	Crit.	Con. Crit.	Crit.	Con.	Con. Crit.		Con. Crit.
Tsoutsos et al., [60]	Con. Crit.	Crit.	Con. Crit.	Con. Crit.	Con. Crit.	Con. Crit.	Con. Crit.	Con.
Voivontas et al., [64]					Con.	Con.		Con.
Watson and Hudson, [66]	Con. Crit.		Crit.	Crit.		Con. Crit.		Con. Crit.

Table A.2 Overview of the evaluation criteria and constraints used in the literature for wind farms site selection (Continued)

					Distance From:				
Authors	**Wind speed**	**Slope**	**Elevation**	**Land uses**	**Tourist Accommodations**	**Shoreline**	**Forests**	**Ports/ marinas**	**Military installations**
Atici et al., [4]		Con. Crit.	Con.						
Aydin et al., [5]	Con. Crit.								
Baban and Parry, [6]	Con.	Con. Crit.	Con.	Con. Crit.					
Bennui et al., [8]	Crit.	Con.	Con. Crit.						Crit.
Gorsevski et al., [20]	Crit.			Crit.					
Van Haaren and Fthenakis, [22]	Crit.	Con.		Crit.					
Hansen, [24]	Crit.		Crit.			Crit.	Crit.		
Hofer et al., [26]	Con. Crit.	Con. Crit.		Con. Crit.					
Janke, [29]	Crit.			Crit.					
Latinopoulos and Kechagia, [31]	Con. Crit.	Con. Crit.		Con. Crit.	Con. Crit.				
Sanchez-Lozano et al., [47]	Crit.	Crit.		Con.		Con.		Con.	Con.
Noorollahi et al., [39]	Crit.	Con.	Con.			Con.			
Rodman and Meentemeyer, [43]	Con.	Crit.	Crit.	Crit.			Crit.		
Schallenberg-Rodriguez and Notario-del Pino, [50]	Con.	Con.							
Sliz-Szkliniarz and Vogt, [53]		Con.	Con.	Con.			Con.		
Szurek et al., [57]		Crit.					Crit.		
Tegou et al., [59]	Con. Crit.	Con. Crit.		Con. Crit.		Crit.			
Tsoutsos et al., [60]	Crit.	Crit.		Con.	Con.			Con.	Con. Crit.
Voivontas et al., [64]	Con.	Con.	Con.						
Watson and Hudson, [66]	Crit.	Con.		Con.					

Table A.3 Overview of less used evaluation criteria and constraints from the literature review of wind farm site selection

Authors	Capacity factor	Carrying capacity	Electricity demand	Wind direction	Surface roughness	Soil type	Population density	Karst grounds	Area	Fault lines	Aspect
Atici et al., [4]	Con. Crit.									Con. Crit.	
Baban and Parry, [6]				Con.							
Bennui et al., [8]					Crit.						
Gorsevski et al., [20]						Crit.	Crit.				
Van Haaren and Fthenakis, [22]								Con.			
Janke, [29]							Crit.				
Sanchez-Lozano et al., [47]									Crit.		
Szurek et al., [57]											Crit.
Noorollahi et al., [39]										Con.	
Tegou et al., [59]			Crit.								
Tsoutsos et al., [60]		Con.									

Annex B

In this Section the most common criteria (Crit.) and constraints (Con.) for the studies presented in Section 2 are presented in Table B.1 and Table B.2. Other less used criteria are: sunshine hours, relative humidity, land value, population density, flooding risk, area and distance from airports, national defense infrastructure and mines.

Table B.1 Overview of the distance criteria and constraints used in the literature for solar farms site selection

	Distance From:						
Authors	**Areas of environmental interest**	**Water bodies**	**Road network**	**Electricity transmission lines**	**Residential areas**	**Areas of cultural interest**	**Shoreline**
Asakereh et al., [3]	Con. Crit.	Con. Crit.	Con. Crit.	Crit.	Con. Crit.		
Tavana et al., [58]			Crit.	Crit.	Crit.		
Al Garni and Awasthi, [10]	Con.		Con. Crit.	Crit.	Con. Crit.	Con.	
Sun et al., [56]	Con.	Con.					
Charabi and Gasli, [12]		Con.	Con. Crit.		Con.	Con.	
Merrouni et al., [35]		Con. Crit.	Con. Crit.	Crit.	Con. Crit.		
Carrion et al., [11]	Con.	Con.	Con. Crit.	Crit.	Crit.		Con.
Sindhu et al., [52]	Crit.		Crit.	Crit.	Crit.		
Uyan, [62]	Con.	Con.	Con. Crit.	Crit.	Con. Crit.	Con.	
Hott et al., [28]				Crit.	Crit.		
Watson and Hudson, [66]	Con. Crit.		Crit.	Crit.	Con. Crit.	Con. Crit.	
Janke, [29]	Con.		Crit.	Crit.	Crit.	Con.	
Sadeghi and Karimi, [46]	Con.	Con.	Con. Crit.	Crit.	Con. Crit.		
Georgiou and Skarlatos, [21]	Con.	Con.	Con. Crit.	Crit.	Con.	Con.	Con.
Sanchez-Lozano et al., [48], [49]	Con.	Con.	Con. Crit.	Crit.	Con. Crit.	Con.	Con.
Aly et al., [2]	Con.	Con. Crit.	Crit.	Crit.	Con. Crit.		
Yushchenko et al., [68]	Con.		Crit.	Crit.	Con. Crit.		
Mondino et al., [36]	Con.	Con.			Con.		
Merrouni et al., [34]		Crit.	Crit.	Crit.			

Table B.2 Overview of the criteria and constraints used in the literature for solar farms site selection

Authors	Solar potential	Slope	Elevation	Land uses	Temperature	Aspects	Visual impact
Asakereh et al., [3]	Crit.	Con. Crit.		Crit.			
Tavana et al., [58]	Crit.		Crit.				
Al Garni and Awasthi, [10]	Crit.	Con. Crit.			Crit.	Crit.	
Sun et al., [56]	Crit.	Con.		Con.			
Charabi and Gasli, [12]	Crit.	Con.		Con.			
Merrouni et al., [35]	Crit.	Crit.		Con.			
Carrion et al., [11]	Crit.	Crit.		Con. Crit.	Crit.	Crit.	Crit.
Sindhu et al., [52]	Crit.			Crit.			Crit.
Uyan, [62]		Crit.		Con. Crit.			
Hott et al., [28]	Crit.	Crit.		Crit.		Crit.	
Watson and Hudson, [66]	Crit.	Con.		Con.		Con.	
Janke, [29]	Crit.			Crit.			
Sadeghi and Karimi, [46]	Crit.	Crit.	Crit.	Con. Crit.		Crit.	
Georgiou and Skarlatos, [21]	Crit.	Crit.	Crit.	Con.		Con.	Crit.
Sanchez-Lozano et al., [48], [49]	Crit.	Crit.	Con.	Con. Crit.	Crit.	Crit.	
Aly et al., [2]	Con. Crit.	Con.		Con.			
Yushchenko et al., [68]	Crit.	Con.		Con.			
Mondino et al., [36]	Crit.	Con.	Con.	Con.	Crit.	Con.	
Merrouni et al., [34]	Crit.	Crit.		Crit.			

Annex C

In this Section, the criteria classification and buffer distances used in the literature, concerning the criteria selected in this study for the evaluation of the available siting areas for wind energy installations, are presented. For the classification of the available areas according to their suitability for each criterion, some authors employ trapezoid membership equations and others apply value scores to each criterion class (Tables C.1 to C.10). For this study, the criteria classification and assigned value scores of suitability are presented in detail in Section 3.2.2.

Table C.1 Literature review on the criterion of the distance from areas of environmental interest for wind energy installations site selection

Authors	Distance from areas of environmental interest	Details
Atici et al., [4]	Constraint	>2,000m from protected areas
Aydin et al., [5]	Constraint Criterion	>1,000m from areas of ecological value, >250m from ecologically sensitive areas, >500m from wildlife conservation areas Trapezoid fuzzy membership equation (control points: 300, 1,000m) For important bird habitats: Trapezoid fuzzy membership equation (control points: 2,500, 5,000m)
Baban and Parry, [6]	Constraint	>1000m from areas of ecological value/special scientific interest
Gorsevski et al., [20]	Criterion	For important bird habitats: Trapezoid fuzzy membership equation (control points: 5,000, 30,000m)
Hofer et al., [26]	Criterion	Areas of environmental interest without important bird habitats: Distance(m) Score (10 being the best) - 0 - 1 0-100 2 100-200 3 - 4 200-300 5 - 6 300-400 7 400-500 8

Table C.1 Literature review on the criterion of the distance from areas of environmental interest for wind energy installations site selection

Authors	Distance from areas of environmental interest	Details
		- 9 >500 10
Latinopoulos and Kechagia, [31]	Constraint Criterion	>1,000m from protected landscapes For NATURA 2000 sites: Trapezoid fuzzy membership equation (control points: 0, 3,000m)
Noorollahi et al., [39]	Constraint	>2,000m from environmental protected areas
Schallenberg-Rodriguez and Notario-del Pino, [50]	Constraint	>1,000m from protected areas
Sliz-Szkliniarz and Vogt, [53]	Constraint	>500m from Natura 2000 sites >1,000m from important bird areas
Szurek et al., [57]	Constraint	>2,000m
Watson and Hudson, [66]	Constraint	>1,000m from landscape and wildlife designations

Table C.2 Literature review on the criterion of the distance from water bodies for wind energy installations site selection

Authors	Distance from water bodies	Details
Atici et al., [4]	Constraint	>3,000m
Aydin et al., [5]	Constraint	>400m
Baban and Parry, [6]	Constraint	>400m
Bennui et al., [8]	Constraint Criterion	Distance -Suitability 0-200m Exclusion Zone 200-400m Less suitable 400-600m suitable 600-800m Moderate suitable 800-1,000m High suitable >1,000m Extremely suitable
Van Haaren and Fthenakis, [22]	Constraint	>3,000m from lakes
Hansen, [24]	Criterion	Trapezoid fuzzy membership equation (control points: 150, 500m)
Hofer et al., [26]	Constraint	>50m
Noorollahi et al., [39]	Constraint	>500m from rivers >1,000m from lakes
Szurek et al., [57]	Criterion	Distance-Score (5 being the best) 0-200m 0 200-350m 1 350-500m 2 500-650m 3 650-800m 4 >800m 5

Table C.2 Literature review on the criterion of the distance from water bodies for wind energy installations site selection

Authors	Distance from water bodies	Details
Sliz-Szkliniarz and Vogt, [53]	Constraint	>200m from inland water >250m from streams

Table C.3 Literature review on the criterion of the distance from areas of cultural interest for wind energy installations site selection

Authors	Distance from areas of cultural interest	Details
Baban and Parry, [6]	Constraint	>1,000m
Bennui et al., [8]	Criterion	Distance-Suitability 0-2km Exclusion Zone 2-2.5km Less suitable 2.5-3km Suitable 3-3.5km Moderate suitable 3.5-4km High suitable > 4km Extremely suitable
Hansen, [24]	Criterion	For churches: Trapezoid fuzzy membership equation (control points: 300, 500m)
Hofer et al., [26]	Criterion	Distance-Score (10 being the best) - 0 0-600m 1 600-700m 2 700-800m 3 800-900m 4 900-1,000m 5 1,000-1,100m 6 1,100-1,200m 7 1,200-1,300m 8 1,300-1,400m 9 >1,400m 10
Latinopoulos and Kechagia, [31]	Criterion	Trapezoid fuzzy membership equation (control points: 1,000,3,000m)
Noorollahi et al., [39]	Constraint	>700m from ancient and cultural monuments
Sliz-Szkliniarz and Vogt, [53]	Constraint	>1,000m from castles and cultural relicts
Tegou et al., [59]	Constraint Criterion	>500m,3,000m,6,000m with different value scores
Voivontas et al., [64]	Constraint	>2,000m
Watson and Hudson, [66]	Constraint	>1,000m

Table C.4 Literature review on the criterion of the distance from antennas for wind energy installations site selection

Authors	Distance from antennas	Details
Atici et al., [4]	Constraint	>600m
Hansen, [24]	Criterion	Trapezoid fuzzy membership equation (control points: 1,000,1,500m)
Szurek et al., [57]	Criterion	< 200m 0 (0:constrain, 5 most suitable) 200–350m 1 351–500m 2 501–650m 3 651–800m 4 >800 m 5
Sanchez-Lozano et al., [47]	Criterion	<400m(regular), 400-1,000m(good), 1,000-4,000m (very good), >4,000m(excellent)

Table C.5 Literature review on the criterion of the distance from airports for wind energy installations site selection

Authors	Distance from airports	Details
Atici et al., [4]	Constraint	>5,000m
Aydin et al., [5]	Criterion	Trapezoid fuzzy membership equation (control points: 3,000,6,000m)
Bennui et al., [8]	Criterion	Distance-Suitability 0-3km Exclusion Zone 3-6km Less suitable 6-9km suitable 9- 12km Moderate suitable 12-15km High suitable >15km Extremely suitable
Hansen, [24]	Criterion	Trapezoid fuzzy membership equation (control points: 5,000,7,500m)
Latinopoulos and Kechagia, [31]	Constraint	>3,000m
Sanchez-Lozano et al., [47]	Criterion	<7,000m (regular) 7,000-20,000m (good) 20,000-35,000m (very good) >35,000m(excellent)
Noorollahi et al., [39]	Constraint	>15,000m from military airport >2,500m from commercial airport
Schallenberg-Rodriguez and Notario-del Pino, [50]	Constraint	>3,500m
Sliz-Szkliniarz and Vogt, [53]	Constraint	>3,000m
Voivontas et al., [64]	Constraint	>2,500m

Table C.6 Literature review on the criterion of the distance from electricity transmission lines for wind energy installations site selection

Authors	Distance from transmission lines	Details
Baban and Parry, [6]	Constraint	<10,000m
Gorsevski et al., [20]	Criterion	Trapezoid fuzzy membership equation (control points: 1,000, 20,000m)
Hansen, [24]	Criterion	Trapezoid fuzzy membership equation (control points: 200, 500m)

Table C.6 Literature review on the criterion of the distance from electricity transmission lines for wind energy installations site selection

Authors	Distance from transmission lines	Details
Hofer et al., [26]	Criterion	Distance(m) Score (10 being the best) 0-100 0 >9,000 1 8,000-9,000 2 7,000-8,000 3 6,000-7,000 4 5,000-6,000 5 4,000-5,000 6 3,000-4,000 7 2,000-3,000 8 1,000-2,000 9 100-1,000 10
Sanchez-Lozano et al., [47]	Criterion	Distance (m)-Suitability >5,000(regular) 5,000-1,500(good) 1,500- 500(very good) <500(excellent)
Noorollahi et al., [39]	Criterion	Distance Score (10 being the best) 250–2,000m 10 2,000–4,000m 9 4,000–6,000m 7 6,000–8,000m 5 8,000–10,000m 3 >10,000m 1

Table C.7 Literature review on the criterion of the distance from the road network for wind energy installations site selection

Authors	Distance from the road network	Details
Baban and Parry, [6]	Criterion	Distance- Score (10 constraint, 1 best) 0–100m 10 101-999m 1 1,000–1,999m 2 2,000–2,999m 3 3,000–3,999m 4 4,000–4,999m 5 5,000–5,999m 6 6,000–6,999m 7 7,000–7,999m 8 8,000–8,999m 9
Bennui et al., [8]	Criterion	Distance-Suitability 0-0.5km Exclusion Zone 0.5-1.0km Less suitable 1.0-1.5km suitable 1.5-2.0km Moderate suitable 2.0-2.5km High suitable > 2.5km Extremely suitable
Gorsevski et al., [20]	Criterion	Trapezoid fuzzy membership equation (control points: 1,000, 10,000m)
Hofer et al., [26]	Criterion	Distance-Score (0 constraint, 10 best) - 0

Table C.7 Literature review on the criterion of the distance from the road network for wind energy installations site selection

Authors	Distance from the road network	Details
		>500m 1 450-500m 2 400-450m 3 350-400m 4 300-350m 5 250-300m 6 200-250m 7 150-200m 8 100-150m 9 0-100m 10
Latinopoulos and Kechagia, [31]	Criterion	Trapezoid fuzzy membership equation (control points: 200,5,000m)
Sanchez-Lozano et al., [47]	Criterion	>5,000m(regular) 5,000-2,000m(good) 2,000-500m(very good) <500(excellent)
Noorollahi et al., [39]	Criterion	Distance-Score (10 being the best) <500m 0 500–2,000m 10 2,000–4,000m 9 4,000–6,000m 8 6,000–8,000m 6 8,000–10,000m 4 >10,000m 2

Table C.8 Literature review on the criterion of the slope for wind energy installations site selection

Authors	Slope	Details
Atici et al., [4]	Constraint	<10%
Baban and Parry, [6]	Constraint	<10%
Bennui et al., [8]	Constraint	<15%
Van Haaren and Fthenakis, [22]	Constraint	<10%
Hofer et al., [26]	Criterion	Slope-Score (10 being the best) >30% 0 27-30 1 24-27 2 21-24 3 18-21 4 15-18 5 12-15 6 19-12 7 6-9 8 3-6 9 0-3 10
Latinopoulos and Kechagia, [31]	Criterion	Trapezoid fuzzy membership equation (control points: 5, 20%)
Sanchez-Lozano et al., [47]	Criterion	Slope-Suitability > 50%(regular) 50-30(good) 30-15 (very good) <15(excellent)
Noorollahi et al., [39]	Constraint	<15%
Rodman and Meentemeyer, [43]	Criterion	Slope-Suitability

Table C.8 Literature review on the criterion of the slope for wind energy installations site selection

Authors	Slope	Details
		0-7degrees(excellent) 7-16degrees(good) 16-30degrees (fair) 30-40degrees(poor) >40degrees (unsuitable)
Schallenberg-Rodriguez and Notario-del Pino, [50]	Constraint	<45degrees=100%
Tegou et al., [59]	Criterion	Slope Score (1 being the best) 0% 1 0-10 0.9 10-15 0.6 15-20 0.2 20-25 0.1 25-74 0.0
Voivontas et al., [64]	Constraint	<60%
Watson and Hudson, [66]	Constraint	<10degrees=18%

Table C.9 Literature review on the criterion of the elevation for wind energy installations site selection

Authors	Elevation	Details
Atici et al., [4]	Constraint	<1,500m
Noorollahi et al., [39]	Constraint	<2,000m
Voivontas et al., [64]	Constraint	<1,000m

Table C.10 Literature review on the criterion of the wind potential for wind energy installations site selection

Authors	Wind potential	Details
Baban and Parry, [6]	Constraint	>5m/s
Gorsevski et al., [20]	Criterion	Wind speed(m/s)-Suitability (Class 4 being the best) 0–5.6 (Class 1) 5.6–6.4 (Class 2) 6.4–7.0 (Class 3) 7.0–7.5 (Class 4)
Hofer et al., [26]	Criterion	Wind speed-Score (10 being the best) <6.00m/s 0 >7.00m/s 10
Latinopoulos and Kechagia, [31]	Criterion	Trapezoid fuzzy membership equation (control points: 5, 7.5m/s)
Sanchez-Lozano et al., [47]	Criterion	Wind speed (m/s)-Suitability <3.20 (regular) 3.20-5.50 (good) 5.50 -7.00 (very good) >7.00 (excellent)
Noorollahi et al., [39]	Criterion	Wind speed-Score (10 being the best) <5.6 m/s 0 5.6–6.4 m/s 2 6.4–6.9 m/s 4 6.9–7.5 m/s 6

Table C.10 Literature review on the criterion of the wind potential for wind energy installations site selection

Authors	Wind potential	Details
		7.5–9.5 m/s 8 >9.5 m/s 10
Rodman and Meentemeyer, [43]	Constraint	>7m/s
Schallenberg-Rodriguez and Notario-del Pino, [50]	Constraint	>4.8m/s
Tegou et al., [59]	Constraint	>4m/s
Tsoutsos et al., [60]	Criterion	>8m/s
Voivontas et al., [64]	Constraint	>6m/s

Annex D

Similar to wind energy installations, a literature review was conducted for solar energy installations, presenting the buffer distances and criteria classification applied in the studies, found in the literature. Tables D.1 to D.7 present the criteria classification and constraint values applied in the literature for the criteria selected in this study. Consulting these Tables the criteria classes for this study were produced, as presented in detail in Section 3.3.2.

Table D.1 Literature review on the criterion of the distance from the road network for solar energy installations site selection

Authors	Distance from the road network	Details
Asakereh et al., [3]	Constraint Criterion	>100m Trapezoid fuzzy membership equation (control points: 13, 40km)
Al Garni and Awasthi, [10]	Constraint	>500m
Merrouni et al., [35]	Constraint Criterion	>100m (more suitable to less suitable) <1.5km 1.5-5km 5-7.5km >7.5km
Carrion et al., [11]	Criterion	(more suitable to less suitable) <1km 1–2km 2–3km >3km
Uyan, [62]	Constraint Criterion	>100m (more suitable to less suitable) 100-1,000m 1,000-3,000m 3,000-5,000m >5,000m
Sadeghi and Karimi, [46]	Constraint	>100m
Georgiou and Skarlatos, [21]	Constraint	>50m <2,500m
Aly et al., [2]	Criterion	(more suitable to less suitable) 0-5km 5- 10km 10 – 15km 15 – 20km >20km
Yushchenko et al., [68]	Criterion	Less suitable: > 5km Moderately suitable: 3–5km Suitable: 1–3km Best suitable: < 1km

Table D.2 Literature review on the criterion of the distance from the electricity transmission lines for solar energy installations site selection

Authors	Distance for the electricity transmission lines	Details
Merrouni et al., [35]	Criterion	(more suitable to less suitable) <1km 1-5km 5-10km >10km
Carrion et al., [11]	Criterion	(more suitable to less suitable) <1km 1–2km 2 –10km >10km
Uyan, [62]	Criterion	(more suitable to less suitable) <3,000m 3,000–6,000m 6,000–10,000m >10,000m
Georgiou and Skarlatos, [21]	Criterion	<2,000m
Aly et al., [2]	Criterion	(more suitable to less suitable) 5 – 10km 10 – 15km 15 -20km 20 – 25km 25 -30km 30 – 40km 40 – 50km >50 km
Yushchenko et al., [68]	Criterion	Less suitable: > 30 km Moderately suitable: 5–30 km Suitable: 1–5 km Best suitable: < 1 km

Table D.3 Literature review on the criterion of the slope for solar energy installations site selection

Authors	Slope	Details
Asakereh et al., [3]	Criterion	Trapezoid fuzzy membership equation (control points: 3, 10%)
Al Garni and Awasthi, [10]	Constraint	<5deg=8.8%
Sun et al., [56]	Constraint	<4deg=7%
Charabi and Gasli, [12]	Constraint	<5deg=8.8%
Merrouni et al., [35]	Criterion	(more suitable to less suitable) <1% 1-2.5% 2.5-5% >5%
Carrion et al., [11]	Criterion	(more suitable to less suitable) <3% 4–6% 7–9% 10–12% 13–15% 16–18%

Table D.3 Literature review on the criterion of the slope for solar energy installations site selection

Authors	Slope	Details
		19–21% 22–24% 25–27% 28–30% >30%
Uyan, [62]	Criterion	(more suitable to less suitable) <1% 1–2% 2-3% >3%
Hott et al., [28]	Constraint	<15deg=27%
Watson and Hudson, [66]	Constraint	<10deg=17.6%
Georgiou and Skarlatos, [21]	Constraint	<45deg=100%
Aly et al., [2]	Constraint	<3%
Yushchenko et al., [68]	Constraint	<10%
Mondino et al., [36]	Constraint	<15%
Merrouni et al., [34]	Constraint	<5%

Table D.4 Literature review on the criterion of the aspect for solar energy installations site selection

Authors	Aspect	Details
Al Garni and Awasthi, [10]	Criterion	South-facing slope is ideal
Carrion et al., [11]	Criterion	(most suitable to less suitable) South Southeast Southwest East West Northeast Northwest North
Hott et al., [28]	Constraint	Southeast to southwest (112.5-247.5^o is suitable)
Watson and Hudson, [66]	Constraint	Southeast to southwest is ideal
Georgiou and Skarlatos, [21]	Constraint	Exclude areas with aspect east | west | north | northeast | northwest
Mondino et al., [36]	Constraint	For slopes 3-15%, aspect 135-225^o

Table D.5 Literature review on the criterion of the land uses for solar energy installations site selection

Authors	Land uses	Details
Asakereh et al., [3]	Criterion	Trapezoid fuzzy membership equation(control points: 0, 1km) for the distance from agriculture areas Trapezoid fuzzy membership equation (control points: 100,500m) for the distance from forests Trapezoid fuzzy membership equation (control points: 100,400m) for the distance from shrubberies and reed-bed (important land covers)
Merrouni et al., [35]	Constraint	Buffer 500m from vegetation

Table D.5 Literature review on the criterion of the land uses for solar energy installations site selection

Authors	Land uses	Details
Carrion et al., [11]	Criterion	(most suitable to less suitable) Area without vegetation Dryland herbaceous crops Irrigated herbaceous crops Herbaceous and woody crops Woody crops Other uses
Uyan, [62]	Criterion	(most suitable to less suitable) Barren Agricultural
Hott et al., [28]	Constraint	Suitable are open, barren grasslands
Watson and Hudson, [66]	Constraint	Exclusion of agricultural land
Sadeghi and Karimi, [46]	Criterion	(most suitable to less suitable) Arid Cultivation Grass Orchard and woods
Georgiou and Skarlatos, [21]	Constraint	Exclusion of high vegetation
Yushchenko et al., [68]	Constraint	Exclusion of surfaces occupied by built-up areas, agricultural zones, forests, wetlands, and water bodies

Table D.6 Literature review on the criterion of the distance from water bodies for solar energy installations site selection

Authors	Distance from water bodies	Details
Aly et al., [2]	Criterion	(more suitable to less suitable for CSP) 0 – 3km 3 – 5km 5 – 7km 7 – 9km >9km
Asakereh et al., [3]	Criterion	Trapezoid fuzzy membership equations (control point: 100,400m) from rivers (control points: 300,500m) from lakes
Merrouni et al., [35]	Criterion	(most suitable to less suitable) Distance from water ways (km) <5, 5-10, 10-15, >15 Distance from dams (km) <10, 10-15, 15-25, >25
Carrion et al., [11]	Constraint	>105m from rivers
Sadeghi and Karimi, [46]	Constraint	>500m from wetlands
Georgiou and Skarlatos, [21]	Constraint	>100m from surface waters

Table D.7 Literature review on the criterion of the solar potential for solar energy installations site selection

Authors	Solar potential	Details
Asakereh et al., [3]	Criterion	Gaussian fuzzy membership equation >6kWh/m^2/day (excellent)
Merrouni et al., [35]	Criterion	(most suitable to less suitable)

Table D.7 Literature review on the criterion of the solar potential for solar energy installations site selection

Authors	Solar potential	Details
		2,175-2,304 kWh/m^2/year 2,050-2,175 kWh/m^2/year 1,925-2,050 kWh/m^2/year 1,816-1,925 kWh/m^2/year
Carrion et al., [11]	Criterion	(most suitable to less suitable) 4,557–4,596 Wh/m^2/day 4,596–4,636 Wh/m^2/day 4,636–4,675 Wh/m^2/day 4,675–4,714 Wh/m^2/day 4,714–4,754 Wh/m^2/day 4,754–4,793 Wh/m^2/day 4,793–4,832 Wh/m^2/day 4,832–4,872 Wh/m^2/day 4,872–4,911 Wh/m^2/day
Sadeghi and Karimi, [46]	Criterion	(most suitable to less suitable) <900,000 Wh/m^2/year 900,000-1,200,000 Wh/m^2/year 1,200,000-1,500,000 Wh/m^2/year >1,500,000 Wh/m^2/year
Aly et al., [2]	Constraint Criterion	>1,700kWh/m$_2$/year GHI for PVs >1,800kWh/m^2/year DNI for CSPs (most suitable to less suitable) GHI(kWh/m^2/year) 2,250-2,300 2,200-2,250 2,150-2,200 2,100-2,150 2,050-2,100 2,000-2,050 1,950-2,000 1,900-1,950 1,850-1,900 1,800-1,850 1,750-1,800 1,700-1,750 DNI(kWh/m^2/year) 2,150-2,200 100 2,100-2,150 95 2,050-2,100 90 2,000-2,050 85 1,950-2,000 80 1,900-1,950 75 1,850-1,900 50 1,800-1,850
Yushchenko et al., [68]	Criterion	For PV: maximize GHI Less suitable: < 1,800 kWh/m^2/year Moderately suitable: 1,800– 2,100 kWh/m^2/year Suitable: 2,100–2,300 kWh/m^2/year Best suitable: > 2,300 kWh/m^2/year For CSP: maximize DNI Less suitable: < 1,800 kWh/m^2/year Moderately suitable: 1,800– 2,300 kWh/m^2/year Suitable: 2,300–2,700 kWh/m^2/year Best suitable: > 2,700 kWh/m^2/year

Annex E

In this Section, the literature review on the biomass/biogas plants evaluation siting criteria and constraints is presented. Tables E.1 to E.7 present the criteria classification and buffer distances found in the literature, concerning the evaluation criteria selected for this study. A detailed description of the evaluation criteria and related priority scales, for this study, is presented in Section 3.4.2.

Table E.1 Literature review on the criterion of the distance from areas of environmental interest for biomass plants site selection

Authors	Distance from areas of environmental interest	Details
Perpina et al., [40]	Constraint	>500m
Perpina et al., [41]	Constraint	>500m
Silva et al., [51]	Constraint	Exclusion of environmental protected areas
Sliz-Szkliniarz and Vogt, [54]	Constraint	Exclusion of environmental protected areas, such as NATURA 2000 sites
Herrera-Seara et al., [25]	Constraint	
Wu et al., [67]	Constraint	

Table E.2 Literature review on the criterion of the distance from water bodies for biomass plants site selection

Authors	Distance from water bodies	Details
Perpina et al., [40]	Constraint	>100m
Perpina et al., [41]	Constraint	>500m
Silva et al., [51]	Constraint, Criterion	>150m
Sliz-Szkliniarz and Vogt, [54]	Constraint	>50m
Wu et al., [67]	Constraint	>50m

Table E.3 Literature review on the criterion of the distance from areas of cultural interest for biomass plants site selection

Authors	Distance from areas of cultural interest	Details
Perpina et al., [41]	Constraint	>200m

Table E.4 Literature review on the criterion of the distance from the road network for biomass plants site selection

Authors	Distance from the road network	Details
Perpina et al., [40]	Constraint	>30m
Perpina et al., [41]	Constraint	>100m
Silva et al., [51]	Constraint Criterion	>70m
Sliz-Szkliniarz and Vogt, [54]	Constraint	>10m
Wu et al., [67]	Criterion	Acceptable range between 10-3,200m from highways

Table E.5 Literature review on the criterion of the slope for biomass plants site selection

Authors	Slope	Details
Perpina et al., [40]	Constraint	<15%
Perpina et al., [41]	Criterion	minimize Slopes between 0% and 5% Slopes between 5% and 10% Slopes between 10% and 15 % Slopes between 15% and 35 %
Silva et al., [51]	Constraint Criterion	<15%
Wu et al., [67]	Criterion	<10%

Table E.6 Literature review on the criterion of the distance from the electricity transmission lines for biomass plants site selection

Authors	Distance from the electricity transmission lines	Details
Perpina et al., [40]	Constraint	>100m
Perpina et al., [41]	Constraint	>100m
Silva et al., [51]	Constraint Criterion	>100m
Sliz-Szkliniarz and Vogt, [54]	Constraint	<2km
Wu et al., [67]	Criterion	Acceptable range between 10-1,600m

Table E.7 Literature review on the criterion of the biomass potential for biomass plants site selection

Authors	Biomass potential	Details
Perpina et al., [41]	Criterion	maximize 1- Available biomass from 0 - 50 t/ha 2- Available biomass from 50 - 100 t/ ha 3- Available biomass from 100 - 200 t/ha 4- Available biomass from 200 - 300 t/h a
Herrera-Seara et al., [25]	Criterion	Score from the worst to the best 0 - 0.3 t/ha 6 0.3 – 1 t/ha 5 1 – 3 t/ha 4 3 – 4 t/ha 3 4 – 5 t/ha 2 > 5 t/ha 1

Annex F

In this Section, the questionnaire sent to the selected participants is presented. It consists of three tables, one for each of the renewable energy technologies studied, for the implementation of the criteria pair-wise comparisons. In addition, instructions were also enclosed for the correct completion of the tables.

F.1 Cover Letter

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

Θέμα: Ερωτηματολόγιο για την ιεράρχηση κριτηρίων χωροθέτησης μονάδων ΑΠΕ στην ΠΕ Ρεθύμνης

Χανιά, Μάρτιος 2018

Αξιότιμε κύριε/κυρία,

Το παρόν σύντομο ερωτηματολόγιο πραγματοποιείται στα πλαίσια της μεταπτυχιακής διπλωματικής εργασίας μου στο μεταπτυχιακό πρόγραμμα ''Περιβαλλοντική Μηχανική'' της Σχολής Μηχανικών Περιβάλλοντος του Πολυτεχνείου Κρήτης. Η μεταπτυχιακή διπλωματική εργασία, με επιβλέποντα καθηγητή τον κ. Θεοχάρη Τσούτσο, έχει θέμα τη διερεύνηση του δυναμικού ΑΠΕ της ΠΕ Ρεθύμνης και την εκτίμηση των βιώσιμων θέσεων χωροθέτησης αιολικών, ηλιακών και εγκαταστάσεων εκμετάλλευσης βιομάζας στην ΠΕ Ρεθύμνης.

Για κάθε τεχνολογία ΑΠΕ, αφού προσδιορίστηκαν οι περιοχές αποκλεισμού και οι ελάχιστες αποστάσεις από συγκεκριμένες χρήσεις, που ορίζει η νομοθεσία, αναζητούνται οι βιώσιμες περιοχές χωροθέτησης, με την εισαγωγή περιβαλλοντικών, αισθητικών και τεχνοοικονομικών κριτηρίων. Στα πλαίσια αυτά, δημιουργήθηκε το επισυναπτόμενο ερωτηματολόγιο προς συμπλήρωση, από δείγμα ειδικών και εμπλεκόμενων ομάδων που σχετίζονται άμεσα με το προς μελέτη αντικείμενο. Συγκεκριμένα, στους τρεις πίνακες του ερωτηματολογίου παρουσιάζονται τα κριτήρια για την ιεράρχηση των νομοθετικά διαθέσιμων περιοχών, κάθε τεχνολογίας ΑΠΕ που μελετάται και παρακαλείται η συμπλήρωσή τους, ακολουθώντας τις οδηγίες που επισυνάπτονται.

Η συμμετοχή σας θα μας βοηθούσε ιδιαίτερα στην ολοκλήρωση της μελέτης και στην εξαγωγή αξιόπιστων αποτελεσμάτων για τις βιώσιμες περιοχές χωροθέτησης, λαμβάνοντας υπόψη και τη σχετική σημαντικότητα κάθε κριτηρίου, σύμφωνα με τις απαντήσεις των εμπλεκόμενων ομάδων. Για τη διαδικασία αυτή, θα χρειαστείτε το πολύ 10-15 λεπτά, ακολουθώντας και τις οδηγίες που επισυνάπτονται. Τέλος, τα αποτελέσματα της έρευνας, εφόσον σας ενδιαφέρουν, θα είναι στη διάθεσή σας.

Σας ευχαριστούμε θερμά για το χρόνο σας και την πολύτιμη βοήθειά σας!

Με εκτίμηση,

Μαρίνα Γιαμαλάκη,
Πολιτικός Μηχανικός ΕΜΠ,
Μεταπτυχιακή Φοιτήτρια της Σχολής Μηχανικών Περιβάλλοντος,
Πολυτεχνείου Κρήτης
E-mail: mgiamalaki@isc.tuc.gr

F.2 Instructions

Οδηγίες για τη Συμπλήρωση των Πινάκων

Στο τρίτο αρχείο, που επισυνάπτεται, με τίτλο «Πίνακες», θα βρείτε τρείς πίνακες, έναν για κάθε τεχνολογία ΑΠΕ που μελετάται, στους οποίους η πρώτη σειρά και στήλη περιλαμβάνει τα κριτήρια αξιολόγησης, που εδώ παρουσιάζονται αναλυτικά, στους Πίνακες 2-4.

Για τον προσδιορισμό της σχετικής σημαντικότητας κάθε κριτηρίου, ζητείται η κατά ζεύγη σύγκρισή τους, σύμφωνα με την κλίμακα προτίμησης, που δίνεται στον Πίνακας 1.

Πίνακας 1 Κλίμακα Σχετικής Προτίμησης

Ένταση Σχετικής Σημαντικότητας	Ορισμός	Επεξήγηση
1	Ίση προτίμηση	**Ίση** προτίμηση μεταξύ των δύο κριτηρίων
2	Μέτρια προτίμηση	**Μέτρια** προτίμηση του πρώτου κριτηρίου έναντι του δεύτερου
3	Ουσιώδης προτίμηση	**Ουσιώδης** προτίμηση του πρώτου κριτηρίου έναντι του δεύτερου
4	Ισχυρή προτίμηση	**Ισχυρή** προτίμηση του πρώτου έναντι του δεύτερου κριτηρίου
5	Ακραία προτίμηση	Η **κυριαρχία** του πρώτου κριτηρίου έναντι του δεύτερου παίρνει τη μέγιστη δυνατή τιμή

Έτσι, παρακαλείται η συμπλήρωση των τετραγώνων **ΜΟΝΟ ΤΗΣ ΚΙΤΡΙΝΗΣ ΠΕΡΙΟΧΗΣ** των τριών πινάκων σύμφωνα με το παράκατω παράδειγμα.

ΠΑΡΑΔΕΙΓΜΑ

		ΑΠΟΣΤΑΣΗ ΑΠΟ:										
		ΤΚΣ και ΖΕΠ του Δικτύου NATURA 2000	Υδάτινα στρώμα-τα	Αρχαιολο-γικούς χώρους και μνημεία	Κεραίες	Εγκατα-στάσεις εθνικής άμυνας	Γραμμές υψηλής τάσης	Οδικό δίκτυο	Κλίση εδάφους	Υψόμετρο	Θέαση από πολύ-σύχναστους χώρους	Αιολικό δυναμικό
ΑΠΟΣΤ	ΤΚΣ και ΖΕΠ του Δικτύου NATURA 2000	1										
	Υδάτινα στρώματα		1									
	Αρχαιολογι-κούς χώρους και μνημεία			1								

Σχήμα 1 Απόσπασμα από τον Πίνακα 1, για τις συγκρίσεις των κριτηρίων χωροθέτησης των αιολικών μονάδων

Για παράδειγμα συμπληρώνεται ο πρώτος πίνακας, που αφορά τα κριτήρια για την χωροθέτηση αιολικών μονάδων και έστω ότι συγκρίνεται το κριτήριο της απόστασης από υδάτινα στρώματα, με το κριτήριο της απόστασης από το οδικό δίκτυο (στην 3^{η} γραμμή της κίτρινης περιοχής και στην 8^{η} στήλη, σημειώνεται με κόκκινο κύκλο στο παραπάνω σχήμα).

Έστω ότι θεωρείται ισχυρή προτίμηση (υπεροχή κατά την γνώμη μας) του κριτηρίου της απόστασης από τα υδάτινα στρώματα, έναντι του κριτήριου της απόστασης από το οδικό δίκτυο, τότε συμπληρώνεται στο αντίστοιχο κελί του Πίνακα ο αριθμός 4 (σύμφωνα και με τον Πίνακα 1). Αντίθετα, αν θεωρείται ισχυρή προτίμηση στο κριτήριο της απόστασης από το οδικό δίκτυο (που βρίσκεται στη στήλη), τότε στο κελί αυτό συμπληρώνεται ο αριθμός 1/4.

Συνεχίζοντας τις κατά ζεύγη συγκρίσεις, περνάμε στη σύγκριση του κριτηρίου της απόστασης από τα υδάτινα στρώματα με το κριτήριο της κλίσης εδάφους. Έστω ότι θεωρείται ακραία προτίμηση του κριτηρίου της κλίσης εδάφους, τότε συμπληρώνεται στο αντίστοιχο κελί (σημειώνεται με μπλε κύκλο στο παραπάνω Σχήμα) η τιμή 1/5.

Συνεχίζοντας, περνάμε στη σύγκριση του κριτηρίου της απόστασης από τα υδάτινα στρώματα με το κριτήριο του υψομέτρου. Έστω ότι θεωρείται ίση προτίμηση των δύο κριτηρίων, οπότε στο αντίστοιχο κελί (πράσινος κύκλος) εισάγεται η τιμή 1.

Συνεχίζονται έτσι οι συγκρίσεις, για το κριτήριο της απόστασης από τα υδάτινα στρώματα, με το κριτήριο της θέασης από πολυσύχναστους χώρους. Έστω ότι θεωρείται μέτρια προτίμηση του κριτηρίου της απόστασης από υδάτινα στρώματα (κριτήριο γραμμής), τότε στο αντίστοιχο κελί (μωβ κύκλος) σημειώνεται η τιμή 2.

Ολοκληρώνονται έτσι οι συγκρίσεις της συγκεκριμένης γραμμής, με τη σύγκριση του κριτηρίου της απόστασης από υδάτινα στρώματα με το κριτήριο του αιολικού δυναμικού. Όταν ολοκληρωθούν οι συγκρίσεις για τη συγκεκριμένη γραμμή, περνάμε στην επόμενη. Σημειώνεται ότι δεν απαιτείται η συμπλήρωση όλου του πίνακα, παρά μόνο των τετραγώνων της κίτρινης περιοχής.

Με αυτό τον τρόπο, συμπληρώνονται τα τετράγωνα των κίτρινων περιοχών των τριών πινάκων που επισυνάπτονται. Γενικά, κατά τις κατά ζεύγη συγκρίσεις, αν προτιμάτε το κριτήριο, που βρίσκεται στη γραμμή του πίνακα, τότε το αντίστοιχο κελί συμπληρώνεται με το βαθμό της προτίμησης, σύμφωνα με τον Πίνακα 1. Αντίθετα, αν προτιμάτε το κριτήριο που βρίσκεται στη στήλη, έναντι του κριτηρίου που βρίσκεται στη γραμμή, τότε το αντίστοιχο κελί συμπληρώνεται με την τιμή 1/α, όπου α αντιστοιχεί στον βαθμό προτίμησης του κριτηρίου αυτού, σύμφωνα με τον Πίνακα 1.

Αν θέλετε μπορείτε να συνεχίσετε την ανάγνωση του παρόντος κειμένου, όπου παρουσιάζονται αναλυτικά τα κριτήρια για την αξιολόγηση των διαθέσιμων περιοχών χωροθέτησης κάθε τεχνολογίας ΑΠΕ που μελετάται, όπου μπορείτε να δείτε και τον τύπο του κριτηρίου και αν ο στόχος είναι η μεγιστοποίηση ή η ελαχιστοποίησή του (Πίνακες 2-4).

Σας ευχαριστούμε θερμά για το χρόνο, που αφιερώσατε στην ανάγνωση των οδηγιών,

Μαρίνα Γιαμαλάκη,
Πολιτικός Μηχανικός ΕΜΠ,
Μεταπτυχιακή Φοιτήτρια της Σχολής Μηχανικών Περιβάλλοντος,
Πολυτεχνείου Κρήτης

Πίνακας 2 Κριτήρια Ιεράρχησης Διαθέσιμων Περιοχών Χωροθέτησης Αιολικών Εγκαταστάσεων

Κριτήριο	Τύπος Κριτηρίου	Στόχος
Απόσταση από Τόπους Κοινοτικής Σημασίας (ΤΚΣ) και Ζώνες Ειδικής Προστασίας (ΖΕΠ) του Δικτύου NATURA 2000	Περιβαλλοντικό	Μεγιστοποίηση
Απόσταση από Υδάτινα Στρώματα	Περιβαλλοντικό	Μεγιστοποίηση
Απόσταση από Αρχαιολογικούς Χώρους και Μνημεία	Αισθητικό	Μεγιστοποίηση
Απόσταση από Κεραίες	Τεχνικό/Ασφαλείας* **προστασία από ηλεκτρομαγνητικά κύματα*	Μεγιστοποίηση
Απόσταση από Εγκαταστάσεις Εθνικής Άμυνας	Τεχνικό/Ασφαλείας* **προστασία επικοινωνιών*	Μεγιστοποίηση
Απόσταση από τις Γραμμές Υψηλής Τάσης	Τεχνοοικονομικό	Ελαχιστοποίηση
Απόσταση από το Οδικό Δίκτυο	Τεχνοοικονομικό	Ελαχιστοποίηση
Κλίση Εδάφους	Τεχνοοικονομικό	Ελαχιστοποίηση
Υψόμετρο	Τεχνοοικονομικό/Περιβαλλοντικό	Ελαχιστοποίηση
Θέαση από Πολυσύχναστους Χώρους	Αισθητικό* **ως πολυσύχναστοι χώροι ορίστηκαν: ακτές, κατασκηνώσεις, μαρίνες, ξενοδοχειακά καταλύματα, οικισμοί, παραδοσιακοί οικισμοί,*	Ελαχιστοποίηση

	αρχαιολογικοί χώροι, μνημεία	
Αιολικό Δυναμικό	Τεχνοοικονομικό	Μεγιστοποίηση

Πίνακας 3 Κριτήρια Ιεράρχησης Διαθέσιμων Περιοχών Χωροθέτησης Ηλιακών Εγκαταστάσεων

Κριτήριο	**Τύπος Κριτηρίου**	**Στόχος**
Απόσταση από Υδάτινα Στρώματα	Περιβαλλοντικό	Μεγιστοποίηση
Απόσταση από την ακτογραμμή	Αισθητικό/Τεχνικό* **Η αλμύρα δύναται να μειώσει το χρόνο ζωής και την απόδοση των ηλιακών πάνελ*	Μεγιστοποίηση
Καλύψεις γης	Περιβαλλοντικό/Αισθητικό	Άγονες και μικρής παραγωγικότητας εκτάσεις, με μικρή αισθητική αξία
Προσανατολισμός κλίσεων	Τεχνοοικονομικό	ΝΑ-ΝΔ
Απόσταση από τις Γραμμές Υψηλής Τάσης	Τεχνοοικονομικό	Ελαχιστοποίηση
Απόσταση από το Οδικό Δίκτυο	Τεχνοοικονομικό	Ελαχιστοποίηση
Κλίση Εδάφους	Τεχνοοικονομικό	Ελαχιστοποίηση
Υψόμετρο	Τεχνοοικονομικό/Περιβαλλοντικό	Ελαχιστοποίηση
Θέαση από Πολυσύχναστους Χώρους	Αισθητικό	Ελαχιστοποίηση
Ηλιακό Δυναμικό	Τεχνοοικονομικό	Μεγιστοποίηση

Πίνακας 4 Κριτήρια Ιεράρχησης Διαθέσιμων Περιοχών Χωροθέτησης Μονάδων Εκμετάλλευσης Βιομάζας/Βιοαερίου

Κριτήριο	**Τύπος Κριτηρίου**	**Στόχος**
Απόσταση από Υδάτινα Στρώματα	Περιβαλλοντικό	Μεγιστοποίηση
Απόσταση από ΤΚΣ του Δικτύου NATURA 2000	Περιβαλλοντικό	Μεγιστοποίηση
Απόσταση από αρχαιολογικούς χώρους, μνημεία και ιερές μονές	Αισθητικό	Μεγιστοποίηση
Απόσταση από τις Γραμμές Υψηλής Τάσης	Τεχνοοικονομικό	Ελαχιστοποίηση
Απόσταση από το Οδικό Δίκτυο	Τεχνοοικονομικό	Ελαχιστοποίηση
Κλίση Εδάφους	Τεχνοοικονομικό	Ελαχιστοποίηση
Θέαση από Πολυσύχναστους Χώρους	Αισθητικό	Ελαχιστοποίηση
Δυναμικό Βιομάζας/Βιοαερίου	Τεχνοοικονομικό	Μεγιστοποίηση

F.3 Pair-wise Comparisons Tables

Πίνακες Κατά Ζεύγη Συγκρίσεων

Πίνακας 1 Κατά Ζεύγη Συγκρίσεων για τα κριτήρια αξιολόγησης των διαθέσιμων περιοχών χωροθέτησης ΜΟΝΑΔΩΝ ΕΚΜΕΤΑΛΛΕΥΣΗΣ ΑΙΟΛΙΚΗΣ ΕΝΕΡΓΕΙΑΣ

		Α Π Ο Σ Τ Α Σ Η Α Π Ο :										
		ΤΚΣ και ΖΕΠ του Δικτύου NATURA 2000	Υδάτινα στρώμα-τα	Αρχαιολο-γικούς χώρους και μνημεία	Κεραίες	Εγκατα-στάσεις εθνικής άμυνας	Γραμμές υψηλής τάσης	Οδικό δίκτυο	Κλίση εδάφους	Υψόμετρο	Θέαση από πολυ-σύχναστους χώρους	Αιολικό δυναμικό
ΑΠΟΣΤΑΣΗ ΑΠΟ:	ΤΚΣ και ΖΕΠ του Δικτύου NATURA 2000	1										
	Υδάτινα στρώματα		1									
	Αρχαιολογι-κούς χώρους και μνημεία			1								
	Κεραίες				1							
	Εγκαταστά-σεις εθνικής άμυνας					1						
	Γραμμές υψηλής τάσης						1					
	Οδικό δίκτυο							1				
	Κλίση εδάφους								1			
	Υψόμετρο									1		
	Θέαση από πολυσύχνα-στους χώρους										1	
	Αιολικό δυναμικό											1

ΤΚΣ: Τόποι Κοινοτικής Σημασίας και **ΖΕΠ**: Ζώνες Ειδικής Προστασίας του Δικτύου NATURA 2000

Πίνακας 2 Κατά ζεύγη συγκρίσεων για την αξιολόγηση των διαθέσιμων περιοχών χωροθέτησης ΜΟΝΑΔΩΝ ΕΚΜΕΤΑΛΛΕΥΣΗΣ ΗΛΙΑΚΗΣ ΕΝΕΡΓΕΙΑΣ

		ΑΠΟΣΤΑΣΗ ΑΠΟ:									
		Ακτο-γραμμή	Υδάτινα στρώμα-τα	Γραμμές υψηλής τάσης	Οδικό δίκτυο	Προσανα-τολισμός κλίσεων	Καλύψεις γης	Κλίση εδάφους	Υψόμετρο	Θέαση από πολυ-σύχναστους χώρους	Ηλιακό δυναμικό
ΑΠΟΣΤΑΣΗ ΑΠΟ:	Ακτογραμ-μη	1									
	Υδάτινα στρώματα		1								
	Γραμμές υψηλής τάσης			1							
	Οδικό δίκτυο				1						
	Προσανα-τολισμός κλίσεων					1					
	Καλύψεις γης						1				
	Κλίση εδάφους							1			
	Υψόμετρο								1		
	Θέαση από πολυσύχνα-στους χώρους									1	
	Ηλιακό δυναμικό										1

Πίνακας 3 Κατά ζεύγη συγκρίσεων για την αξιολόγηση των διαθέσιμων περιοχών χωροθέτησης ΜΟΝΑΔΩΝ ΕΚΜΕΤΑΛΛΕΥΣΗΣ ΒΙΟΜΑΖΑΣ/ΒΙΟΑΕΡΙΟΥ

		ΑΠΟΣΤΑΣΗ ΑΠΟ:							
		ΤΚΣ του Δικτύου NATURA 2000	Υδάτινα στρώμα-τα	Αρχαιολο-γικούς χώρους, μνημεία και ιερές μονές	Γραμμές υψηλής τάσης	Οδικό δίκτυο	Κλίση εδάφους	Θέαση από πολυ-σύχναστους χώρους	Δυναμικό Βιομάζας
ΑΠΟΣΤΑΣΗ ΑΠΟ:	ΤΚΣ του Δικτύου NATURA 2000	1							
	Υδάτινα στρώματα		1						
	Αρχαιολογι-κούς χώρους, μνημεία και ιερές μονές			1					
	Γραμμές υψηλής τάσης				1				
	Οδικό δίκτυο					1			
	Κλίση εδάφους						1		
	Θέαση από πολυσύχνα-στους χώρους							1	
	Δυναμικό Βιομάζας								1

Σας ευχαριστούμε θερμά για τη συμμετοχή σας!

MAP ANNEX

In this Section, some of the Maps produced in this study, are presented. All cartographic data and Maps have a spatial reference according to the Greek Geodetic Reference System 1987 (GGRS 1987). In addition, for a map scale approximately equal to 1:150,000 and by taking a rather optimistic approach, the error was estimated as the one quarter of the 150m, namely 37.5m. Moreover, for practical reasons, this value was rounded to 50m, which was also selected as the resolution of the raster maps, produced in this study.

Contents:

Map W.2 Minimum Allowable Distances from Areas of Environmental Interest for Wind Energy Installations Siting

Map W.3 Minimum Allowable Distances from Areas of Cultural Interest for Wind Energy Installations Siting

Map W.4 Minimum Allowable Distances from Urban Activities for Wind Energy Installations Siting

Map W.5 Minimum Allowable Distances from the Technical Infrastructure for Wind Energy Installations Siting

Map W.6 Minimum Allowable Distances from Production Activities for Wind Energy Installations Siting

Map W.7 Legally Available Areas for Wind Energy Installations Siting

Map W.8 Available Areas for Wind Energy Installations Siting-Environmental Scenario

Map W.9 Evaluation Criterion for Wind Energy Installations Siting: Distance from the NATURA 2000 Sites

Map W.10 Evaluation Criterion for Wind Energy Installations Siting: Visibility from the Most-Visited Sites

3. Solar Energy Installations Siting: Exclusion and Evaluation Criteria

Map S.1 Exclusion Areas for Solar Energy Installations Siting

Map S.2 Legally Available Siting Areas for Solar Energy Installations Siting

Map S.3 Exclusion Areas of the Socio-Environmental Scenario for Solar Energy Installations Siting

Map S.4 Available Siting Areas of the Socio-Environmental Scenario for Solar Energy Installations Siting

Map S.5 Evaluation Criterion for Solar Energy Installations Siting: Aspects

Map S.6 Evaluation Criterion for Solar Energy Installations Siting: Land Cover

4. Biomass/Biogas Plants Siting: Exclusion and Evaluation Criteria

Map B.1 Exclusion Areas for Biomass/Biogas Plants Siting

Map B.2 Minimum Allowable Distances from Areas of Environmental Interest for Biomass/Biogas Plants Siting

Map B.3 Minimum Allowable Distances from Urban Activities for Biomass/Biogas Plants Siting

5. Wind Energy Installations Siting: Priority Maps

6. Solar Energy Installations Siting: Priority Maps

7. Biomass Plants Siting: Priority Maps

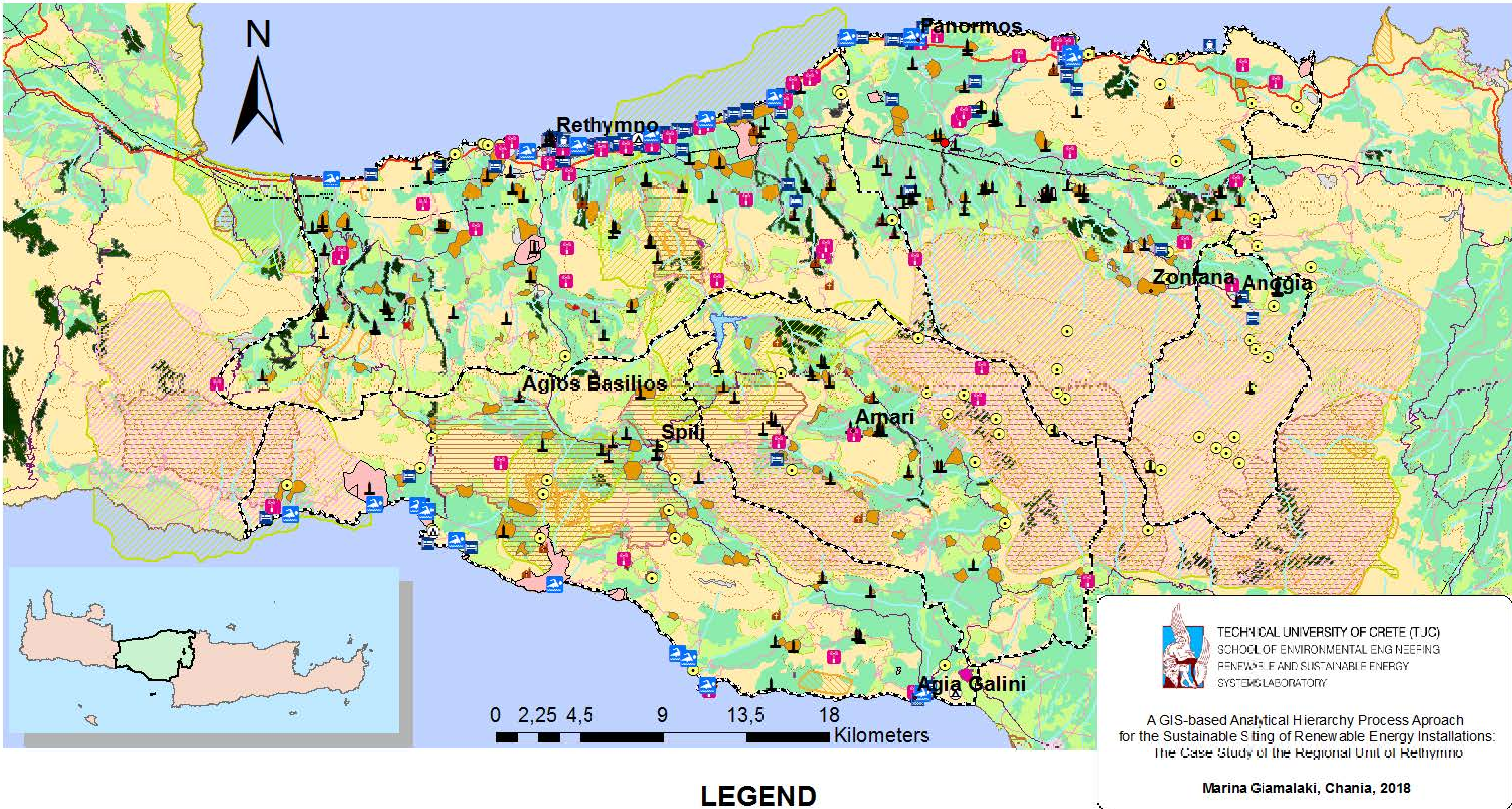
Map P.13 Priority Map for Biomass Plants Siting Based on the Criteria Weights Derived from the AHP

Map P.14 Priority Map for Biomass Plants Siting Based on the Equal-Weighted Scenario

Map P.15 Priority Map for Biomass Plants Siting Based on the Techno-Economic Scenario

Map P.16 Priority Map for Biomass Plants Siting Based on the Socio-Environmental Scenario

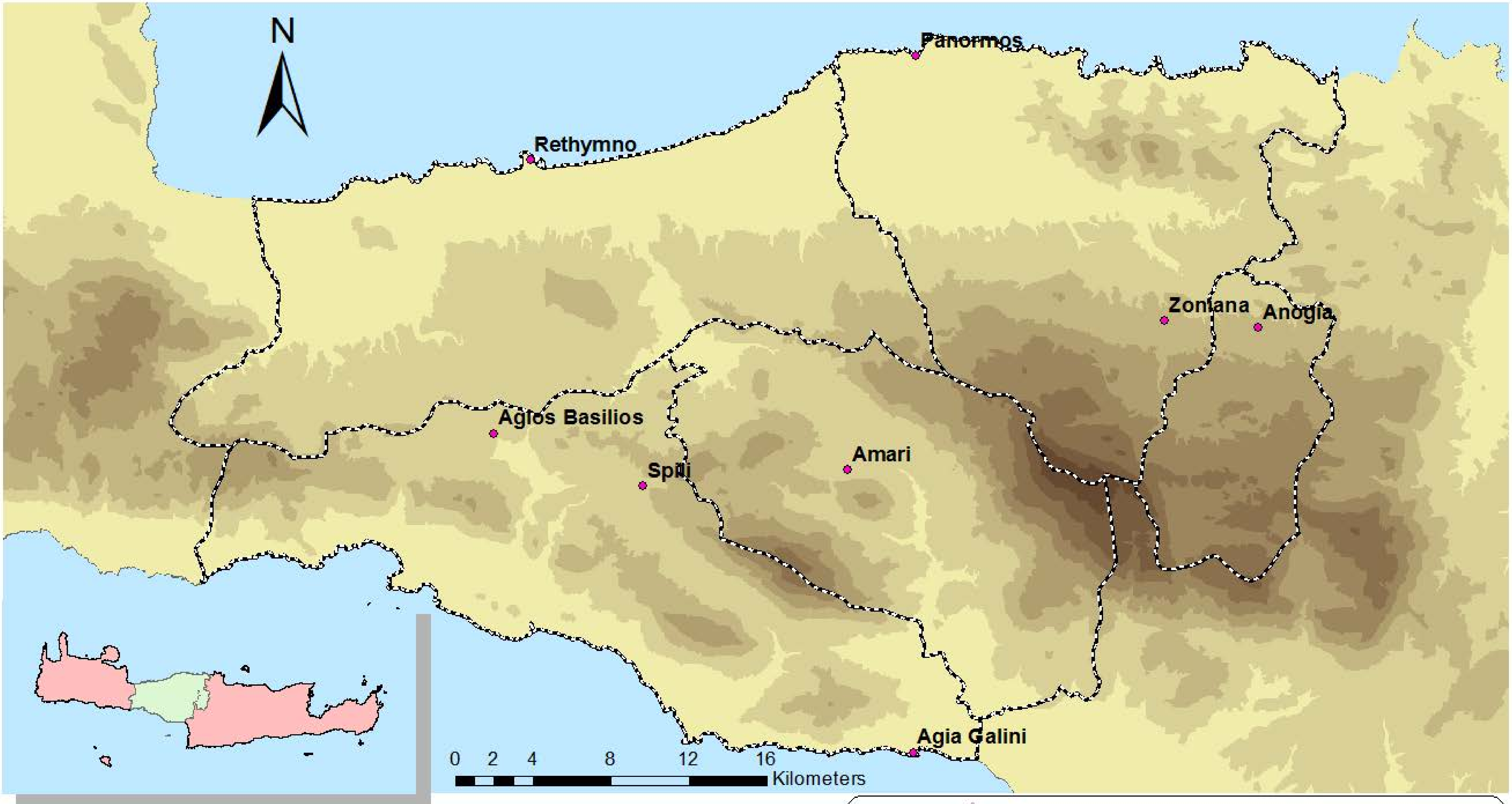
R.1 Current Situation of the Regional Unit of Rethymno



LEGEND

- Beaches
- Ports-Marinas
- Traditional Settlements
- Monasteries
- Camps
- Telecommunication Antennas
- Monuments
- Tourist Accomondations
- Geotopes
- Settlements
- Lakes
- Urban Control Zone Georgioupolis-Episkopi
- Traditional Settlements
- Archaeological Sites
- National Defense Installations
- Quarries
- Municipalities Boundaries of the Regional Unit of Rethymno
- National Road Network
- Provincial Road Network
- Community Road Network
- High Voltage Lines
- Hydrographic Network
- 500m Countor Lines
- Areas of Absolute Protection of Nature
- Important Places for Bird Priority Species
- Sites of Community Importance (SCI) of the NATURA 2000 Network
- Special Protection Areas (SPA) of the NATURA 2000 Network
- Forests- CORINE 2012
- Permanent Crops- CORINE 2012
- Other Agricultural Areas- CORINE 2012
- Urban Fabric- CORINE 2012
- Other Forest and Semi-forest Areas- CORINE 2012

R.2 Elevation Map of the Regional Unit of Rethymno



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Elevation (m)

- 0 - 300
- 300 - 600
- 600 - 900
- 900 - 1,200
- 1,200 - 1,500
- 1,500 - 1,800
- 1,800 - 2,100
- >2,100

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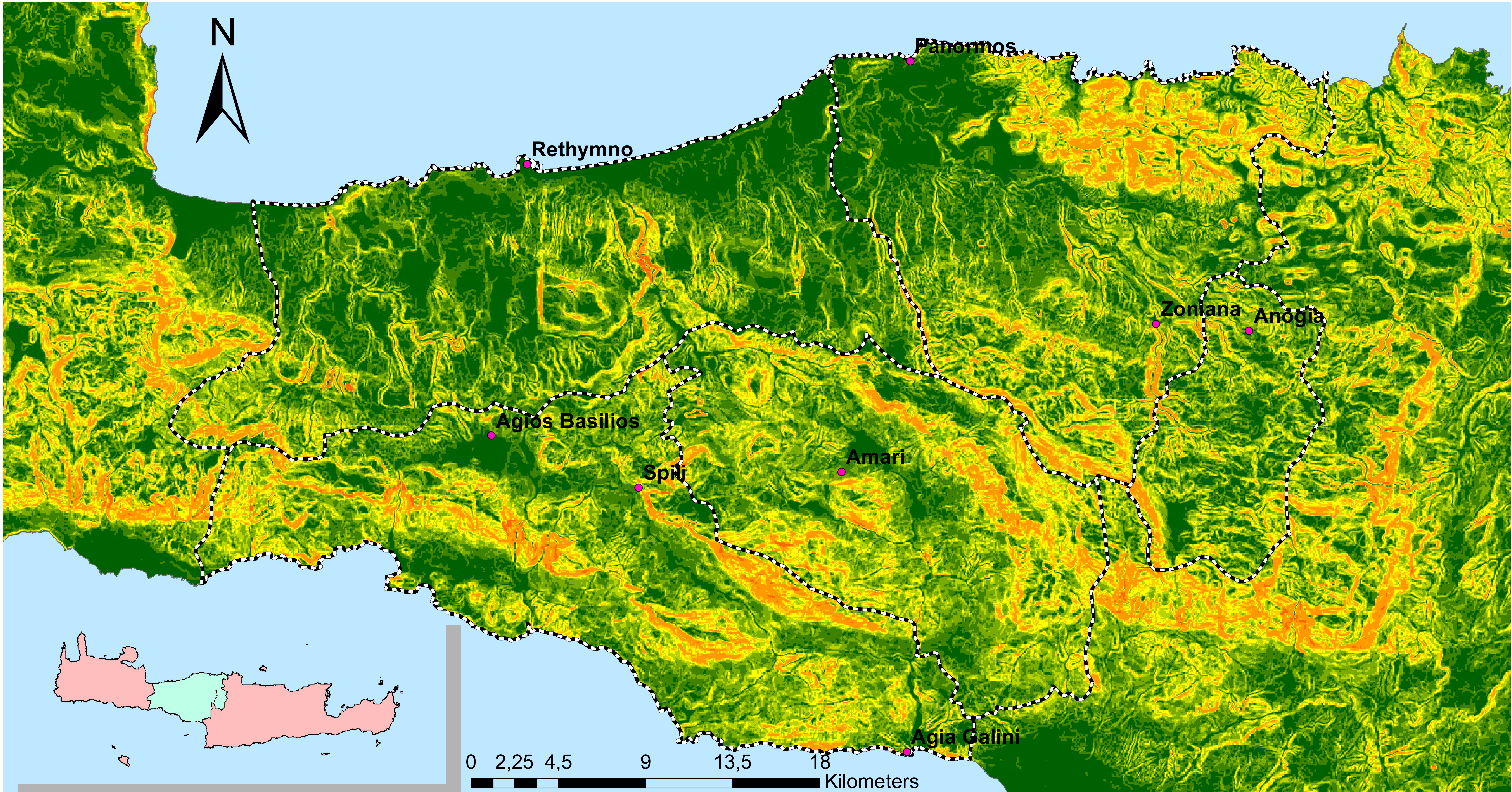
Marina Giamalaki, Chania, 2018

R.3 Slope Map of the Regional Unit of Rethymno



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Slope (%)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 100
- 100 - 1,000
- > 1,000

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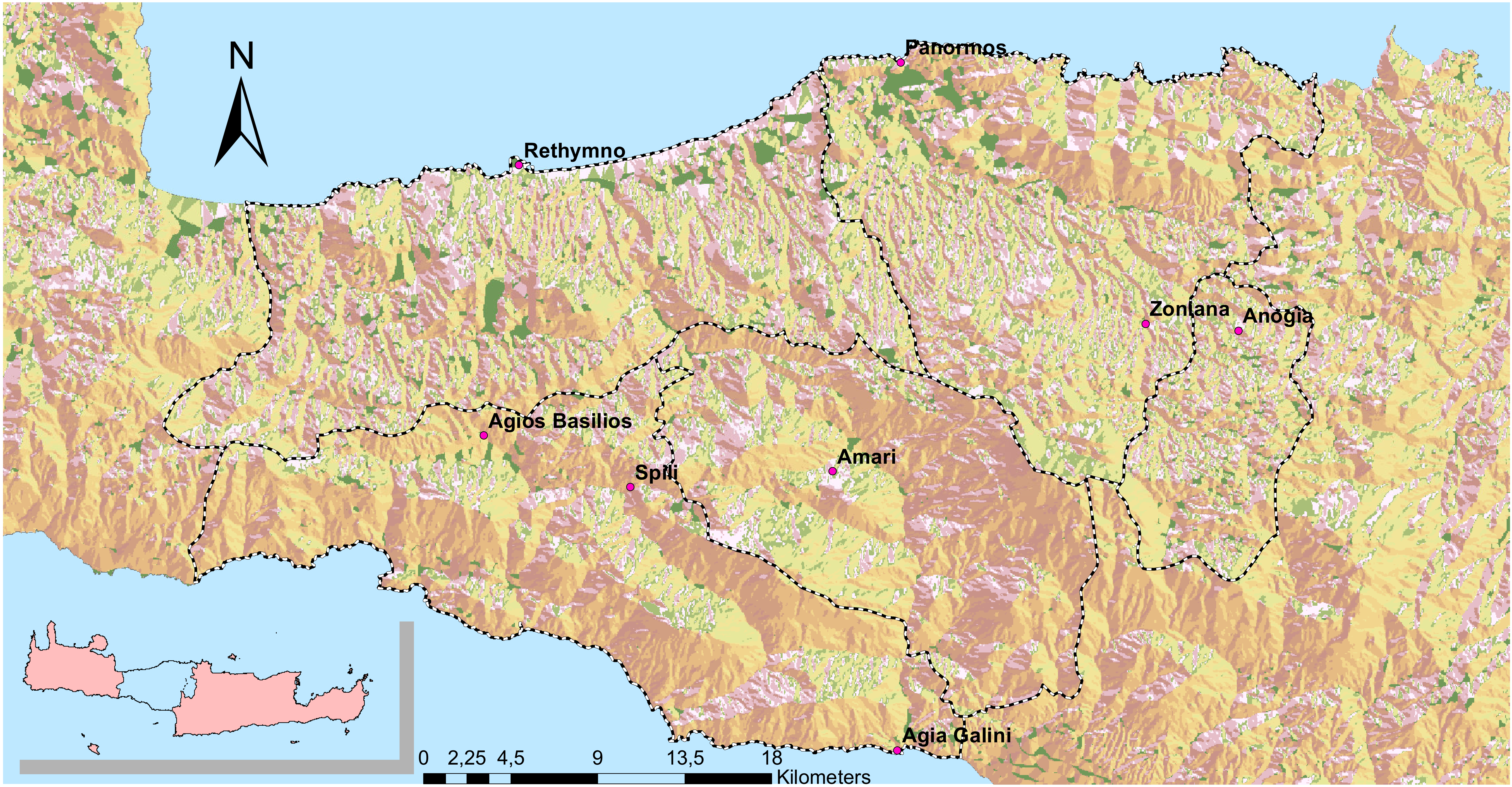
R.4 Aspects Map of the Regional Unit of Rethymno



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Aspects

- Flat
- Northern (0 - 22.5)
- Northeastern (22.5 - 67.5)
- Eastern (67.5 - 112.5)
- Southeastern (112.5 - 157.5)
- Southern (157.5 - 202.5)
- Southwestern (202.5 - 247.5)
- Western (247.5 - 292.5)
- Northwestern (292.5 - 337.5)
- Northern (337.5 - 360)

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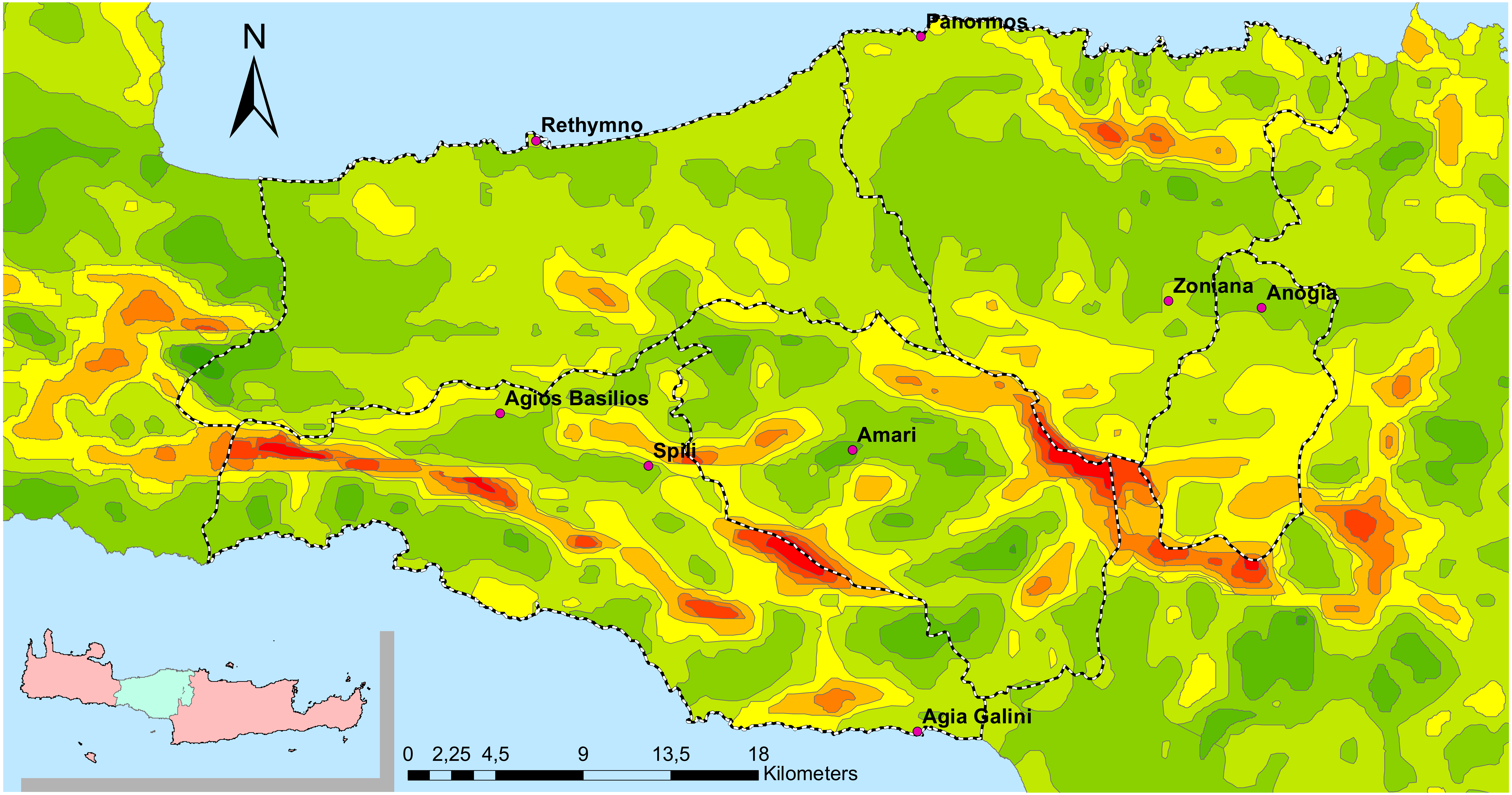
R.5 Wind Potential of the Regional Unit of Rethymno



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Wind Speed (m/s)

- 3-5
- 5-6
- 6-7
- 7-8
- 8-9
- 9-10
- 10-11
- 11-12
- 12-14

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The Case Study of the Regional Unit of Rethymno

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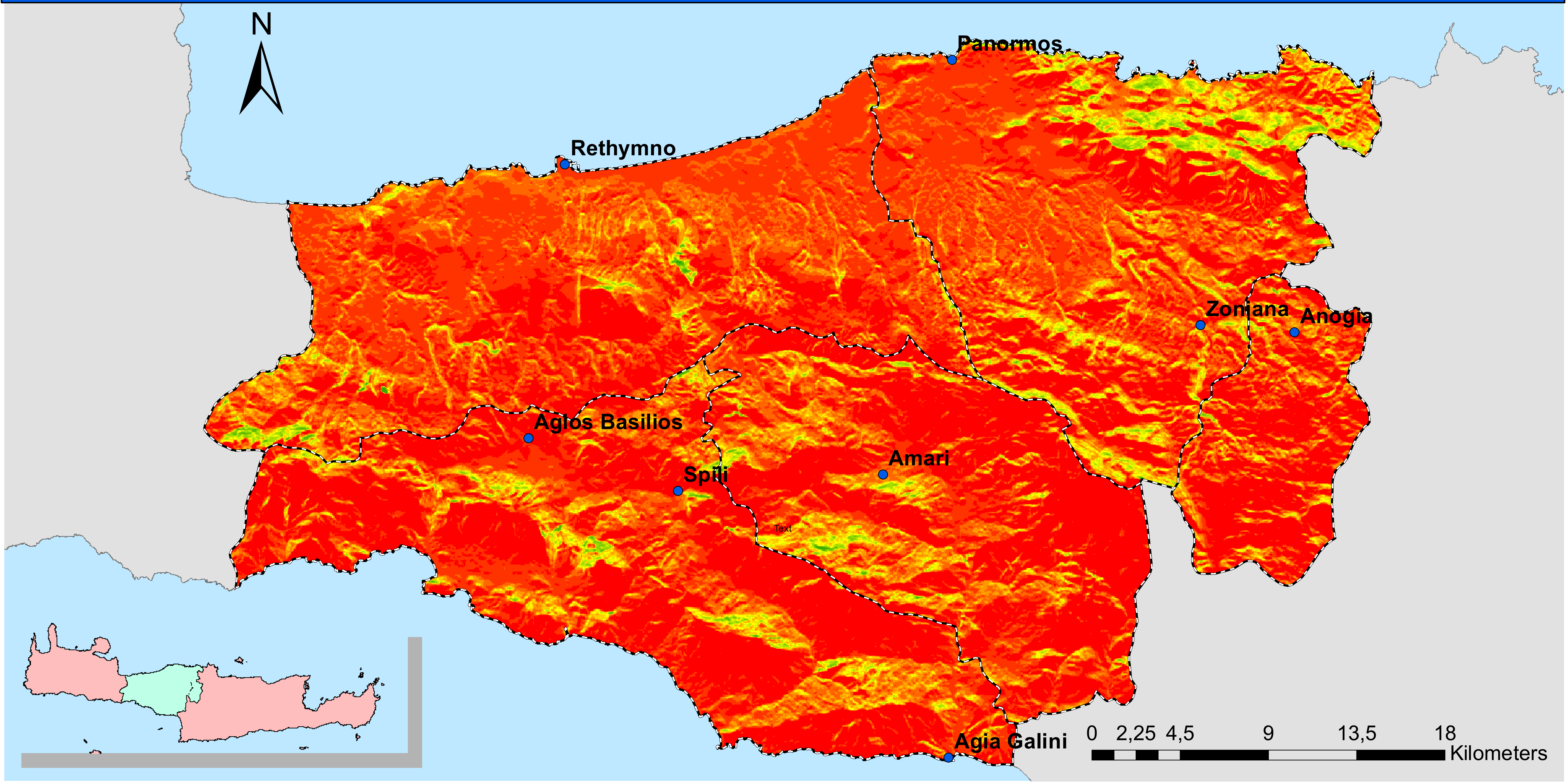
R.6 Solar Potential of the Regional Unit of Rethymno-
Global Horizontal Irradiance (GHI)



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Yearly Average GHI (kWh/m2)

- <800
- 800-1,000
- 1,000-1,100
- 1,100-1,200
- 1,200-1,300
- 1,300-1,400
- 1,400-1,500
- 1,500-1,600
- 1,600-1,700
- 1,700-1,800
- >1,800

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The Case Study of the Regional Unit of Rethymno

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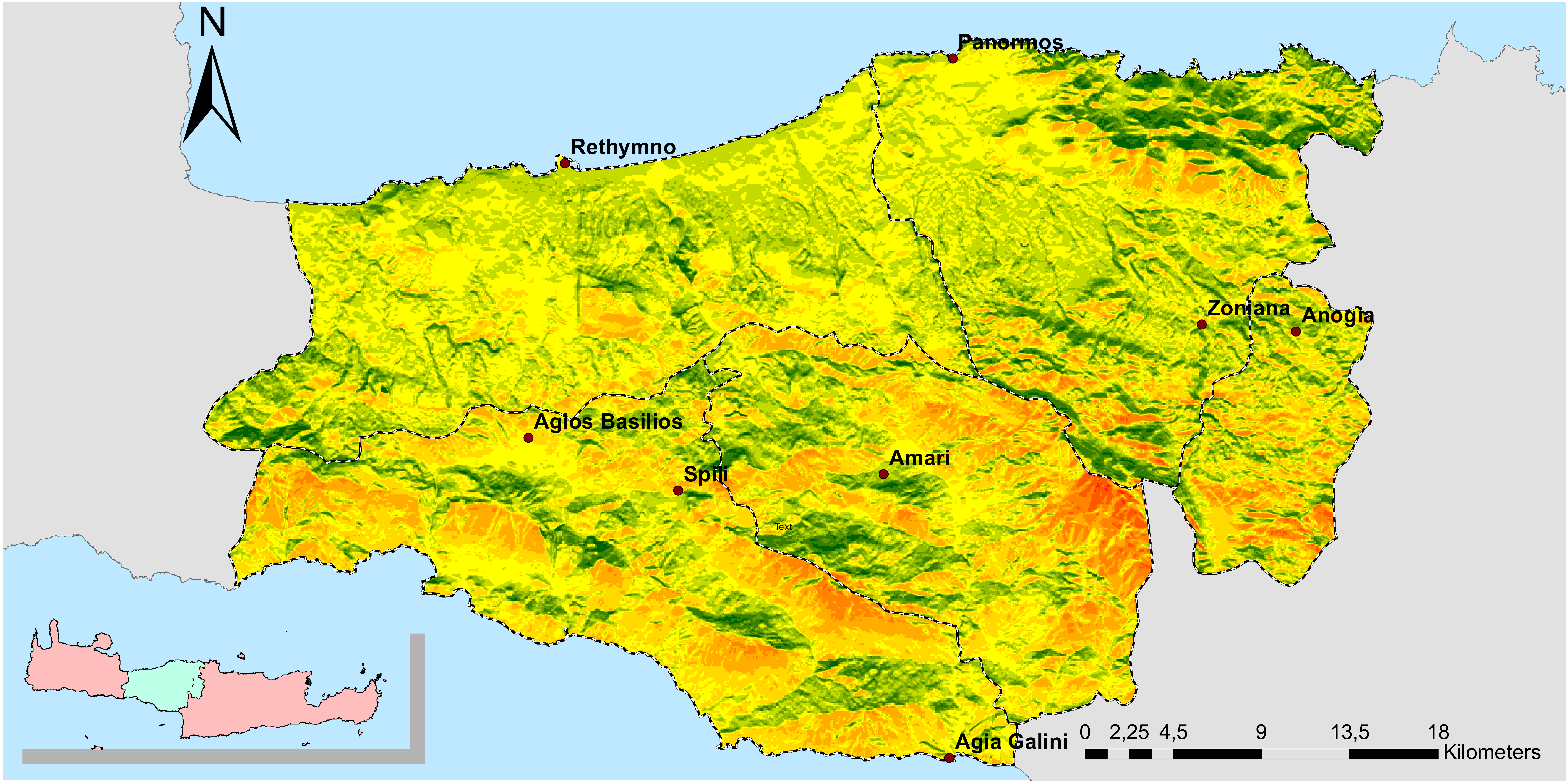
R.7 Solar Potential of the Regional Unit of Rethymno- Direct Normal Irradiance (DNI)



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Yearly Average DNI (kWh/m2)

- <800
- 800-1,000
- 1,000-1,100
- 1,100-1,200
- 1,200-1,300
- 1,300-1,400
- 1,400-1,500
- 1,500-1,600
- 1,600-1,700
- 1,700-1,800
- >1,800

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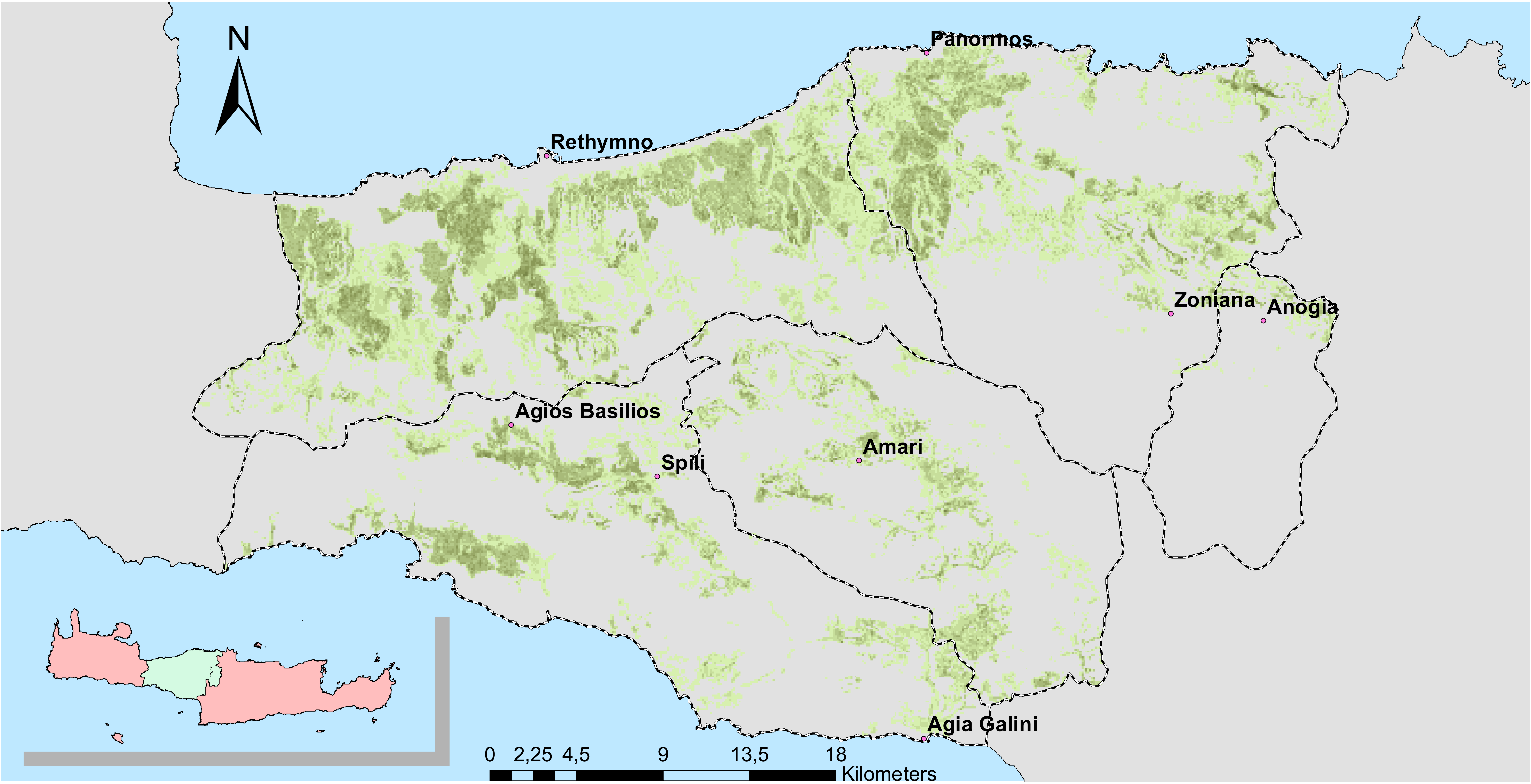
R.8 Agricultural and Forest Prunning Wood Biomass Potential of the Regional Unit of Rethymno



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Biomass Potential kg/ha

- <200
- 200-600
- 600-1,000
- 1,000-1,400
- 1,400-1,800
- 1,800-2,200
- 2,200-2,600
- 2,600-3,000
- >3,000

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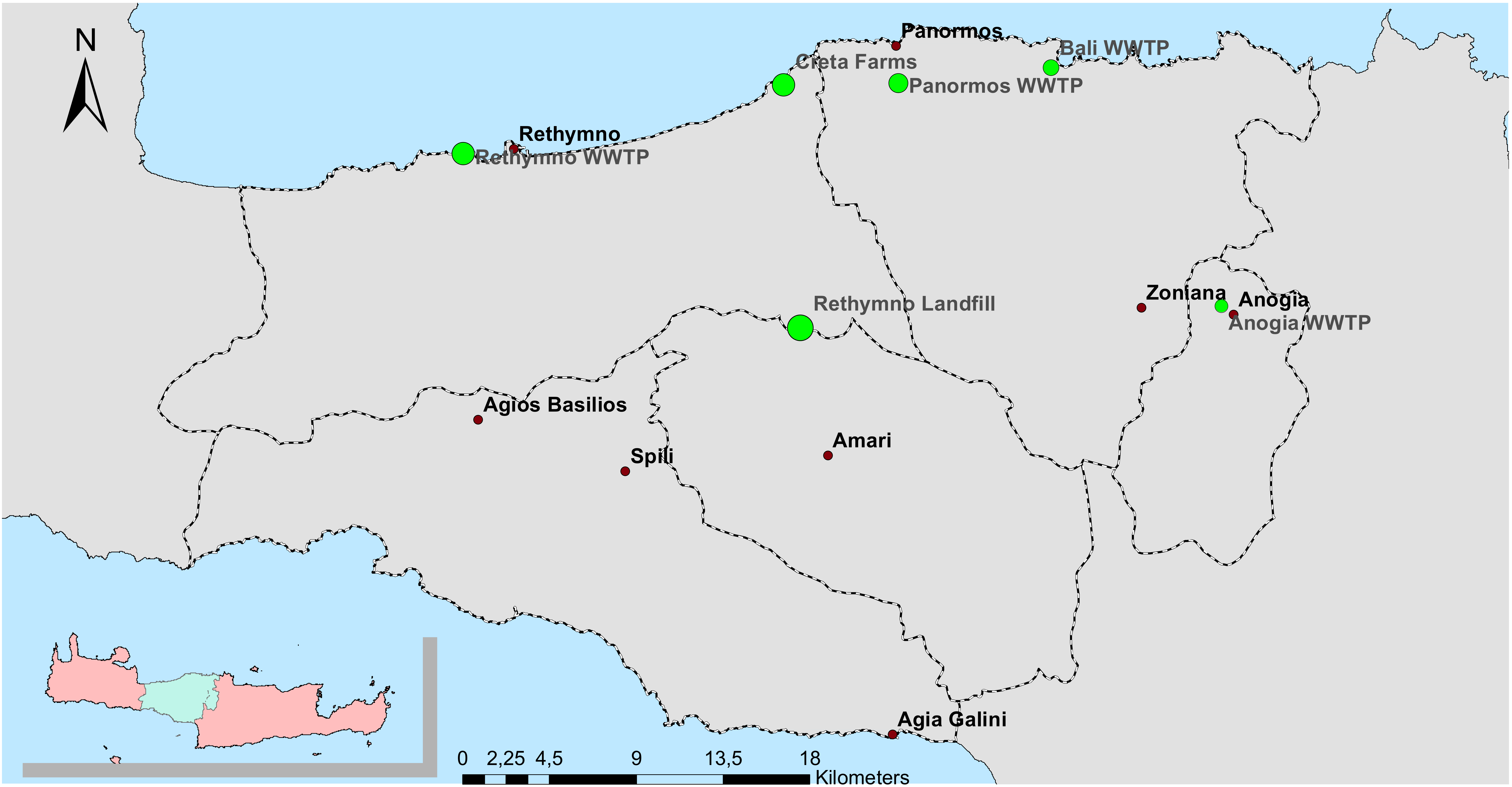
R.9. Biogas Potential from Large Biogas Sources of the Regional Unit of Rethymno



LEGEND

Biogas Potential (m3/y)

- 23,715.51
- 23,715.51 - 36,102.15
- 36,102.15 - 45,969.56
- 45,969.56 - 594,311.3
- 594,311.3 - 10,920,000
- Municipalities Boundaries of the Regional Unit of Rethymno

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The Case Study of the Regional Unit of Rethymno

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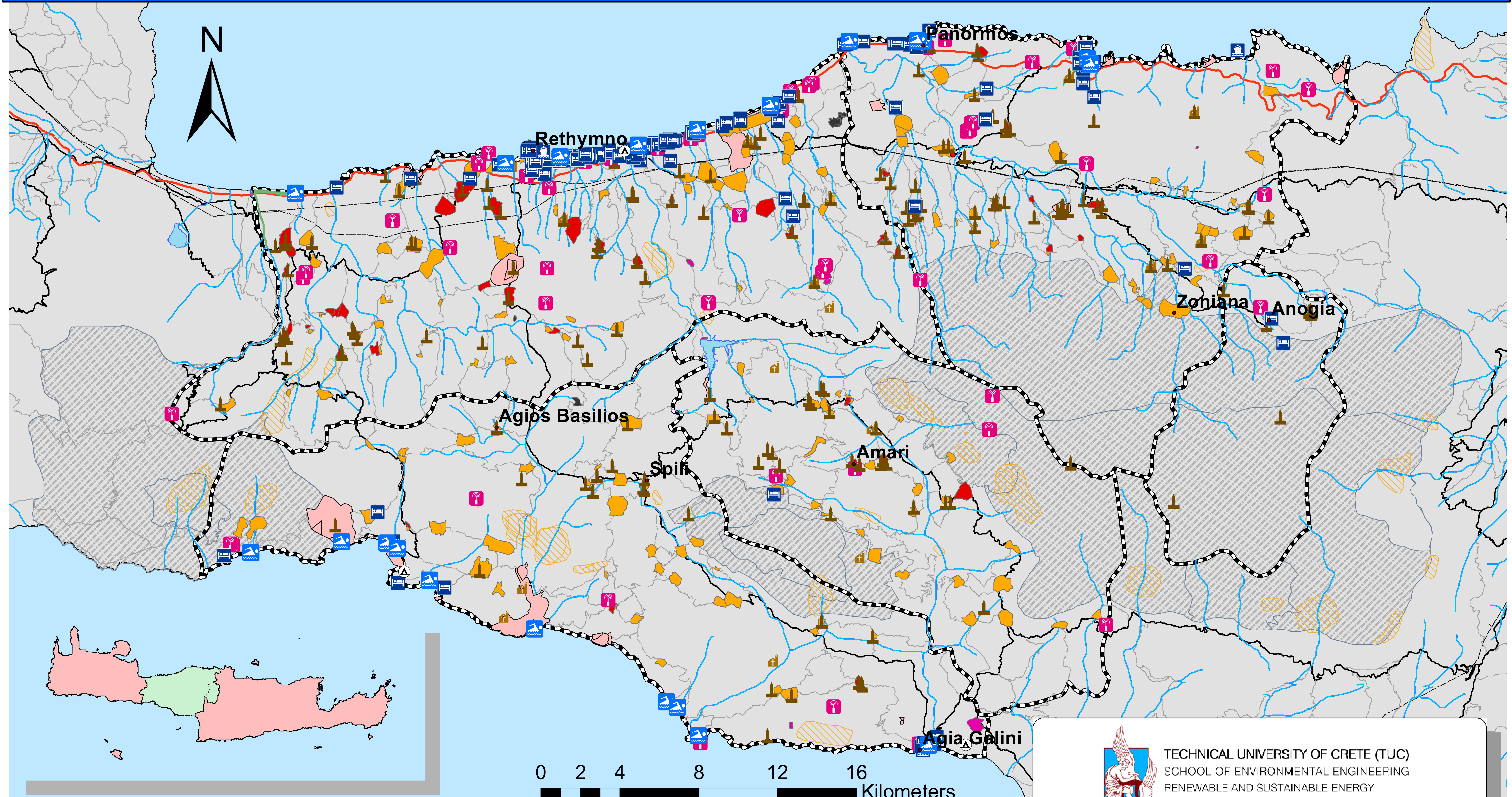
W.1 Exclusion Areas for Wind Energy Installations Siting



LEGEND

- Beaches
- Ports-Marinas
- Camps
- Tourist Accomondations
- Monuments
- Monasteries
- Traditional Settlements
- Telecommunication Antennas
- National Defense Installations
- Traditional Settlements
- Settlements
- Archaeological Sites
- Quarries
- Lakes
- Hydrographic Network
- National Road Network
- Provincial Road Network
- Community Road Network
- High Voltage Lines
- Urban Control Zone Georgioupolis-Episkopi
- Municipalities Boundaries of the Regional Unit of Rethymno
- Important Areas for Bird Priority Species
- Areas of Absolute Protection of Nature

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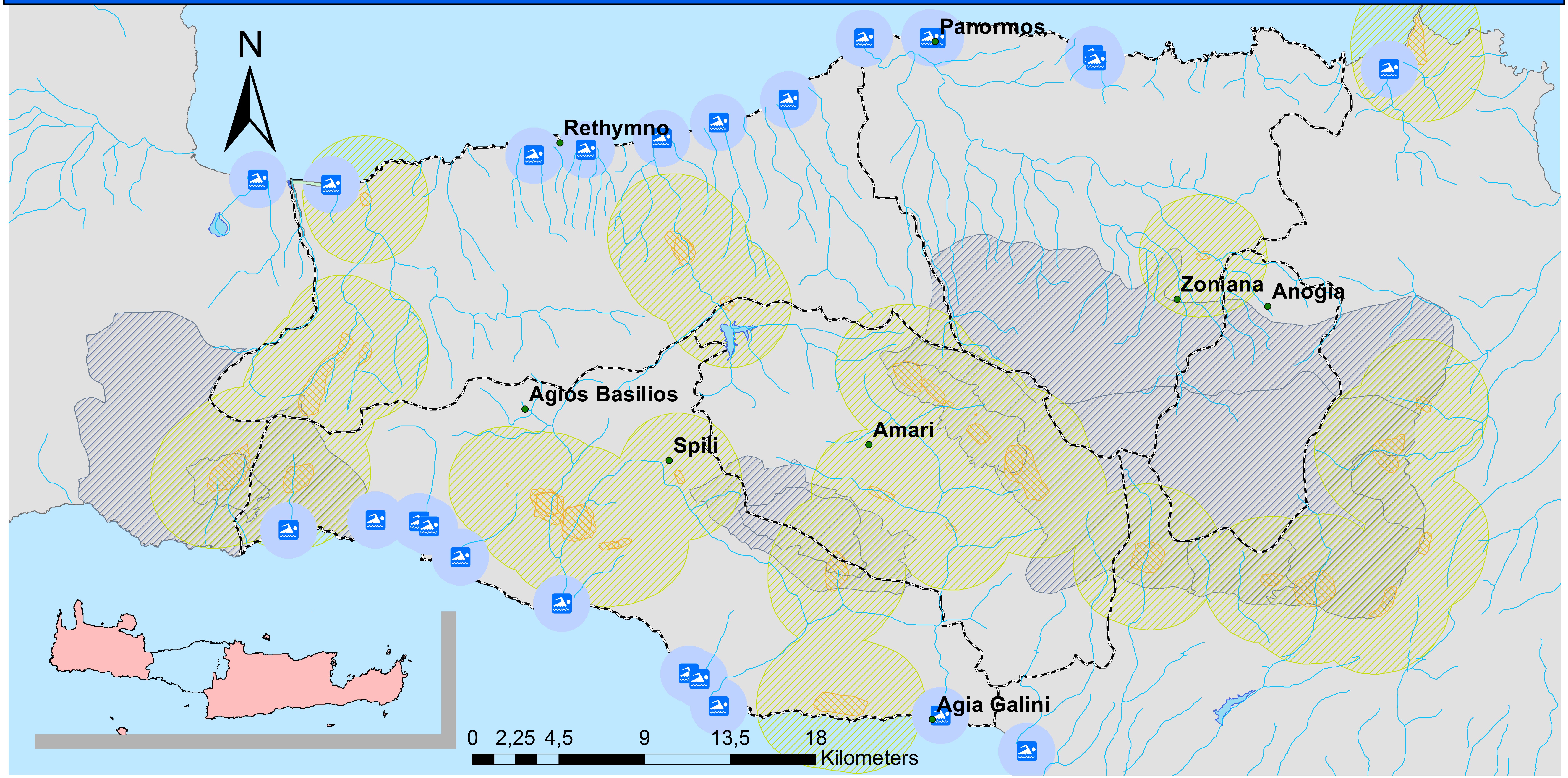
W.2 Minimum Allowable Distances from Areas of Environmental Interest for Wind Energy Installations Siting-Legislation



LEGEND

- Beaches
- Hydrographic Network
- Urban Control Zone Georgioupolis-Episkopi- Area 3
- Lakes
- Buffer Distance 1,500m from Beaches
- Municipalities Boundaries of the Regional Unit of Rethymno
- Important Areas for Bird Priority Species
- Buffer Distance 3,000m from Important Areas for Bird Priority Species
- Areas of Absolute Protection of Nature

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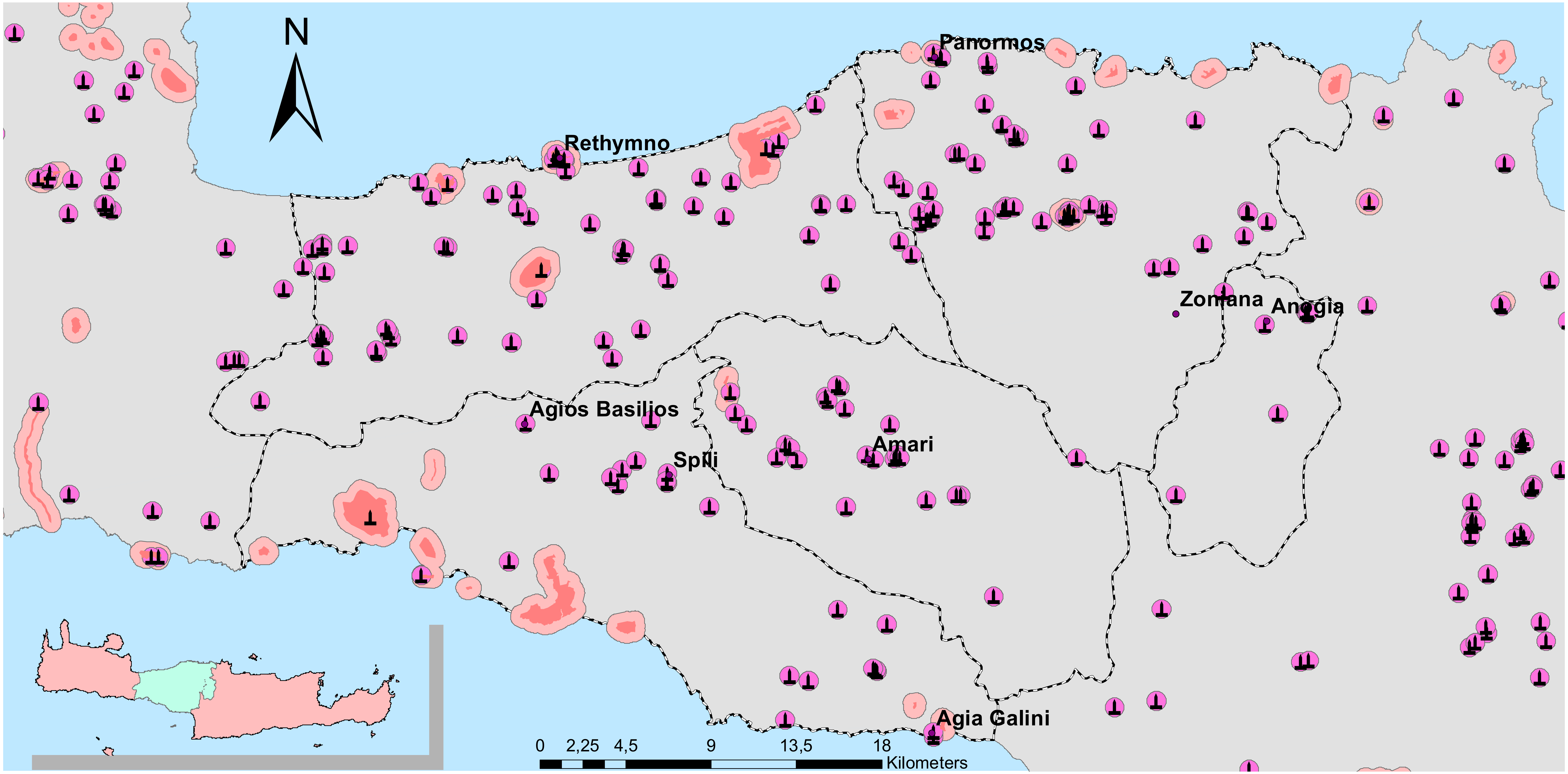
W.3 Minimum Allowable Distances from Areas of Cultural Interest for Wind Energy Installations Siting-Legislation



LEGEND

- Monuments
- Archaeological Sites
- Buffer Distance of 500m from Monuments
- Buffer Distance of 500m from Archaeological Sites
- Municipalities Boundaries of the Regional Unit of Rethymno

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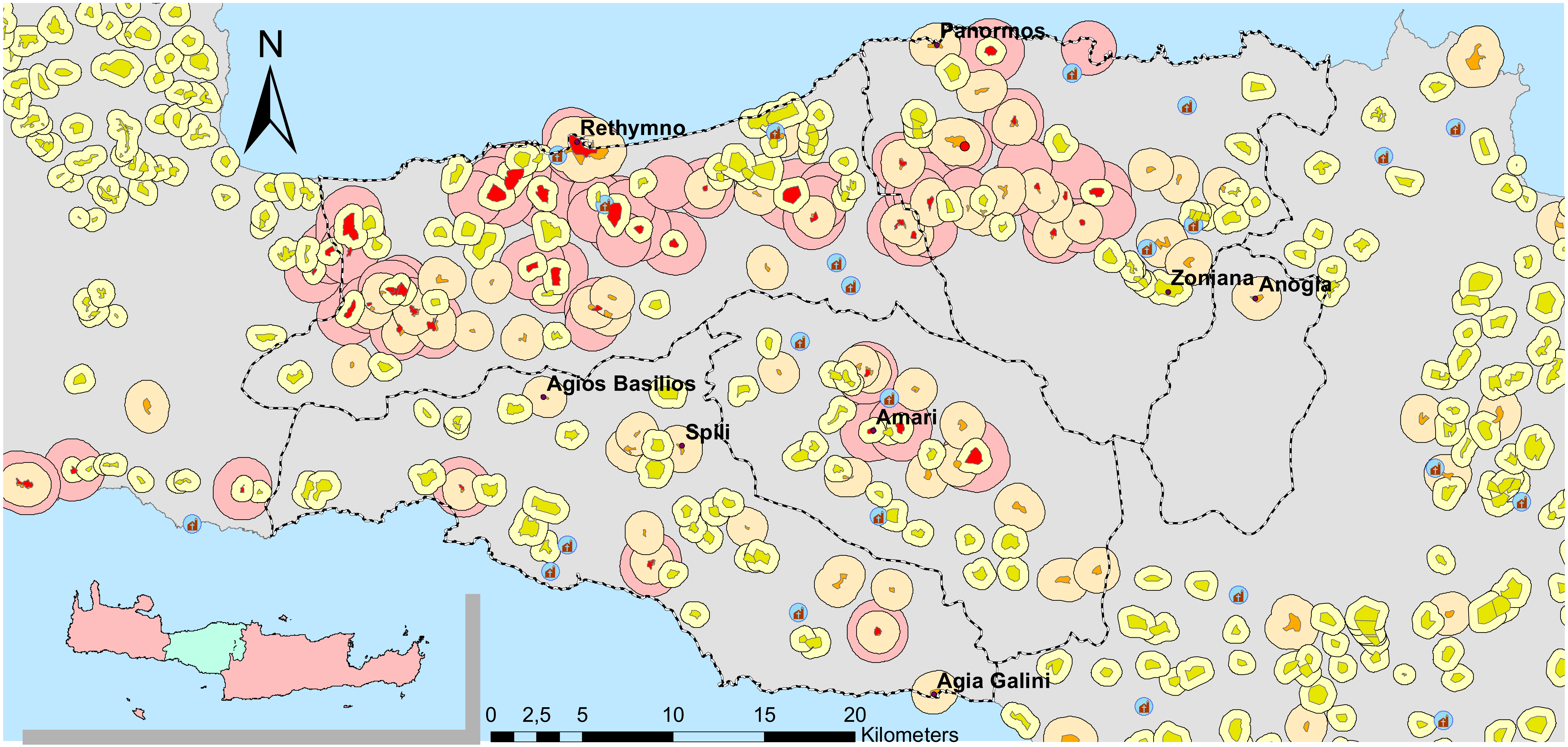
W.4 Minimum Allowable Distances from Urban Activities for Wind Energy Installations Siting-Legislation



LEGEND

- Monasteries
- Traditional Settlements
- Traditional Settlements
- Municipalities Boundaries of the Regional Unit of Rethymno
- Settlements with Population <2,000 Residents
- Settlements with Population > 2,000 Residents- Remarkable
- Buffer Distance of 500m from Monasteries
- Buffer Distance of 500m from Settlements with Population <2,000 Residents
- Buffer Distance of 1,000m from Settlements with Population >2,000 Residents
- Buffer Distance of 1,500m from Traditional Settlements

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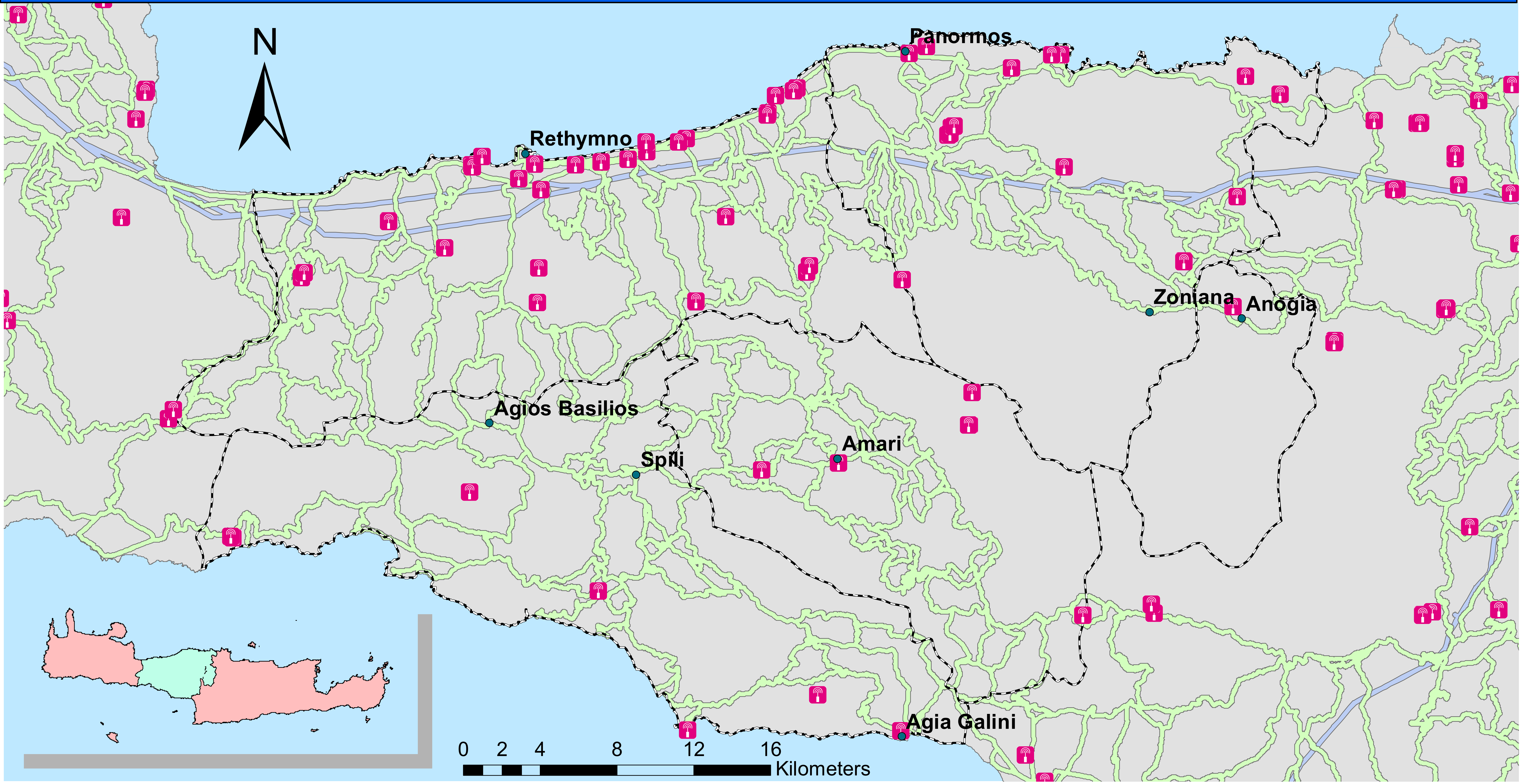
W.5 Minimum Allowable Distances from the Technical Infrastructure for Wind Energy Installations Siting- Legislation



LEGEND

Telecommunication Antennas

Municipalities Boundaries of the Regional Unit of Rethymno

Buffer Distance of 127.5m from the Road Network

Buffer Distance of 127.5m from the High Voltage Lines

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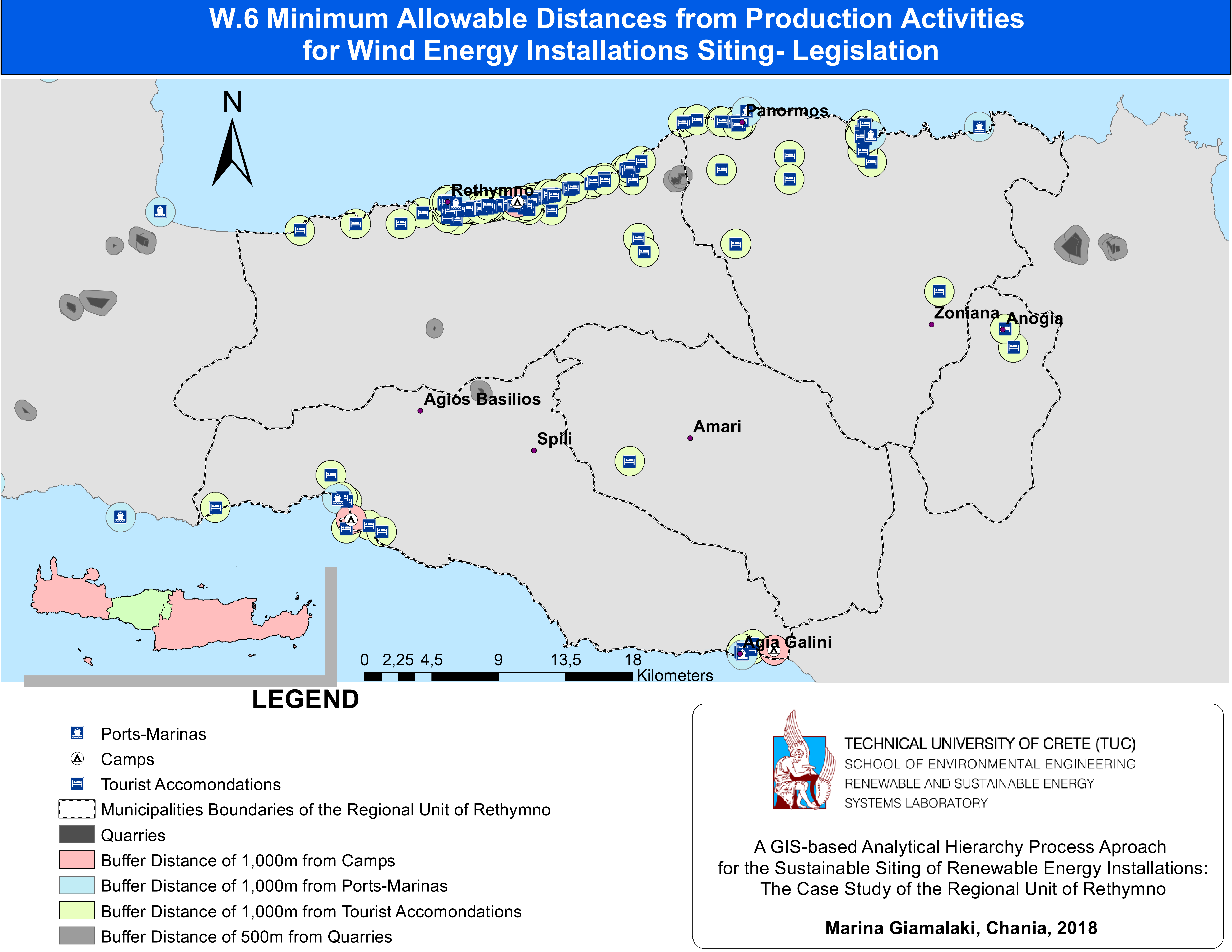
W.6 Minimum Allowable Distances from Production Activities
for Wind Energy Installations Siting- Legislation
N
Panormos
Rethymno
Zoniana
Anogia
Agios Basilios
Amari
Spili
Agia Galini
0 2,25 4,5 9 13,5 18
Kilometers
LEGEND
Ports-Marinas
Camps
Tourist Accomondations
Municipalities Boundaries of the Regional Unit of Rethymno
Quarries
Buffer Distance of 1,000m from Camps
Buffer Distance of 1,000m from Ports-Marinas
Buffer Distance of 1,000m from Tourist Accomondations
Buffer Distance of 500m from Quarries
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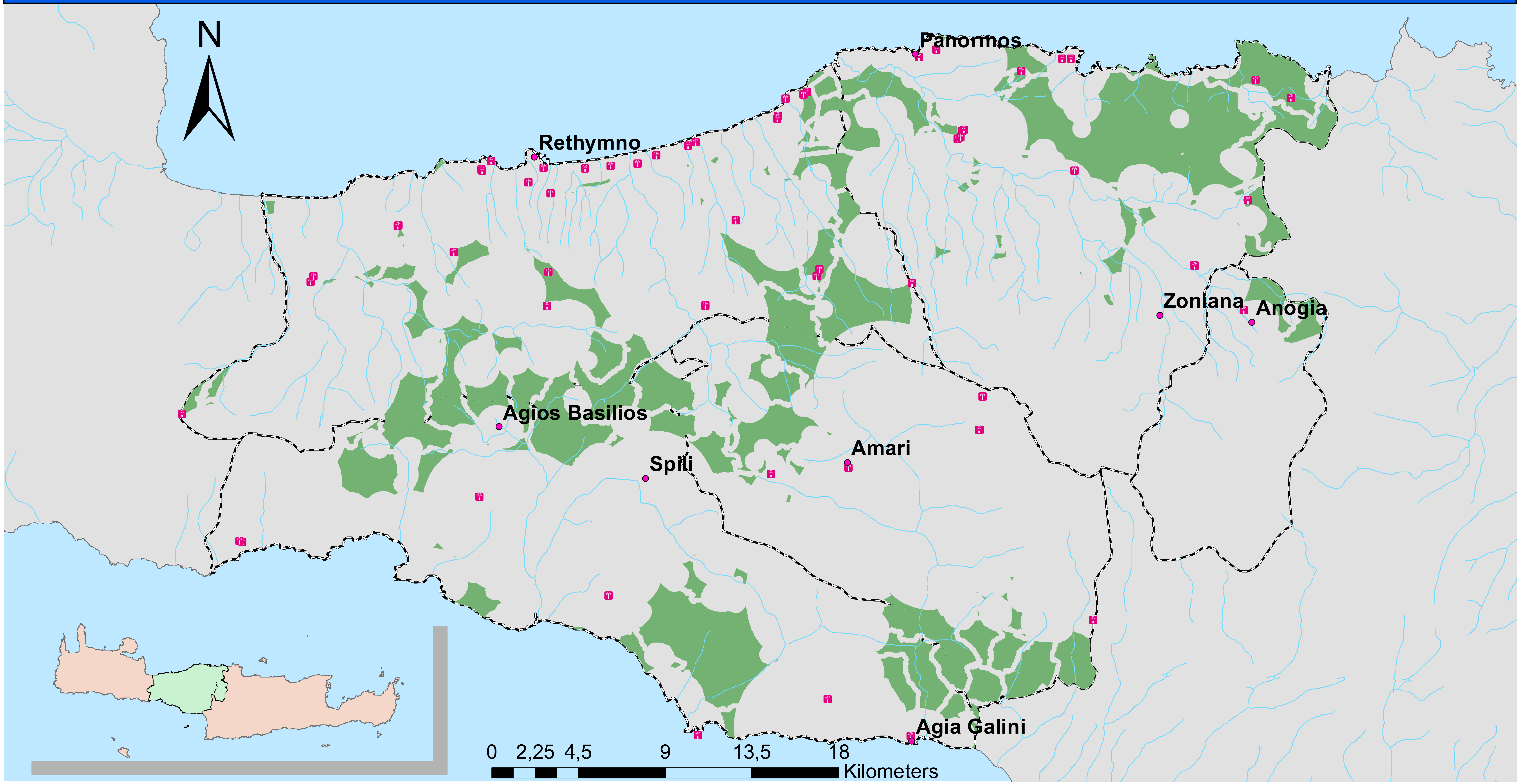
W.7 Legally Available Areas for Wind Energy Installations Siting



LEGEND

- Telecommunication Antennas
- Hydrographic Network
- Available Siting Areas
- Municipalities Boundaries of the Regional Unit of Rethymno

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The Case Study of the Regional Unit of Rethymno

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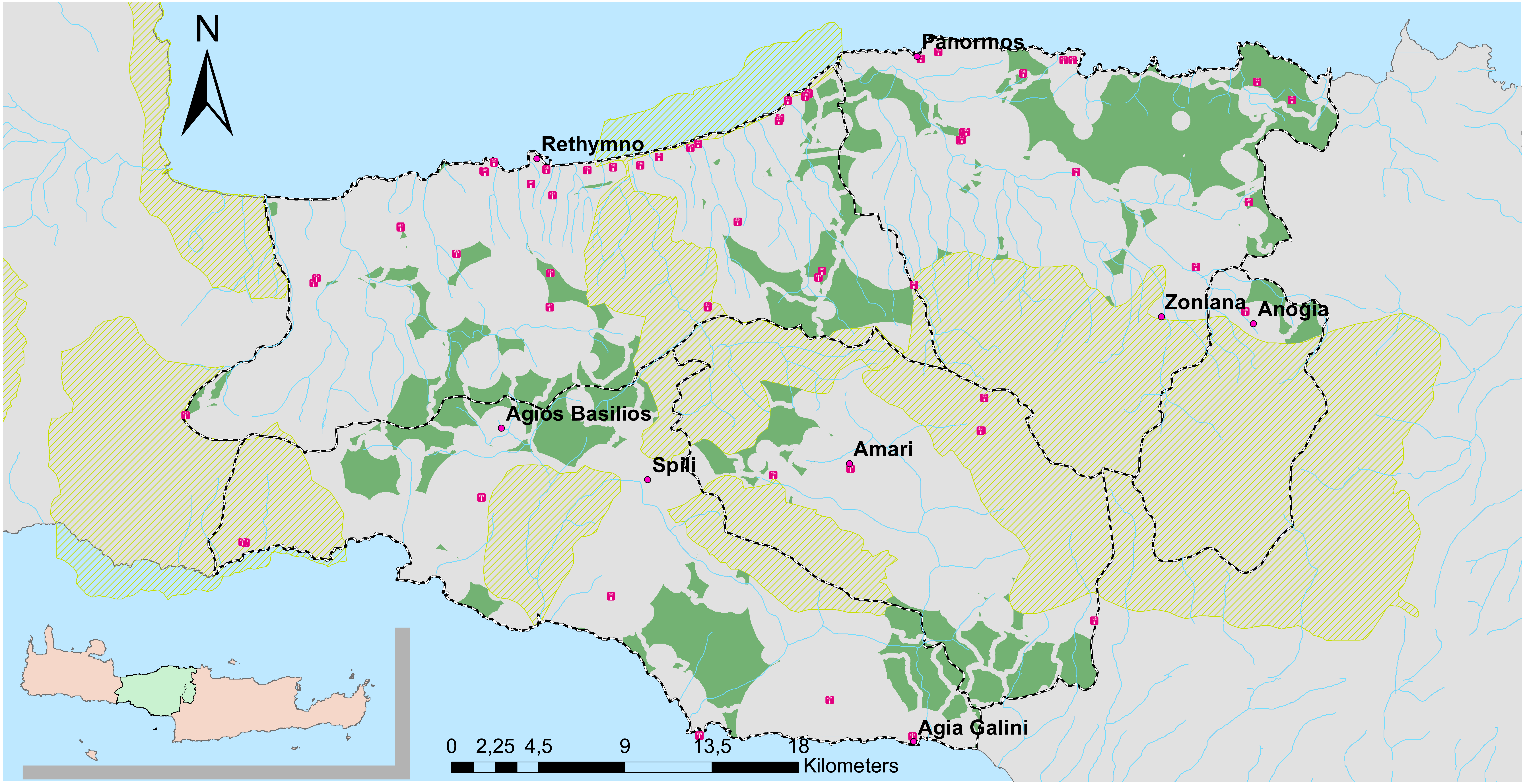
W.8 Available Areas for Wind Energy Installations Siting-Environmental Scenario



LEGEND

- Telecommunication Antennas
- Hydrographic Network
- Municipalities Boundaries of the Regional Unit of Rethymno
- Available Siting Areas
- Sites of Community Importance (SCI) of the NATURA 2000 Network

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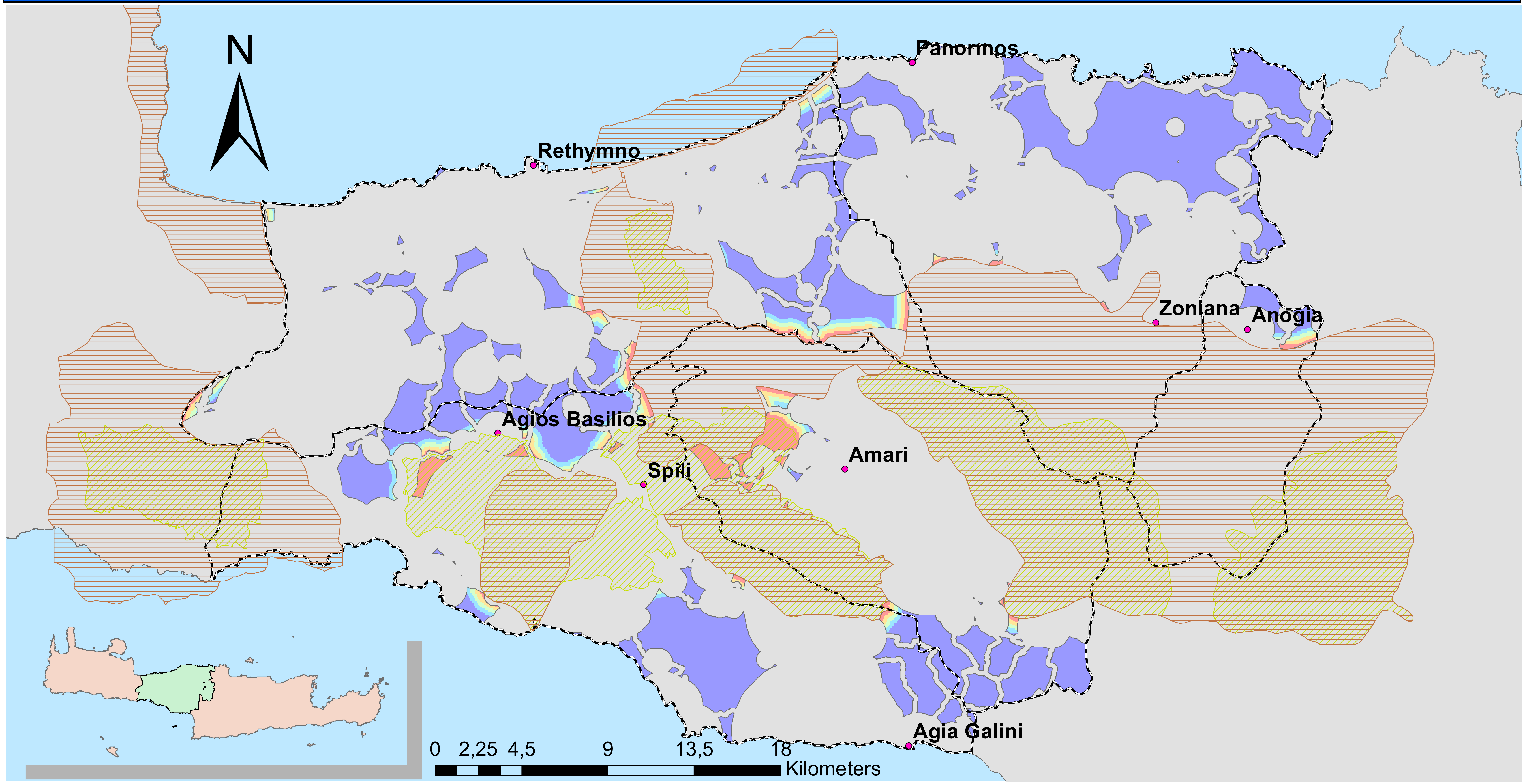
W.9 Evaluation Criterion for Wind Energy Installations Siting: Distance from NATURA 2000 Sites



LEGEND

NATURA 2000 Network

- Sites of Community Importance
- Special Protection Areas
- Municipalities Boundaries of the Regional Unit of Rethymno
- Exclusion Areas of the Environmental Scenario

Evaluation Zones

- 0 - 200m Unsuitable
- 200 - 400m Less Suitable
- 400 - 600m Moderately Suitable
- 600 - 800m Suitable
- >800m Particularly Suitable

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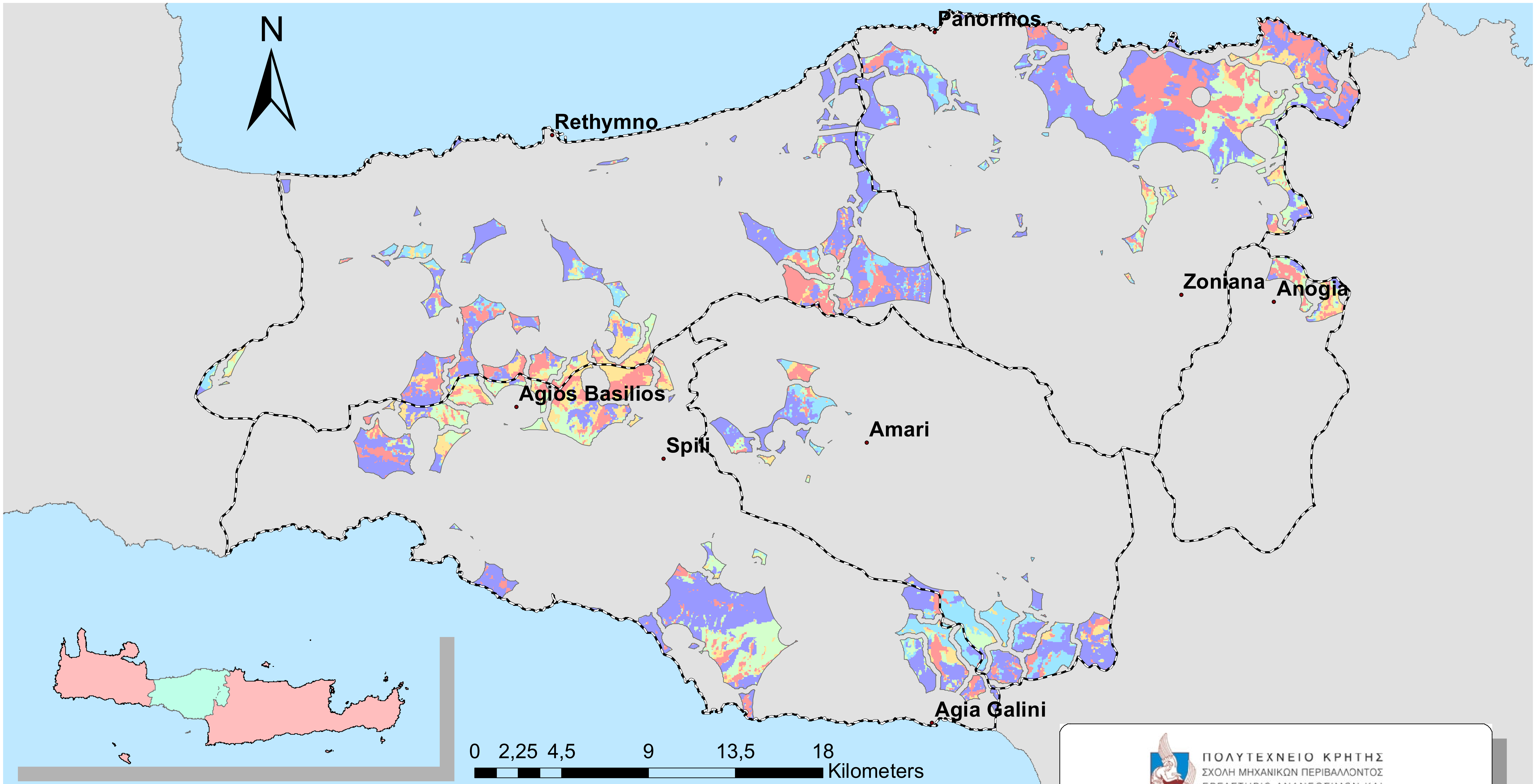
W.10 Evaluation Criterion for Wind Energy Installations Siting: Visibility from the Most Visited Sites



ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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LEGEND

Exclusion Areas of the Environmental Scenario

Evaluation Zones

Invisible Areas from Most Visited Sites- Particularly Suitable

Invisible Areas from Archaeological Sites, Traditional Settlements, Monuments, Beaches, Ports-Marinas, Camps and Tourist Accomondations- Suitable

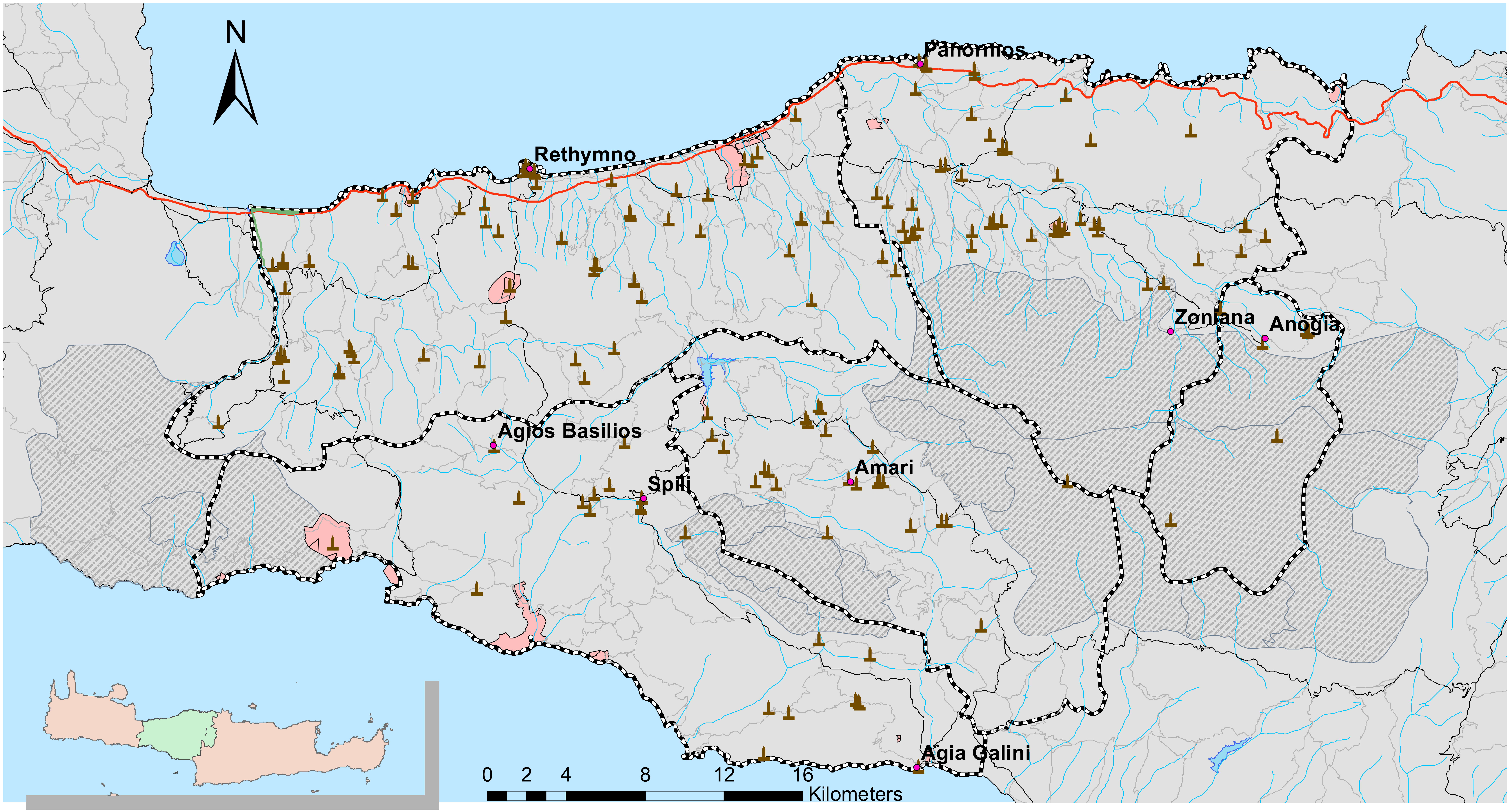
Invisible Areas from Archaeological Sites and Traditional Settlements- Moderately Suitable

Invisible Areas from Archaeological Sites- Less Suitable

Visible Areas from Most Visited Sites- Unsuitable

Municipalities Boundaries of the Regional Unit of Rethymno

S.1 Exclusion Areas for Solar Energy Installations Siting



LEGEND

- Monuments
- National Road Network
- Provincial Road Network
- Community Road Network
- Hydrographic Network
- Lakes
- Urban Control Zone Georgioupolis-Episkopi- Area 3
- Municipalities Boundaries of the Regional Unit of Rethymno
- Archaeological Sites
- Areas of Absolute Protection of Nature

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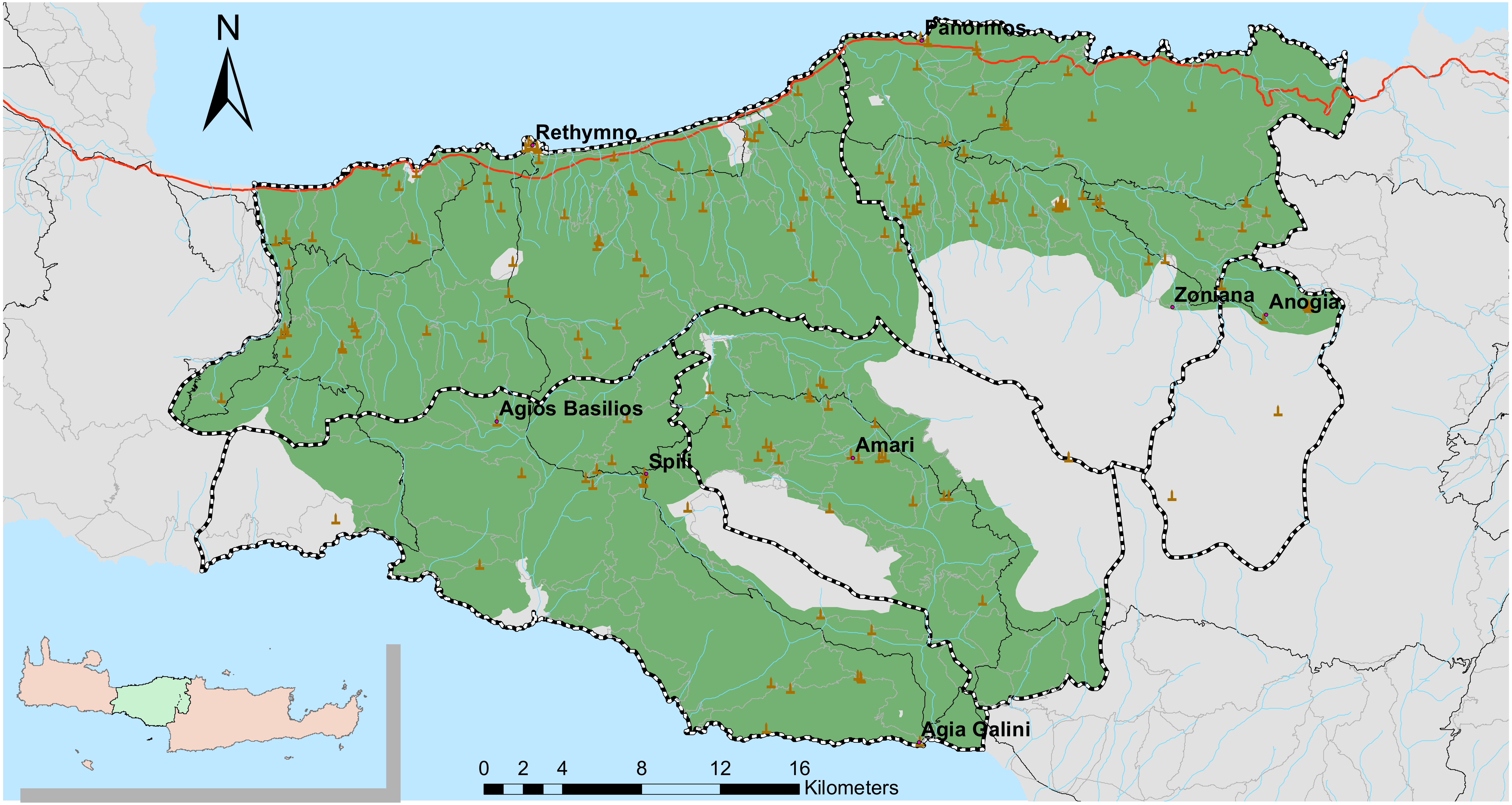
S.2 Legally Available Siting Areas for Solar Energy Installations Siting



LEGEND

Monuments
Hydrographic Network
National Road Network
Provincial Road Network
Community Road Network
Municipalities Boundaries of the Regional Unit of Rethymno
Available Siting Areas
Exclusion Areas

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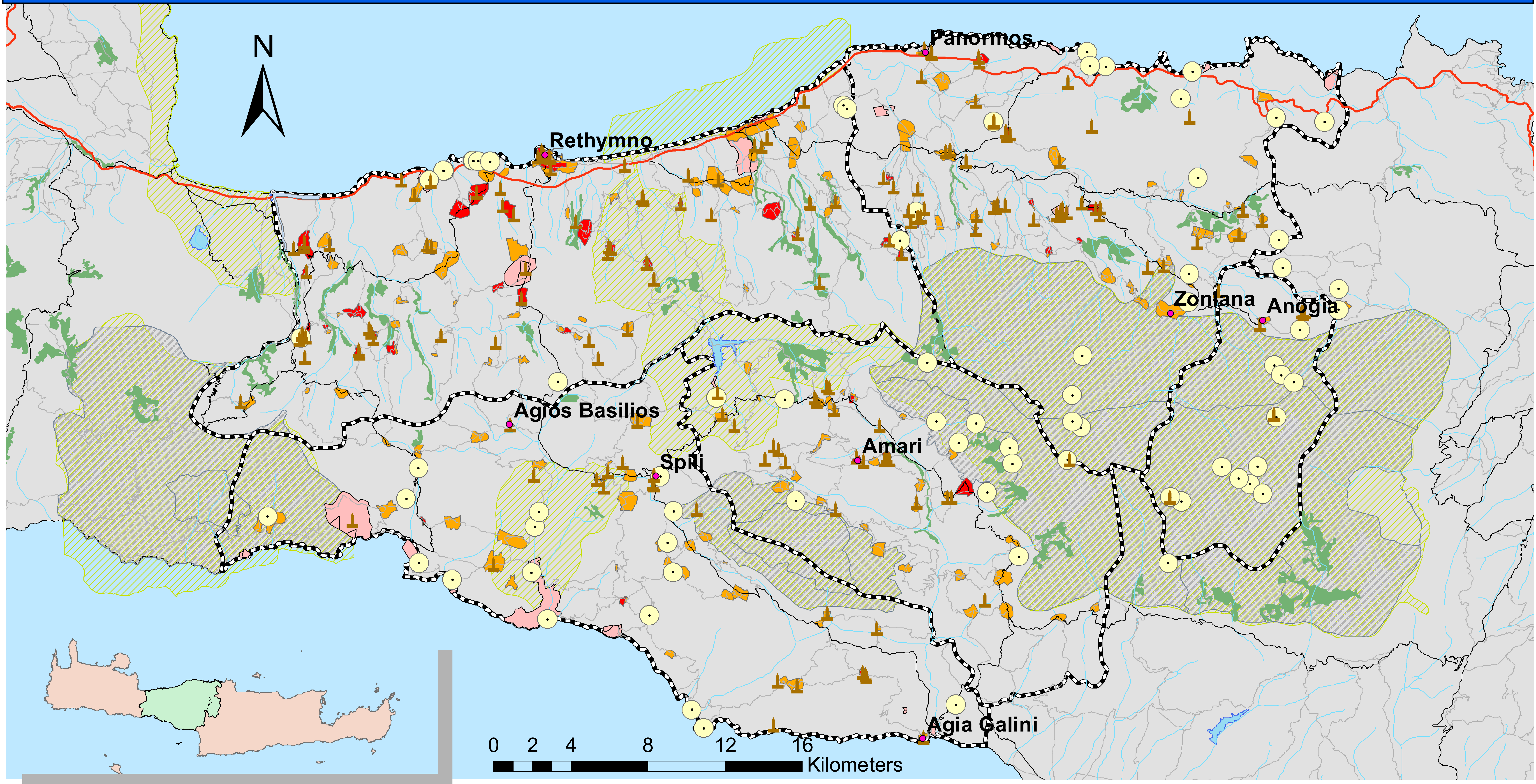
S.3 Exclusion Areas of the Socio-Environmental Scenario for Solar Energy Installations Siting



LEGEND

- Monuments
- Geotopes
- National Road Network
- Provincial Road Network
- Community Road Network
- Traditional Settlements
- Settlements
- Hydrographic Network
- Lakes
- Forests
- Archaeological Sites
- Urban Control Zone Georgioupolis-Episkopi- Area 3
- Municipalities Boundaries of the Regional Unit of Rethymno
- Areas of Absolute Protection of Nature
- Sites of Community Importance (SCI) of the NATURA 2000 Network

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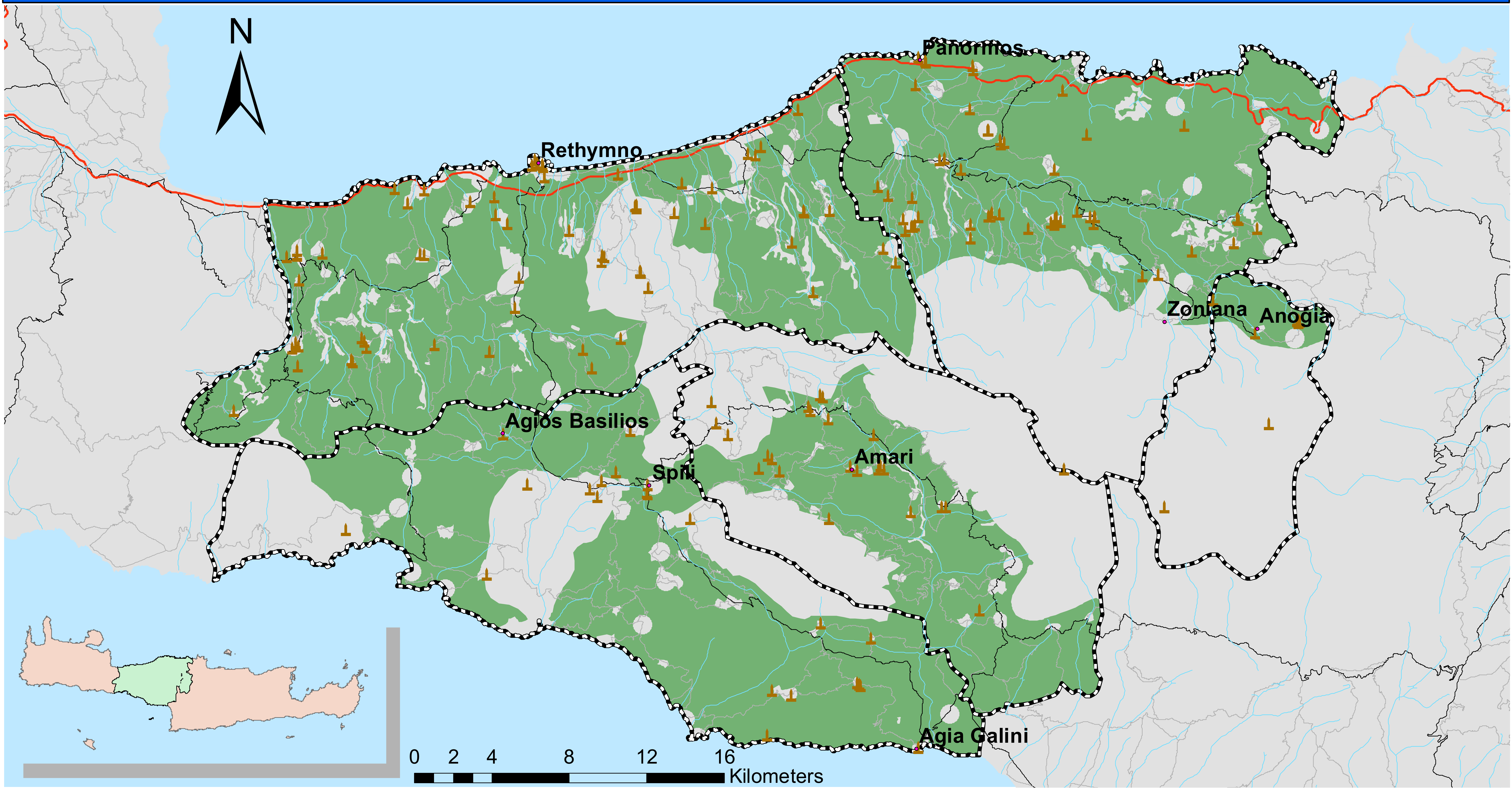
S.4 Available Siting Areas of the Socio-Environmental Scenario for Solar Energy Installations Siting



LEGEND

- Monuments
- Hydrographic Network
- National Road Network
- Provincial Rod Network
- Community Road Network
- Available Siting Areas
- Municipalities Boundaries of the Regional Unit of Rethymno
- Exclusion Areas

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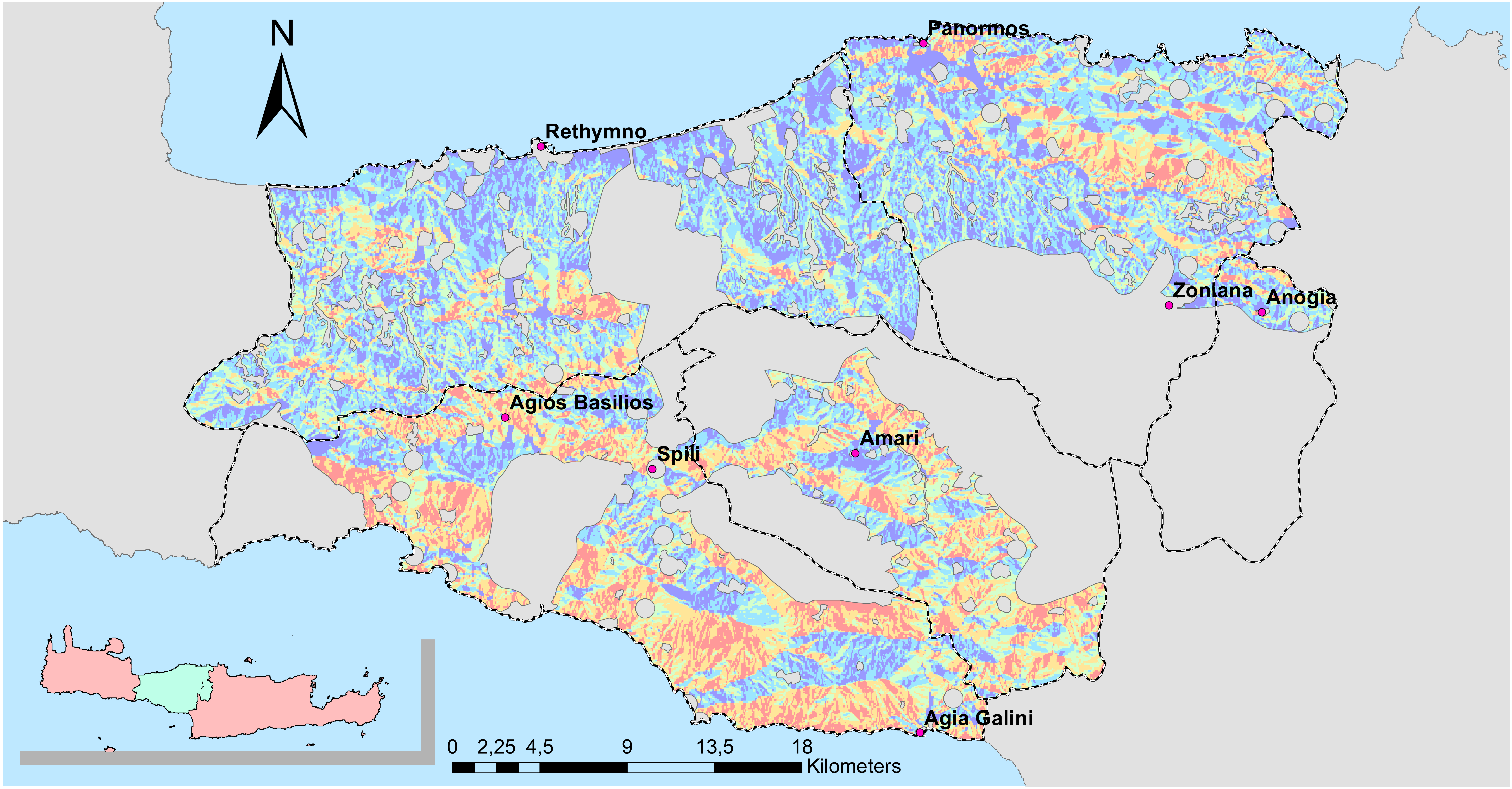
S.5 Evaluation Criterion for Solar Energy Installations Siting: Aspects



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Exclusion Areas of the Socio-Environmental Scenario

Evaluation Zones

Southern- Particularly Suitable

Southeastern and Southwestern- Suitable

Eastern and Western- Moderately Suitable

Northeastern and Northwestern- Less Suitable

Northern- Unsuitable

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ
ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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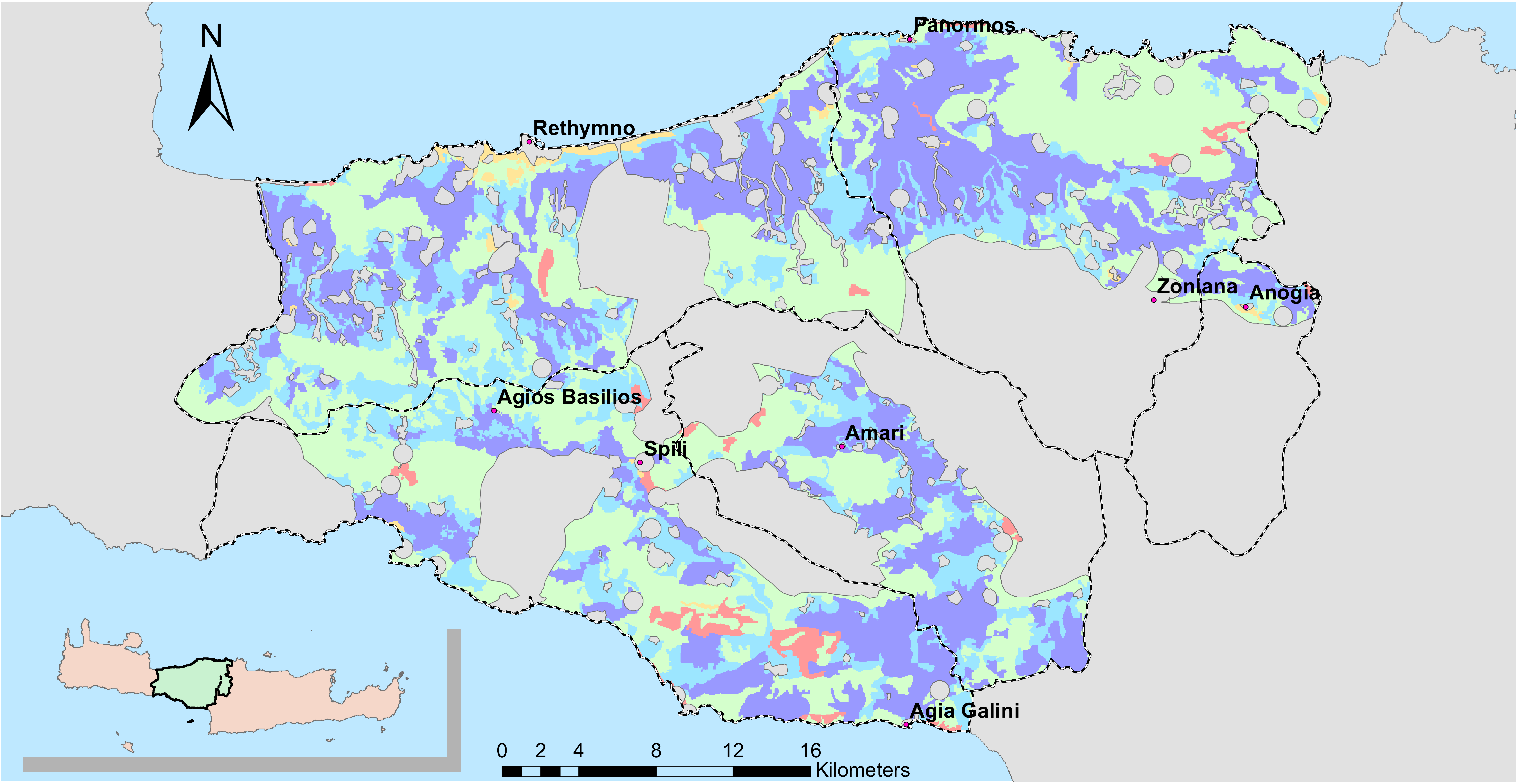
S.6 Evaluation Criterion for Solar Energy Installations Siting: Land Cover



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Exclusion Areas of the Socio-Environmental Scenario

Land Cover Evaluation

- Barren Areas with Little or no Vegetation-Particularly Suitable
- Urban Areas and Other Land Uses- Suitable
- Low Vegetation Lands- Moderately Suitable
- Other Agricultural Areas-Less Suitable
- Permanent Crops and Forests-Unsuitable

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ
ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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The Case Study of the Regional Unit of Rethymno

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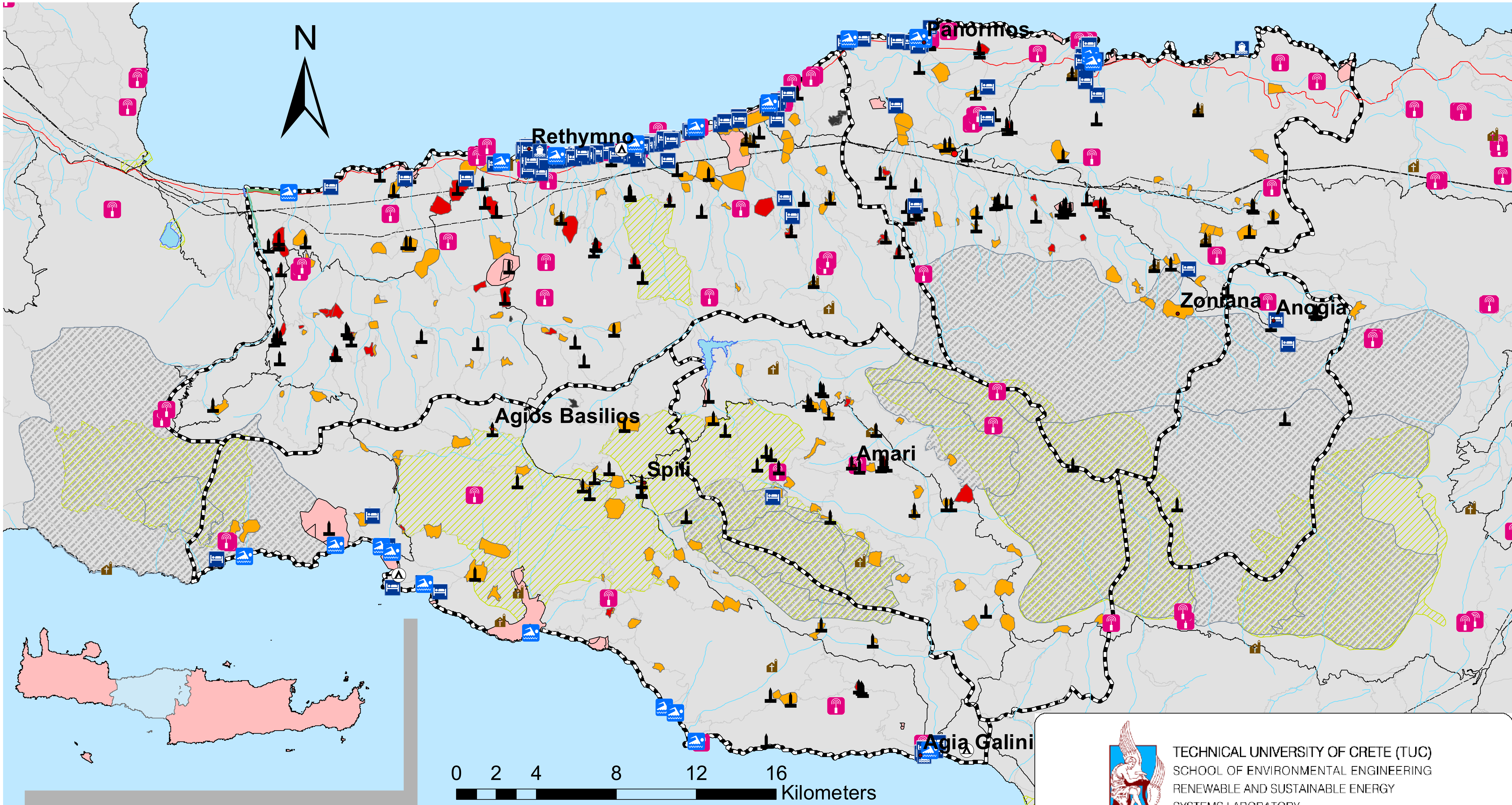
B.1 Exclusion Areas for Biomass/Biogas Plants Siting



LEGEND

Beaches
Ports-Marinas
Camps
Tourist Accomondations
Monuments
Monasteries
Traditional Settlements
Telecommunication Antennas
Traditional Settlements
Settlements
Archaeological Sites
Quarries
Lakes
Hydrographic Network
National Road Network
Provincial Road Network
Community Road Network
High Voltage Lines
Urban Control Zone of Georgioupolis-Episkopi- Area 3
Municipalities Boundaries of the Regional Unit of Rethymno
Areas of Absolute Protection of Nature
Special Protection Zones (SPA) of the NATURA 2000 Network

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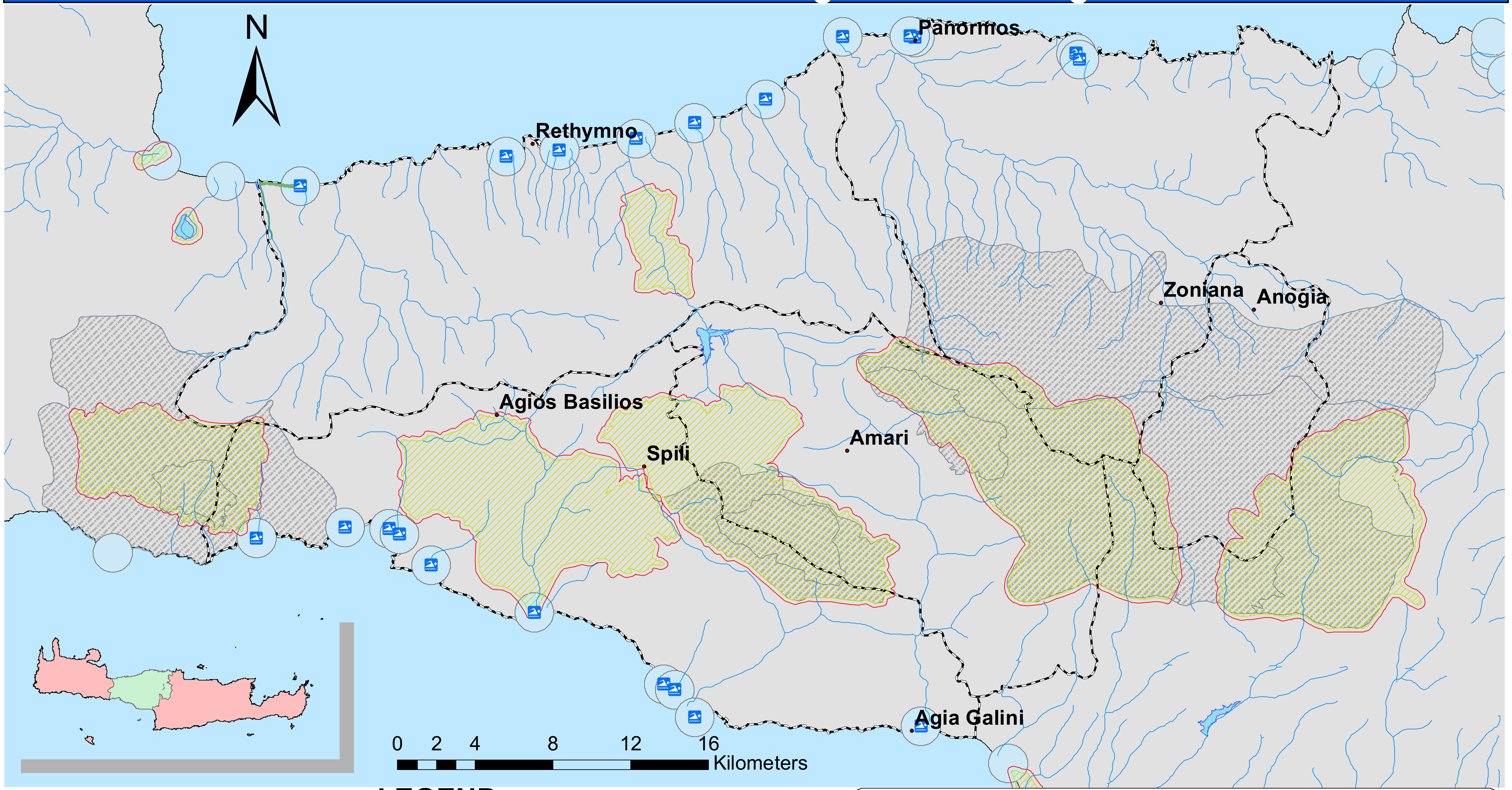
B.2 Minimum Allowable Distances from Areas of Environmental Interest for Biomass/Biogas Plants Siting



LEGEND

- Beaches
- Hydrographic Network
- Lakes
- Urban Control Zone of Georgioupolis-Episkopi- Area 3
- Special Protection Areas (SPA) of the NATURA 2000 Network
- Buffer Distance of 200m from SPAs
- Buffer Distance of 1,000m from Beaches
- Municipalities Boundaries of the Regional Unit of Rethymno
- Areas of Absolute Protection of Nature

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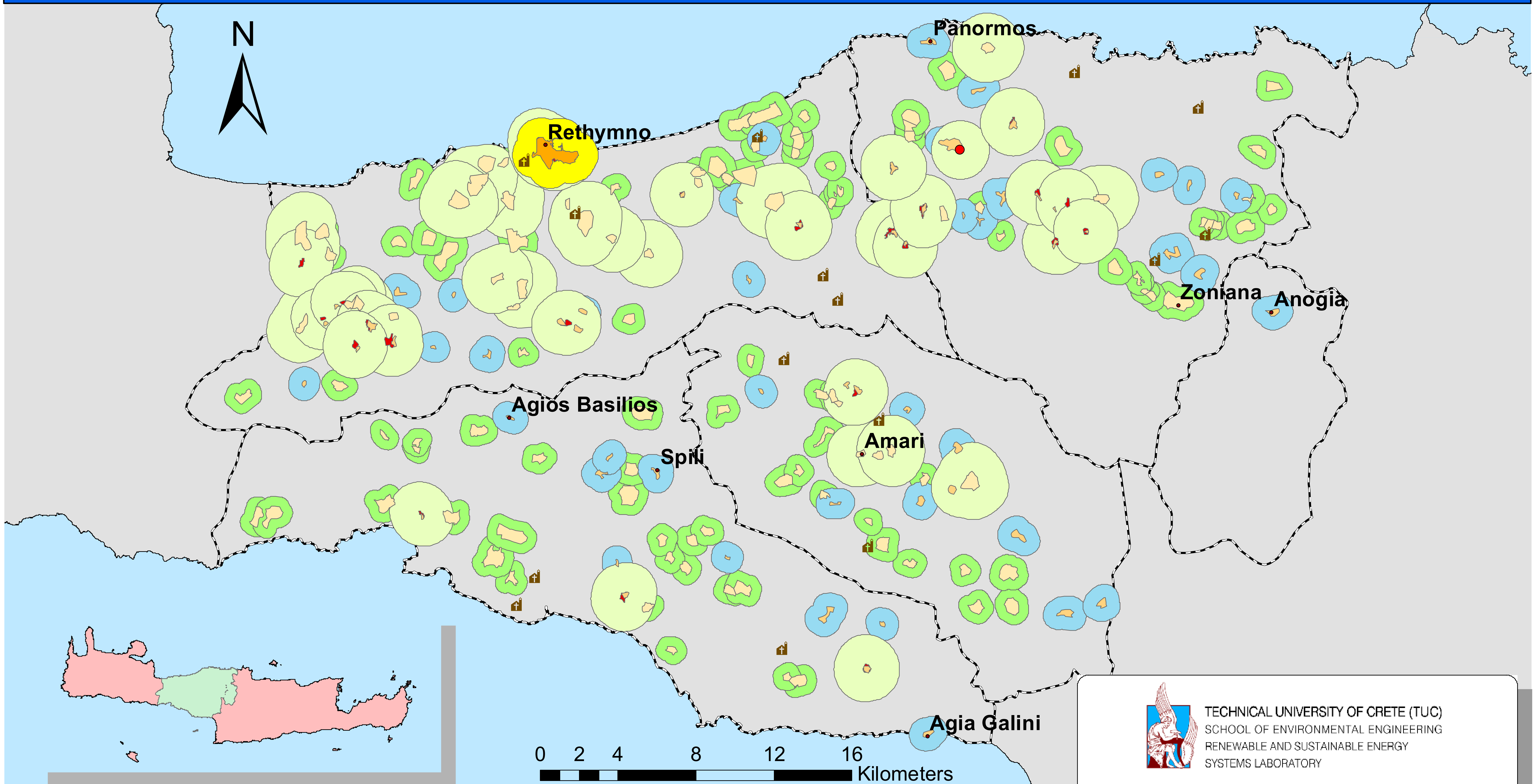
B.3 Minimum Allowable Distances from Urban Activities for Biomass/Biogas Plants Siting



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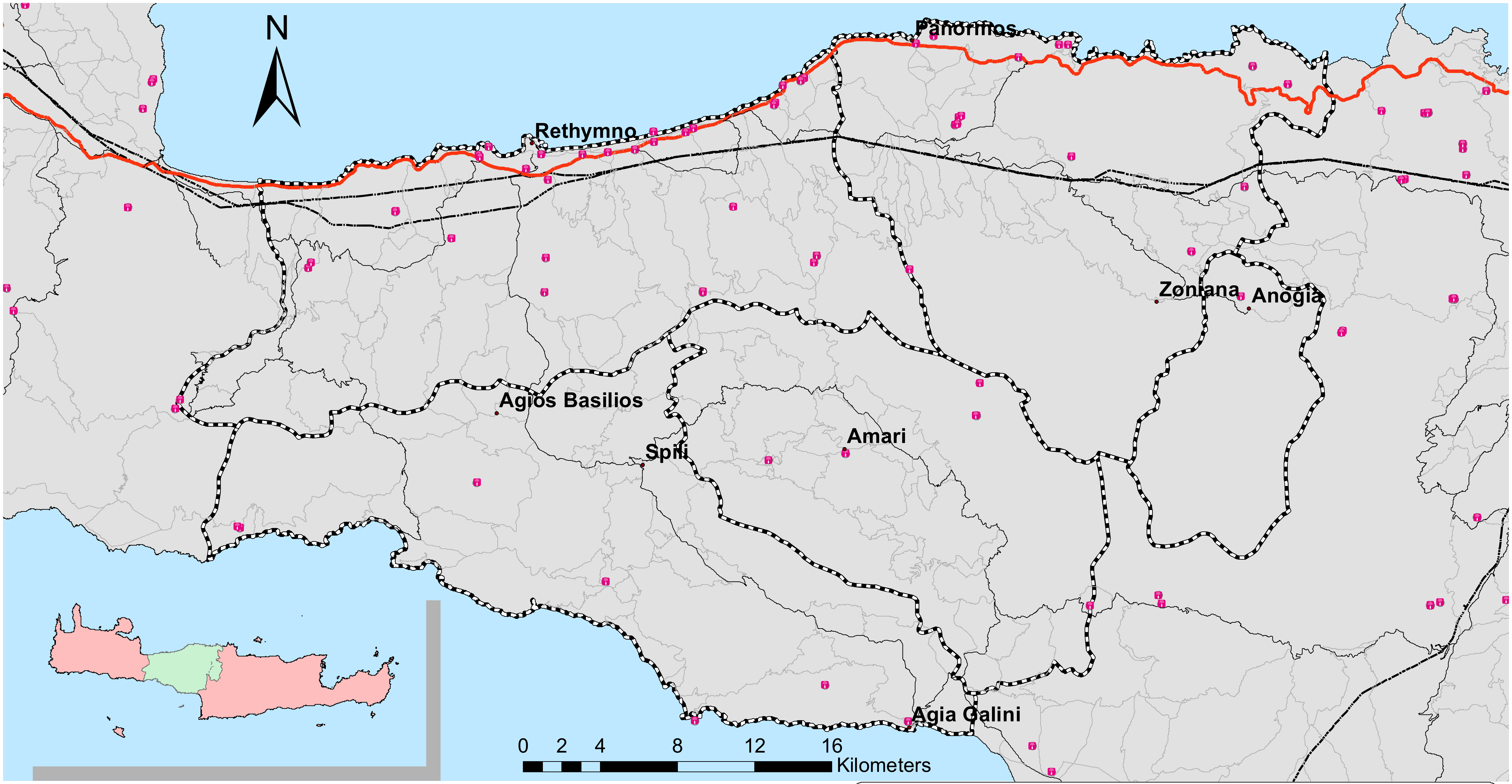
LEGEND

- Monasteries
- Traditional Settlements
- Settlements with Population >10,000 Residents
- Settlements with Population 2,000-10,000 Residents-Remarkable
- Settlements with Population <2,000 Residents
- Traditional Settlements
- Buffer Distance of 1,000m from Settlements with Population >10,000 Residents
- Buffer Distance of 1,500m from Traditional Settlements
- Buffer Distance of 700m from Settlements with Population 2,000-10,000 Residents
- Buffer Distance of 500m from Settlements with Population <2,000 Residents
- Municipalities Boundaries of the Regional Unit of Rethymno

B.4 Minimum Allowable Distances from the Technical Infrastructure for Biomass/Biogas Plants Siting



LEGEND

- Telecommunication Antennas
- National Road Network
- Provincial Road Network
- Community Road Network
- High Voltage Lines
- Buffer Distance of 200m from the Telecommunication Antennas
- Municipalities Boundaries of the Regional Unit of Rethymno

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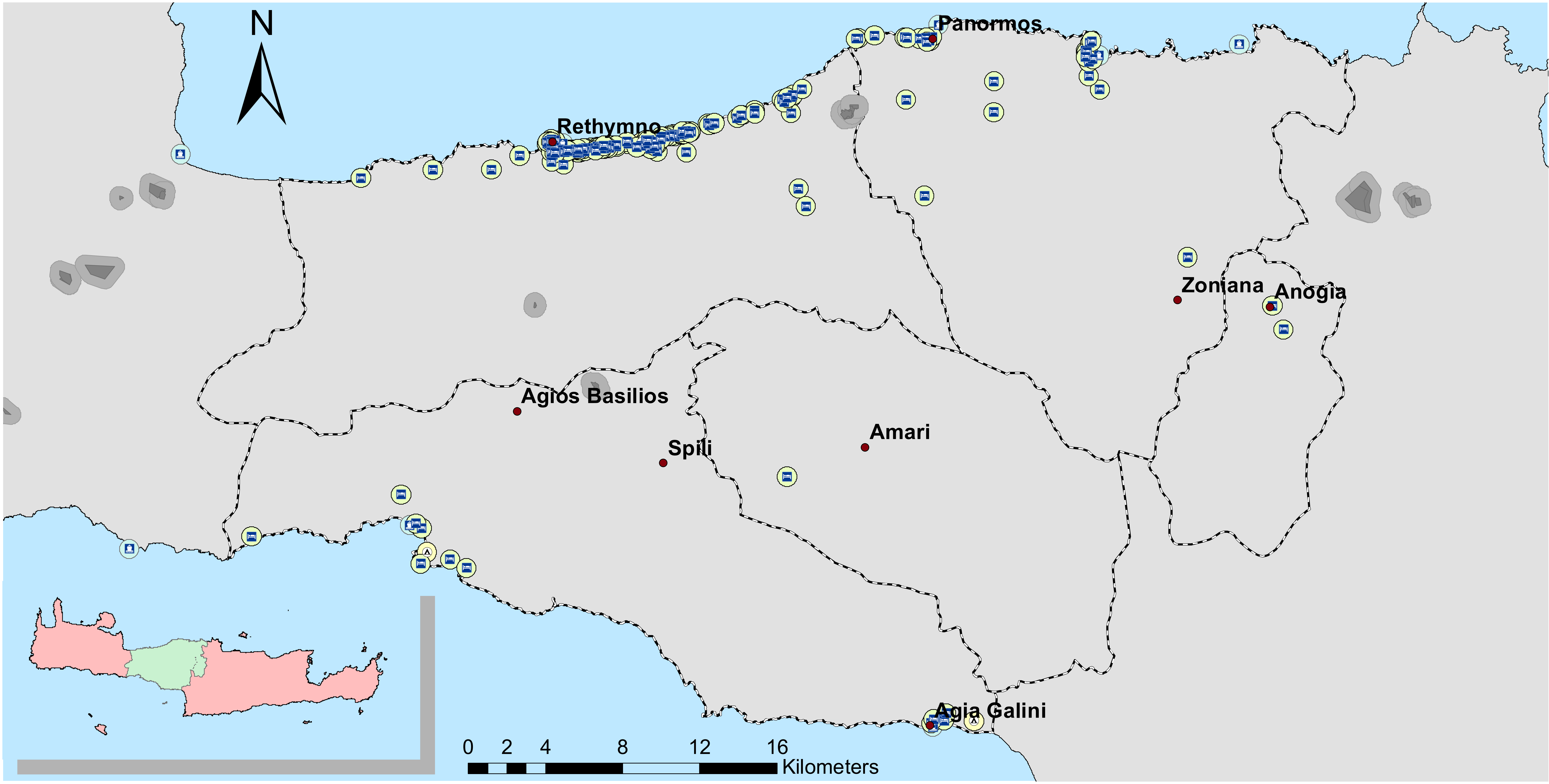
B.5 Minimum Allowable Distances from Production Activities for Biomass/Biogas Plants Siting



LEGEND

- Tourist Accomondations
- Camps
- Ports-Marinas
- Quarries
- Buffer Distance of 500m from Tourist Accomondations
- Buffer Distance of 500m from Ports-Marinas
- Buffer Distance of 500m from Camps
- Buffer Distance of 500m from Quarries
- Municipalities Boundaries of the Regional Unit of Rethymno

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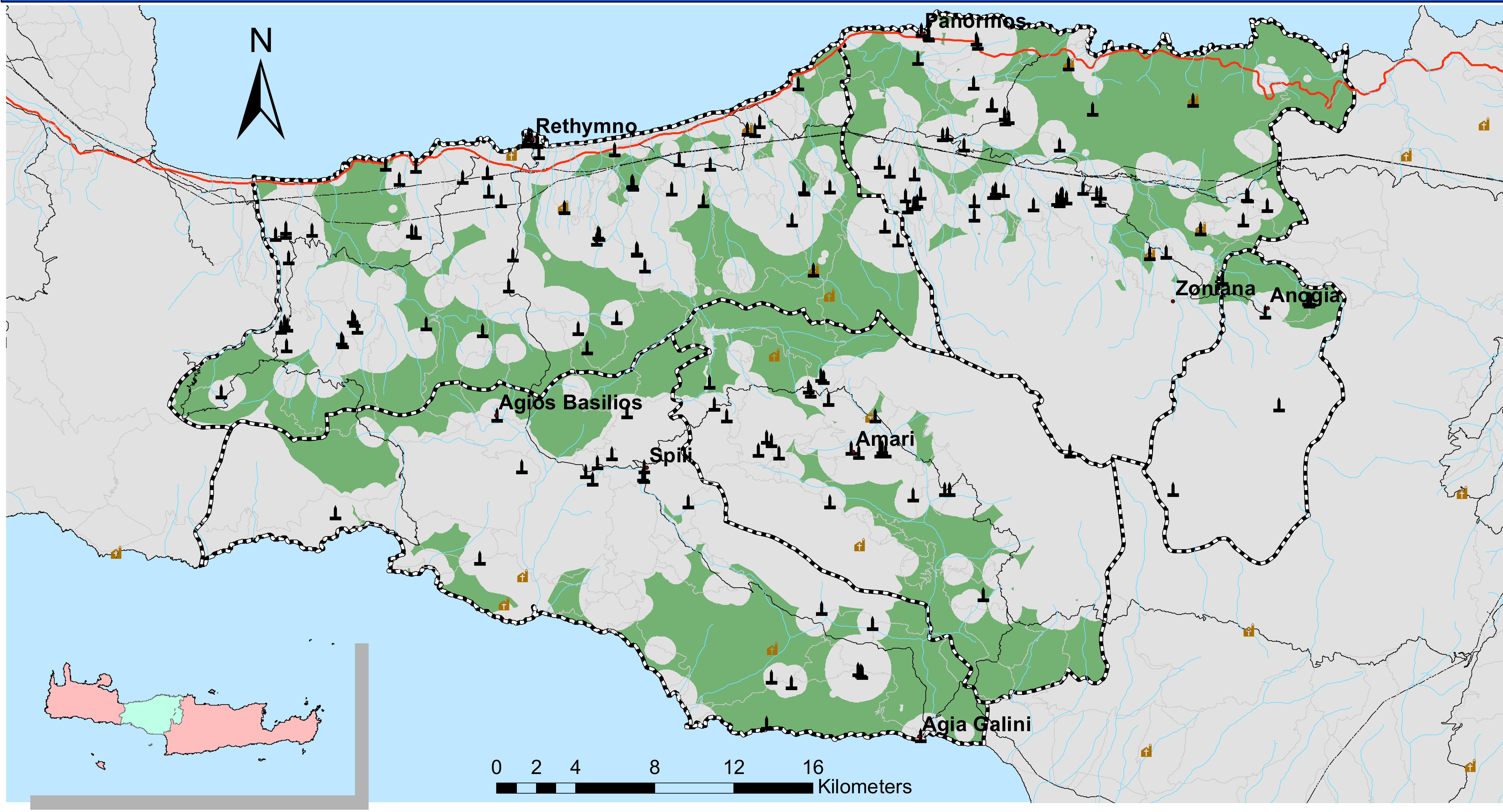
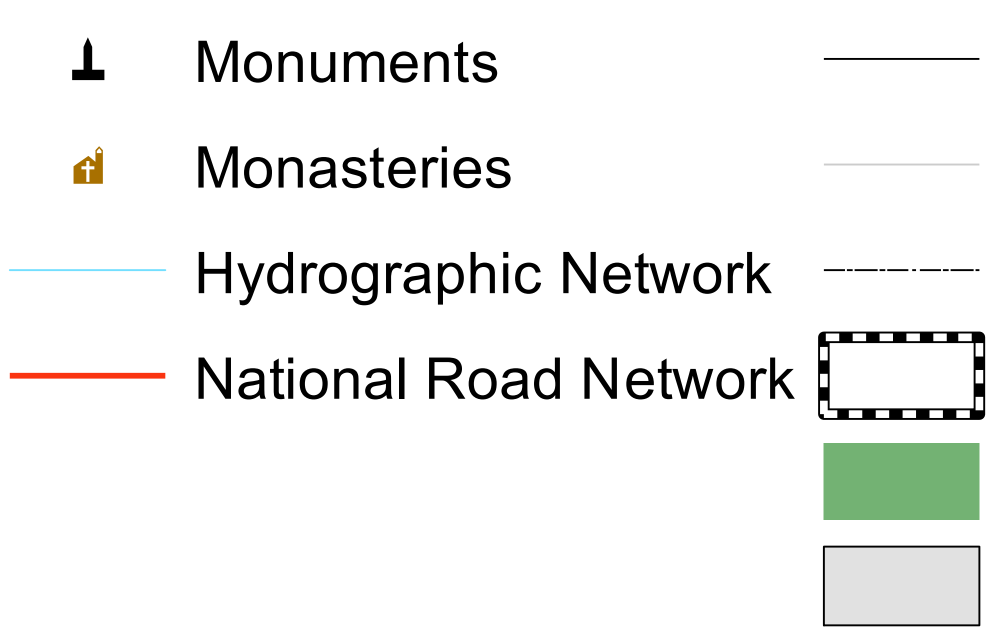
B.6 Legally Available Siting Areas for Biomass/Biogas Plants Siting



LEGEND



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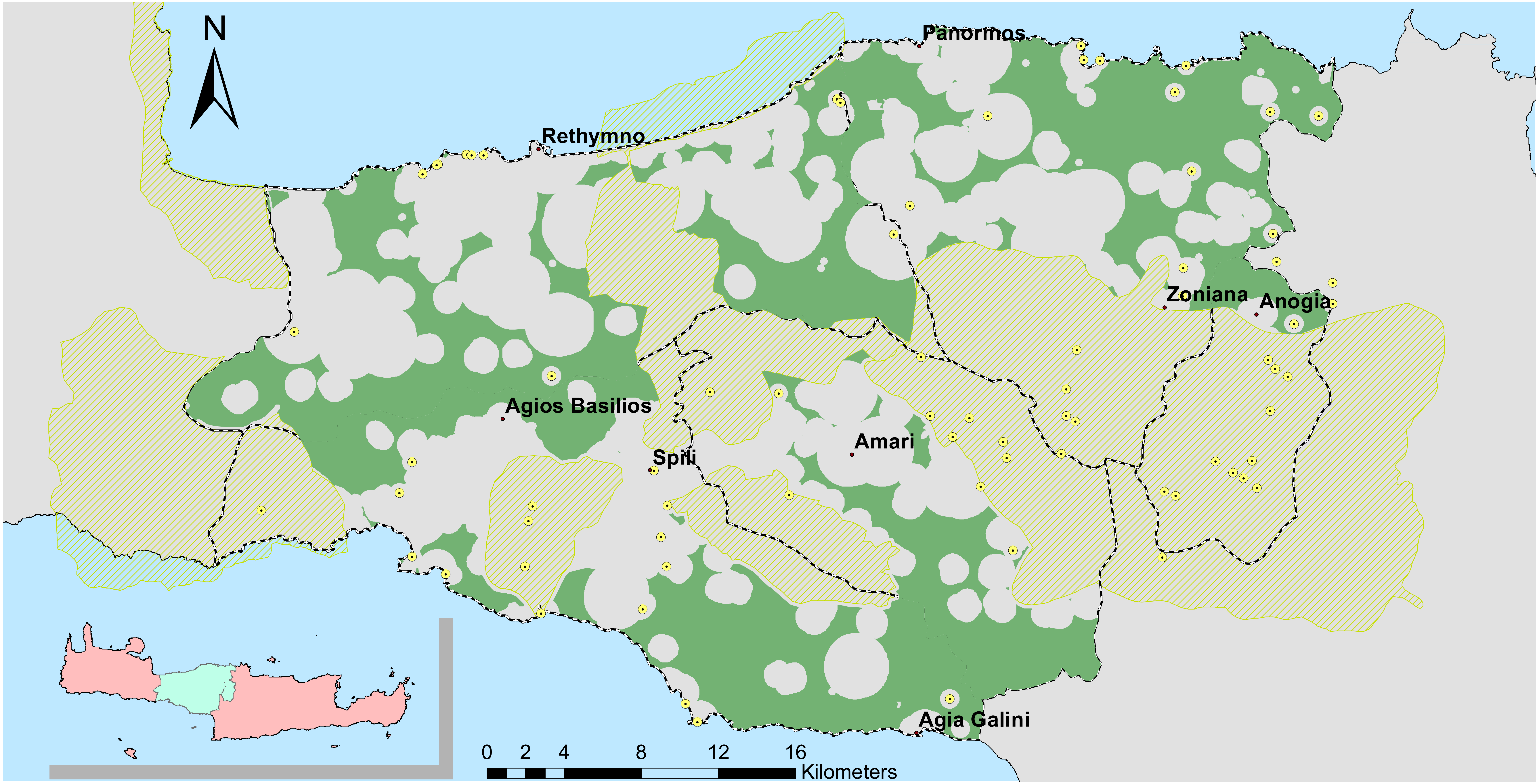
B.7 Available Areas for Biomass/Biogas Plants Siting-Environmental Scenario



LEGEND

Geotopes

Available Siting Areas

Municipalities Boundaries of the Regional Unit of Rethymno

Sites of Community Importance (SCI) of the NATURA 2000 Network

Exclusion Areas

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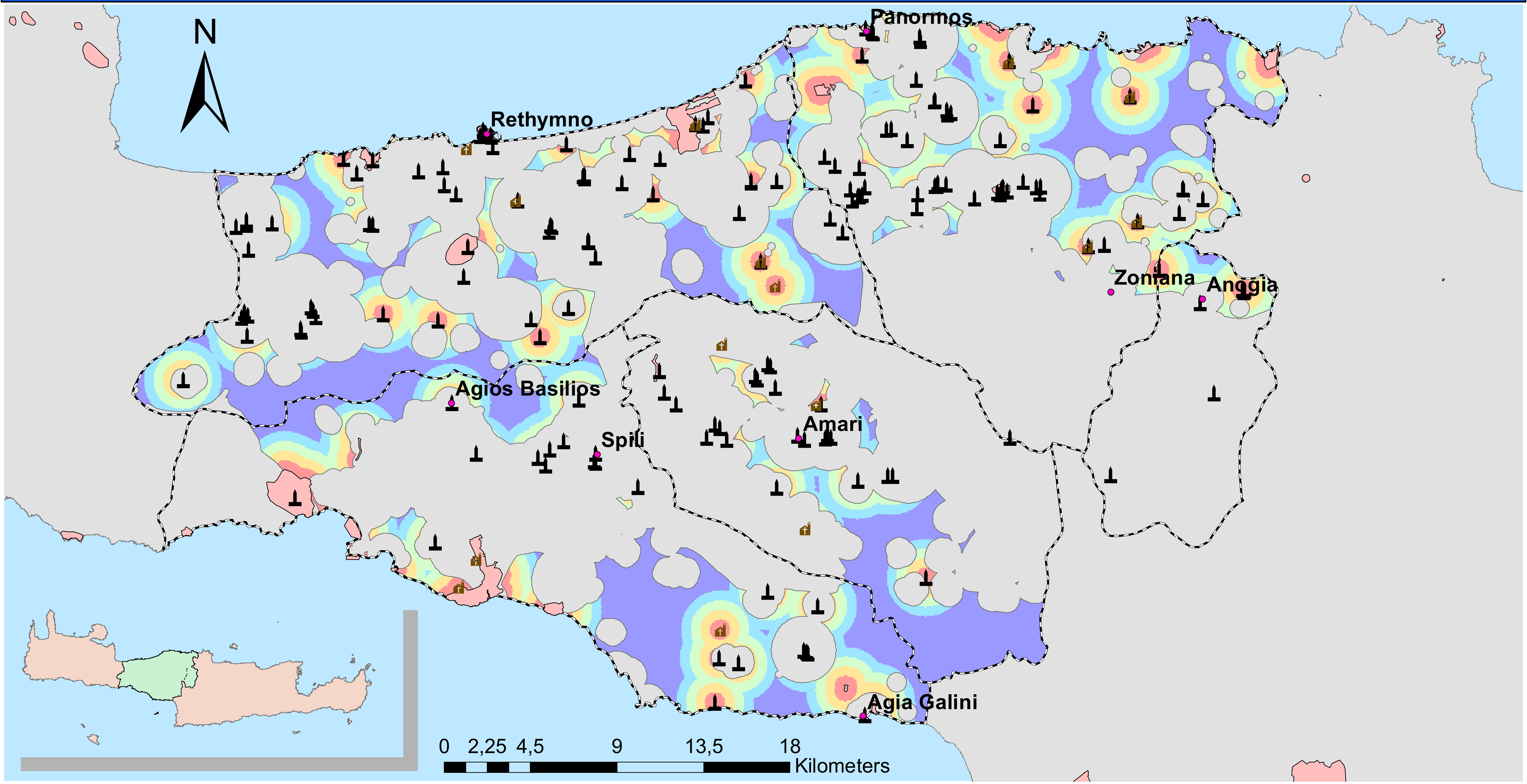
B.8 Evaluation Criterion for Biomass/Biogas Plants Siting: Distance from Areas of Cultural Interest



LEGEND

Monasteries

Monuments

Archaeological Sites

Municipalities Boundaries of the Regional Unit of Rethymno

Exclusion Areas of the Environmental Scenario

Evaluation Zones

0 - 500m Unsuitable

500 - 1,000m Less Suitable

1,000 - 1,500m Moderately Suitable

1,500 - 2,000m Suitable

> 2,000m Particularly Suitable

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ
ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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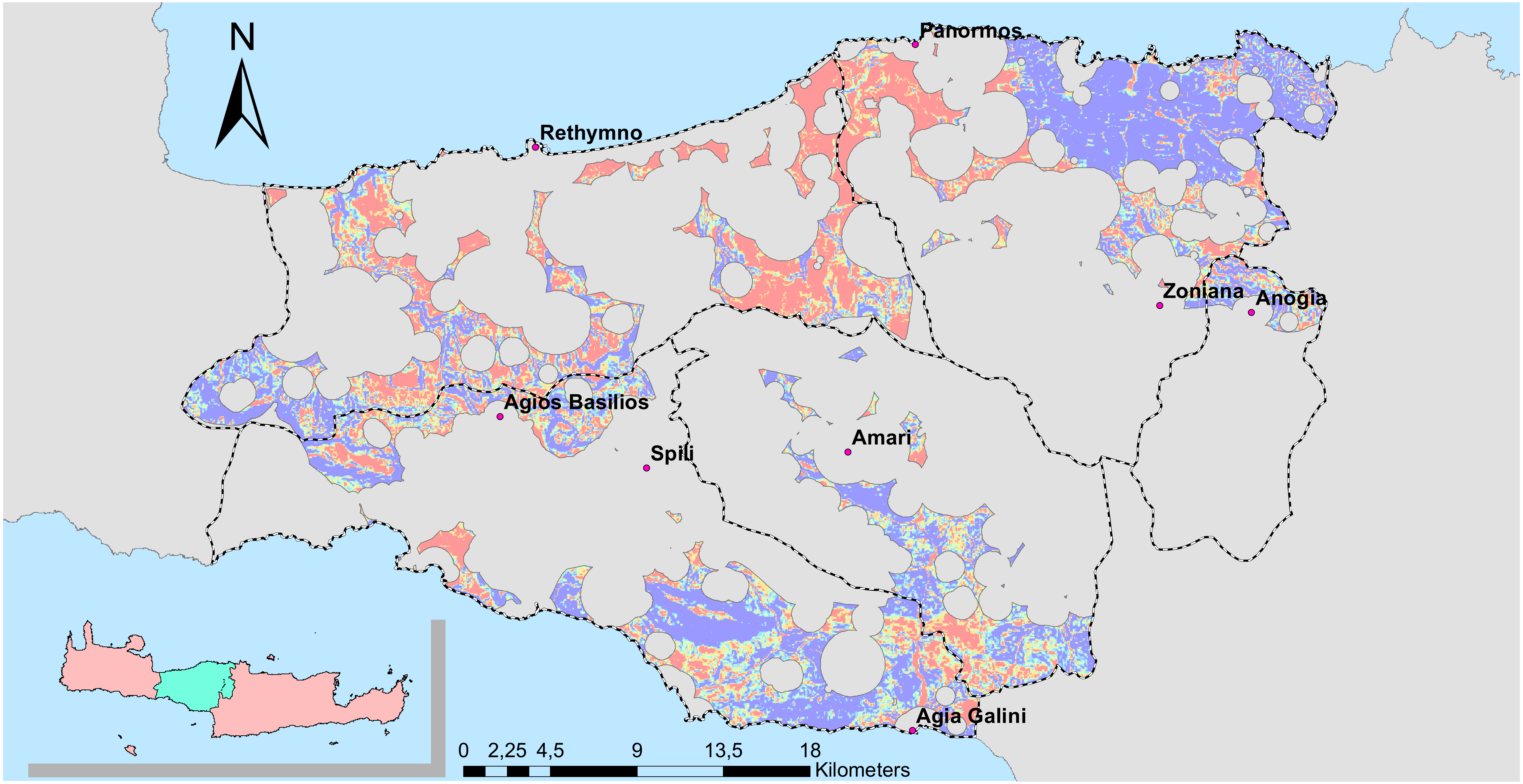
B.9 Evaluation Criterion for Biomass/Biogas Plants Siting: Slopes



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Exclusion Areas of the Environmental Scenario

Evaluation Zones

0 - 15% Particularly Suitable

15 - 20% Suitable

20 - 25% Moderately Suitable

25 - 30% Less Suitable

>30% Unsuitable

ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΕΡΓΑΣΤΗΡΙΟ ΑΝΑΝΕΩΣΙΜΩΝ ΚΑΙ
ΒΙΩΣΙΜΩΝ ΕΝΕΡΓΕΙΑΚΩΝ ΣΥΣΤΗΜΑΤΩΝ

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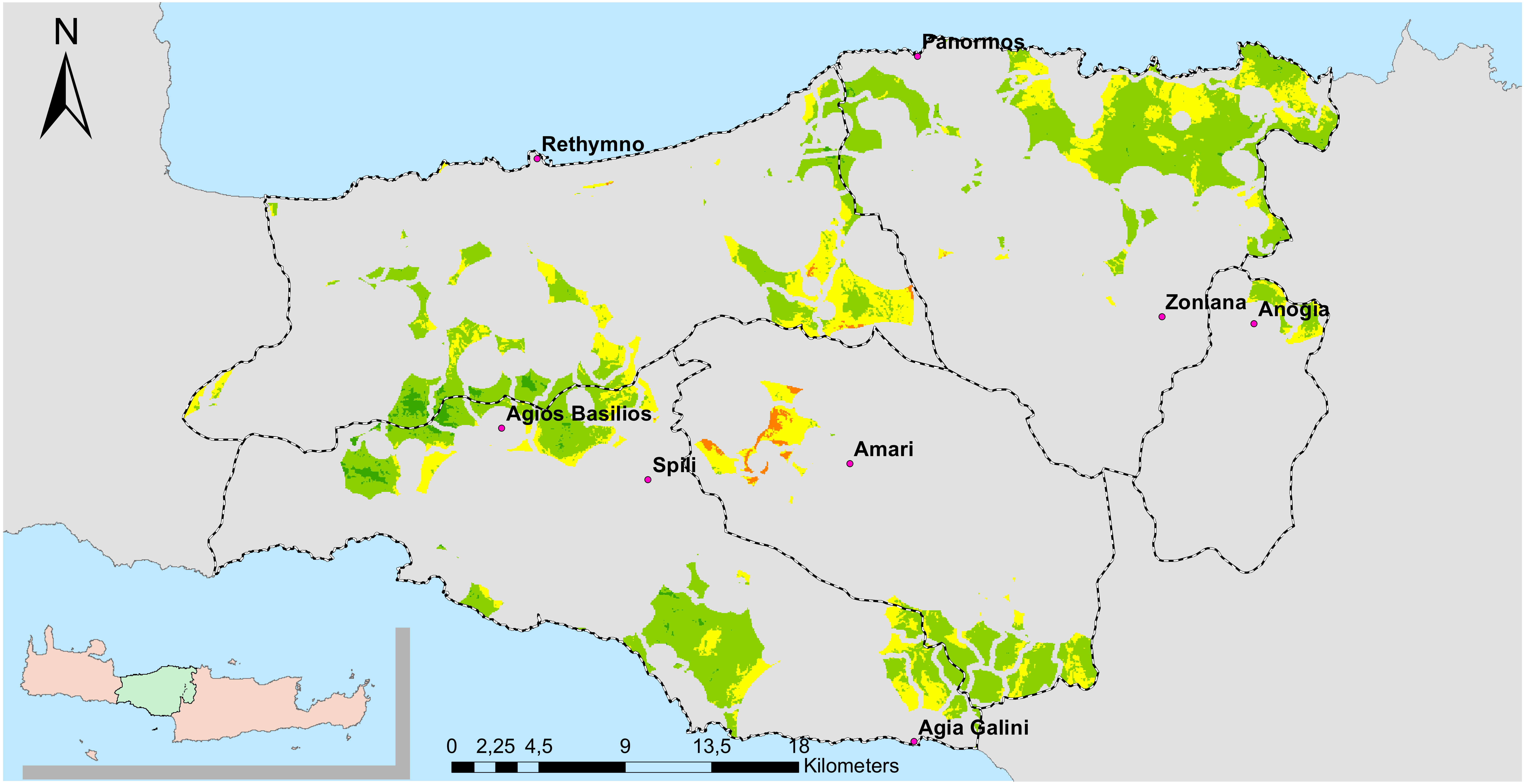
P.1 Priority Map for Wind Energy Installations Siting Based on the Criteria Weights Derived from the AHP



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
- 60-40%
- 40-20%
- 20-0%
- Exclusion Areas

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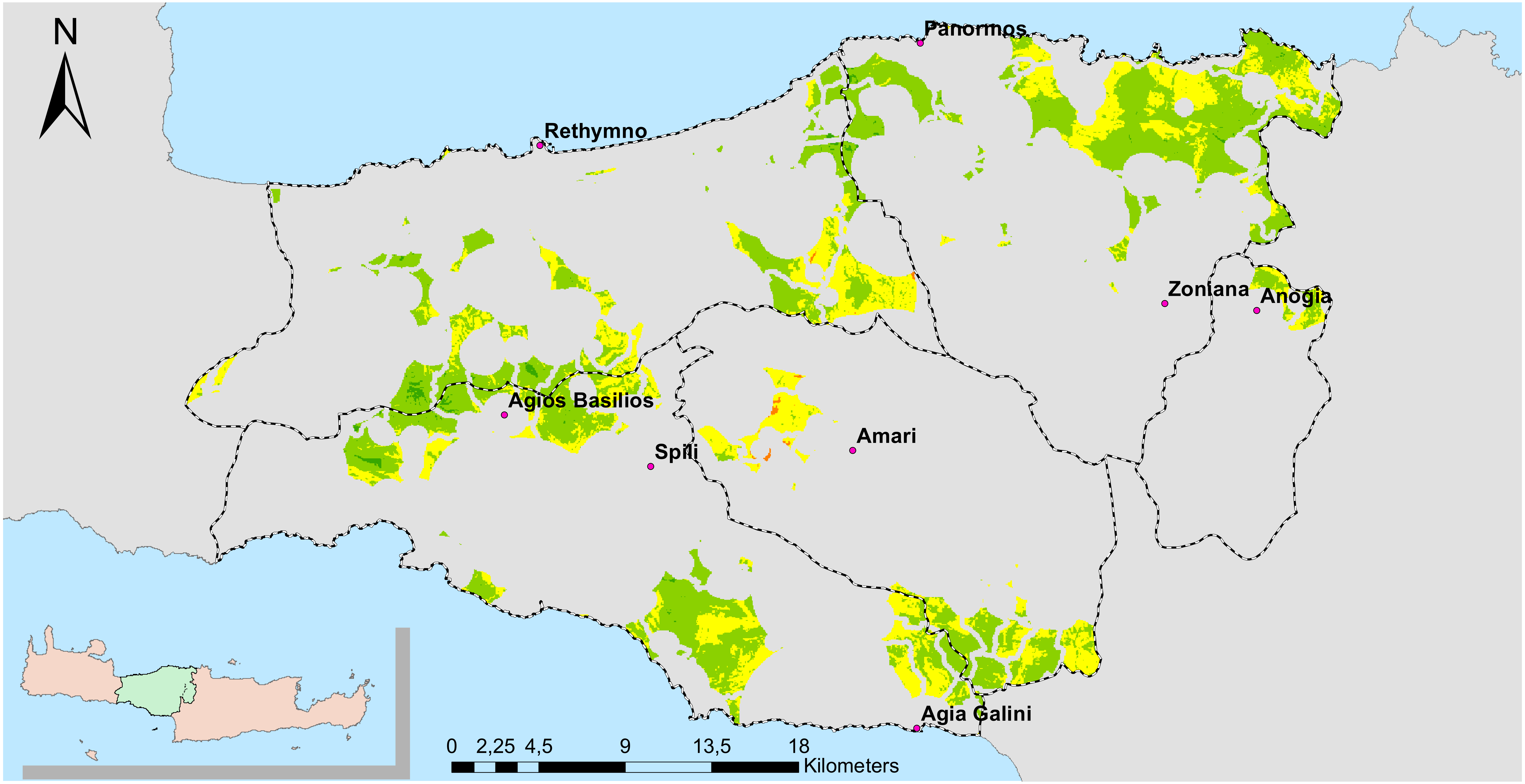
P.2 Priority Map for Wind Energy Installations Siting Based on the Equal-Weighted Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
- 60-40%
- 40-20%
- 20-0%
- Exclusion Areas

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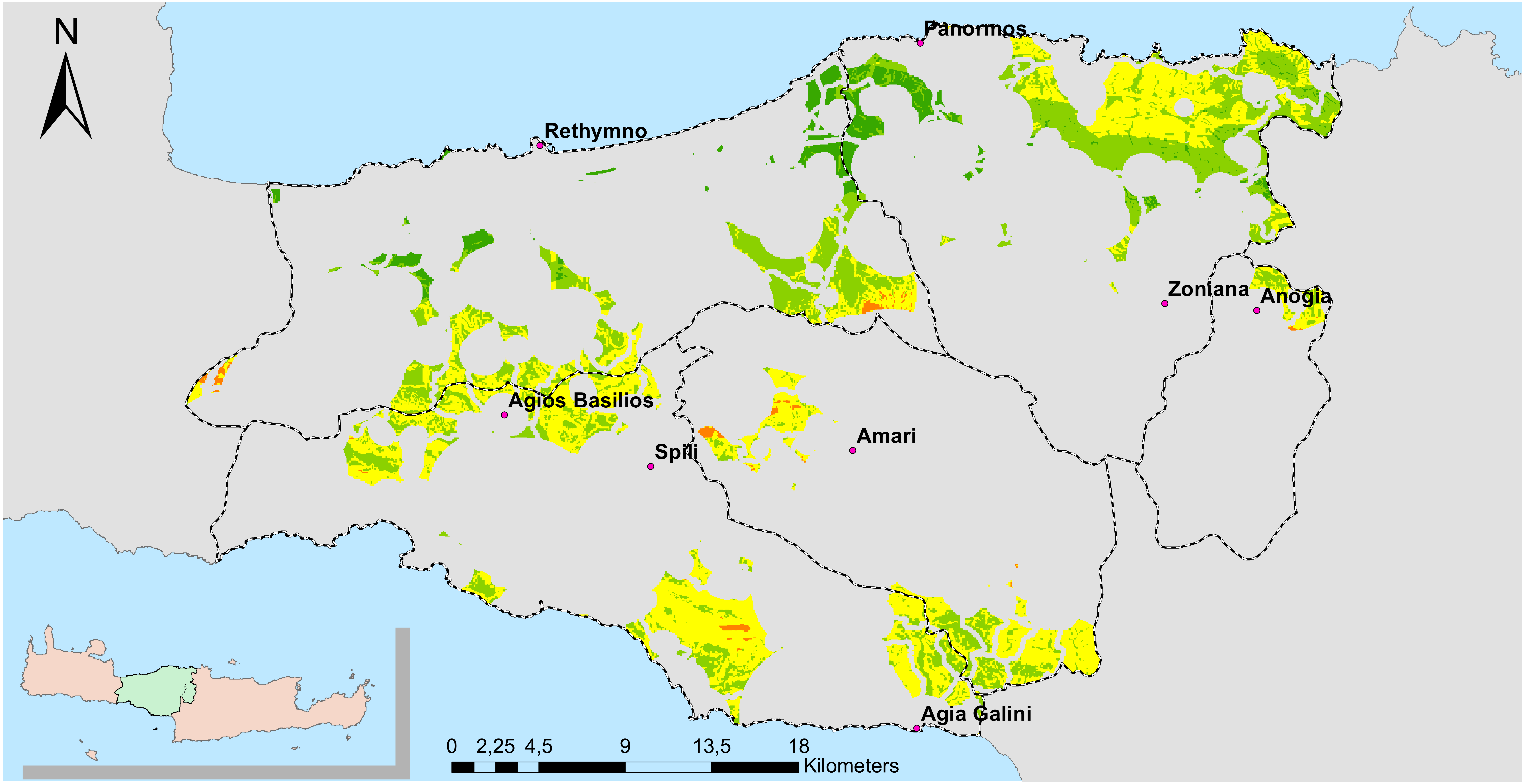
P.3 Priority Map for Wind Energy Installations Siting Based on the Techno-Economic Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
- 60-40%
- 40-20%
- 20-0%
- Exclusion Areas

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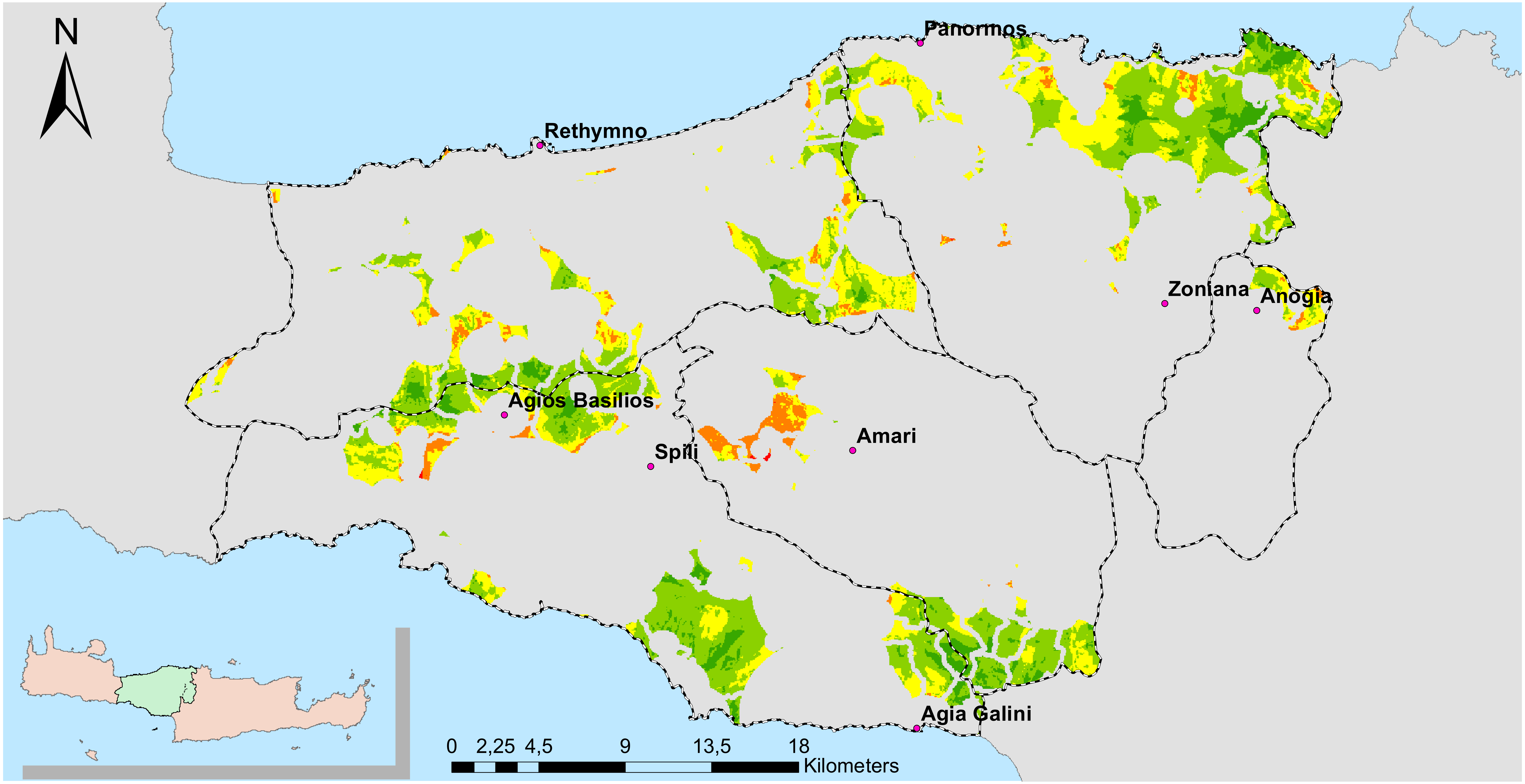
P.4 Priority Map for Wind Energy Installations Siting Based on the Socio-Environmental Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
- 60-40%
- 40-20%
- 20-0%
- Exclusion Areas

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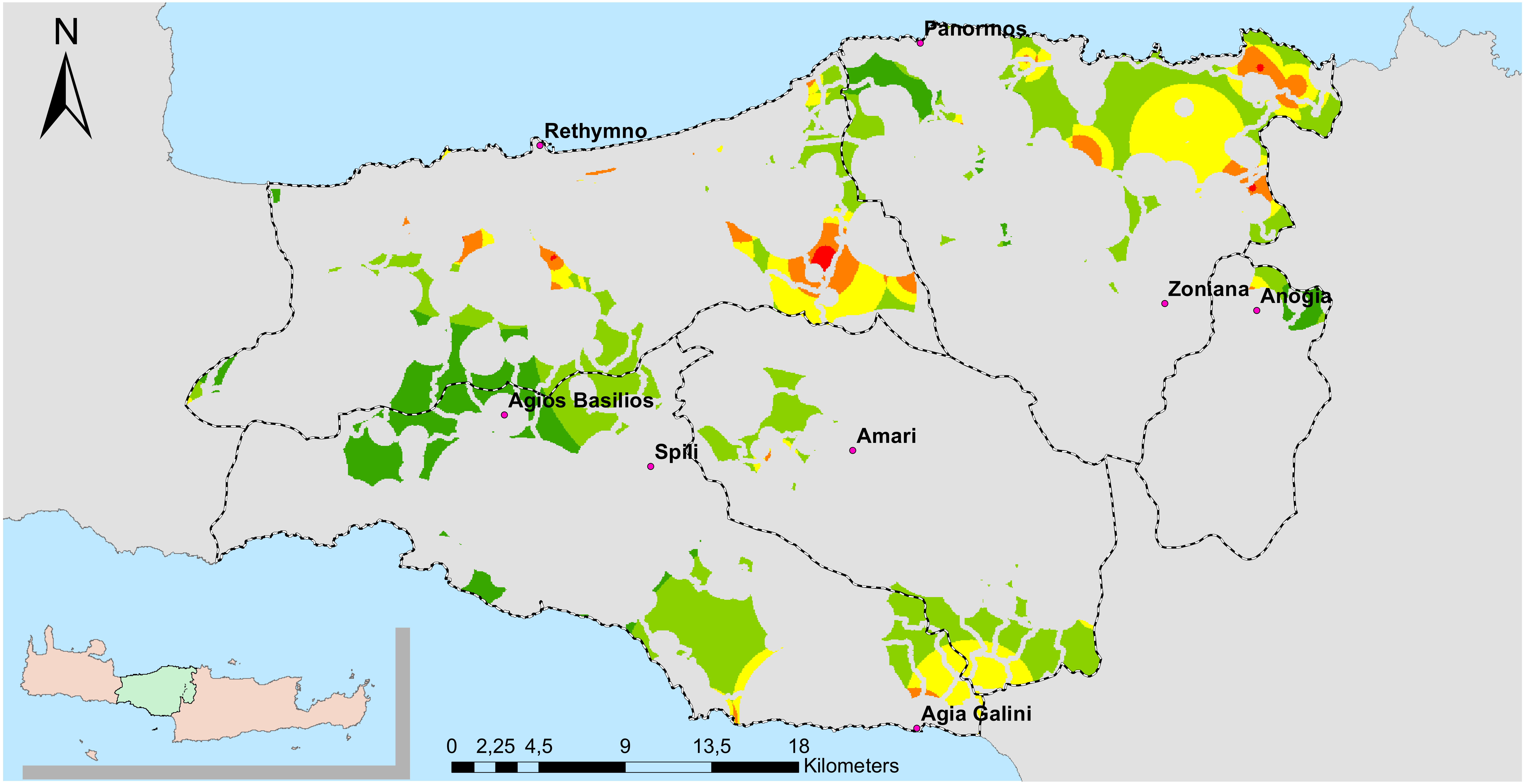
P.5 Priority Map for Wind Energy Installations Siting Based on the Safety Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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- 40-20%
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- Exclusion Areas

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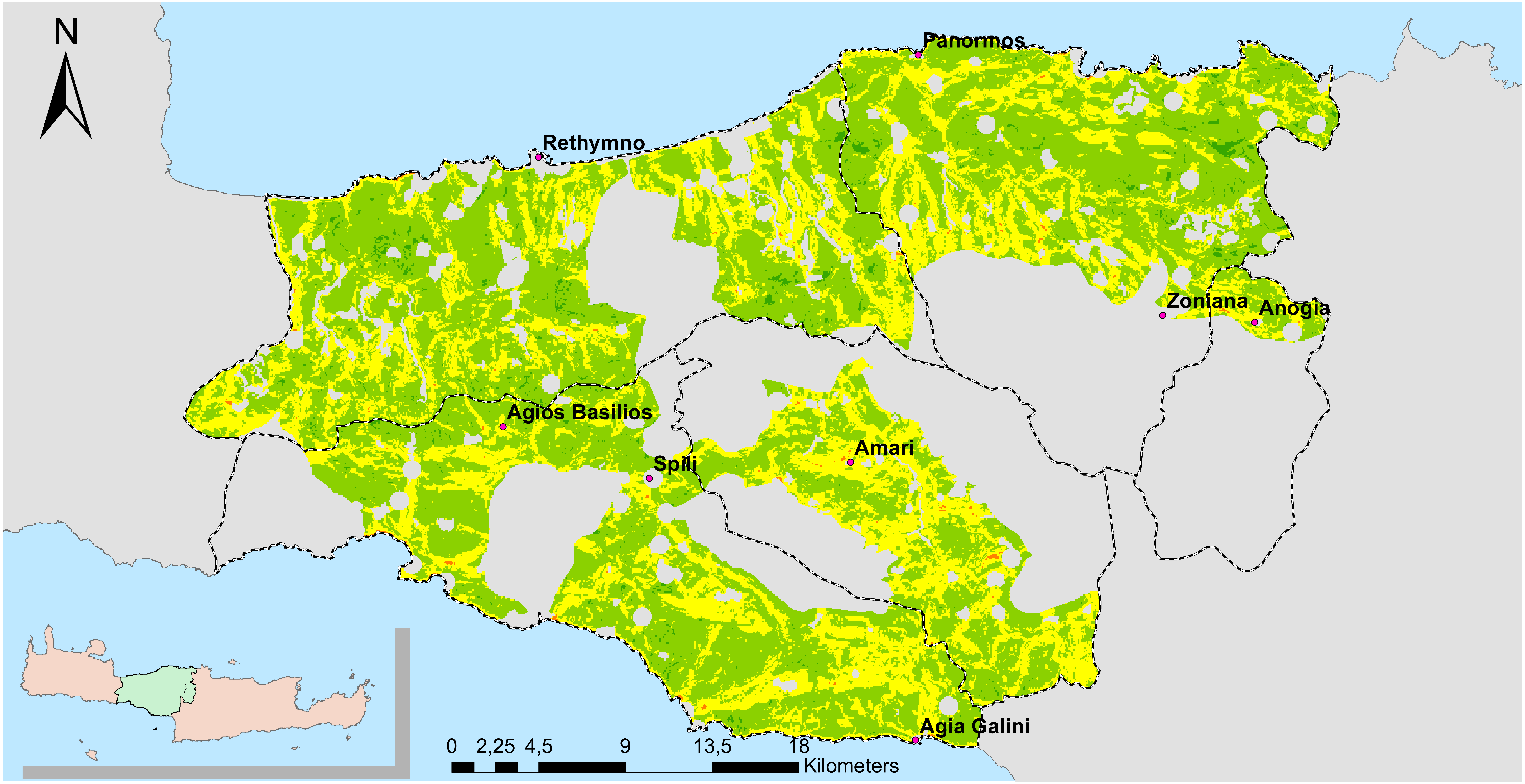
P.6 Priority Map for Large-Scale PV Farms Siting Based on the Criteria Weights Derived from the AHP



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
- 60-40%
- 40-20%
- 20-0%
- Exclusion Areas

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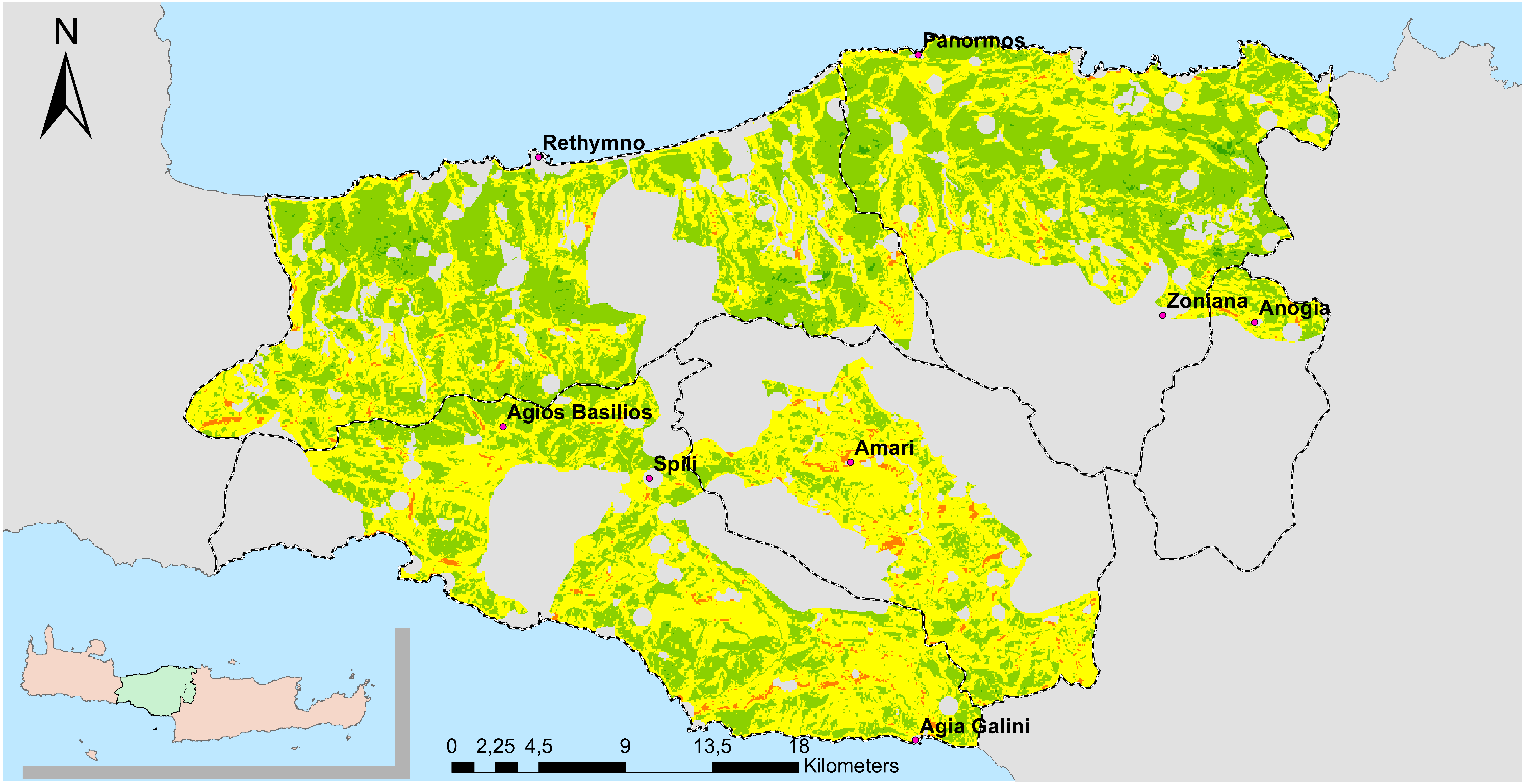
P.7 Priority Map for Large-Scale PV Farms Siting Based on the Equal-Weighted Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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- Exclusion Areas

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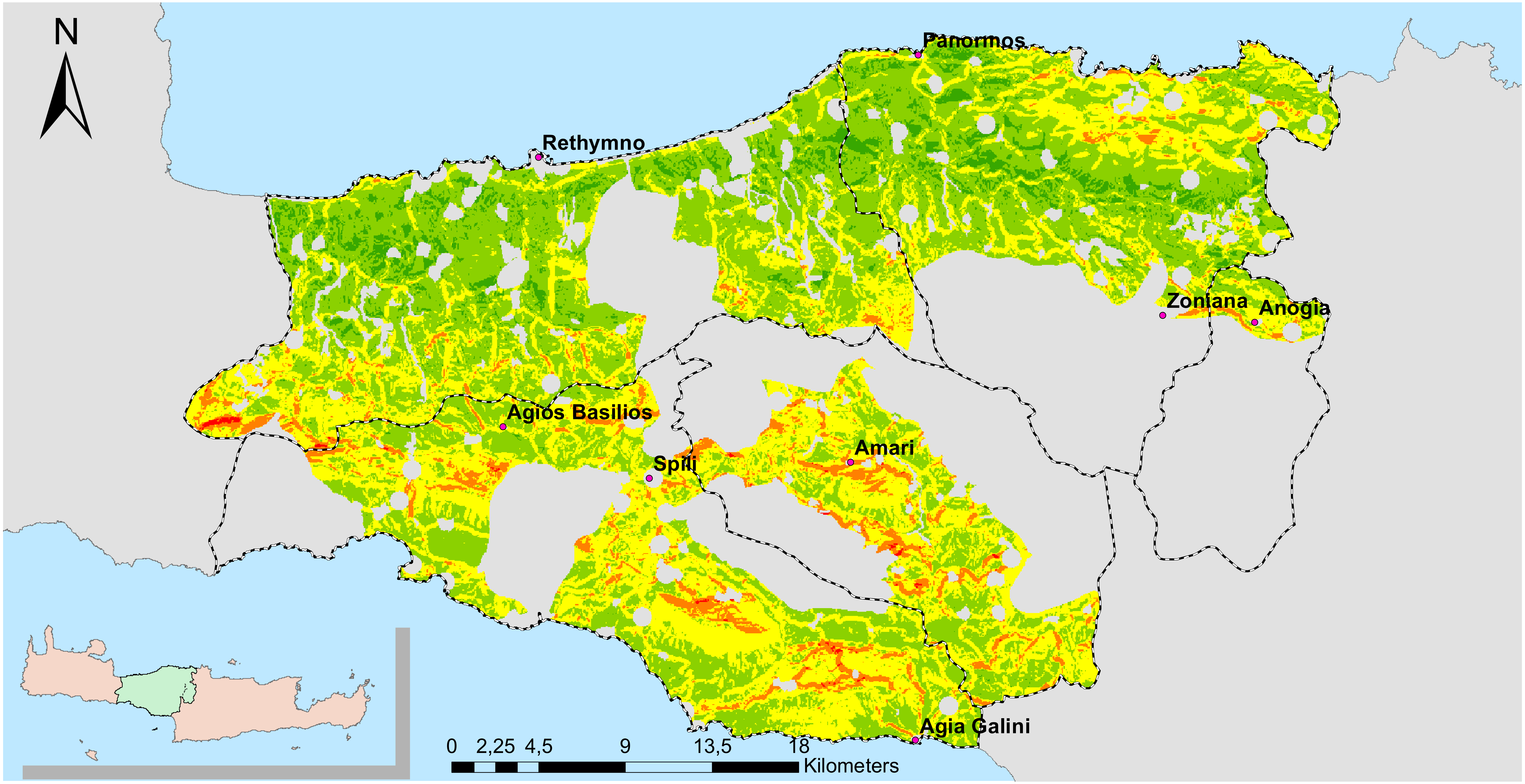
P.8 Priority Map for Large-Scale PV Farms Siting Based on the Techno-Economic Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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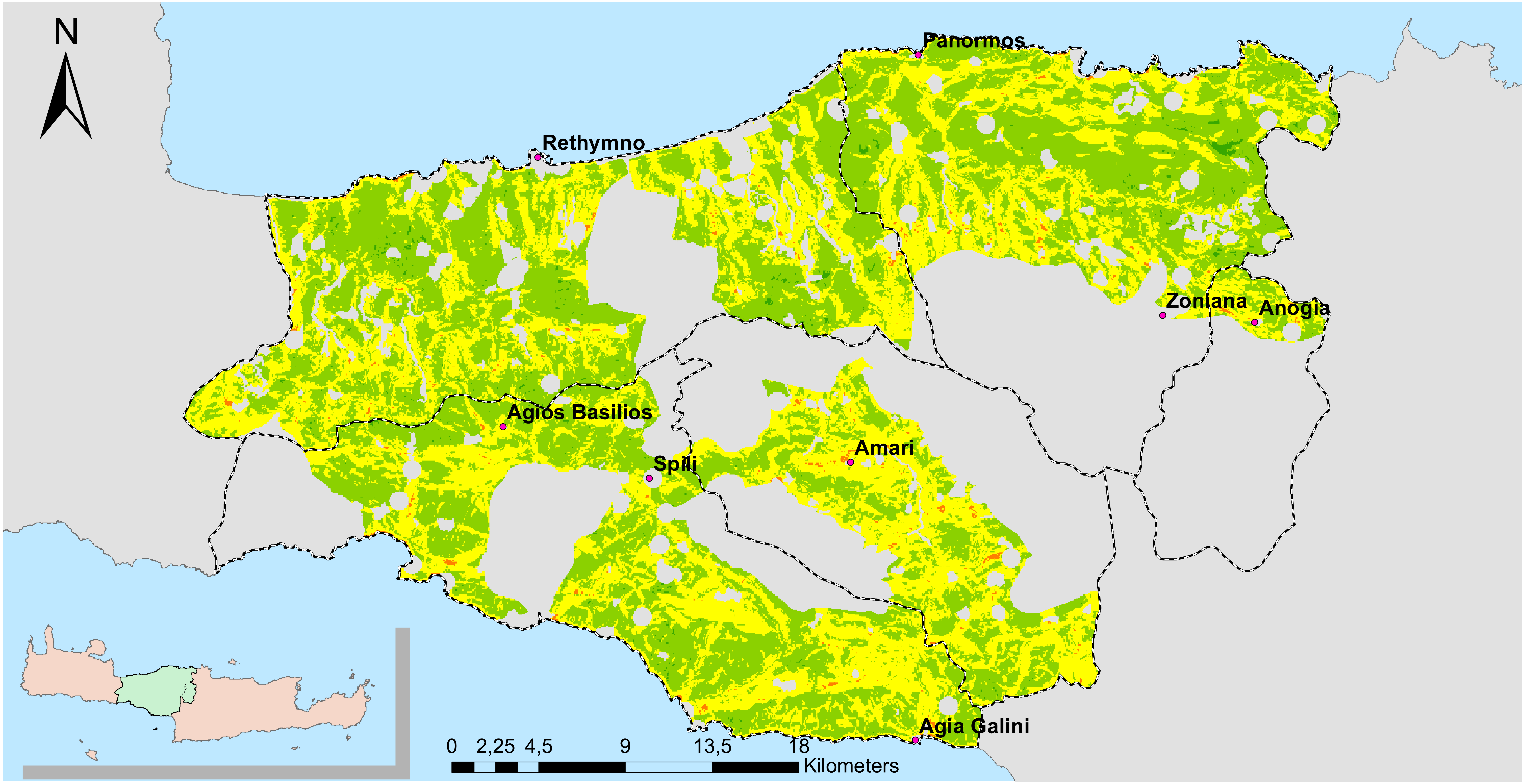
P.9 Priority Map for CSP Farms Siting Based on the Criteria Weights Derived from the AHP



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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- Exclusion Areas

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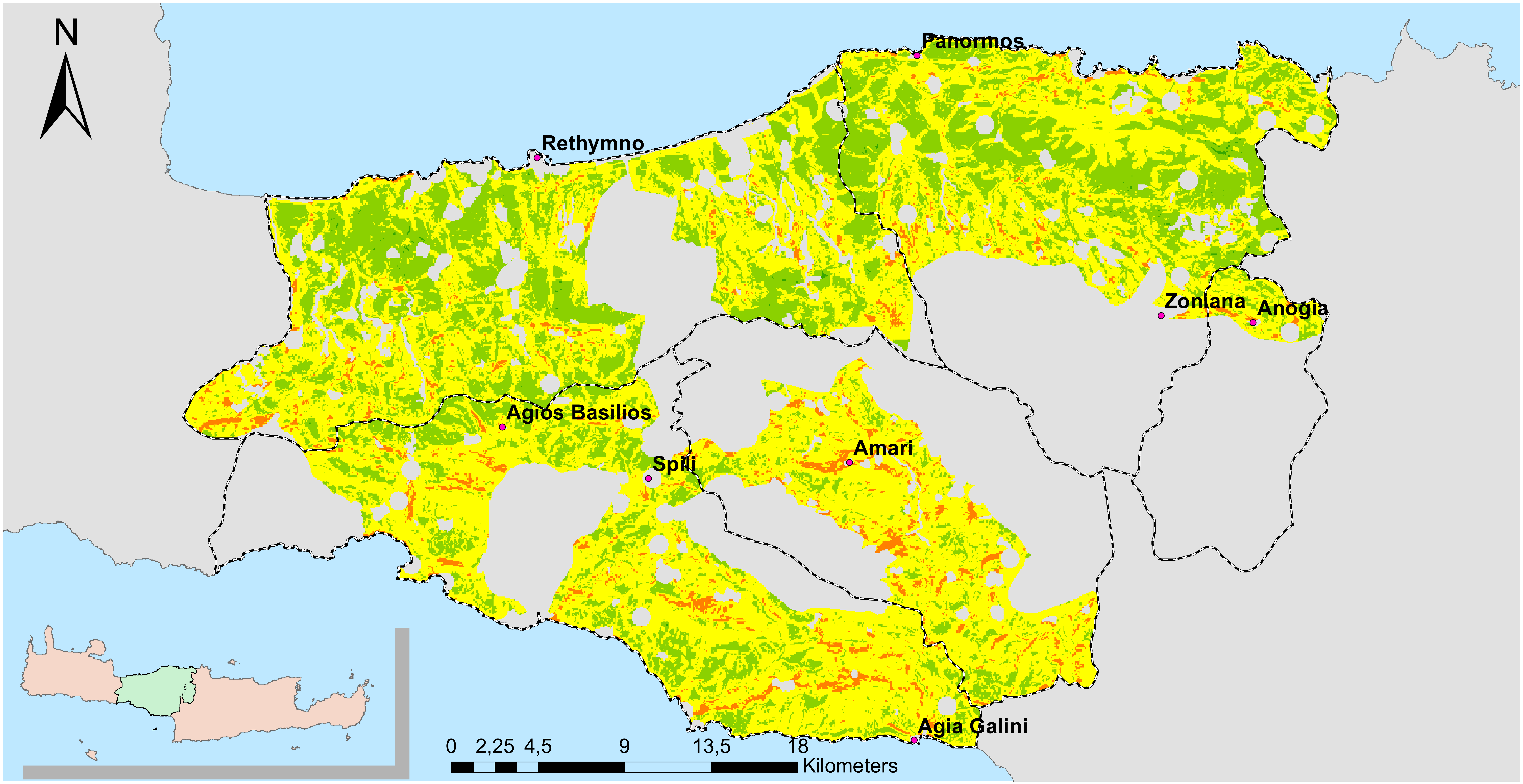
P.10 Priority Map for CSP Farms Siting Based on the Equal-Weighted Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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- Exclusion Areas

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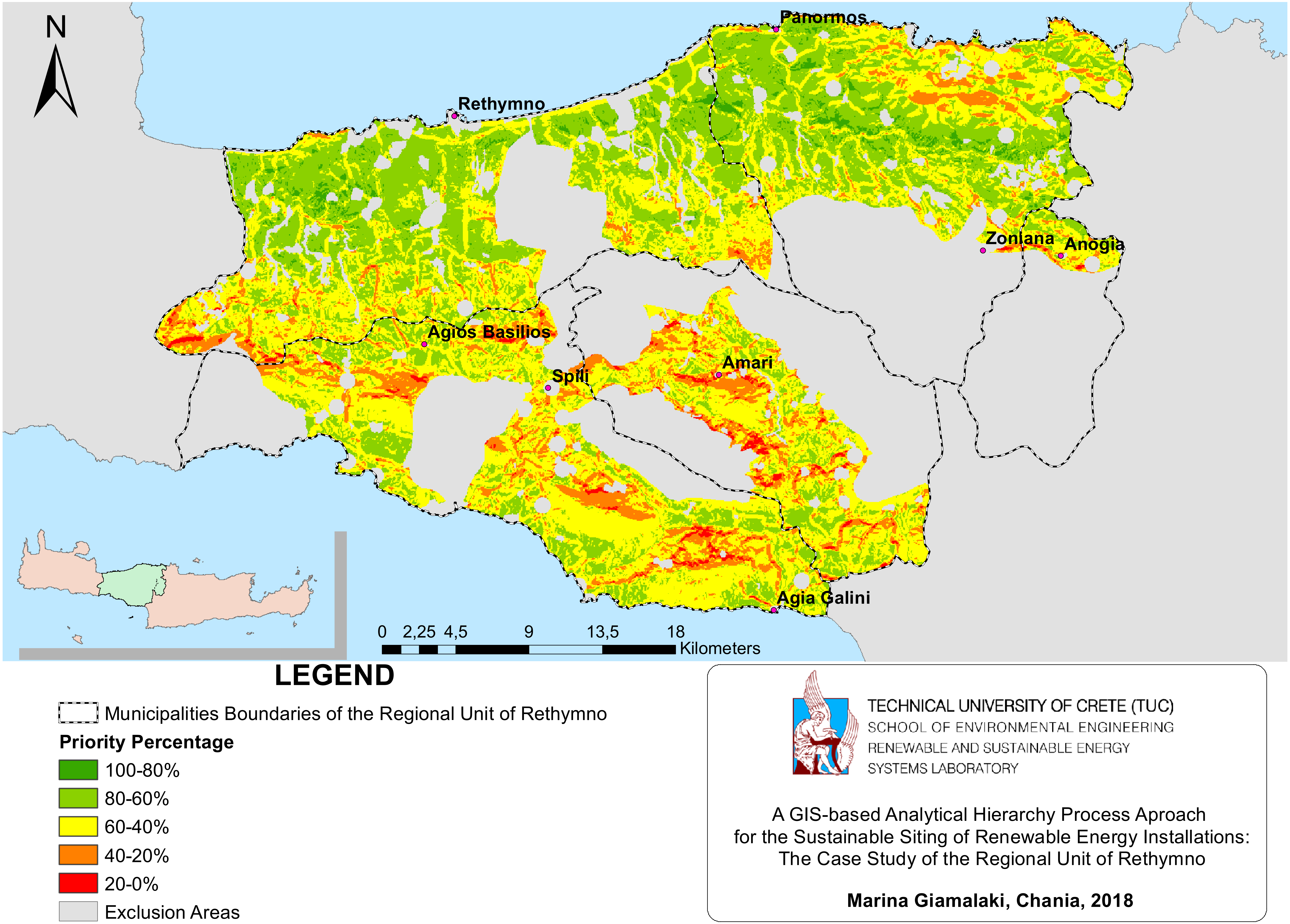
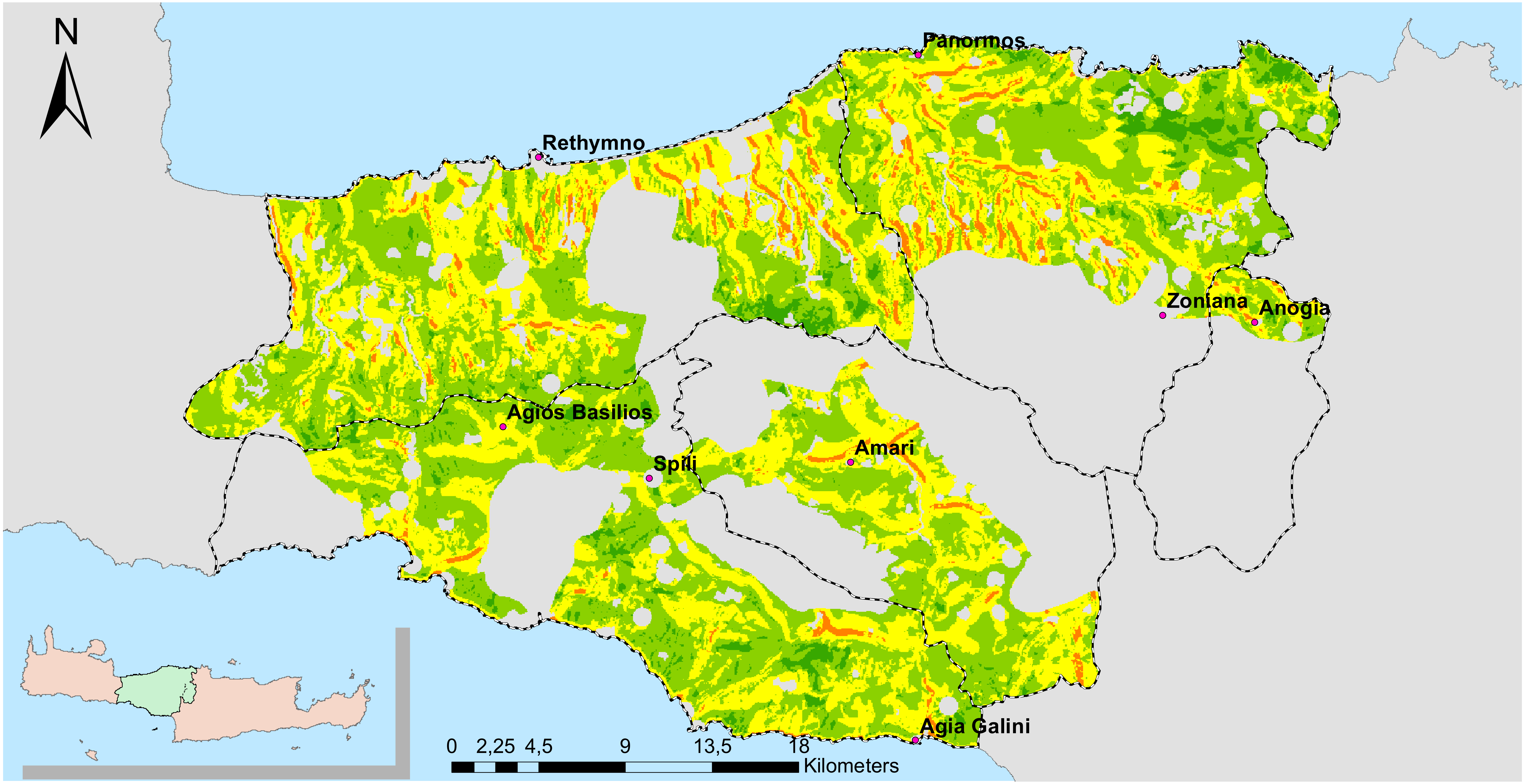
P.11 Priority Map for CSP Farms Siting Based on the Techno-Economic Scenario



P.12 Priority Map for Large-Scale PV and CSP Farms Siting Based on the Socio-Environmental Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

- 100-80%
- 80-60%
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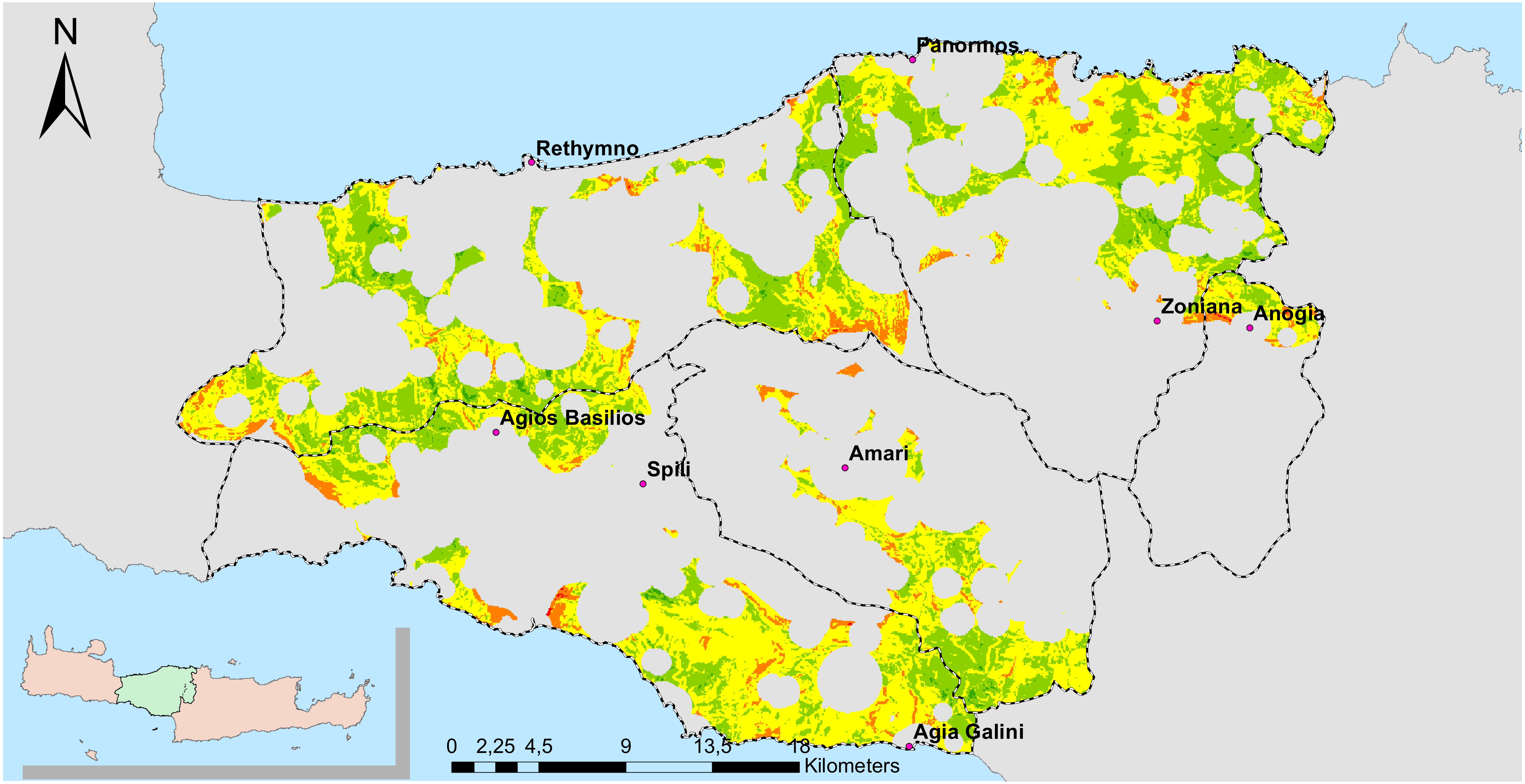
P.13 Priority Map for Biomass Plants Siting Based on the Criteria Weights Derived from the AHP



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

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- 80-60%
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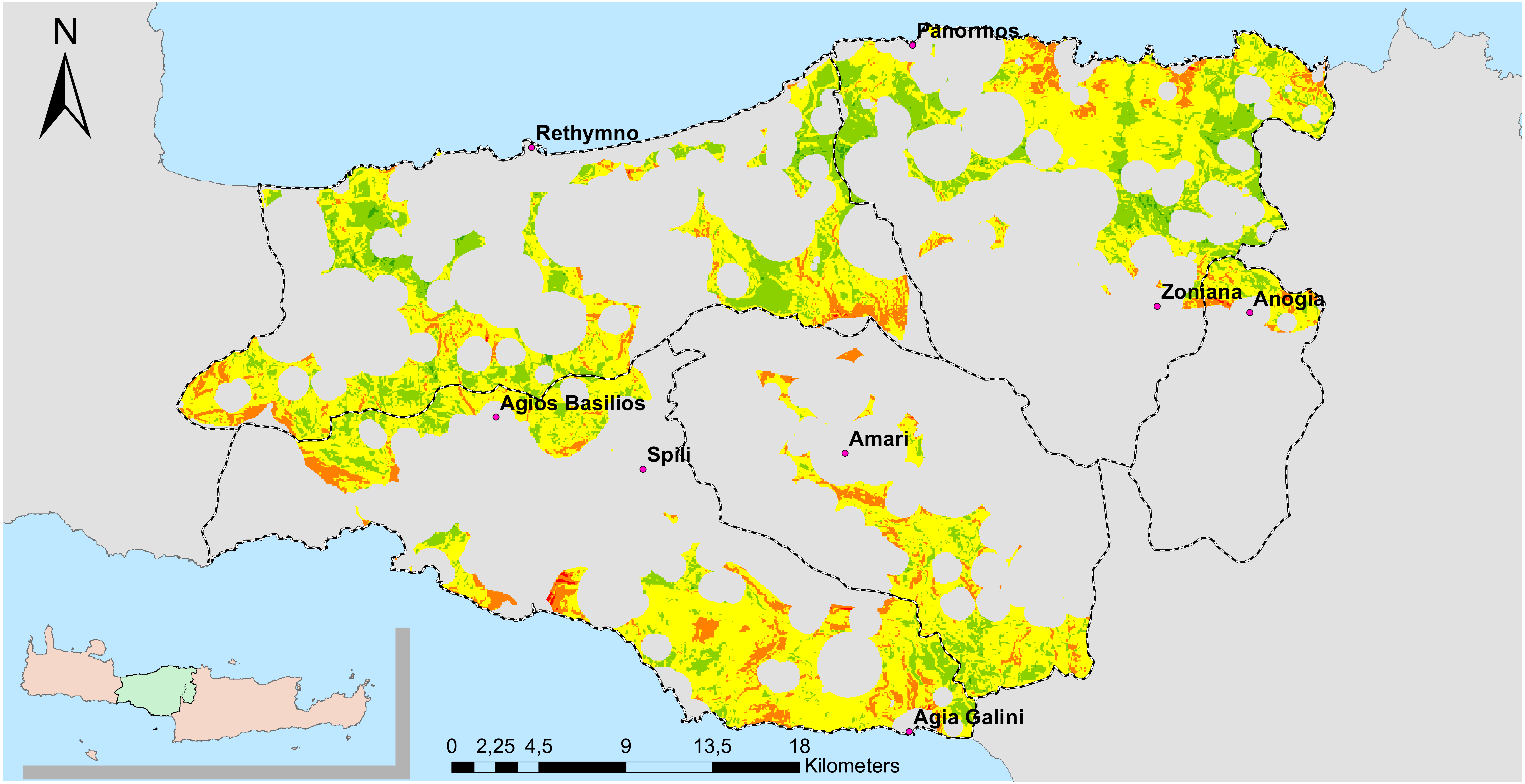
P.14 Priority Map for Biomass Plants Siting Based on the Equal-Weighted Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

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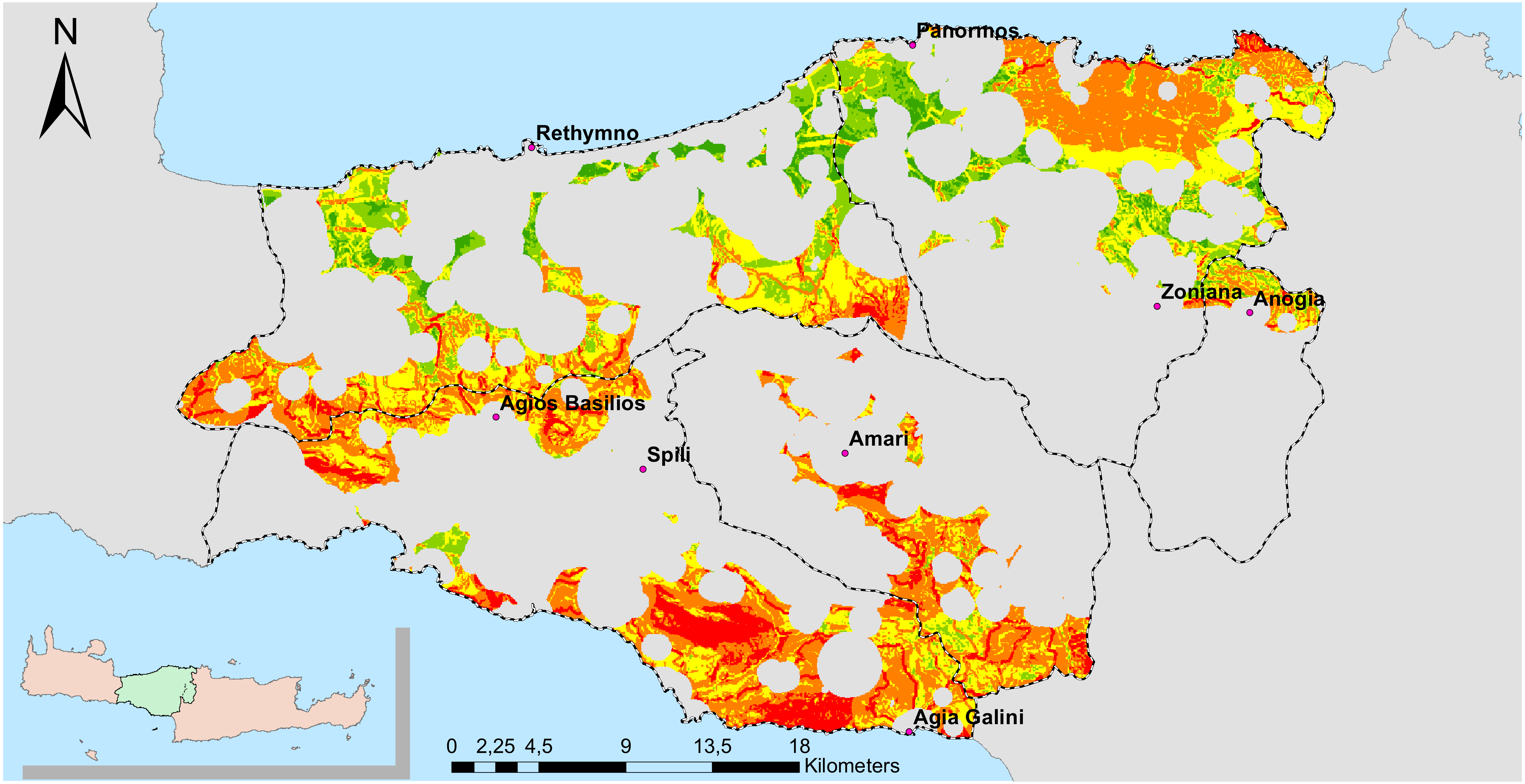
P.15 Priority Map for Biomass Plants Siting Based on the Techno-Economic Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

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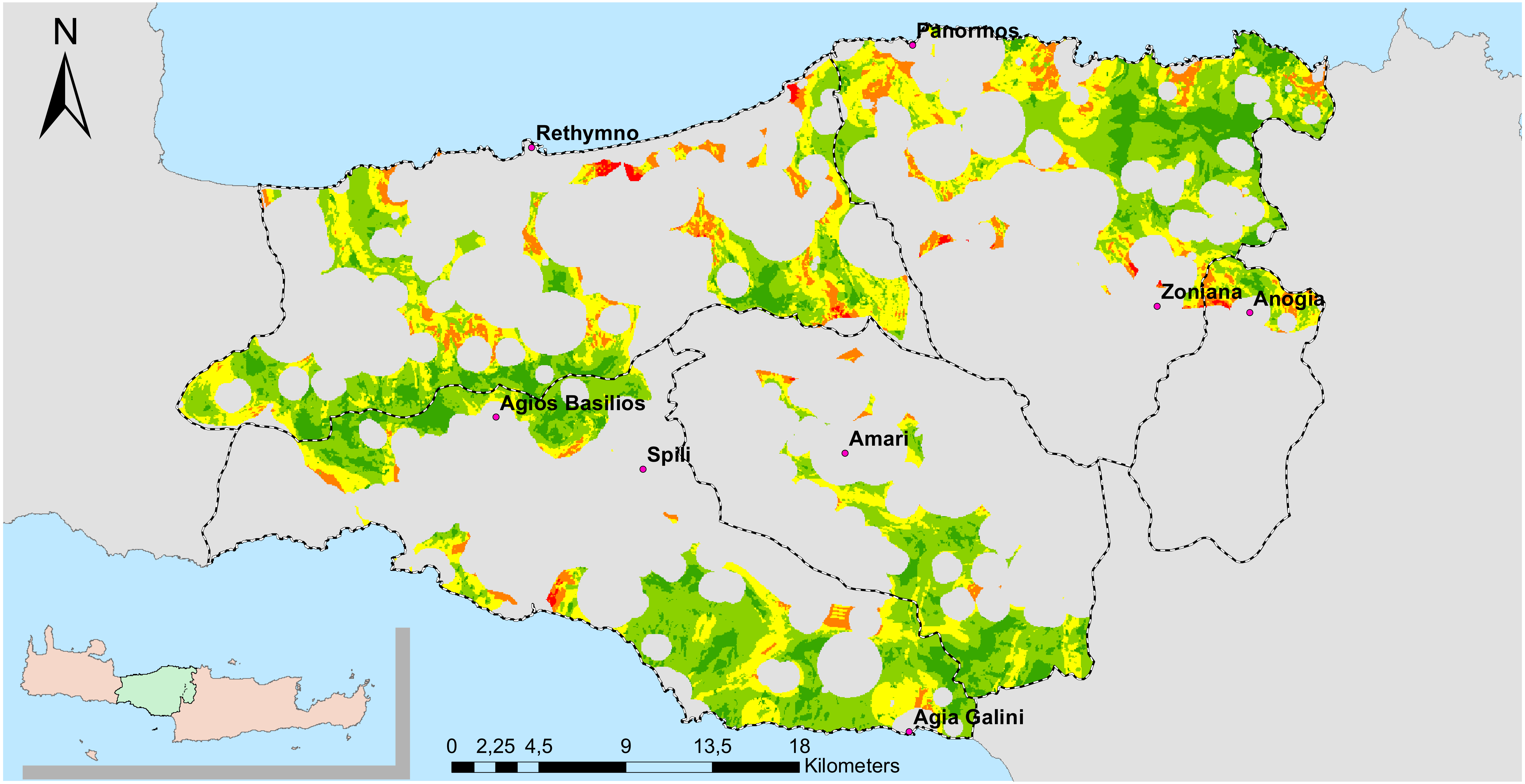
P.16 Priority Map for Biomass Plants Siting Based on the Socio-Environmental Scenario



LEGEND

Municipalities Boundaries of the Regional Unit of Rethymno

Priority Percentage

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- 80-60%
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