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Sustainable siting of offshore wind farms

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This dissemination thesis was written by a human researcher, using Wordtune editor only for rewriting sentences in a more formal style. It was not produced by artificial intelligence (AI).

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Ph.D. Dissertation Committee

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Περίληψη

Ένας σημαντικός παγκόσμιος στόχος είναι η μείωση των εκπομπών των αερίων του θερμοκηπίου όσον αφορά στην παραγωγή ενέργειας. Σημαντικό ρόλο θα διαδραματίσουν τα υπεράκτια αιολικά πάρκα (ΥΑΠ) σε αυτό το στόχο, τα επόμενα χρόνια. Οι συγκρούσεις χρήσεων γης, μαζί με την αυξανόμενη ζήτηση για πράσινη ενέργεια και το αναξιοποίητο υπεράκτιο αιολικό δυναμικό, θα συμβάλλουν στην ανάπτυξη των ΥΑΠ. Η βιώσιμη χωροθέτησή τους αποτελεί ένα ανοιχτό ερευνητικό ερώτημα, διότι: (i) υπάρχει η ανάγκη για ενεργειακή ανεξαρτησία των νησιών (ii) υπάρχουν μεγάλες αποστάσεις από την ηπειρωτική χώρα και (iii) υπάρχει αναξιοποίητο αιολικό δυναμικό για παραγωγή υπεράκτιας αιολικής ενέργειας. Στις περισσότερες περιπτώσεις, το υψηλό αιολικό δυναμικό εντοπίζεται στη θάλασσα και κυρίως σε περιοχές με μεγάλο βάθος, καθιστώντας αδύνατη την εγκατάσταση ανεμογεννητριών σταθερής έδρασης. Συνεπώς, καθαρή ενέργεια θα μπορούσε να παραχθεί από πλωτά αιολικά πάρκα, τα οποία μπορούν να αναπτυχθούν σε βαθιά νερά. Ως μέρος του επόμενου σταδίου αυτής της διατριβής, εφόσον προκύψουν οι κατάλληλες περιοχές, είναι να ληφθούν υπόψη τόσο η πιθανή οπτική όχληση από το αιολικό πάρκο των προτεινόμενων τοποθεσιών όσο και η τεχνοοικονομική αξιολόγηση, με στόχο να διασφαλιστεί η αποδοχή τους.

Στο πρώτο στάδιο αυτής της μελέτης, ο στόχος ήταν να εξεταστούν οι πιο συχνά χρησιμοποιούμενες μέθοδοι χωροθέτησης ΥΑΠ και να εντοπιστούν ποιες προτάσεις θα μπορούσαν να γίνουν για τη βελτίωση αυτής της προσέγγισης. Ο στόχος ήταν να αξιολογηθούν οι ήδη δημοσιευμένες μεθοδολογίες σε άρθρα με κριτές των τελευταίων οκτώ ετών, να συγκριθούν και να κατηγοριοποιηθούν σύμφωνα με τη μελέτη περίπτωσης (γεωγραφική περιοχή), το περιοδικό, τον τύπο της ανεμογεννήτριας και το είδος της μεθοδολογίας. Τα εξεταζόμενα άρθρα κατανεμήθηκαν σε 34 διαφορετικά επιστημονικά περιοδικά, με τα περισσότερα να εμφανίζονται στα περιοδικά «Renewable Energy», «Renewable and Sustainable Energy Reviews» και «Energies». Η πλειοψηφία των μελετών διεξήχθησαν στην Τουρκία, στην Κίνα και στην Ελλάδα. Το 50% των ερευνών που εξετάστηκαν χρησιμοποίησαν μεθόδους λήψης αποφάσεων πολλαπλών κριτηρίων. Οι περισσότερες μελέτες αφορούσαν τεχνολογίες σταθερής έδρασης για ΥΑΠ, οι οποίες είναι οι πιο δημοφιλείς και πιο συχνά χρησιμοποιούμενες τεχνολογίες σήμερα. Οι 80 μελέτες που εξετάστηκαν χωρίστηκαν σε πέντε κατηγορίες με βάση τις μεθοδολογίες που χρησιμοποιήθηκαν: Θαλάσσιος Χωροταξικός Σχεδιασμός, Ανάλυση Σκοπιμότητας, Πιθανολογικές Μέθοδοι, Μετεωρολογικά Δεδομένα και Πολυκριτηριακές Μέθοδοι. Οι 80 εργασίες που εξετάστηκαν κατηγοριοποιήθηκαν με βάση 170 διαφορετικά κριτήρια που χρησιμοποίησαν και ομαδοποιώντας τα προέκυψε ένα τελικό σύνολο 41 κριτηρίων.

Στο δεύτερο μέρος της παρούσας διατριβής, στόχος ήταν ο εντοπισμός των καταλληλότερων θαλάσσιων περιοχών για την ανάπτυξη των ΥΑΠ, χρησιμοποιώντας την μέθοδο Αναλυτικής Ιεράρχησης και τα Γεωγραφικά Συστήματα Πληροφοριών, καθώς και 14 κριτήρια αποκλεισμού και 16 κριτήρια αξιολόγησης. Σε αυτή τη μελέτη ζητήθηκε η γνώμη ενός εκτεταμένου φάσματος τοπικών φορέων και ειδικών, λαμβάνοντας υπόψη τα ιδιαίτερα χαρακτηριστικά του νησιού της Κρήτης. Επτά διαφορετικά εμπορικά διαθέσιμα μοντέλα ανεμογεννητριών χρησιμοποιήθηκαν για την αξιολόγηση της ενεργειακής αξιολόγησης των θαλάσσιων περιοχών που ήταν «πολύ κατάλληλες». Επιπρόσθετα, αναπτύχθηκε παράλληλα μια τεχνική βάσει συστήματος γεωγραφικών πληροφοριών, προκειμένου να εντοπιστούν οι

καταλληλότερες περιοχές στην Κρήτη για την εγκατάσταση πλωτών αιολικών πάρκων ανάλογα με τα ενεργειακά τους χαρακτηριστικά. Για τον προσδιορισμό των καταλληλότερων περιοχών για την βιώσιμη χωροθέτησή τους, οι διαθέσιμες περιοχές αναλύθηκαν με βάση ενεργειακά κριτήρια, τεχνοοικονομικά, περιβαλλοντικά, ασφάλειας, καθώς και όχλησης. Τρεις ήταν οι περιοχές που αναδείχθηκαν ως οι καταλληλότερες για εγκατάσταση των πλωτών ΥΑΠ, αξιολογώντας τα ενεργειακά τους χαρακτηριστικά.

Στη συνέχεια, η διατριβή παρουσίασε μια ολοκληρωμένη τεχνοοικονομική μελέτη στο Ηρακλείο Κρήτης, περιοχή που αναδείχθηκε κατάλληλη από την προηγούμενη φάση της παρούσας έρευνας. Στα πλαίσια της διατριβής, αξιολογήθηκαν τρία διαφορετικά τεχνοοικονομικά σενάρια για την εγκατάσταση και λειτουργία ανεμογεννητριών, συνδυασμού, σταθερής και πλωτής έδρασης. Χρησιμοποιώντας το λογισμικό WAsP, η ενεργειακή απόδοση των ανεμογεννητριών αναλύθηκε υπό διάφορες συνθήκες ανέμου και οι τεχνικές προδιαγραφές και ο εκτιμώμενος εξοπλισμός συνέβαλαν σε μια συνολική αξιολόγηση της απόδοσης των ανεμογεννητριών. Στη συνέχεια, αναλύοντας κόστη όπως το ισοσταθμισμένο κόστος ενέργειας (LCOE), το κόστος εγκατάστασης (CAPEX), τα λειτουργικά έξοδα (OPEX) και τα κόστη παροπλισμού (DECEX), καθώς και δείκτες όπως ο χρόνος αποπληρωμής (PP), ο εσωτερικός συντελεστής απόδοσης (IRR), καθαρές ταμειακές ροές και καθαρή παρούσα αξία (NPV), λήφθηκε μια ολοκληρωμένη προσέγγιση του οικονομικού και χρονικού προφίλ των επιλεγμένων τύπων ανεμογεννητριών.

Ως τελικός στόχο, η παρούσα διατριβή εξέτασε τα υπάρχοντα εργαλεία για την αξιολόγηση της οπτικής όχλησης των ΥΑΠ. Προτάθηκε επίσης να γίνουν βελτιώσεις όταν διαπιστώθηκε ότι οι υπάρχουσες μέθοδοι δεν ανταποκρίνονταν στην πραγματικότητα. Προκειμένου να ελαχιστοποιηθεί η οπτική όχληση, η μεθοδολογία που υιοθετήθηκε σύγκρινε τα αποτελέσματα της αρχικής ισπανικής μεθόδου, της ισπανικής μεθόδου II, της ελληνικής νομοθεσίας, και των αποτελεσμάτων από τις γνώμες των κατοίκων της εξεταζόμενης περιοχής. Χρησιμοποιήθηκαν επίσης τα εργαλεία λογισμικού AutoCAD, ArcGIS και Google Earth. Επιλέχθηκε για τη μελέτη περίπτωσης ο κόλπος της Κισάμου, Δυτική Κρήτη, ως κατάλληλη περιοχή από το προηγούμενο στάδιο της παρούσας έρευνας. Επιπλέον, αναπτύχθηκε μια ακόμη μεθοδολογία που ποσοτικοποίησε την οπτική όχληση, σύγκρινε τα αποτελέσματα με τις απόψεις των κατοίκων της εξεταζόμενης περιοχής και πρότεινε μια προσέγγιση που είναι πιο κοντά στην πραγματικότητα. Οι συνεντεύξεις έλαβαν μέρος τον Αύγουστο για να συγκεντρωθεί όσο το δυνατόν μεγαλύτερο δείγμα, καθώς αυτές οι περιοχές-χωριά ήταν κυρίως τουριστικοί/καλοκαιρινοί προορισμοί.

Σύμφωνα με τους περισσότερους ερωτηθέντες, η απόσταση από περιοχές περιβαλλοντικού ενδιαφέροντος ήταν το πιο σημαντικό κριτήριο για την επιλογή κατάλληλων τοποθεσιών για την ανάπτυξη ΥΑΠ. Με βάση τα αποτελέσματα της μελέτης, η τελική διαθέσιμη περιοχή για την χωροθέτηση των ΥΑΠ ανέρχεται 205,5 km^2. Τα 126,25 km^2 από τη συνολική επιφάνεια αξιολογήθηκαν με υψηλή καταλληλόλητα και με χωρητικότητα εγκατεστημένης ισχύος περίπου από 620 έως 900 MW. Επιπρόσθετα, τονίστηκε ο ρόλος που μπορούν να διαδραματίσουν τα πλωτά αιολικά πάρκα στην περίπτωση της Κρήτης, καθώς μπορούν να καλύψουν έως και το 56% των ενεργειακών αναγκών του νησιού και να παρέχουν ηλεκτρική ενέργεια σε 396.000 νοικοκυριά.

Η τεχνοοικονομική ανάλυση χρησιμοποίησε δύο σενάρια τιμών για την ενέργεια, μία μεσαία και μία υψηλή. Ως αποτέλεσμα αυτής της προσέγγισης, κατέστη δυνατό να προσδιοριστεί το ιδανικότερο σενάριο για τις αποφάσεις της εξεταζόμενης επένδυσης. Μέσα από την αναλυτική της προσέγγιση, η παρούσα διατριβή εξέτασε τους παράγοντες που επηρεάζουν την αποδοτικότητα, τη βιωσιμότητα και την ανταγωνιστικότητα της υπεράκτιας αιολικής ενέργειας σε αυτή την ιδιαίτερη περιοχή, επισημαίνοντας τις ευκαιρίες και τις προκλήσεις που συνδέονται με την υιοθέτηση αυτής της τεχνολογίας. Ως τελικό βήμα, παρέχεται μια στρατηγική κατεύθυνση για τη λήψη πολιτικών, οικονομικών και περιβαλλοντικών αποφάσεων.

Τέλος, τα αποτελέσματα των μεθοδολογιών οπτικής όχλησης έδειξαν ότι η αρχική ισπανική μέθοδος απέκλινε κατά 88,0% από τις γνώμες των κατοίκων. Ως εκ τούτου, η μέθοδος χρήζει βελτίωσης, λαμβάνοντας υπόψη τα σημερινά δεδομένα. Αντιθέτως, ένα από τα νέα προτεινόμενα σενάρια έδειξε ότι είναι πιο συνοπτικό και ακριβές, φτάνοντας σε πολύ μικρότερη απόκλιση της τάξεως του 19,7%. Επιπλέον, σύμφωνα με τα αποτελέσματα της μεθοδολογίας (ελληνική νομοθεσία), ο πρώτος περιορισμός πληρούταν και στα δύο εξεταζόμενα σενάρια, με αποτέλεσμα η οπτική όχληση να είναι ελάχιστή έως καθόλου. Παράλληλα, σύμφωνα με τα αποτελέσματα, οι περισσότεροι ερωτηθέντες δήλωσαν ότι δεν θα αντιμετωπίσουν σημαντική οπτική όχληση από την ανάπτυξη ενός υπεράκτιου αιολικού πάρκου στην περιοχή τους. Τέλος, το 64% των ερωτηθέντων απάντησε θετικά όσον αφορά την εκμετάλλευση των ανανεώσιμων πηγών ενέργειας, ενώ μόνο ένα μικρό ποσοστό της τάξεως του 11% απάντησε αρνητικά, ανεξαρτήτως ηλικίας.

Abstract

A major global goal is to reduce the carbon footprint of energy power generation. There will be a significant role for offshore wind farms (OWFs) in the new era of renewable energy. Land-use conflicts, together with the growing demand for green energy and the untapped offshore wind potential, contribute to the development of OWFs. It remains an open research question regarding their sustainable siting. This is because: (i) there is a need for the islands to generate energy on their own; (ii) there are long distances to the mainland; and (iii) there is a high potential for offshore wind. In most cases, wind power potential is located at sea and primarily in areas with significant depth, making it impossible to install fixed wind turbines. Clean energy could be produced by floating wind farms, which can be deployed in deep waters. As part of the next stage, it is essential to consider both the potential visual impact of the emerging sites as well as the techno-economic assessment to ensure their acceptability.

In the first stage of this study, the objective was to examine the most commonly used methods and to identify what suggestions might be made to improve this approach. The aim was to evaluate already published methodologies in peer-reviewed papers during the last eight years, compare them, and identify them according to their geographical location, journal type, foundation type, and methodology dimension. The reviewed articles are distributed across 34 different scientific journals, with the majority appearing in the journals Renewable Energy, Renewable and Sustainable Energy Reviews, and Energies; the majority of the studies conducted were conducted in Turkey, China, and Greece; half of the papers reviewed employed multi-criteria decision-making methods; most studies are concerned with bottom-fixed technologies for OWFs, which are the most popular and most frequently used technologies today. The 80 papers reviewed were divided into five categories based on the methodologies used: Marine Spatial Planning, Feasibility Analysis, Probabilistic Methods, Meteorological Data, and Multi-Criteria Decision Making. The 80 papers analysed were categorized based on 170 criteria, resulting in a final set of 41 criteria.

In the second part of this thesis, the objective was to identify the most suitable marine areas for the development of OWFs, using the Analytical Hierarchy Process and Geographic Information Systems, as well as the 14 exclusion criteria and 16 evaluation criteria. An extensive range of local stakeholders and experts have been consulted in this study, taking into account the specific characteristics of the island of Crete. Seven different commercially available models are used to assess the energy capacity of the high-suitable marine areas. Additionally, a geographical information system-based technique was developed in parallel in order to identify the most suitable areas in the Cretan Sea for the installation of floating wind farms according to their energy characteristics. To determine the most suitable areas for their sustainable siting, the available areas were analysed on the basis of energy, techno economic, environmental, safety, and project nuisance criteria. There were three areas that were ranked as the most suitable for energy production, and their energy characteristics were evaluated.

The thesis then presented a comprehensive and multi-layered techno-economic analysis of the Gulf of Heraklion, Crete, based on the emerging areas. As part of the thesis, three different techno-economic scenarios for the installation and operation of wind turbines were evaluated, including both bottom-fixed and floating turbines. Using the WAsP program, the energy efficiency of wind turbines is analysed under various wind conditions, and the technical

specifications and estimated equipment contribute to a global assessment of wind turbine performance. Further, by analyzing costs such as Levelized Cost of Energy (LCOE), Installation Cost (CAPEX), Operating Expenses (OPEX), and Decommissioning Costs (DECEX), as well as indicators such as Payback Time, Internal Rate of Return (IRR), net cash flows, and net present value (NPV), a comprehensive picture of the financial and time profile of the selected types of wind turbines is obtained.

As a final objective, this study tested existing tools for assessing the visual impact of OWFs. It was also suggested that improvements be made when it was discovered that the factors did not correspond to reality. In order to minimize the visual impact, the adopted methodology compared the results from the original Spanish method, Spanish method II, Greek legislation, local people surveys, and novel combinations of scenarios. The software tools AutoCAD, ArcGIS, and Google Earth were also employed. As a result of the previous stage of analysis, Kissamos, Western Crete, was chosen for the study. Moreover, an additional methodology was developed that quantified the visual impact, compared the results with the opinions of nearby citizens, and suggested an approach that is realistic. Interviews were conducted in August in order to meet as many people as possible since these villages were primarily tourist destinations.

According to most respondents, the distance from environmental interest areas was the most important criterion for choosing suitable sites for development. Based on the results of the study, it was determined that the final available area for OWF siting is 205.5 km2; 126.25 km2 of high suitability with a potential of 620 to 900 MW. Additionally, the role floating wind farms can play in the case of Crete is emphasized, as they can cover up to 56% of the island's energy needs and provide electricity for 396,000 households.

The techno-economic analysis revealed a range of values for energy, focusing on the middle and highest values. As a result of this observation, it was possible to determine the most ideal scenario for investment efficiency. Through its analytical approach, this thesis examined the factors that affect the efficiency, sustainability, and competitiveness of offshore wind energy in this special region, highlighting the opportunities and challenges associated with the adoption of this technology. As a final step, a strategic direction for political, economic, and environmental decision-making is provided.

Lastly, the results of visual impact methodologies indicated that the original Spanish method deviated by 88.0% from the public opinion, and, therefore, that the method needs to be improved considering current data. On the contrary, one of the new suggested scenarios was verified to be more concise and accurate, reaching a deviation of 19.7%. In addition, according to the results of the methodology (Greek legislation), the first limitation is met in both examined scenarios, resulting in minimal or no visual impact. In addition, respondents stated that they would not experience any optical disturbances as a result of an offshore wind farm in their region. In addition, 64% of respondents are positive or very positive about renewable energy exploitation, while only 11% are against it, regardless of their age.

Publications

Journal Publications-Book chapters

1. Pandora Gkeka-Serpetsidaki, Theocharis Tsoutsos, 13 - Sustainable site selection of offshore wind farms using GIS-based multi-criteria decision analysis and analytical hierarchy process. Case study: Island of Crete (Greece), Editor(s): Grigorios L. Kyriakopoulos, (in) **Low Carbon Energy Technologies in Sustainable Energy Systems**, Academic Press, 2021, pp 329-342, ISBN 9780128228975, https://doi.org/10.1016/B978-0-12-822897-5.00013-4.

2. A methodological framework for optimal siting of offshore wind farms: A case study on the island of Crete, Pandora Gkeka-Serpetsidaki, Theocharis Tsoutsos, **Energy Journal**, Volume 239, Part D, 2022, 122296, https://doi.org/10.10/j.energy.2021.122296.

3. Assessment of visual impact of offshore wind farms, P. T. Gkeka-Serpetsidaki, S. Papadopoulos, T. Tsoutsos, **Renewable Energy Journal**, Volume 190, May 2022, Pages 358-370, https://doi.org/10.1016/j.renene.2022.03.091.

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5. Integration criteria of offshore wind farms in the landscape: Viewpoints of local inhabitants, P. Gkeka-Serpetsidaki, T. Tsoutsos, **Journal of Cleaner Production**, Vol. 417, 2023, 137899, https://doi.org/10.1016/j.jclepro.2023.137899.

6. A critical review of the sustainable siting of offshore wind farms,P. Gkeka-Serpetsidaki, G. Skiniti, S. Tournaki, T. Tsoutsos (**Under review, Journal of Cleaner Production**)

7. Techno-economic assessment of offshore wind farms: A case study in Heraklion Bay, Crete P. Gkeka-Serpetsidaki, D. Fotiou, T. Tsoutsos **(Under submission)**

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4. Integration criteria of offshore wind farms in the landscape: Viewpoints of local inhabitants, P. Gkeka-Serpetsidaki, T. Tsoutsos, SpliTech2022, 7th International conference on smart and sustainable technologies, July 5-8, 2022, Split and Bol, Croatia.

5. SusTainablE siting of offshore wind Parks. APplication in Crete Step – Ap, P. Gkeka-Serpetsidaki, T. Tsoutsos, SUSTENG 2023, 2nd International Conference on Sustainable Chemical and Environmental Engineering (SUSTENG 2023), 14th-18th June 2023, Limassol, Cyprus.

6. A critical review of the site selection process for offshore wind farms, P. Gkeka-Serpetsidaki, T. Tsoutsos, 18th International conference environmental science & technology (CEST 2023), 30 Aug-2 Sep, Athens, Greece.

Research projects

SusTainablE siting of offshore wind Parks. APplication in Crete - **Step – Ap**, Funding Program "PHYSICAL ENVIRONMENT & INNOVATIVE ACTIONS 2022" / Priority Axis 3 "RESEARCH AND APPLICATION", Green Fund, 06/2023-06/2025.

Table of Contents

List of Tables

List of Figures

Abbreviations

Abbreviation	Description
AEP	Annual Energy Production
AHP	Analytical Hierarchy Process
BFWT(s)	Bottom-Fixed Wind Turbine(s)
CAPEX	Capital Expenditure
CF	Capacity Factor
DECEX	Decommissioning Cost
EEZ	Exclusive Economic Zone
ELECTRE	Élimination et Choix Traduisant la Réalité
EPA	Environmentally Protected Areas
EU	European Union
EVC	Evaluation Criteria
EXC	Exclusion Criteria
FWF	Floating Wind Farm
FWT(s)	Floating Wind Turbine(s)
GIS	Geographic Information System
GWC	GWC
HEDNO	Hellenic Electricity Distribution Network Operator
HVG	High Voltage Grid
IBA	Important Bird Areas
IRR	Internal rate of return
LCOE	Levelized Cost of Electricity
MCDM	Multi-Criteria Decision Making
n.m.	Nautical Miles

NIMBY	Not In My Backyard
NPV	Net Present Value
O&M	Operation and Maintenance Cost
OPEX	Operating Expenses
OWF(s)	Offshore Wind Farm(s)
OWT(s)	Offshore Wind Turbines(s)
PA	Partial Assessment
PP	Payback Period
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PV	Photovoltaics
RD	Rotor Diameter
RES	Renewable Energy Sources
RET	Renewable Energy Technologies
RU	Regional Unit
SPM	Spanish method
SPMII	Spanish method II
TLP	Tension Leg Platform
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VI	Visual Impact
VR	Virtual Reality
WF(s)	Wind farm(s)
WT(s)	Wind Turbine(s)

1. Introduction

1.1 Description of the problem

As a result of concerns over climate change, global warming, carbon emission reductions, and energy supply, interest in renewable energy sources (RES) has significantly revitalized in the past few decades. In order to address adverse effects and environmental degradation, international treaties such as the Kyoto Protocol, the Paris Agreement, and the European 2030 climate and energy framework have been adopted. Most countries worldwide have agreed to a concession that the global average temperature should not exceed 2oC above pre-industrial levels since the sixth assessment report AR6 of the Intergovernmental Panel on Climate Change (IPCC) [1]. For the optimal decarbonization scenarios and projections to be achieved, a significant penetration of RES is a critical component.

With its limited resources, less variable resources, improved efficiency, and relatively low socioeconomic impacts, offshore wind energy (OWE) has demonstrated considerable growth among the various RES technologies since the beginning of the 21st century, becoming a technologically competitive renewable energy technology.

More specifically, concerning the energy independence/electrifying of, in terms of the decarbonisation transition, the conventional coal-power plants have to be shut down during the following years. In this context, RES are a unique solution of energy supply for the islands. However, the insular environments have particularities compared to continental lands [2]:

- Land deficiency because all activities and infrastructure have to be realised on the island.
- Land heterogeneity sometimes makes the siting of solar and wind installations extremely difficult.
- Fluctuations of energy needs, especially if they are touristic resorts, during peak season.
- Electric submarine interconnectivity is realised in some cases, but it is generally a highly demanding project to be performed on all islands.

There is an increasing need to move RE from land to sea for a variety of reasons, including the vast space available for installing RE installations, as well as the inexhaustible and much higher offshore wind potential (compared to onshore wind).

The global interest in Offshore Wind Farms (OWFs) is increasing due to their numerous advantages. Wind is inexhaustible, and relevant studies and reports have shown that the global offshore wind potential could easily cover the worldwide electricity needs up to 1.5 times [3]. Additionally, OWFs have many advantages compared to the onshore ones, such as [4][5][6]:

- There is a more robust and consistent wind flow in marine areas because there are no physical restrictions, such as mountains or high buildings that could prevent the wind flow.
- Offshore wind turbines (OWTs) could be produced at a larger and taller size, along with a greater rated capacity than onshore wind turbines (WTs), meaning that the percentage of energy produced could be undoubtedly higher.

- In comparison with the onshore one, OWF could alleviate the potential land-use conflicts.
- The noise produced by an OWF could be better eliminated than those of the onshore for the nearby communities.
- This is a valuable yet unexploited asset for regional and national policymakers.

Releasing land in order to avoid land-use conflicts, along with the increasing need for green renewable energy and the unexploited offshore wind potential, intensify the necessity of the development of OWFs installations, especially in insular environments. Additionally, there is an increasing gap, concerning social acceptance, which has been partially investigated. Studies have shown that the public often protests new offshore wind projects, which has been provoked by the fact that the decision-makers and the local stakeholders were ignored during the first project development stages. Since the dominant emotion is that they are no longer being listened to, they feel weak to intervene and remain sceptical about a possibly negative environmental impact. So, it is crucial to catch up with the one-way opinion expressed by investors and producers. In this way, the previous difficulties concerning the onshore wind projects and social protest could dramatically be minimised or avoided.

Despite the advantages, one of the significant constraints of this technology is considered to be the visual impact (VI) that an OWF might cause on the local communities. This obstacle could be a critical bottleneck in the decarbonisation process. On the other hand, numerous advantages towards onshore Wind Farms (WFs), such as steadier wind speeds with less turbulence and higher wind energy potential, can accept larger wind energy installations, have minor impacts on the environment and marine life, and finally could cause less optical and acoustic disturbances [7][8].

From this perspective, it is noteworthy that stakeholders and policymakers have been concerned about the development of renewable energy installations. A number of conflicting criteria exist concerning different aspects of the proposed project, such as the conservation of natural areas, the economic feasibility, the technical constraints, and even the social acceptance, such as the potential visual effect of these large-scale projects. For the identification of sustainable siting, these factors must be considered [9]. The integration of conflicting environmental, social, and techno-economic criteria requires a transparent and reliable methodology.

In order for the public to have real confidence in the developers and investors, a transparent, open, and dynamic process must be developed. In addition, the problems of the central insular island could be addressed, such as the demand for energy and the unavailability of land. Therefore, a methodological framework for a sustainable siting of OWFs is urgently required, which should incorporate the viewpoints and conceptions of local experts as well.

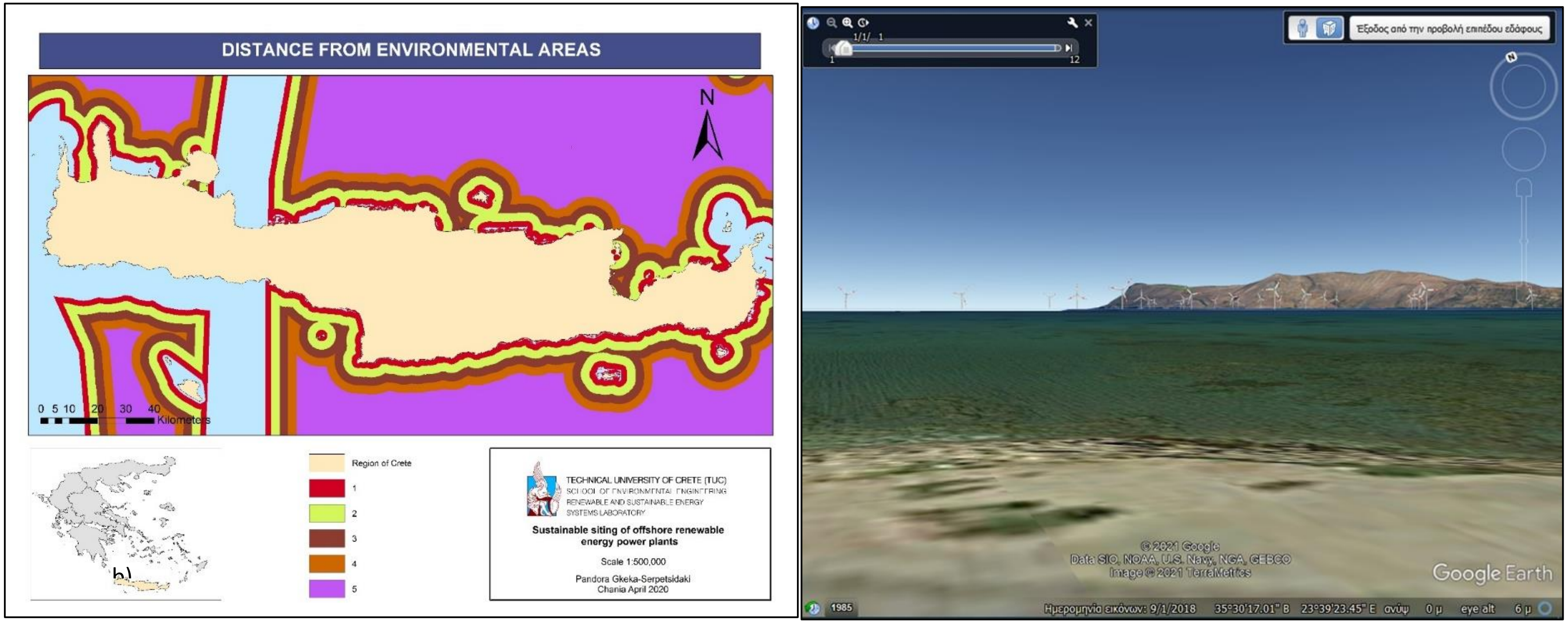


Figure 1.1: Sample of the Thesis work concerning a) the sustainable siting and b) the assessment of VI

1.1.1 Literature Review-An overview of the most commonly used DM tools

Many studies have been conducted that concern OWFs regarding technical requirements [10][11][12], environmental impact assessment [13][14][15][16], and other related topics [17]. However, the site selection process of an OWF has only been examined in a limited number of studies. These studies mainly concentrate on the use of Geographic Information System (GIS) [18], or/and the use of decision-making (DM) methodologies [19][20].

Therefore, it is rare to find a review approach that collects and assesses a considerable number of papers concerning general methodologies for the siting of an OWF. This literature review aims to address a gap in the global literature by examining and consolidating best practices related to OWF site selection. In conclusion, this review assesses and analyses methodologies regarding the siting of OWFs, gathers and describes criteria used in the literature and summarizes essential conclusions and recommendations on the critical topic of the site selection process.

The following section describes some of the most common MCDM methods, followed by an analysis of the literature review process that was used. The major findings are then discussed in terms of the categories in which they were obtained, from subsections 1.1.3-1.1.9.

(a) Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) assumes that every criterion increases or decreases in utility monotonically, thus making it easier to identify positive and negative ideal solutions. In order to evaluate the distance between the alternatives and the ideal solution, Euclidean distance is proposed. By comparing the relative distances between the alternatives, it is possible to determine their preference order. A TOPSIS procedure begins by converting the various criteria dimensions into non-dimensional criteria. Accordingly, the chosen alternative should be the closest to the positive ideal solution and the furthest from the negative ideal solution [21].

(b) Analytic Hierarchy Process (AHP) involves decomposing complex decision problems into a hierarchy of criteria, sub-criteria, and alternatives and then making pairwise comparisons among these elements to determine their relative significance. The process involves normalizing the comparisons, calculating priority vectors for each level of the hierarchy, and checking the consistency of the priorities. AHP has a wide range of applications in business and management, engineering, healthcare, and environmental DM. It can be used to compare and evaluate different options, prioritize resources, allocate funding, and make strategic decisions. AHP is useful in situations where decision-makers need to consider multiple criteria (MC) and make trade-offs between conflicting objectives [22].

(c) Analytic network process (ANP) is a development of AHP. ANP is designed to identify and resolve decision problems that involve interdependencies and feedback loops among criteria and alternatives, which cannot be captured by a simple hierarchy. ANP is the process of decomposing a decision problem into a network of clusters and elements and determining their relative importance by comparing them pairwise. The process involves normalizing the comparisons, calculating priority vectors for each level of the network, and checking the consistency of the priorities. It can be used to evaluate complex systems, prioritize resources, allocate funding, and make strategic decisions that take into account the interdependencies and feedback loops among criteria and alternatives. ANP is advantageous in situations where decision-makers need to consider MC and their interactions and make trade-offs between conflicting objectives in a complex environment [23].

(d) Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) ranks alternatives according to certain criteria. Using priority functions, it determines the degree of preference or indifference between each alternative and the others based on each criterion used to break down the decision problem. PROMETHEE then aggregates the preferences for each alternative to generate a ranking of the alternatives. The method also provides sensitivity analysis to evaluate the robustness of the ranking results. It can be used to evaluate and rank alternatives based on MC, considering the preferences and indifference of decision-makers towards each criterion. PROMETHEE proves valuable in scenarios where decision-makers need to make choices between alternatives that have different strengths and weaknesses based on MC [24].

(e) Decision Making Trial and Evaluation Laboratory (DEMATEL) is used for analysing the cause-and-effect relationships among a set of criteria in a complex DM problem. It involves breaking down the decision problem into a set of criteria and sub-criteria and then using the DEMATEL method to construct a directed graph representing the relationships among these criteria. The method allows decision-makers to identify the driving factors and critical issues that are most important in the DM process. It also provides a way to determine the relative importance per criterion and sub-criterion by calculating its degree of influence and dependence in the DM process. It can be used to support DM processes by helping decision-makers identify the most critical issues and factors that should be considered in a decision problem, as well as to weigh the importance of different criteria in a structured and transparent manner [25].

(f) ELimination and Choice Expressing Reality (ELECTRE) method involves comparing multiple alternatives based on a set of criteria and ranking them in order of preference. The proposed model called the Intuitionistic Fuzzy ELECTRE (IF-ELECTRE), uses IFS to represent the criteria and alternatives and incorporates a decision matrix to calculate the outranking degrees of the alternatives. IF-ELECTRE method involves several steps, including the construction of a preference relation matrix based on the IFS, the calculation of the net flow values for each alternative, and the determination of the final ranking using a weighting scheme. In circumstances where criteria and alternatives are uncertain or imprecise, the IF-ELECTRE model provides an operative framework for decision-makers to evaluate alternatives and make informed judgments [26].

(g) The term 'Delphi method' originated from the Oracle of Delphi in ancient Greece, which was consulted regarding personal matters to public policy. Experts can communicate easily using electronic means through the Delphi method, and their responses are anonymous, which allows them to state their preferences without being influenced by others. Alternatively, expert judgment can be helpful when there is no scientific evidence or, if there is, it is contradictory. The opinions of several experts may be more reliable than those of one expert in a situation such as this [27]. A Delphi survey consists of: (a) the subject of study must be identified and explained, as well as a questionnaire to be prepared; (ii) the panel of experts to be consulted must be identified, and (c) the survey should be sorted out and conducted, usually in two or more rounds. An essential aspect of the method is the iteration of rounds to identify convergences or divergences of views, although consensus is typically sought at some point. The absence of consensus often leads to thought-provoking and vital discussions.

(h) The Best-Worst Method (BWM) involves ranking a set of alternatives based on their relative importance or preference. BWM typically involves presenting respondents with a set of alternatives and asking them to identify the best and worst alternatives from that set. The respondents then assign scores to the alternatives based on their perceived importance or preference. The scores are used to calculate the importance weights of each alternative, which can be used to prioritize DM and allocate resources accordingly. The BWM method is advantageous in situations where there are multiple attributes to be evaluated and subjective preferences are involved. It provides a more comprehensive and accurate assessment of DM criteria and helps decision-makers identify the most critical areas for improvement [28].

(g) Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) is used to evaluate and rank alternative solutions based on MC. The method measures the attractiveness of each alternative solution based on the criteria or factors considered. Also, the method ranks the alternatives according to a compromise solution. Then, the alternatives are rated according to their overall scores, with the highest-scoring alternative considered the most attractive. Overall, the method has been shown to provide a valuable tool for decision-makers to evaluate alternative solutions and identify areas for improvement [29][30][31].

(i) Goal programming is used to find the best possible solution to a problem with multiple conflicting objectives. The goal programming model involves identifying a set of objectives, which may be conflicting, and assigning priority weights to each objective. The model seeks to minimize the deviations from these objectives, subject to constraints. The objectives may include minimizing the cost of resource allocation, maximizing the efficiency of resource utilization, and meeting project deadlines. This model, used for allocation in agile-based software development, involves the identification of objectives and constraints, the determination of the priority weights for each objective, and the formulation of the goal programming model. The model is then solved using a mathematical optimization algorithm to determine the optimal resource allocation plan. The goal programming approach provides a helpful tool for decision-makers to allocate resources in a way that balances multiple competing objectives [32].

(ia) Grey relational analysis (GRA) method is a technique for evaluating the relationships between multiple variables and identifying those variables that are most strongly related to the desired outcome. GRA method works by comparing each variable to the reference variable, which is typically the variable that represents the desired outcome. The method uses a grey number to represent each variable, which accounts for both the known and unknown information about the variable. The grey number is then used to calculate the grey relational coefficient (GRC) between each variable and the reference variable. The GRC indicates the degree of correlation between each variable and the reference variable, with a higher GRC indicating a stronger correlation. The variables with the highest GRCs are considered to be the most important for achieving the desired outcome and can be used to inform DM. The GRA method is used to evaluate the relationships between MC [33].

(ib) Weighted Sum Aggregation (WSA) is a method of aggregating MC or factors that are used to evaluate alternatives in a DM process. A weight is assigned to each criterion in the WSA method to reflect its relative importance in the DM process. In order to calculate the weighted sum score for each alternative, the weights for each criterion are combined. As a result, the alternative with the highest weighted sum score is considered to be the most advantageous. WSA provides decision-makers with a useful tool for aggregating MC and determining the relative importance of each criterion [34].

(ic) The fuzzy logic method is used to determine a rough and distant outcome from a variety of sources of information [35]. This is an effective tool for modelling vague, ambiguous, and inaccurate information. There are numerous applications of fuzzy set theory in the fields of engineering, management, and business. As an alternative approach to human judgments, Zadeh proposes linguistic variables, which essentially transform crisp values of information into fuzzy ones [36]. A fuzzy number $\tilde{A}$ is a convex, normalized fuzzy set of $X \subseteq R$ and indicated as $A=(l,m,u)$ where l and u represent the lower and upper bounds and m is the midpoint [37]. It is worth mentioning that 9 out of 80 papers use methodologies combined with fuzziness. More specifically, the multi-criteria decision-making (MCDM) methods PROMETHEE method [38], Delphi method [39], ELECTRE method [40], AHP [41] are developed with fuzzy logic as well as other combined methodologies [35][42][43][44][45].

1.1.2 Review planning and question formulation

An analysis of previous studies provided insight into key trends that would improve the sustainable siting of OWFs in future practices. More specifically, an overview of analyses in OWF site selection studies was developed based on search terms that were representative of the review. Different technologies like floating, as well as fixed, OWFs were also examined in the review process.

In this review, three a priori questions were addressed: (1) what methods are most commonly used for securing an optimum OWF site; (2) which criteria are most popular, and (3) what suggestions could be made for the improvement of this approach?

A systematic literature review was conducted using the search terms «OWF site selection» and «OWF siting».

A systematic review was conducted in November and December of 2023 on two databases, Scopus (Elsevier) and ScienceDirect (Elsevier). The terms «Offshore Wind Farm site selection» and «Offshore Wind Farm siting» were searched in the advanced research option in the field of title, abstract, keywords. The results in ScienceDirect were about 276 articles (Offshore Wind Farm siting) and 59 articles (Offshore Wind Farm site selection), whereas in Scopus 108 articles (Offshore Wind Farm siting) and 240 articles (Offshore Wind Farm site selection).

As a first step, the papers were grouped according to their relevance to the terms of the search, which had to appear in the title, abstract, and keywords of the articles. Following that, a further in-depth examination of the abstract and methodology of each paper was carried out to determine whether it was relevant to the topic studied. Based on the methodology described above, 80 papers were finally selected under the current analysis. In both databases evaluated, there were duplicate papers, so they were excluded from the analysis. In addition, relevant review papers were excluded from our analysis since they focused on research papers and case studies in order to assess and draw conclusions regarding the siting procedures of OWFs. Review papers are excluded because they contain circular secondary sources of data rather than detailed experimental or observational data, methodologies, and analyses that contribute to the overall understanding of the field. The review process is depicted in Figure 1.2.

The selected time range was set for the period after the years 2015 till today to ensure the newest and freshest approaches in this sector. After that, the criterion of the type of articles had to be taken seriously under consideration. During the search, only peer-reviewed publications were considered; conference proceedings and grey literature were not included for original and scientific reasons. The fact that such investigations were unpublished and proprietary helped mitigate any potential bias that might have existed.

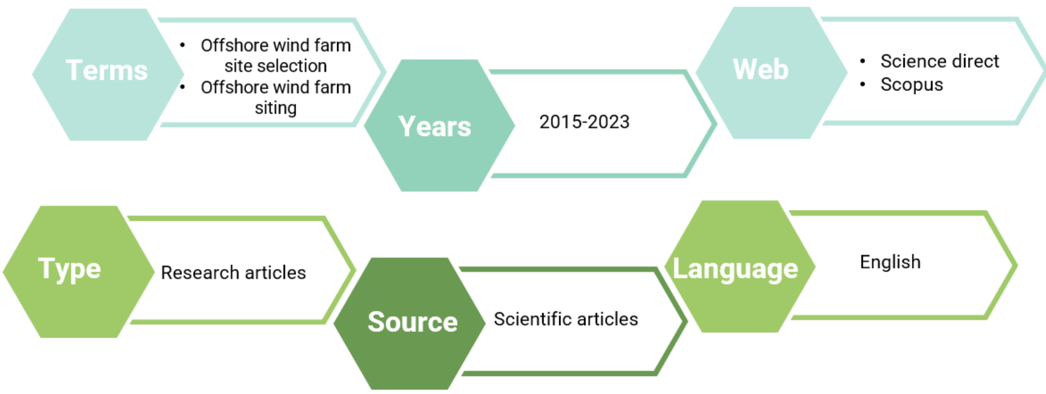


Figure 1.2: Overview of the review process

1.1.3 Keywords analysis

VosViewer was used to identify the occurrences (keyword frequency in documents) of all kinds of keywords appearing in the 80 papers under investigation. For that reason, 80 Scopus files were created and inserted into the software. All keywords (Author & Index keywords) were 866, from which 59 met the threshold of 5 occurrences, while by selecting 10 occurrences, as demonstrated in the above figure, only 23 keywords met the threshold. It is notable that in Figure 1.3, 19 keywords out of the 23 remained, which is a result of cropping identical keywords, i.e. “OWF” and “wind farm”, were unselected, as “OWFs” had more occurrences and remained in the figure.

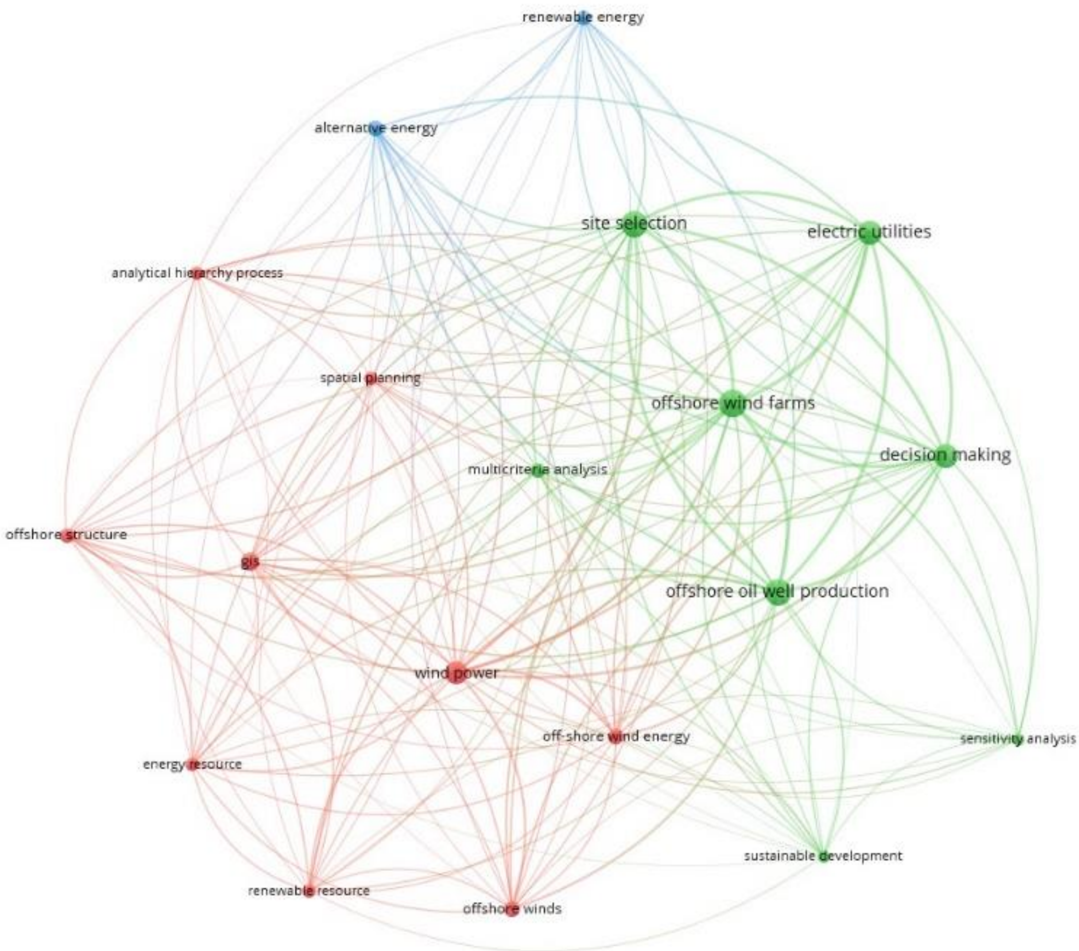


Figure 1.3: VosViewer Network visualization: Author and Index keywords, of 10 occurrences and more, in 80 papers

Accordingly, the size of the label and circle of an item is determined by its weight; this means that if an item has a high weight, its label and circle will be larger, for example, "OWFs" has a high weight. There are three clusters (blue, green, and red) that determine the colour of an item. In addition, the lines between the items indicate links between them (Figure 1.3). As shown in the visualization, the distance between two items approximately indicates the relationship between the keywords (in terms of both being referred to in the same publication). There is a connection between two keywords that strengthens the closer they are located to each other, for example, multicriteria analysis is related to both sensitivity analysis and spatial planning (Figure 1.4), though it is closer to the last one owing to its proximity. In Table 1.1 the words' occurrences and link strength are demonstrated from those of high importance to the least important keywords.

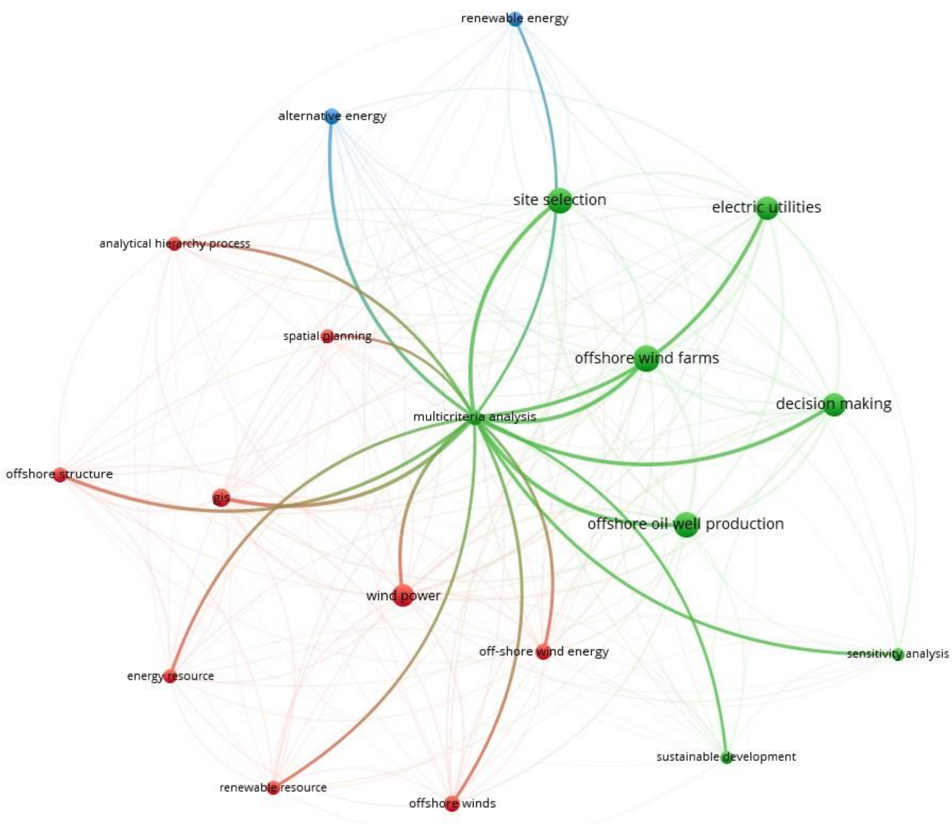


Figure 1.4: VosViewer network visualization: all links to "multicriteria analysis" keyword

Table 1.1: Keywords with more than 10 occurrences in a descended hierarchy, demonstrated with the indicators: i) number of occurrences and ii) total link strengths

High importance	keyword	occurrences	Total link strength
↑	OWFs	50	331
	Offshore oil well production	46	298
	Site selection	44	280
	Electric utilities	39	273
	Decision making	39	264
	Wind power	33	235
	GIS	22	161
	Offshore wind energy	17	129
	Offshore winds	17	117

	Alternative energy	16	134
	Multicriteria analysis	15	119
	Offshore structure	15	113
	Renewable energy	15	95
	Renewable resource	12	95
	AHP	12	80
	Energy resource	11	89
	Spatial planning	11	76
	Sustainable development	10	70
Low importance	Sensitivity analysis	10	69

1.1.4 Allocation per Journal

Between 2015 and 2023, 34 different scientific journals published the reviewed articles Table A.2. Six journals accounted for half (50%) of these publications. The highest percentage of the reviewed papers was in Renewable Energy with 16% (13 articles), Renewable and Sustainable Energy Reviews and Energies each with 8% (6 articles) and then Energy, Ocean and Coastal Management and Energy Conversion & Management each with 6% (5 articles) (Figure 1.5). The diverse distribution across various journals suggests a growing complexity in the offshore wind market. It also reflects a multi-disciplinary interest in this emerging technology, indicating the concentration of many scientists on studying it.

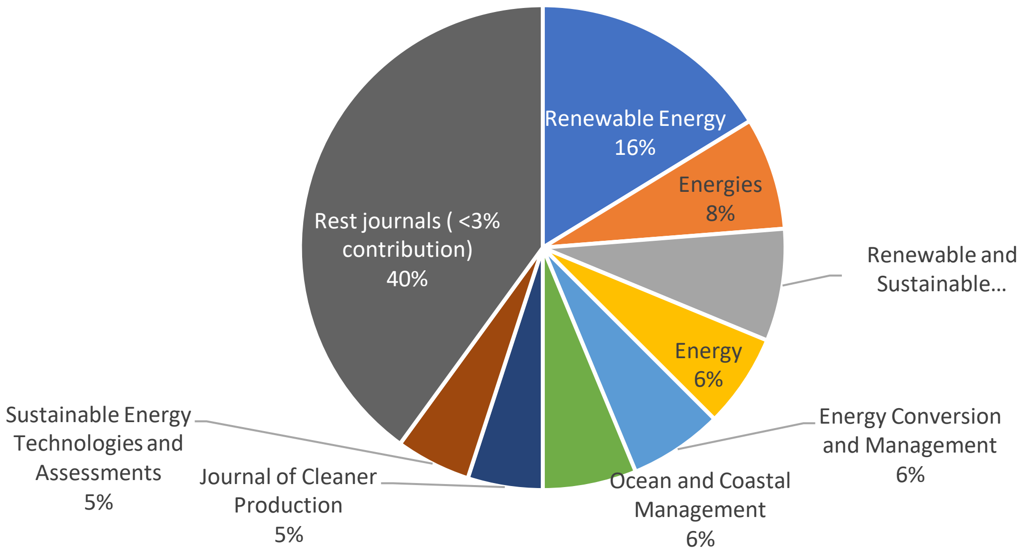


Figure 1.5: Paper allocation per journal

1.1.5 Allocation per geographic area

The studies were distributed to 24 different study geographical areas (Table A.2). The higher percentage was conducted in Turkey at 14% (12 studies), then China followed at 13% (11 studies) and Greece at 12 % (10 studies). UK and Atlantic coastal areas, including Portugal, Spain and France, follow with percentages of 6% (5 studies) (Figure 1.6). As evidenced by the results showing that they invest and conduct worthy research in this sector, East (China) has established itself as a leader in the offshore energy sector. Based on the geographic analysis, the countries with sea areas that have not developed Offshore Wind installations do research in order to be ready to develop when the conditions are favourable (economic status, studies, legislation).

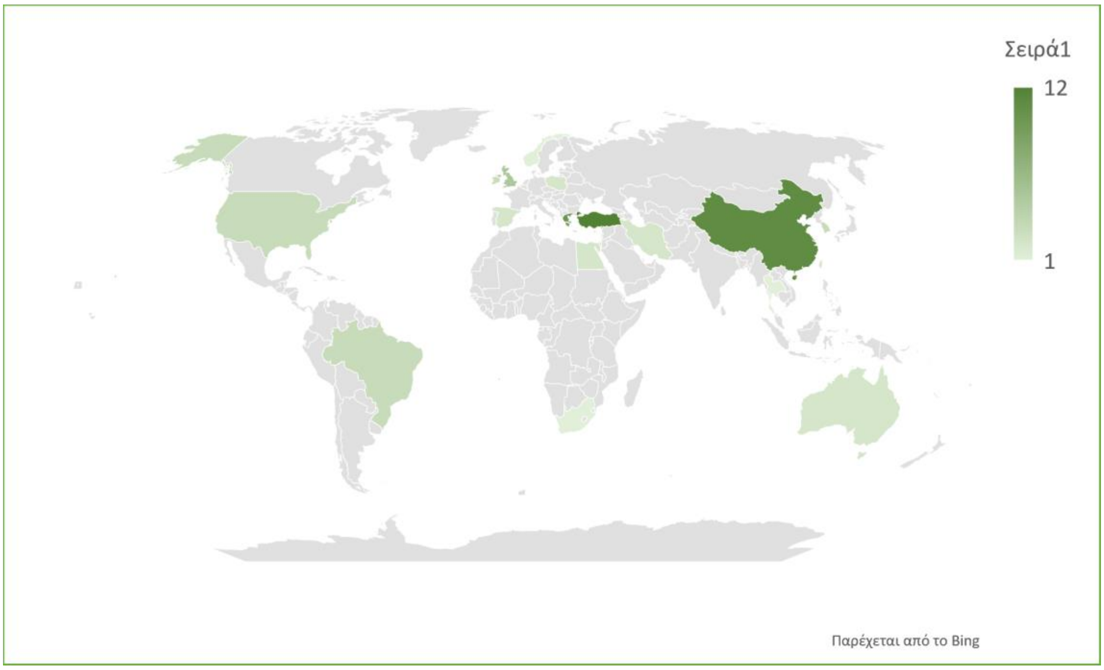


Figure 1.6: Allocation of papers per study area

1.1.6 Allocation per foundation type

The majority of the examined studies focus on bottom-fixed technology, which is currently the most prevalent and commonly utilized. Specifically, 37% (30 studies out of 80) analyse the site selection for exclusively bottom-fixed OWFs (Table A. 2). In contrast, a limited percentage of 15% (12 studies) investigate the site selection process solely for the emerging technology of floating OWFs. Notably, 34% (27 studies) delve into both bottom-fixed and floating technologies. Lastly, a small percentage of 14% (11 studies) do not specify a particular type of foundation in their examination.

Based on the criterion of water depth, it can be concluded that when the criterion is limited to 50-60 m, the technology is bottom-fixed, when it ranges from 50 – 1000 m, it is floating, and when it varies from 0-1000 m, it refers to both types of structures [46]. The papers in which the range of water depth is not defined are classified as n/d, but this is not a limiting factor since both types of technologies might be considered.

1.1.7 Allocation per methodology adopted

In the 80 papers that were reviewed (Table A.2), the methodologies were categorized into five categories: Marine Spatial Planning, Feasibility analysis, Probabilistic methods, Meteorological data, MCDM, and the remaining papers that did not correspond to some of the categories above were categorized under the sixth category that they utilized other methods or a combination of them. The six categories and the relevant percentages are depicted in Figure 1.7 and Table A.3.

Furthermore, in Figure 1.8, all the methodologies used by the reviewed papers are depicted, including all the MCDM methodologies that were found in the review process. The dashed lines in Figure 1.8 mean that one or more methodologies are combined. A brief description section about every MCDM methodology is summarised below (a-ib). In the analysis, 43 out of 80 papers use the geospatial analysis in conjunction with the GIS tool, indicating that the GIS is an appropriate and handy tool for the DM of optimal solutions for the development of an OWF. The reason for this is that GIS is capable of integrating an extensive collection of geospatial data and information and of developing algorithms that can lead to the desired outcomes (Annex A, Table A.3).

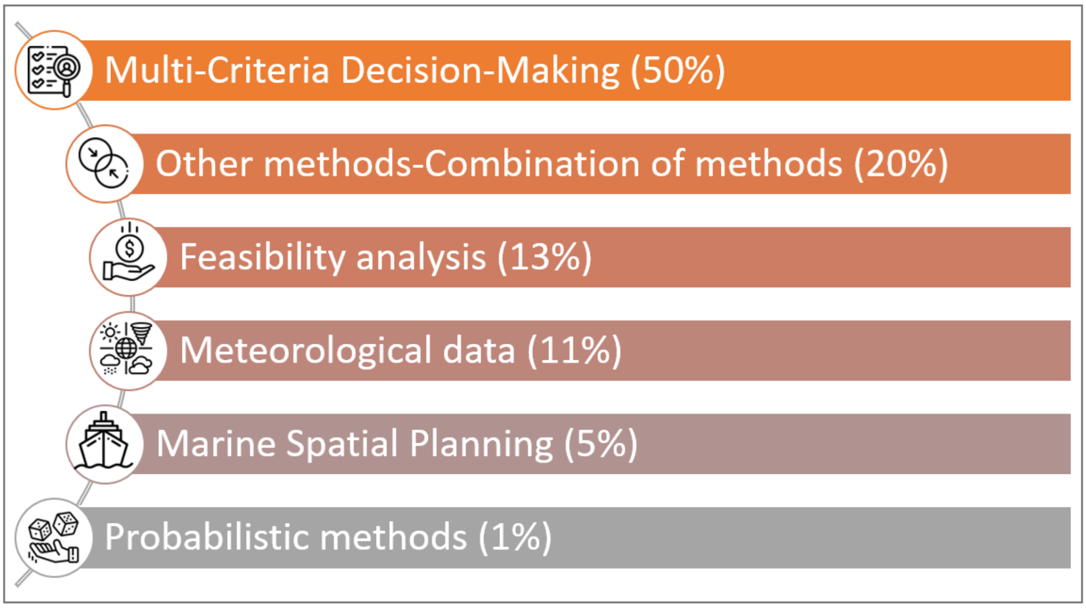


Figure 1.7: Methodology used by the reviewed papers

- In 40 of the 80 papers (50%) reviewed, MCDM methods were used (Table A.4) in order to determine which sites would be more appropriate for developing OWFs (Table A.3). As a result, it is verified from the global literature that these kinds of methods are the most popular for approximating multi-parameter problems, such as the optimal location of an OWF (Figure 1.9).
- In 10 of the 80 papers (13%) that were reviewed, feasibility and technoeconomic analyses were used as a tool to identify which sites would be the most appropriate for OWF deployment in order to determine their feasibility.
- Nine out of the 80 papers (11%) reviewed used meteorological data and models to determine which sites would be most suitable for developing OWFs.
- A total of 4 out of 80 papers (5%) utilize the marine spatial planning methodology to identify potential OWF development sites.
- In regards to the probabilistic method, it appears that it is not very frequently used for this purpose, since only one study has used it to assess Offshore Wind development sites.
- The remaining 16 papers (20%) use a method that is entirely different from the one described above or a combination of both.

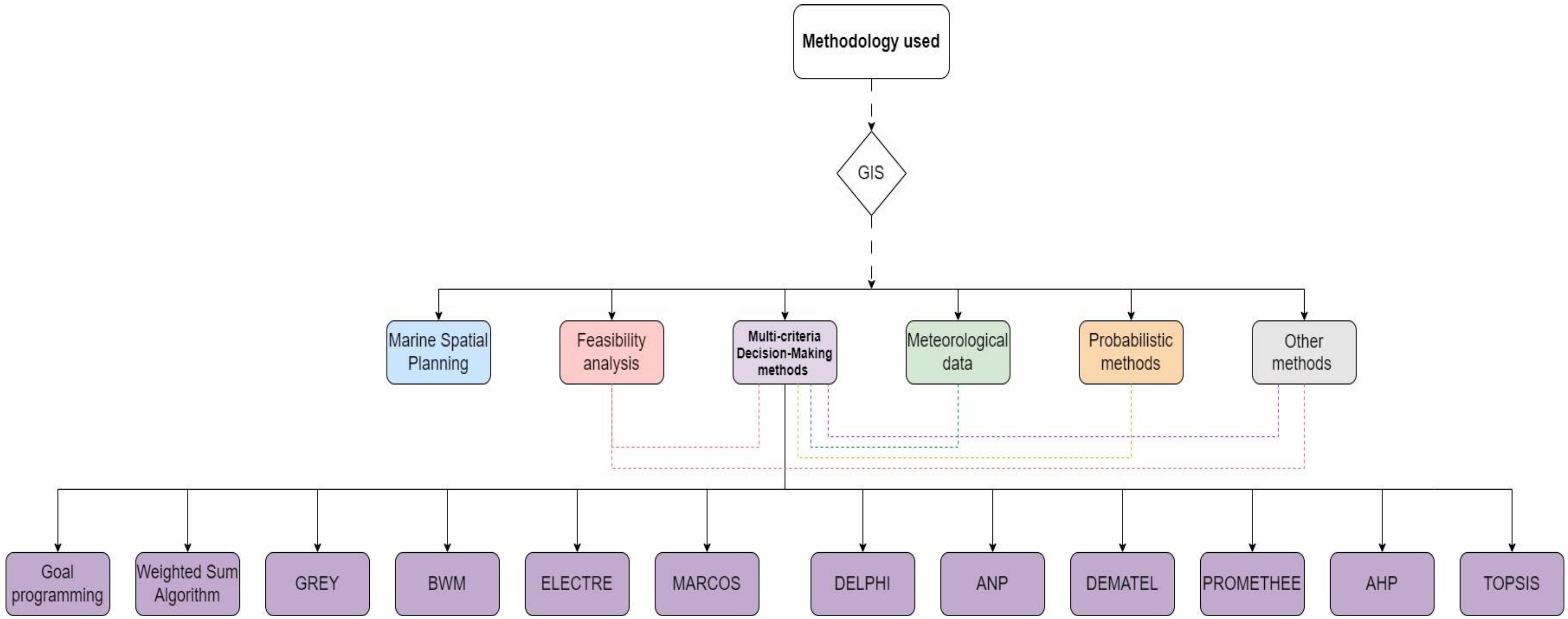


Figure 1.8: Methodologies used per paper and their combination

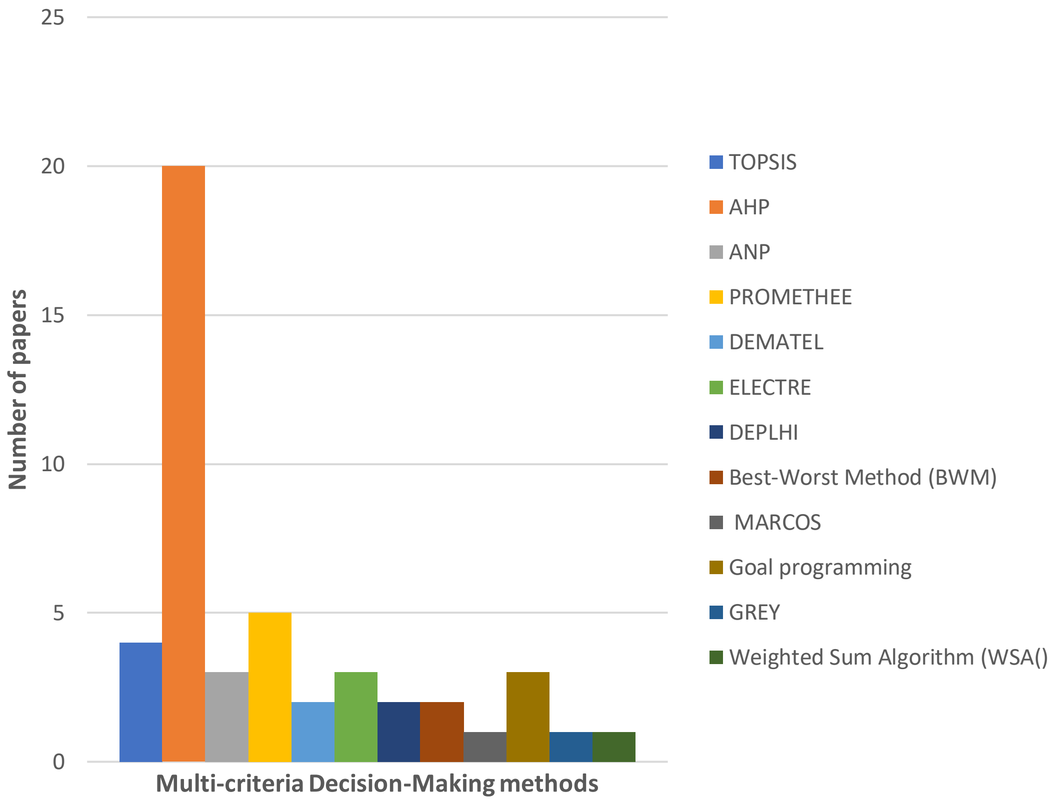


Figure 1.9: Number of papers used MCDM

According to Table 1.2, the MCDM methods employed in the papers are compared below, their advantages, disadvantages, and fields of application.

Table 1.2: Overview of MCDM methods that employ the reviewed papers

	Pros	Cons	Application	Source
AHP	• Flexible, intuitive and easy to use • Incorporate experts' viewpoints • Check inconsistency • No bias in DM • Makes clear the importance of each element	• Irregularities in ranking • Important information may be lost (Additive aggregation) • More pair-wise comparisons are needed • Difficult to reflect index interactions • Collection of data lies on experience	Company valuation methods in legal asset inventory expertise, construction management domain for material and project selection, health sector and manufacturing	[6][38][47][48]
ANP	• Handle complex index systems well • Processing feedback and interdependencies • Independence among elements is not required • Prediction is accurate because priorities are improved by feedback	• Fail to evaluate one element in isolation • Time-consuming • Complex computational processes • Uncertainty – not supported • Hard to convince DM	Health, safety and environmental management, hydrology and water management, business and financial management, human resources management, tourism, logistics and supply chain management, design, engineering and manufacturing systems, energy management	[38][47][49]
BWM	• Most data and time-efficient	• No identification of a global (system) optimal solution	Energy, supply chain management,	[50][51]

	• Checking the consistency of pairwise comparisons	• Weights that are not distinct and can impact the decision outcome • Complicated computational procedures, particularly with a large number of criteria.	transportation, manufacturing, education, investment, performance evaluation, airline industry, communication, healthcare, banking, technology, and tourism	
DEMATEL	• Considering index interaction • Less required in data • Determining causal factors	• Complex computational processes • Lack of objectivity	Supply chain management, environmental planning, healthcare, finance, and engineering	[38][52]
DEPLHI	• Structured system of communication for clear results • Anonymity for unbiased responses • Flexibility in geographical location • Removal of the impact of dominant individuals • Time and cost-effective method of obtaining expert group opinion	• Limited open discussion • Requires commitment if multiple rounds are required • Interpretation of study results is highly dependent on the responder's expertise	Business forecasting, industry predictions, government planning or financial strategies, predict trends in aerospace, automation, broadband connections, and the use of technology in schools	[53][54]

ELECTRE	• DM by thresholds of indifference and preference • Handle the problem of index compensation • Application when the incomparable alternatives exist • Outranking is used	• Requires many parameters • Complex computational processes • Difficult to determine the preferred alternatives • Time-consuming	Engineering, economics, business, environmental management	[38][47][55]
Goal programming	• Handling large-scale problems • Provide infinite alternatives	• Capability of weighting coefficients • Need to be combined with other MCDM methods	Production planning, health care, portfolio selection, distribution systems, energy planning, water management, wildlife management	[56]
GREY	• Perfect information results in a unique solution	• No optimal solution	Oil field development, military decisions, and equipment condition monitoring and wear mode recognition	[47][57]
MARCOS	• Subjectivity in expert judgment is exploited and assumptions are avoided	• A significant amount of data • New method/Not yet extensively investigated and used	Medical, logistics and transportation, life cycle management, materials selection, site selection	[58]

	• Consideration of an anti-ideal and ideal solution in the initial matrix, • Closer determination of utility degree in relation to both solutions, • Proposal of a new way to determine utility functions and their aggregation • Examination of an extensive array of criteria and alternatives while ensuring the steadfastness of the approach.		problems, manufacturing process evaluation, technology evaluation	
PROMETHEE	• No need for raw data process • Reduction in information loss • Reflect various properties of attributes	• Ignore the psychological characteristics of decision-makers	Business, finance, hydrology, and water management	[38][59]
TOPSIS	• Ease of application and understanding • Universality • Consideration of distances to an ideal solution • Not restricted sample size and index quantity • Ideal solution and anti-ideal solution complexity	• High subjectivity, not checking the consistency of judgments • Not indicate the preference of decision-makers • Ignore the relative importance of distances • Max. character of criteria calculation scale	Energy, medicine, engineering and manufacturing systems, safety and environmental fields, chemical engineering and water resources studies	[21][38][60]

Weighted Sum Algorithm (WSA)	• Weight and combine multiple inputs • Incorporation weights or relative importance • Max. of gain • Results min, max • Strong in a single-dimensional problem	• Linear function of gain • Exaggerating extremes • Difficulty with multi-dimensional problems	Economics, agriculture, and risk management	[47]

1.1.8 Criteria used

In the 80 papers reviewed, a comprehensive set of 170 criteria was utilized and subsequently categorized, leading to a condensed list of 41 final criteria. According to Figure 1.10 (and more analytically in Annex A Table A.5), which describes the criteria selected and analysed in 80 papers and the number of papers that examined them), the most frequently employed criteria relate to wind characteristics and water depth (approximately 75% of papers referring to these criteria), navigation and energy criteria (65% of papers), and baseline criteria regarding environmental impacts and distance from the shoreline (54%).

While the above criteria seem to be the only ones used in a percentage greater than 50% of the total papers, there are other factors to complete a holistic examination of spatial planning, related to social and economic factors, i.e. population served, acceptance, employment, various economic indicators, etc., as well as crucial legal and exclusive criteria, including distance from ports and airports, underwater cables, or military prohibited zones.

There are several criteria that have not yet been extensively explored (Figure 1.10). In terms of spatial planning, some of these appear to be important, such as policy planning, heritage areas, and the existence of RES, while others are less well explored, such as the marine habitat and conditions, or the safety level. Additionally, it is noted that some of those unstudied criteria are essential for such research in order to achieve a higher level of acceptance from the local community and to investigate the benefits and negative impacts of the installation holistically [61].

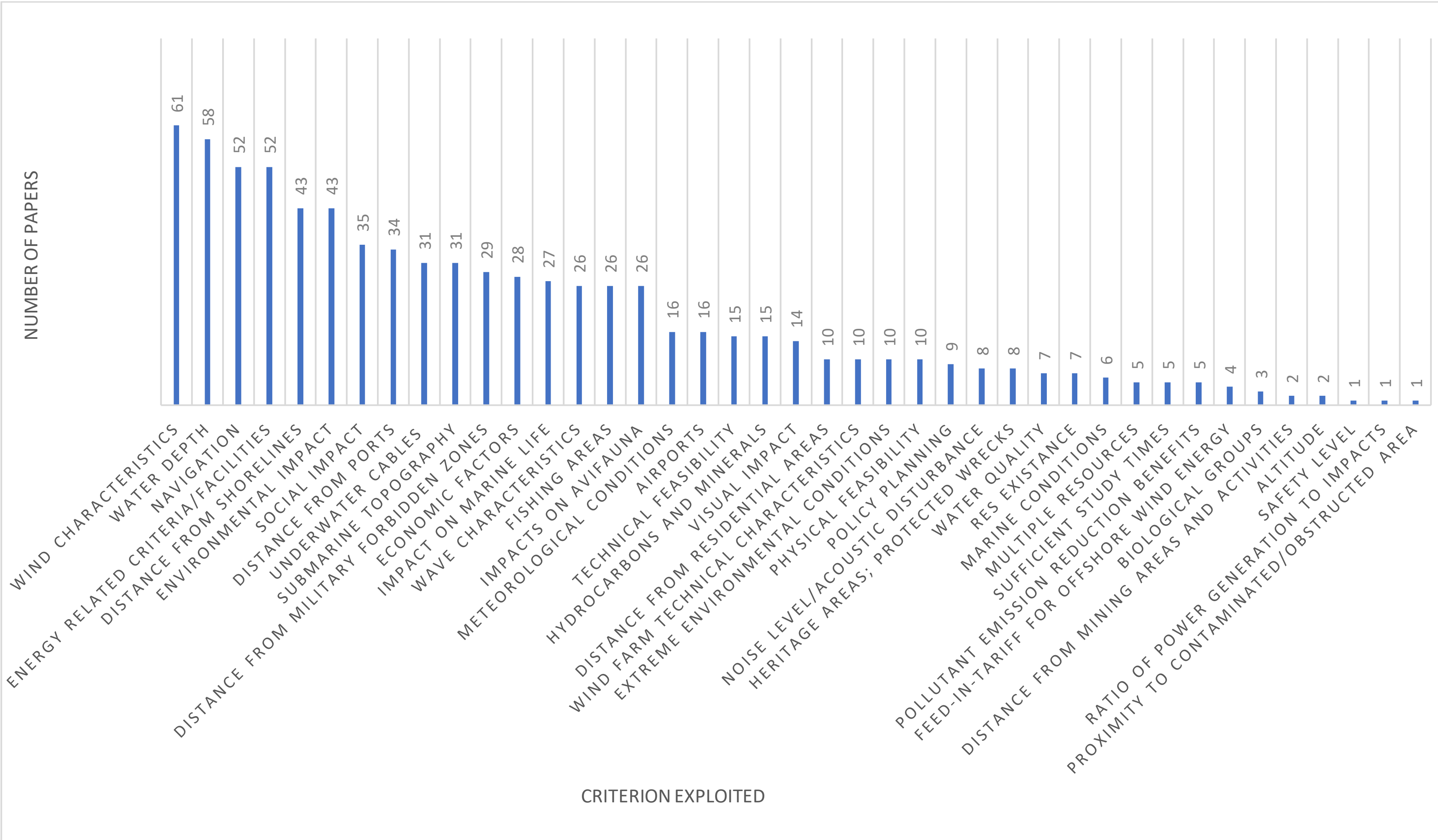


Figure 1.10: Number of papers exploiting each type of criterion

1.1.9 Experts included

The majority of papers (39 out of 80) seem to lack expert opinions concerning their criteria or, more broadly, their methodology. The authors also appear to classify the criteria based on their expertise and knowledge, but this is a time-consuming process which is not objective, and the results are not in accordance with reality. A percentage of 11%, 9 papers do not specify whether or not they include expert opinions in their studies and another percentage of 11%, 9 papers include expert opinions but do not specify the number. A satisfactory number of papers is reviewed in addition to a number of expert opinions, such as 4, 5, 7, or 9. Last but not least, a less widely adopted practice consists of the opinions of 3, 8, 10, 13, 15, 21, 25, 26, 33, and 34 experts (Figure 1.11 and Table A.1).

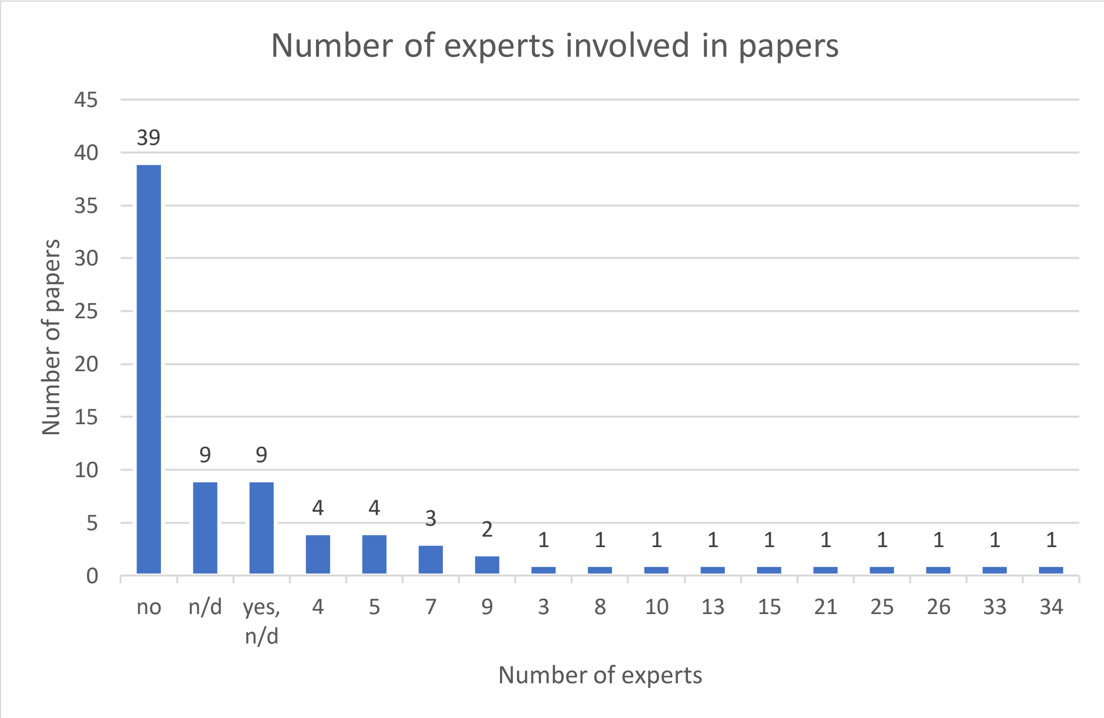


Figure 1.11: Number of experts, including in reviewed papers

1.2 Thesis Innovation

A study [62] incorporated only partially the island of Crete in the Regional Unit (RU) of Chania, which is missing the experts' viewpoint. There are also studies that consider the whole country of Greece as a study area. In our opinion, there is a need to increase the accuracy for a sustainable siting of OWFs and integrate the unique characteristics of the study areas.

Several studies examined the optimal siting of renewables using MCDM methods and GIS. The current research excludes a high number of typical constraints. To the best of our knowledge, the ranking is usually realised based on the authors' expertise and knowledge, which might often lead to unrealistic results. In addition to this, all existing studies incorporating experts' opinions are concerned with onshore wind parks and other renewable energy installations. In parallel, our bottom-up approach includes a high number of local and national (when it was not possible to find a local) experts and stakeholders' opinions (33) related to the current literature, who could recognise and judge better the needs of a specific study area than the international experts (other studies).

Furthermore, given the rapid growth of offshore wind energy and Floating Wind Farms (FWFs), there is limited international literature on the siting of WTs in great depths with strong wind potential. In order to achieve this goal, data are collected on factors that can determine if an area is ineligible to host FWFs, as well as factors related to the evaluation of available areas. Data processing is carried out in ArcMap 10.7 software. The areas rated as most suitable are imported into WAsP 12 software in order to be evaluated, based on energy criteria. This Thesis is one of the first that presents an easy method to define the most suitable sites for the development of FWFs. The proposed methodology takes into account all the crucial factors of an energy project and, despite the equal weights for the criteria, gives a good perspective of where the most suitable sites could be. Additionally, this methodology could be applied in different locations with or without the need of the participation of local stakeholders, while at the same time takes into account multiple aspects of the project. Finally, this Thesis also includes an energy assessment, giving a new perspective on the energy share that floating wind capacity can cover.

Furthermore, this work takes into account the environmental factor of vital importance, combining 4 sub-criteria (Natura 2000, Important Bird Areas (IBAs), migratory corridors of birds, Posidonia oceanica), overcomes other similar studies that refer mainly to NATURA 2000 network. Also, the criteria of disturbance noise and optical could give a more holistic view of the factors which influence sustainable siting.

Also, this work focuses on a limited/specific geographic area, improving the accuracy of results, instead of a whole country or large parts of countries. Finally, our work examines the emerging areas, instead of the usual WT model, with seven different ones.

This methodology is flexible to be adapted to each insular environment, maybe with some variations. So, a robust methodological framework is suggested in order that the more sustainable marine areas could be selected with respect to the local needs and characteristics.

The strategies mentioned above are widely used for the optimal siting of renewables infrastructures [2][63]. However, the actual integration of stakeholders' and policymakers' opinions into the evaluation criteria (EVC) from different categories/groups remains a rarely adopted technique because it is a time-consuming process. The most common practice is that the authors rank the selected criteria based on their expertise and knowledge, resulting in a more subjective scope.

Unlike previous similar studies, this research incorporates a larger number of categories (and a larger number of individuals), such as experts, stakeholders, or residents located near energy installations. In addition to this, the existing studies concentrated mainly on the problem of public acceptance and onshore WFs, along with other energy installations.

Thus, it is rare to find a similar approach in the global literature concerning OWFs installations considering all these perspectives. To the best of my knowledge, this research overcomes previous similar studies because it:

- Providing a RES methodological framework for overcovering the energy needs of the islands and coastal areas
- Incorporates a high number of local's opinions (EVC-pairwise comparisons) (e.g. 33 local experts and stakeholders).
- Examining a specific geographic area, increasing the accuracy, in a spatial resolution 100mx100m
- Ensures the strict environmental framework, concerning the optimal siting of an OWF.
- Examines a wide number of criteria (30 criteria, 14 exclusion, and 16 evaluations).
- Follows an after-assessment analysis of the greater available marine areas, based on characteristics of 7 different WT models.
- Proposing a methodology that expresses all the crucial factors of a floating wind project
- Conducting a holistic technoeconomic assessment of a combination of bottom fixed and floating wind turbines (FWT), assessing three different scenarios in selected areas

Furthermore, as known, visual and noise disturbances are amongst the main reasons for opposition to OWFs. Even though noise and environmental protection problems are investigated, methodologies to measure VI are sparser. Furthermore, the existing studies concentrate on the VI of an OWF, in terms of economic losses [64]. On the other hand, our study focuses on assessing the VI in terms of quantification. It could be a critical first step to comprehend the problem, so it could undoubtedly be easier to suggest solutions. Most of the existing studies suggest completely new methodologies or modifications to existing ones. To the best of our knowledge, there are no similar studies, which compare results from existing and new methodologies on the topic of measurement of the VI. The following are some of the reasons why this study has contributed to the global literature:

- Increase the accuracy considering the approach of the observer
- Improvements to the method will be tested
- A comparison will be made between the results of the methodologies and the responses to the questionnaires from local residents in order to determine whether or not the methodology is representative of reality
- Test existing methodologies, measuring the VI
- Proposes some modifications to the existing methods, as well as tries to find the optimal scenario (i.e., the minimum visual disturbance) among different combinations.

1.3 Research questions, aims and objectives

In this study, two objectives have been identified, the first concerning the sustainable siting of OWFs, both bottom-fixed and floating and the second regarding the VI of these areas.

The proposed Thesis addresses how an option for a potential OWF site could be more optimal and sustainable, in terms of minimising the potential negative effects and the key factor of social acceptance. Answering this statement requires answering the following questions:

1. What is the best method for selecting the most sustainable locations for the development of OWFs?

2. In what manner will the entire spectrum of society be engaged in the preliminary siting process?
3. In what ways could stakeholders assess the potential sites for the development of OWFs?
4. In what way will the technoeconomic viability of the emerging areas candidates for the development of the OWF be assessed?
5. Is there a way for local residents to evaluate the impact of an OWF on their surroundings?
6. What will be the methodology for evaluating the VI of an OWF?

According to the first category, this work incorporates the viewpoints of a broad spectrum of the audience into the pre-assessment stage, in order to fulfil a holistic approach that will meet technical, environmental, economic, and political criteria for the local community. The main goals of this work are the following:

- To provide a methodological framework under strict environmental constraints concerning a sustainable siting of OWFs in insular environments for both bottom-fixed and floating technology.
- To create a transparent and easy-to-use decision support tool for researchers, stakeholders, developers, and policymakers.
- To create a dynamic and robust spatial database, exploitable for future research.
- To develop an approach for a sustainable siting of OWFs, which considers the local experts' and stakeholders' opinions of each case study.
- To examine different technoeconomic scenarios based upon marine availability.
- To estimate the floating wind, share in the electricity mix using only the most suitable locations.

According to the second main objective, which is the evaluation of the VI, it has the following primary objectives:

- To test the existing legislation in order to quantify the VI that will be caused by an OWF.
- To apply the existing method (mainly for onshore WFs) to an OWFs project.
- To compare the results with those of locals in order to provide a more accurate picture of the results.
- To propose a more reality-based approach in order to bring the approach closer to reality.
- Implementing the existing Spanish Method (SPM)
- Testing the recommendations of the Greek ministry, and
- Suggesting and testing improvements to the original SPM, to make it applicable for OWFs.

1.4 Thesis Outline

Finally, In the outline of this study, five steps are taken to examine the prospect of sustainable OWFs siting:

Chapter 1: An introductory section explains the necessity and the innovation of this PhD Thesis.

Chapter 2: An overview of the current status of the offshore wind energy industry is presented.

Chapter 3: A literature review is conducted to highlight the importance and urgency of sustainable siting as well as the potential VI of OWF.

Chapter 4: Methodologies are developed for selecting the most appropriate location for an OWF (fixed or floating), followed by methodologies developed to quantify the VI of an OWF, as well as technoeconomic assessments.

Chapter 5: Results are presented and discussed from the above methodologies.

Chapter 6: The discussion and recommendations also address the urgent issue of the sustainable siting of OWFs, with a view to finding the best solutions and avoiding bad practices.

2. Status and policies

2.1 Global status of offshore wind energy sector

In accordance with the latest reports, over 380 GW of offshore wind capacity is expected to be added over the next decade (2023-2032), bringing total offshore wind capacity to 447 GW by the end of 2032 [66]. Nevertheless, only one-third of this projected new volume is likely to be added in 2023-2027, primarily as a result of challenging market conditions that have delayed offshore wind development in Europe and the United States. It is expected that offshore wind installation capacity will quadruple in 2028 from 8.8 GW in 2022 and pass 60 GW in 2032, bringing its share of global new offshore wind installations from 11% in 2022 to 30% by 2032. In the next ten years, over 380 GW of offshore wind capacity will be added across 32 markets, according to the 2023 Global Offshore Wind Report [66]. Offshore wind is a potential source of large-scale, renewable energy on every continent. Despite feed-in of 8.8 GW of new offshore wind into the grid, which is 58% lower than 2021, 2022 was still the second-highest year for offshore wind installation in history. According to Figure 2.1, the 8.8 GW of new offshore wind installations bring the global offshore wind power capacity to 64.3 GW, representing 16% growth year-over-year (YoY) [66].

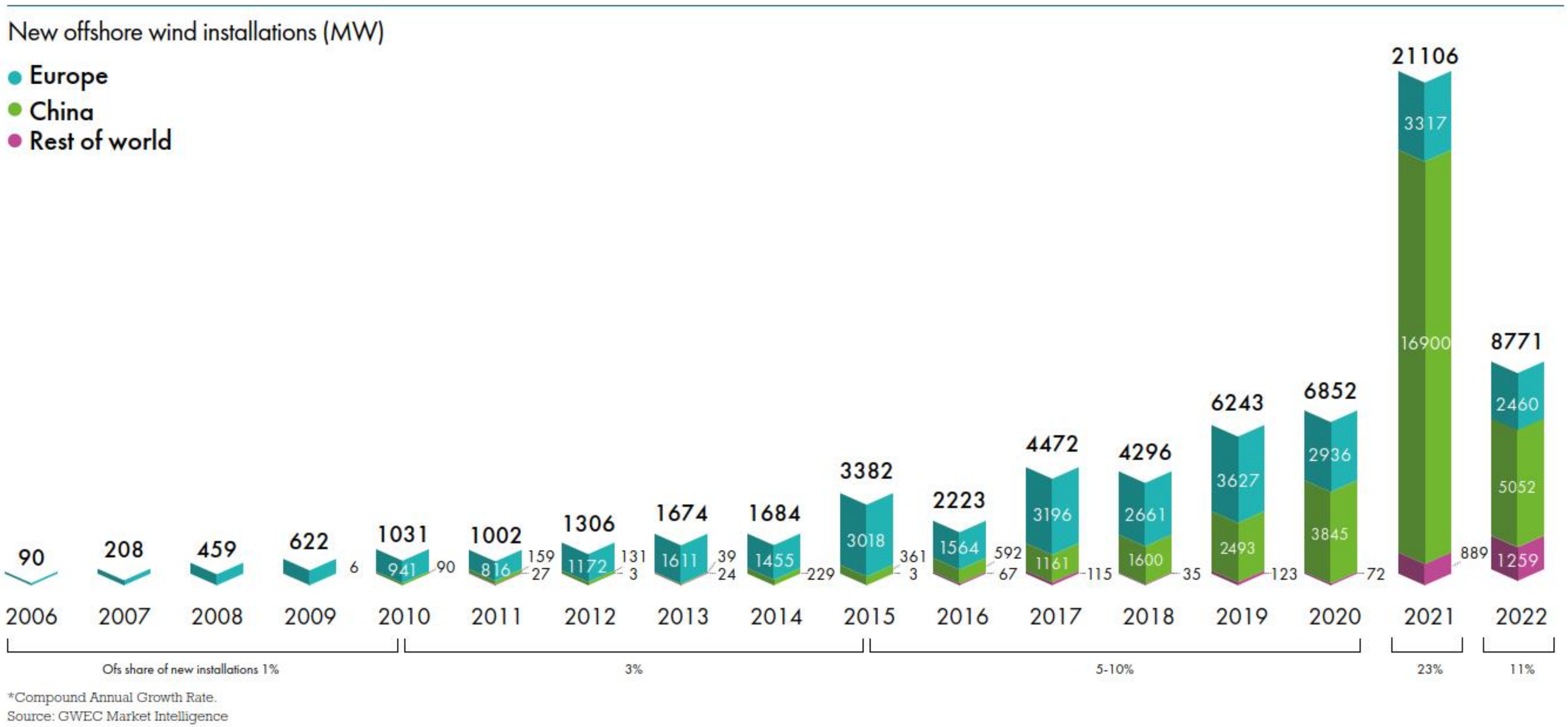
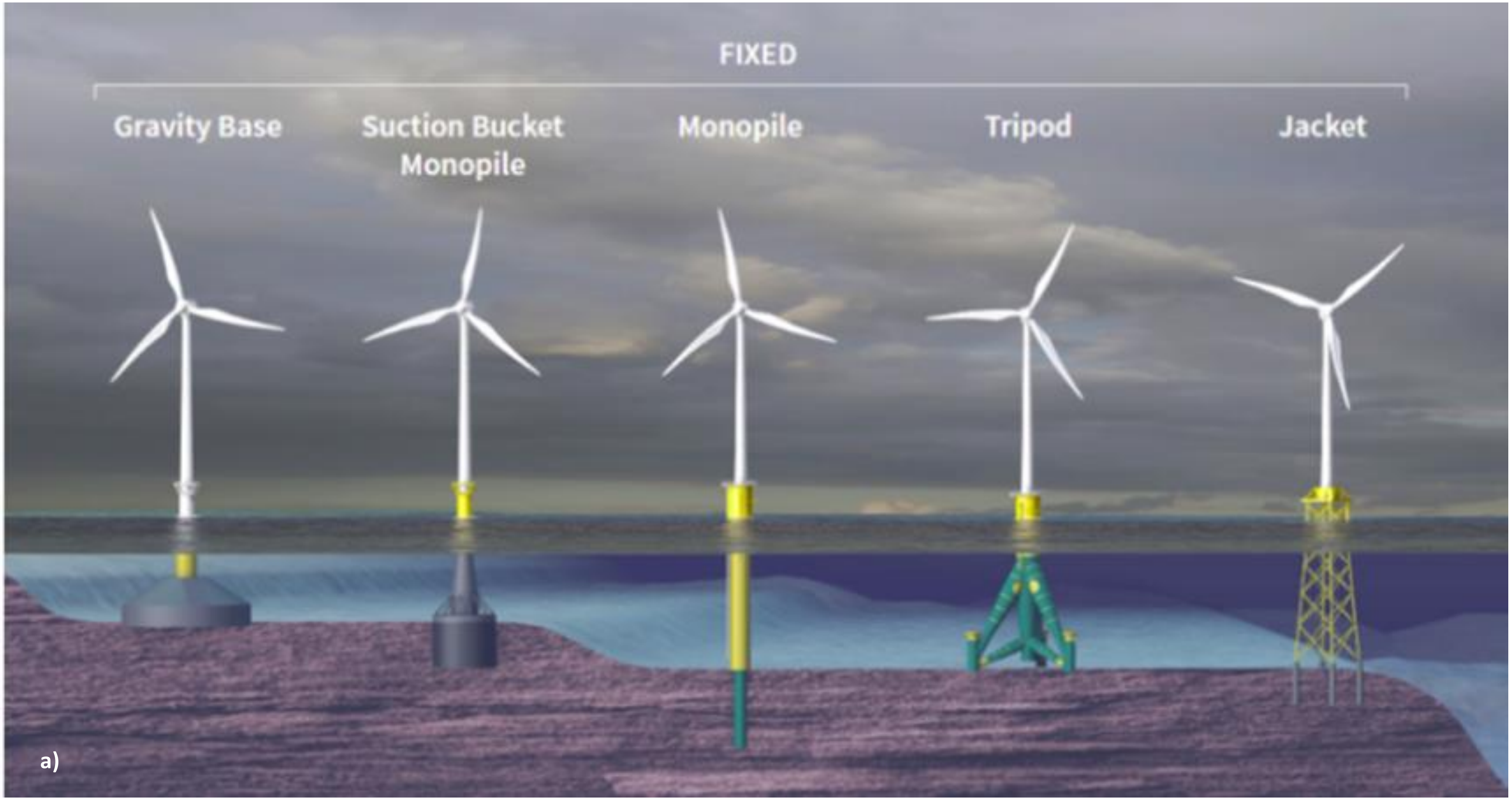


Figure 2.1: New offshore wind installations (MW) [66]

In the next ten years, Asia Pacific (APAC) will account for nearly half of all offshore wind installations worldwide. In fact, the most recent reports indicate there is a pipeline of offshore wind projects with a capacity of more than 180 GW outside of China and significant developments have been observed in several markets, including Bangladesh, Vietnam, South Korea, and the Philippines [66]. Due to the end of the feed-in tariff (FiT), China led the way in offshore wind development, but its new installations declined to 5 GW from 21 GW in 2021. The Chinese Taiwanese market (1,175 MW) and the Japanese market (84 MW) reported new offshore wind installations in Asia-Pacific last year. In 2022, there were no intertidal (nearshore) wind projects that achieved commercial operation in Vietnam [66]. Currently, Australia has a pipeline of 50 GW of offshore wind capacity, with Melbourne, in the state of Victoria, being considered the epicenter of the offshore wind industry in the country. With more than 30 GW of installed capacity, both fixed and floating, Europe occupies a leading position in this sector. A discussion of the status of Europe is presented below in section 2.1. As of the end of last year, North America had 42 MW of offshore wind installed, making up 0.1% of the total number of offshore wind installations [66].

As of 2022, Europe has connected 2.5 GW of offshore wind capacity, with France and Italy launching their first commercial offshore wind projects. Even though the rate of offshore wind installations last year was the lowest since 2016, Europe's total offshore wind capacity reached 30 GW, 46% of which comes from the United Kingdom. In 2022, Asia-Pacific is projected to install 34 GW of offshore wind capacity, displacing Europe as the world's largest offshore wind market [66].

In spite of this, Europe continues to lead the way in floating wind technology. Last year, Norway installed 60 MW of floating wind capacity, making the region's total installations 171 MW, equivalent to 91% of global installations, followed by Asia-Pacific (16.7 MW, or 9% of global installations). It is expected that a small number of 100-500 MW projects will be built successfully over the next five years. At present, the UK, Norway, Portugal, China, and Japan are the top five markets for total net floating wind installations. Although the global floating offshore wind pipeline has doubled in the past 12 months, topping 240 GW, GWEC Market Intelligence still estimates that floating offshore wind will not reach commercialisation until 2030. In light of the rising cost of floating wind power generation, the current challenging economic and financial conditions, and the anticipated bottlenecks in supply chains of floating wind foundations and port facilities, the global floating wind forecast has been revised to 10.9 GW by 2030, 42% lower than our previous forecast [66]. Figure 2.2 illustrates the foundations of OWT, both bottom-fixed and floating.


FIXED
Gravity Base
Suction Bucket Monopile
Monopile
Tripod
Jacket
a)

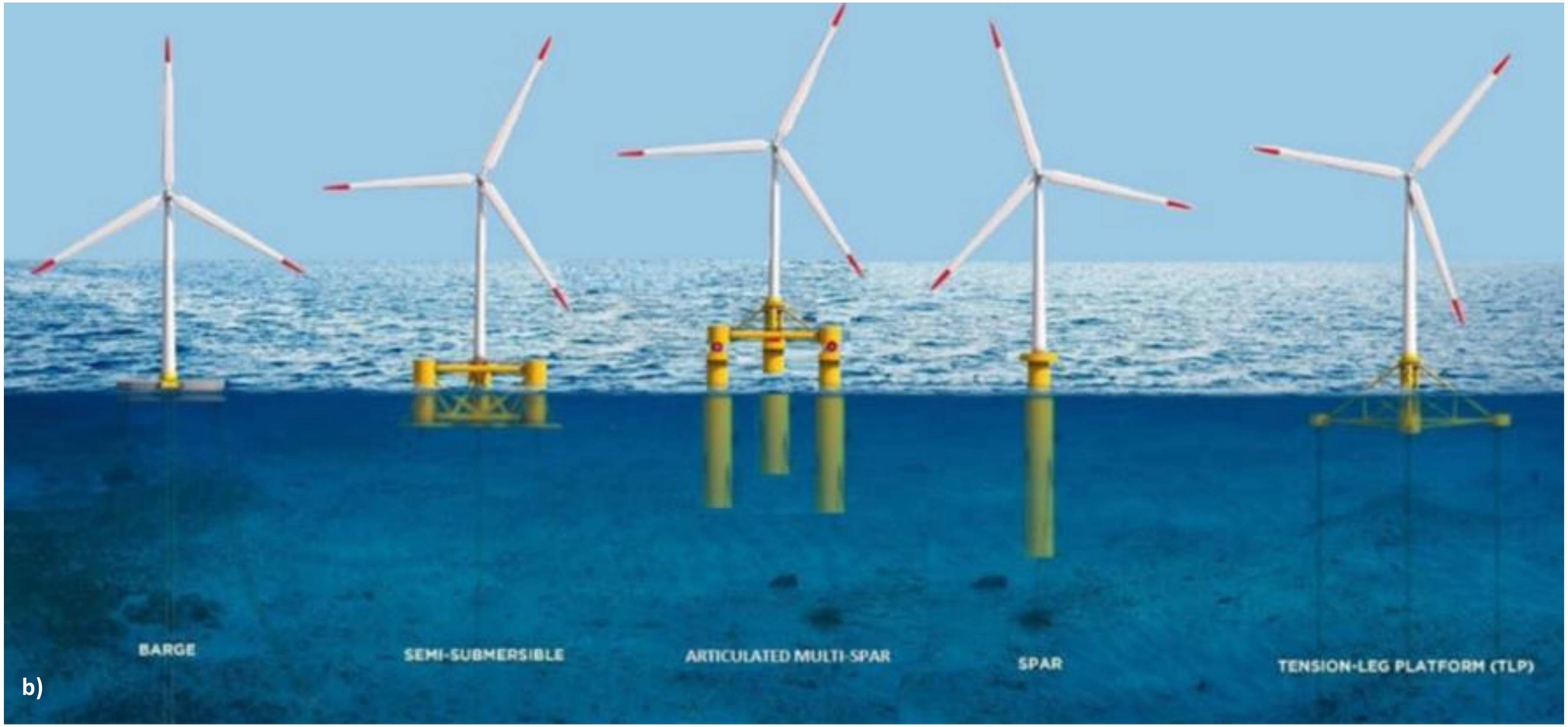


Figure 2.2: Offshore wind foundations a) Bottom-fixed and b) Floating [67][68]

2.2 Global offshore wind industry's policies

Several of the world's leading energy institutions have outlined scenarios that suggest achieving carbon neutrality by 2050 will require rapid and substantial growth in offshore wind installations. These include the International Agency Energy (IEA) and the International Renewable Energy Agency (IRENA). By 2030, the IEA expects offshore wind installations to grow ninefold, from 8.8 GW in 2022 to 80 GW by 2030, with 70 GW being deployed every year between 2031 and 2050. According to IRENA's latest 1.5C-compliant scenario, offshore wind capacity will reach nearly 500 GW by 2030 and about 2,500 GW by 2050. Around the world, there is a great deal of activity. By 2030, offshore wind installations will surpass the milestone of 30 GW and 50 GW. It is estimated that the sector will grow at a compound average annual rate (CAGR) of 31% until 2027 and 12% between 2027 and the early 2030s [66].

In order to achieve exponential offshore wind growth, several key elements must be in place. In order to achieve long-term climate (and offshore wind) targets, it is essential that the amount of seabed available for development is aligned with global long-term targets. As long as the leasing model succeeds, it will facilitate collaboration between the public and private sectors from the onset, as well as working in harmony with broader priorities, such as economic growth, social value creation, job creation, and energy security. To ensure that revenue for governments is not generated at the expense of consumers' energy costs or unsustainable pressure on supply chains, leasing frameworks should emphasize both the short-term and long-term impacts of lease fees and allocations. In order to streamline processes and improve efficiency, an independent leasing authority should take the lead in managing stakeholder conflicts and maritime spatial planning (MSP) concerns. It is necessary to obtain all the permits required before an OWF can be constructed [66].

The actual benefits of offshore wind can best be assessed from a holistic socioeconomic perspective. According to Figure 2.3, governments and the industry should work together to review market design and offtake mechanisms in order to ensure a balance between guaranteeing affordable energy, delivering wider socioeconomic benefits, and maintaining a sustainable supply chain. The industry will be able to overcome challenges and scale up with the help of incentive-based approaches, such as the long-term investment and tax credits provided by the USA's Inflation Reduction Act (IRA). Offshore wind also contributes to the creation of long-term, highly skilled jobs for society. According to the International Energy Agency, the clean energy sector will have a greater number of employees in 2022 than the fossil fuel sector. Due to the rapid growth in offshore wind deployment, there will be multiple opportunities for a diverse workforce on a local and national level [66].

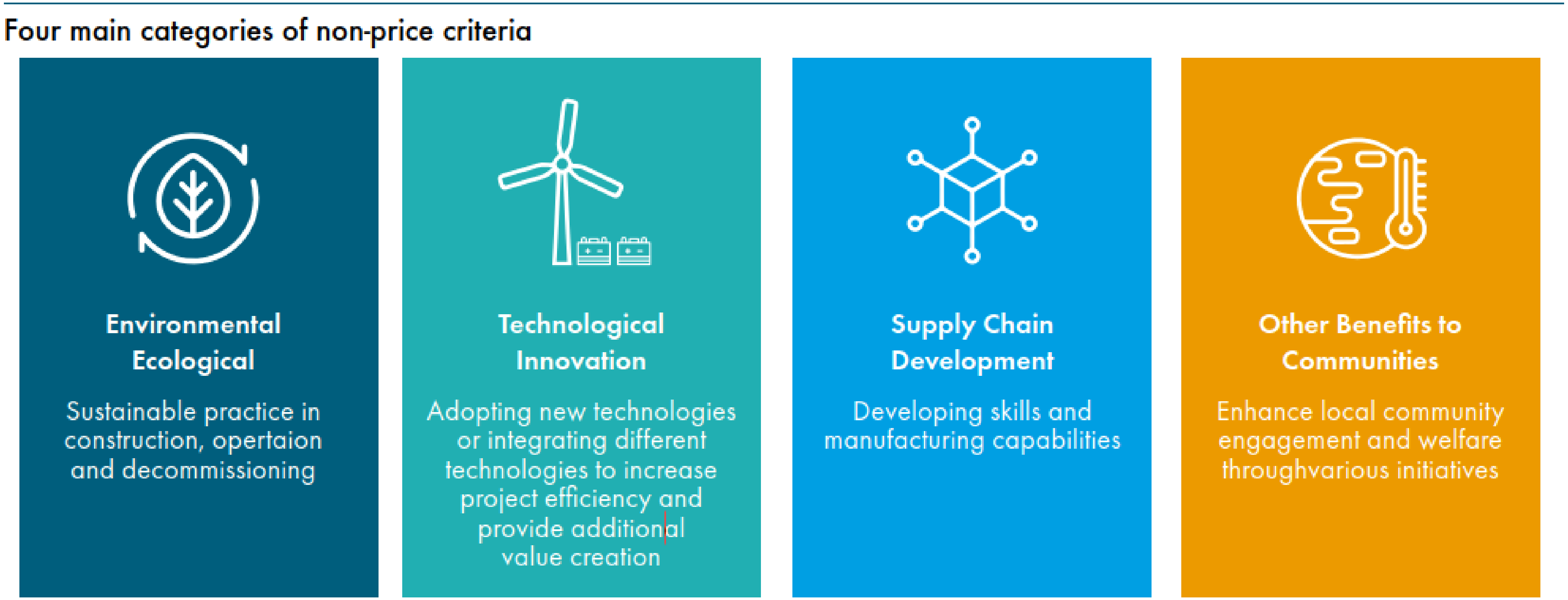


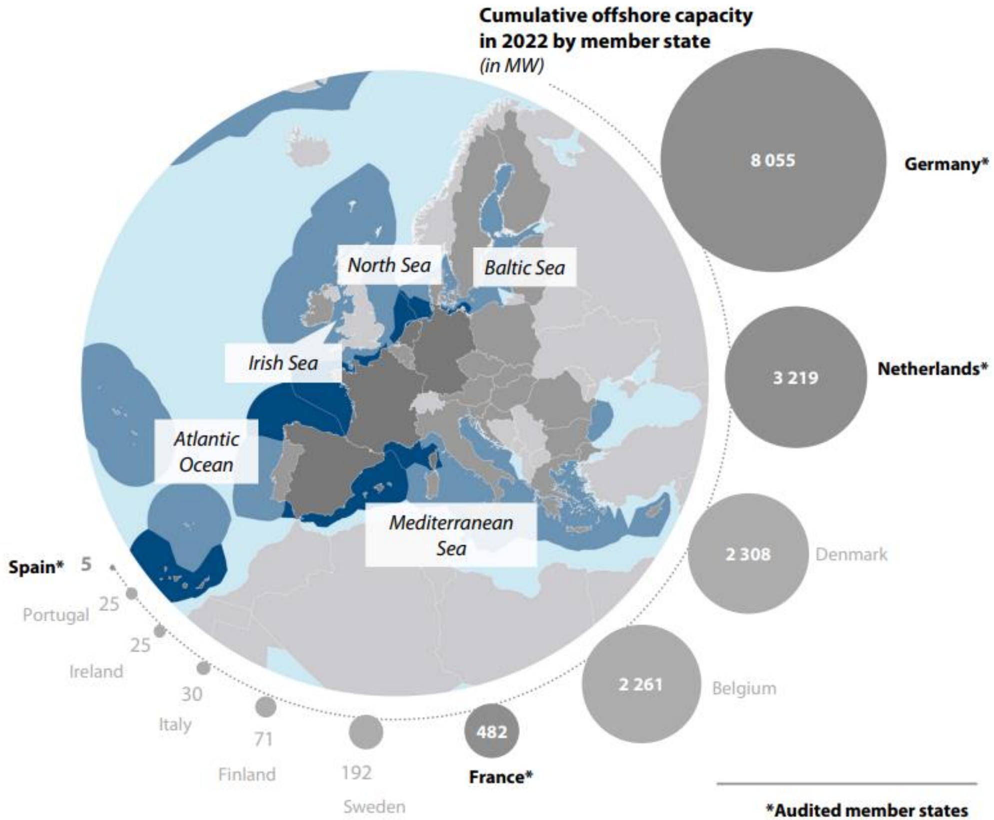
Figure 2.3: Four main categories of non-price criteria [66]

2.3 Status of offshore wind energy sector in Europe

By 2030, the EU aims to increase the share of RES in total energy consumption to 32%. It is expected that WFs will be installed in areas with a high wind potential in order to achieve this goal. The main sources of renewable energy generation in member states of the European Union (EU) are hydroelectric power (38.3%), wind energy (33.1%), solar energy (11.9%), and biomass (5.7%).

As of 2022, Europe has connected 2.5 GW of capacity, with France and Italy each commissioning their first commercial offshore wind projects. Despite the fact that the number of offshore wind installations last year was the lowest since 2016, Europe's total offshore wind capacity reached 30 GW, of which 46% comes from the UK. In 2022, Asia-Pacific is expected to have 34 GW of installed offshore wind capacity, displacing Europe as the world's largest offshore wind market [66]. In accordance with Figure 1.8, Germany, the Netherlands, Denmark, Belgium, and France are the leading countries in the sector, with the largest installed capacity of OWFs by 2022.

Floating wind is an emerging technology that is crucial for maximizing the offshore wind potential. However, Europe continues to lead the way in the development of floating wind. A total of 60 MW of floating wind capacity was commissioned in Norway last year, bringing the region's total wind capacity to 171 MW, accounting for 91% of the world's installed capacity, followed by Asia-Pacific (16.7 MW, or 9% of global capacity). It is possible for countries with deep seawaters, such as Greece and the rest of the Mediterranean countries, to use this technology to increase their renewable energy share and move away from coal and gas-based energy sources. An essential feature of floating wind is the capacity density and the Annual Energy Production (AEP) that could cover a large proportion of the electricity demand, thereby accelerating the transition from fossil fuels to clean energy. It is anticipated that only a few 100-500 MW projects will be successful over the next five years. According to current data, the UK, Norway, Portugal, China, and Japan are the top five markets for floating wind installations [66]. Figure 2.4 illustrates the cumulative offshore capacity by member states in 2022.



Note: The figure presents only those coastal member states which have installed offshore renewable energy capacity.

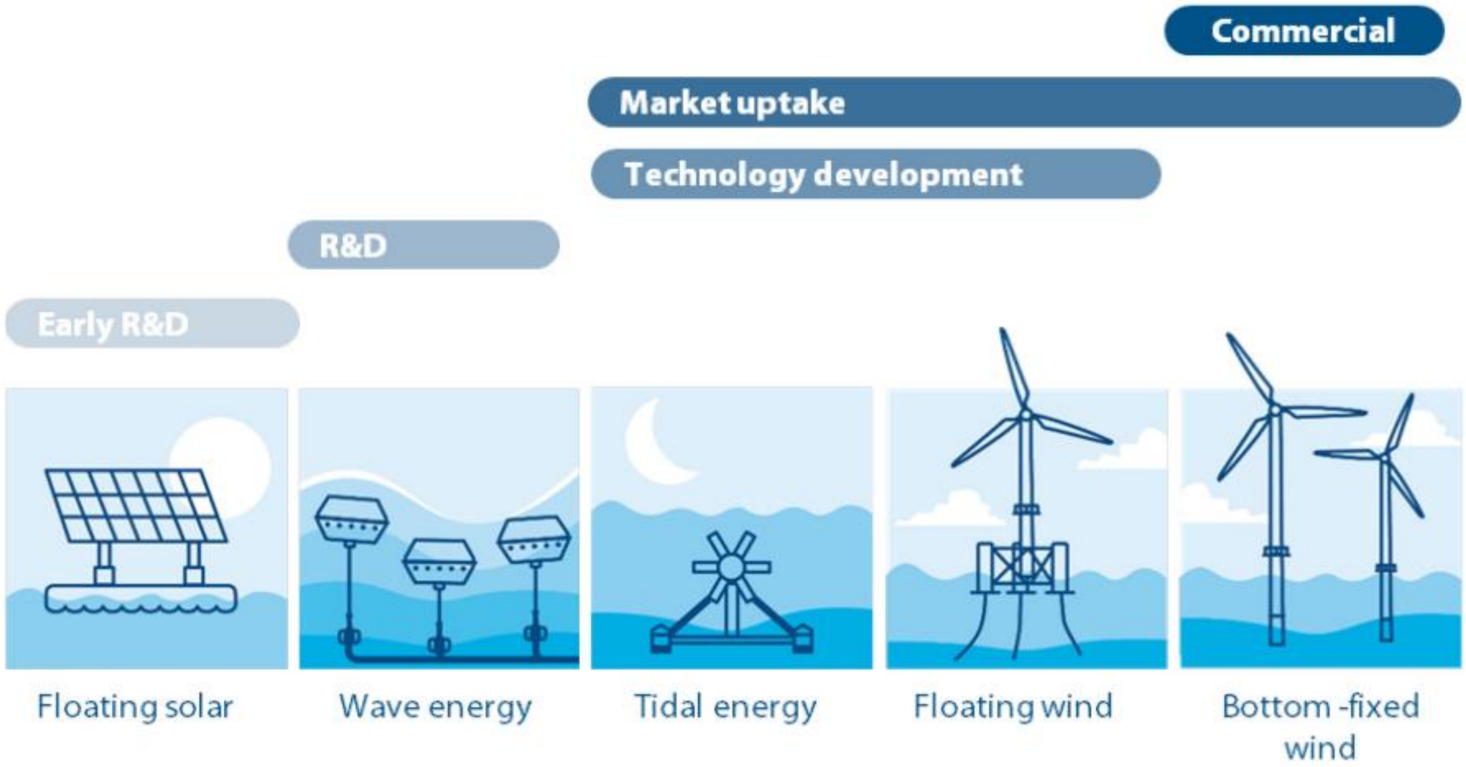
Source: WindEurope 2022 statistics.

Figure 2.4: Overview of offshore wind installations in EU [69]

2.4 Offshore wind industry's policies in Europe

Renewable energy targets have already been set by the EU for 2030, up to 32%, in order to limit the increase in global temperatures to 1.50C [70]. The development of national marine spatial plans is also underway [71]. In order to achieve climate neutrality by 2050 and combat biodiversity loss and pollution, the European Green Deal places energy transition at the center of the EU's efforts. It is necessary to increase the use of renewable energy in a sustainable manner in order to achieve these objectives. Among these RES, offshore renewable energy is expected to contribute significantly to achieving the objectives of the EU Green Deal [69].

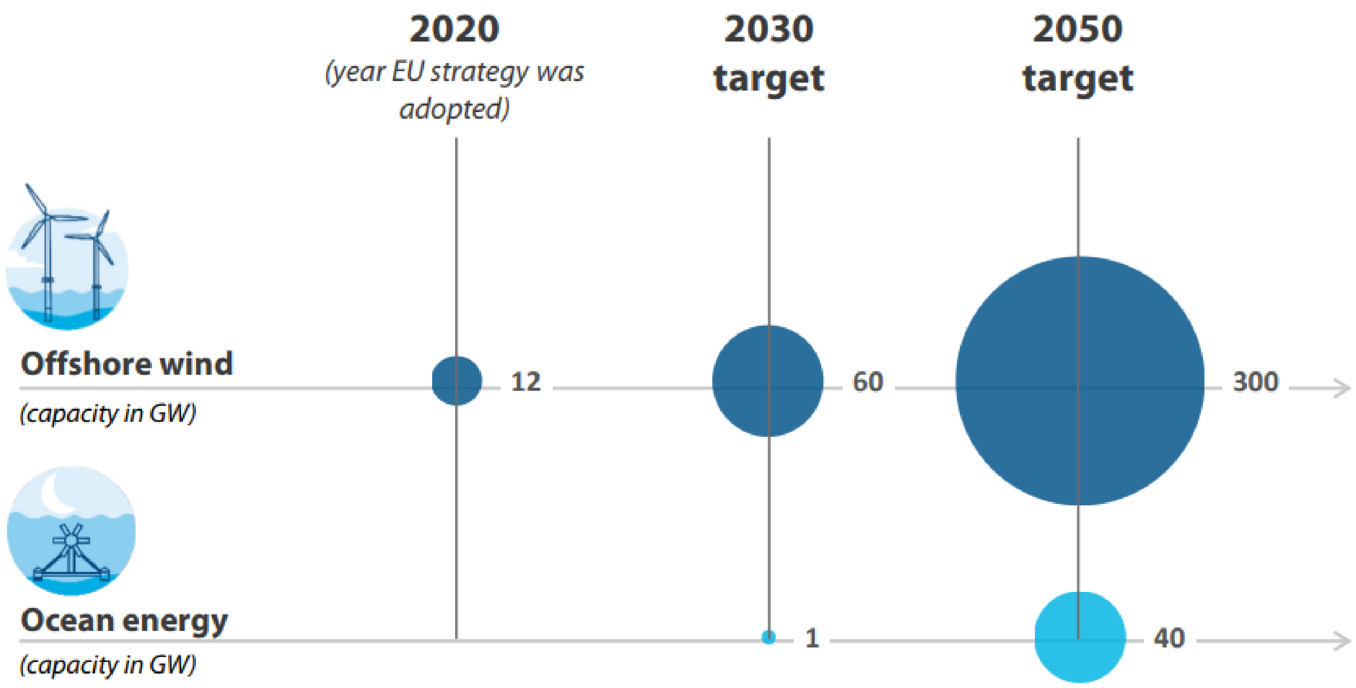
The European Commission adopted its offshore renewable energy policy in 2020 as part of its strategy to promote the sustainable development of offshore RES [72]. Figure 2.5 illustrates the offshore renewable energy technologies (RET), including floating solar, wave energy, tidal energy, and floating and bottom-fixed wind. As part of its objectives, it addresses long-term challenges such as the need for inclusive maritime spatial planning, improved regional cooperation, and environmental protection. There are specific targets in the strategy regarding the capacity of offshore renewable energy in the future. Energy and climate policies are formulated by member states through their national energy and climate plans, which were submitted for the first time in 2020 and will be updated in 2024 [69].



Source: ECA based on the EU ORE strategy.

Figure 2.5: Overview of offshore RET [69]

In the EU Strategic Framework on Offshore Renewable Energy, the goal of offshore renewable energy is 61 GW installed by 2030 and 340 GW by 2050, respectively, according to Figure 2.6. The three Member States we audited have the intention of implementing large-scale offshore renewable energy and intend to contribute significantly to EU-wide targets. Offshore wind development may be slowed by the recent surge in inflation, and annual deployment rates will have to increase significantly. It is not expected that ocean energy will be widely deployed commercially before 2030, and its contribution to achieving the 2030 renewable energy targets will likely be marginal [69].

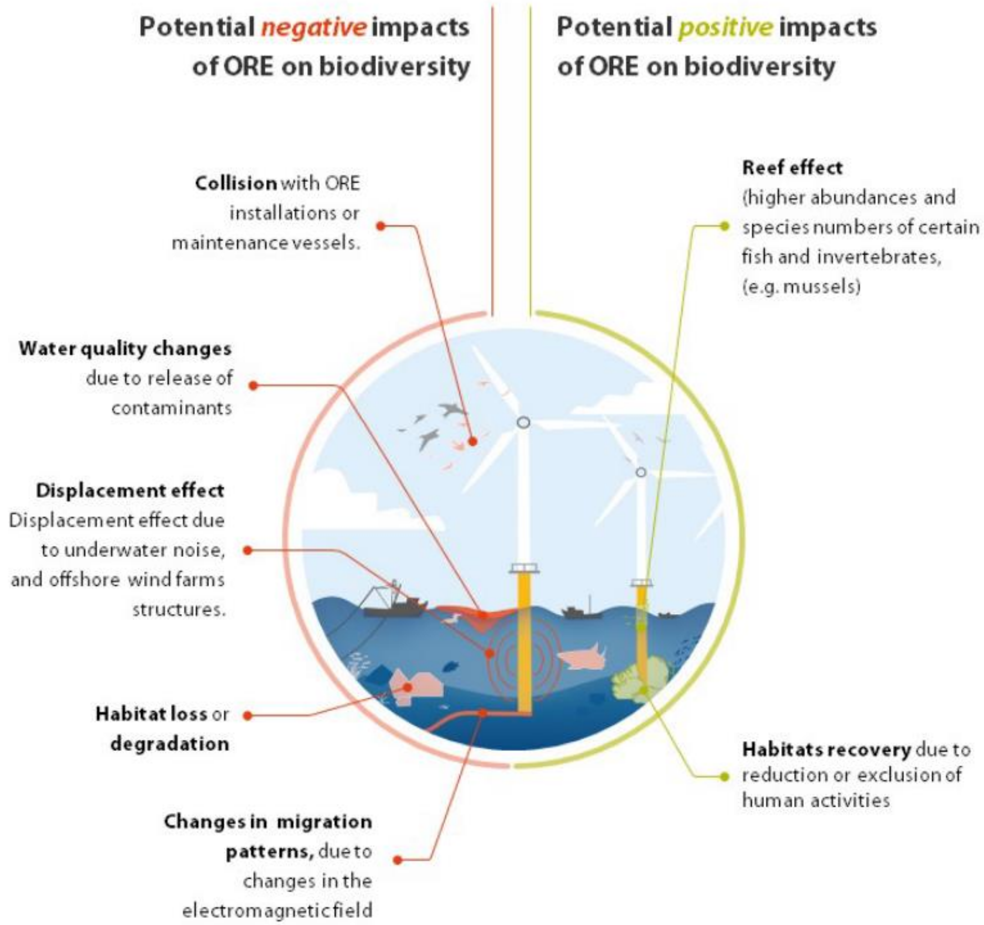


Source: ECA, based on the EU ORE Strategy.

Figure 2.6: Offshore renewable energy targets in the EU [69]

An important aspect of maritime spatial planning is the allocation of sea space for different uses while minimizing the adverse effects on the environment. During the development of offshore renewable energy resources, the Commission actively supported national authorities with maritime spatial planning. Co-using of the sea space is encouraged, however, the coexistence of different sectors with offshore renewables is not yet common practice: in particular, the unresolved conflict with fisheries in some countries will need to be addressed better [69].

A sufficient amount of research has not been conducted on the socioeconomic implications of offshore renewable energy development, such as skill requirements. Also, a number of environmental aspects linked to planned offshore renewable energy deployment have yet to be recognized and given the scale of the planned offshore renewable energy deployment in the coming years, the effect on marine life may be considerable [69]. As shown in Figure 2.7, there are both potentially negative and positive effects on biodiversity.



Source: ECA based on literature review.

Figure 2.7: Overview of the environmental impacts of OWFs [69]

The following Table 2.1 presents the offshore wind targets that the member states have defined for development by 2050.

Table 2.1: Offshore wind targets in EU[1] [66]

Unit (GW)	2027	2030	2035	2040	2045	2050
EU		>=60				>=300
UK		50				
Germany		30	40		>=70	
Netherlands		22.2		50		70
Denmark		12.9				
Belgium		5.7				
France			18			40
Poland	10.9*					
Norway				30		
Ireland		7				30
Spain		3				
Greece		2				
Portugal		10**				
Esbjerg Declaration		>=65				>=150
Marienborg Declaration		19.6				

[1] * Either in operation or under development by 2027, ** Capacity to be awarded through auctions, *** North Sea countries have set a joint target through the Esbjerg Declaration(Germany, Denmark, Belgium and the Netherlands), **** Baltic Sea counties have set a joint target through the Marieborg Declaration (Denmark, Germany, Estonia, Latvia, Lithuania, Poland, Finland and Sweden), ***** North Sea counties have set a joint target through the Ostend Declaration (Belgium, Denmark, Germany, Netherlands, France, Ireland, Luxembourg, Norway and the United Kingdom)

Ostend Declaration		120				300

2.5 Challenges in OWFs development

Large offshore wind markets face a common challenge of scaling up connections involving both the physical volume of offshore and onshore cables and the necessary infrastructure while reducing wait times. In spite of the fact that many large projects are likely to be located further offshore, grid connections may become a major bottleneck in the coming years. Several solutions are being explored, including energy islands, meshed grids, higher-capacity and superconductive cables. Offshore wind is fundamentally dependent on a reliable grid system [66].

The availability of equipment is also a critical issue. In many countries around the world, supply chains are stretched. As of 2027, it is anticipated that Europe's OWT nacelle assembly capacity will struggle to meet the demands of the growth expected within the European continent alone. There is a delicate balance between supply and demand for key turbine components in 2023-2025, with gaps expected to emerge in the second half of this decade if no further investments are made. Considering that China controls over 70% of the global market share for gearboxes, generators, slewing bearings, castings, forgings, towers, and flanges, restrictive trade policies proposed by the EU and the US are almost certain to create bottlenecks. To ensure the timely deployment of large OWT installation vessels (WTIVs) and a trained workforce with adequate operational knowledge, regional cooperation in the Asia Pacific region is necessary. Cooperation is particularly important in new markets such as India, the Philippines, Australia, and New Zealand [66].

Offshore wind is a fast-growing sector that faces many challenges and has a great future ahead of it. The floating offshore wind industry is still in its infancy and faces a steep learning curve as it looks to scale up from a handful of demonstration projects to gigawatt-scale projects. Offshore wind can make a significant contribution to the energy transition, and the industry has a great deal of ambition. A growing gap exists between stated targets and annual installations - and an even wider gap exists between the current rate of growth and 1.5C-compatible deployment volumes. As shown in Figure 2.8 [66], offshore wind energy is predicted to be a significant source of energy by 2050.

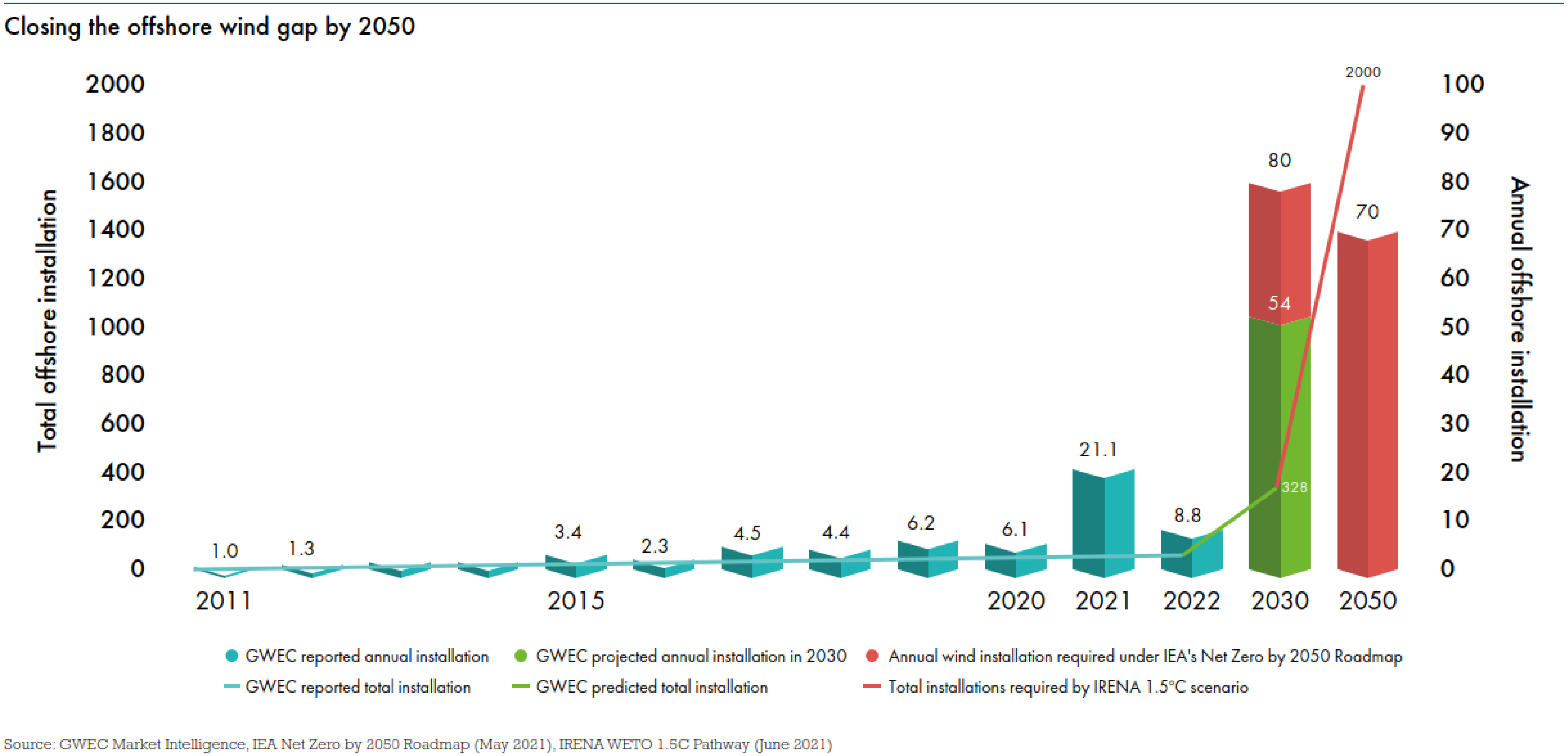


Figure 2.8: Projection of OWFs development until 2050 [66]

2.6 The case of Greece

The EU within the Framework of the European Agreement has already revised (2021) the targets for the integration of RES for 2030 from 32% (RE Directive 2018/2001/EU) to 40%, so that the global temperature is maintained in an increase of up to 1.5 °C [70]. At the same time, the national maritime spatial plans are being developed (Directive 2014/89/EU)[71], according to which, until 2021, all Member States had the obligation to present their own maritime spatial planning. In the context of decarbonization, RES are a unique solution for the dynamic energy independence of the islands.

The European Parliament has already issued (2022) its strategy for increasing OWFs, "A European strategy for offshore renewable energy (2021/2012(INI))"[73], as well as our country according to NECP (Official Gazette B ΄4893/2019) [74] has emphasized the importance of the development of OWFs ("priority will be given .., as well as OWFs with respective multiple combined benefits for the energy system, networks and the national economy (p 283)". Also, according to the announcement of the goals of the new proposed NECP (January '23), the rapid development of RES is foreseen and more specifically, the deployment of Photovoltaics (PV), wind offshore wind, with an addition of >12GW until 2030 and the exploitation of the remaining hydraulic potential of the country. Offshore wind is expected to reach 1.9 GW in 2030 and 17.3 GW in 2050 [75].

The development of OWFs is now a political priority, as they can contribute to decarbonization in accordance with the European Parliament (2022) [73], the NECP (Government Gazette B΄4893/2019) [74], Law No. 4951 (Government Gazette A 129/4.7 .2022)[76], the Regional Plan for Adaptation to Climate Change in Crete (RPACC of Crete) [77], and the new proposed NECP (October 2023) [75].

In addition, according to the new draft law of the Ministry of Environment and Energy (No. 55-Promoting the implementation of pilot projects of OWFs) provides for "1. The marine area extending south of the coastline of the Evros RU and north-northeast of Samothraki is designated as an area for OWF pilot projects with capacities up to 600 MW." [78].

Historically, the first attempt was made in 2010 when the Ministry of Environment and Energy selected 12 offshore wind sites for the development of offshore wind projects for the period 2012-2017: The selected sites were 1 Alexandroupolis, 2 Samothraki, 3 Fanariou, 4 Thassos, 5 North Limnos, 6 South Limnos, 7 Ai Stratis, 8 Kimi, 9 Petaliwn, 10 Karpathos, 11 Leukada and 12 Othones. The criteria that were set were five: 1.< 6 n.m (Territorial waters), 2.Depth <50m, 3.Exclude Natura 2000 sites, 4. Exclude military areas, shipping routes, underwater cables etc (all conflicting uses), 5. Minimise VI. Finally, the processes stopped then and no one project developed. The high offshore wind potential of Greece is presented in Figure 2.9, according to the global wind atlas [79].

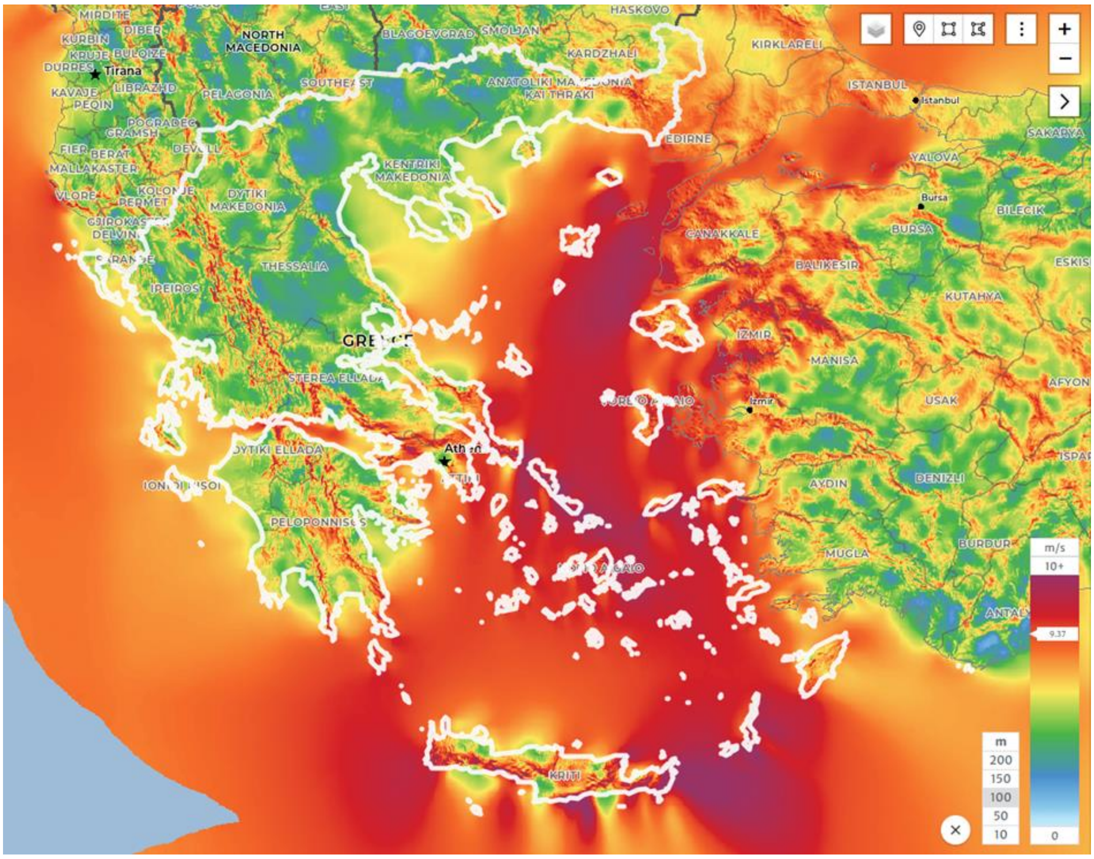


Figure 2.9: Offshore wind potential in Greece (m/sec) [79]

After that, a more vital attempt began, on September 29, 2023, the National Development Program of OWFs [80] and the Strategic Environmental Impact Study [81] were published for the locations that, according to the Ministry of the Interior, the OWFs are located throughout Greece, where 10 potential POAYAPs emerge for development in the medium term with a total area of 978 km2 and an estimated power of approximately 4.9 GW and are as follows:

- Three (3) potential POAYAPs for the location of a fixed NPP location (Diapontia islands, Crete 2a and Patraikos, with a total estimated power of 1,165 MW) if there is available electricity grid capacity at nearby interconnection points
- Seven (7) potential POAAP for siting a floating hydroelectric power station (total estimated power of 3,725 MW).

In the long term, there are 13 potential POAYAPs with a total area of 1,381 km2 and an estimated power of approximately 6.9 GW and they are as follows:

- One (1) potential POAYAP for the siting of a fixed installation of the YAP (Ag. Efstratios 1a, total estimated power of 250 MW)
- Twelve (12) potential POAYAP for siting a floating storage facility (total estimated power of 6,655 MW).

Concerning Crete Island, the areas where the first facilities will be built, where it is planned to install a total of 800 MW, the 600 MW in the northeastern part of the island between Ag. Nikolaou and Sitia and the 200 MW east of Sitia, according to authoritative publications Figure 2.10.

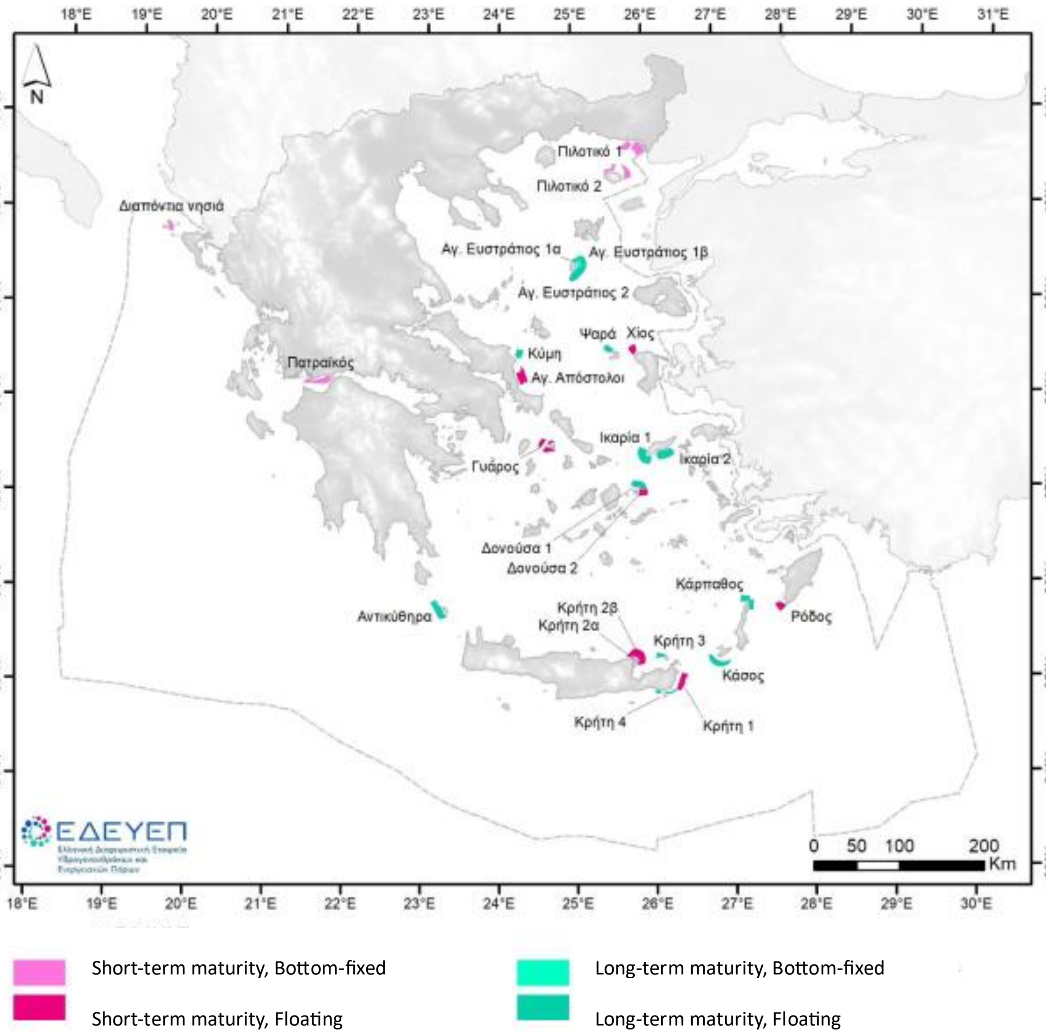


Figure 2.10: Potential sites for offshore wind development, Greece [80]

2.7 Study area

The island of Crete was chosen as a study area due to its unique characteristics and high wind potential, both on land and in the sea area around it [62]. The total area of the island is approximately 8336 km2, with a coastline of 1046 km Figure 2.11. Today, the local inhabitants of the island number over 600,000, a number that usually doubles during the tourist season [82].

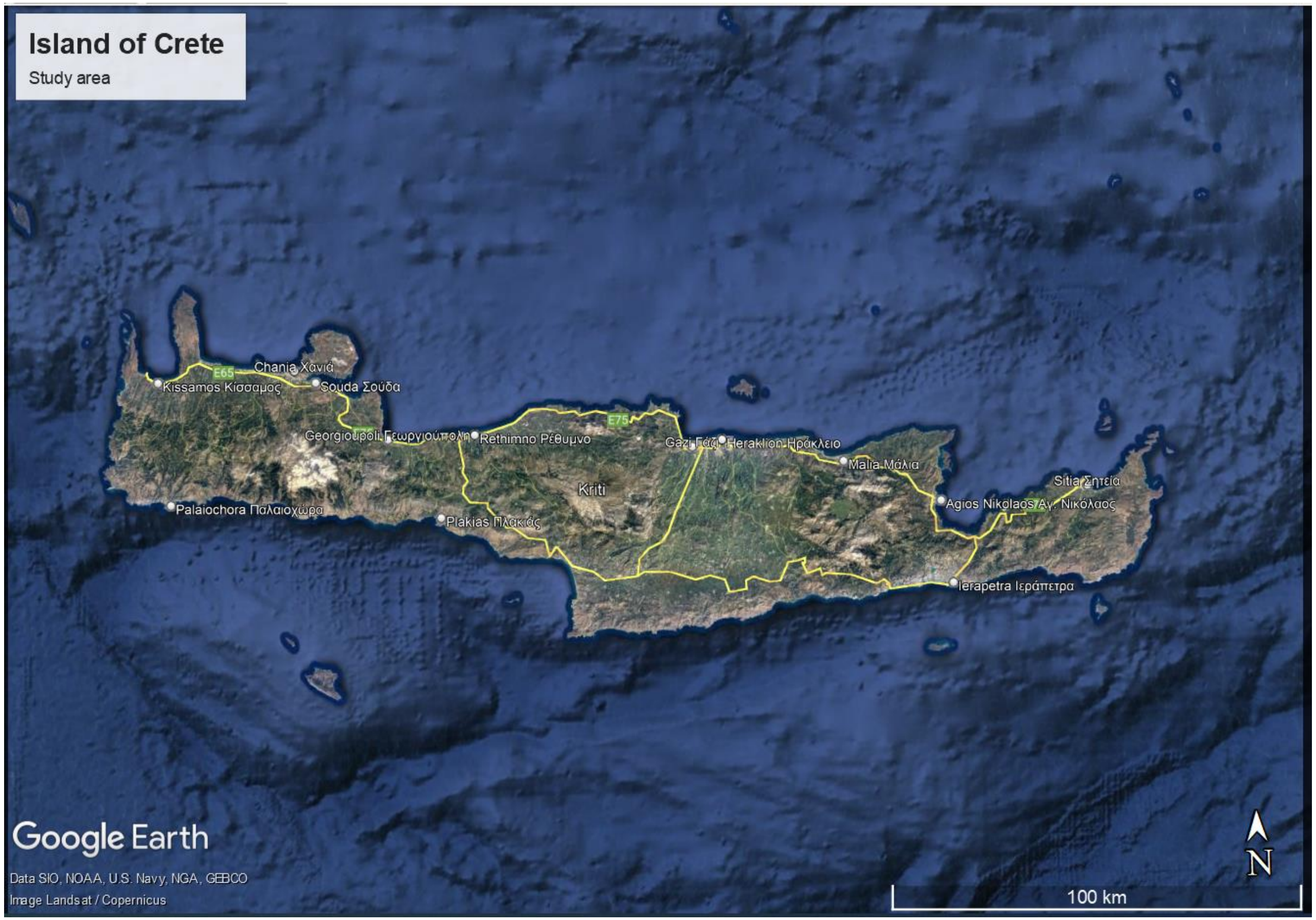


Figure 2.11: Study area, Island of Crete, Greece

Also, it is worth mentioning that on September 29, 2023, the Strategic Environmental Impact Study was published for the locations that, according to the Ministry of the Interior, the YAP are located throughout Greece, with a marking of the areas where the first facilities will be built, where it is planned to install a total of 800 MW, the 600 MW in the northeastern part of the island between Ag. Nikolaou and Sitia and the 200 MW east of Sitia, according to authoritative publications. After the positions were officially announced, they were taken seriously in the context of the present research program.

Regarding the electrical interconnection of the island, according to what is mentioned in section 3.8.15 of the approved DPA of the ESMIE period 2022-2031 (related 24), the Crete-ESMIE interconnection takes place in two phases as follows:

- Phase I: EP interconnection 150 kV, nominal capacity 2 x 200 MVA (Crete - Peloponnese), which has been completed and

- Phase II: SF Interconnection with a nominal capacity of 2 x 500 MW (Crete - Attica), which is expected to be completed in 2024.

According to information published on the website of ADMIE S.A. (data up to March 2022), the total installed power of the operating RES Stations in Crete and the corresponding power of the RES with the issue of a Final Connection Offer (FCO), are distributed as follows [83]:

In operation:

· 210 MW of wind power

· 102.3 MW of PV

· 0.3 MW MUSCLE

With FCO:

· 3.6 MW of wind power

· 2.2 MW of PV

· 3 MW Biomass/Biogas

· 70 MW Solar Thermal Station

Crete's first phase of interconnection with the continental network has been completed, a constant hourly load of the AC interconnection (Phase I) equal to 180 MW is considered, while after the completion of the second interconnection (Phase II, where it will be completed in 2024) it is assumed that the entire load of Crete is taken over by the continental system, without the contribution of local thermal production units in Crete Figure 2.12. Finally, in accordance with the provisions of article 100 par. 4 of Law 4821/2021, as applicable [83]:

1. The power margin of RES projects in Crete after the completion of Phase II Interconnection with the ESMIE is determined dynamically with the following formula:

$$\mathrm{RES}_{\mathrm{total\ margin}} = \mathrm{RES}_{\mathrm{margin}} + 1{,}5 * \sum_{i} \mathrm{Astorage(i)}$$

with $\boldsymbol{REStotal\ margin} \leq \boldsymbol{REScap}$

Where:

- $\boldsymbol{RESmargin}$: has the value of 2150 MW, on which the provision of paragraph 5 of article 100 of Law 4821/2021 is understood.

- $\boldsymbol{ASTORAGE(i)}$, of a station (i) is, as the case may be,

  - the maximum power absorption of a pure electricity storage station (including pumped storage) and/or
  - the maximum absorption (storage) power of a station in paragraph 11B of article 79 of Law 4951/2022 and/or
  - the installed storage capacity (absorption/pumping) of a hybrid station, which is taken into account when granting connection conditions by the competent Administrator

-$\boldsymbol{REScap}$: is the maximum value, which cannot exceed the limit of 2500 MW.

It is clarified that $\boldsymbol{RES}$𝕕$\boldsymbol{Qtal\ margin}$ includes the following categories:

- The installed capacity (existing and new) of RES units of all categories of RES stations (solar energy, wind energy, hydroelectric energy, energy from the oceans, geothermal energy, biomass and biofuels, etc.).
- The installed power of RES units from the stations of paragraph 11A of article 79 of Law 4951/2022,
- The installed capacity of RES units from the stations of paragraph 11B of article 79 of Law 4951/2022,
- The guaranteed power of hybrid stations.

2. The value of the maximum RES cap limit, included in the dynamic formula for determining the power margin of RES projects in Crete after the completion of Phase II of its Interconnection with the ESMIE, will be reviewed within three (3) years from the commissioning of Phase II of the interconnection of Crete.

Figure 2.12: Electrical interconnectivity of Crete [83]

Therefore, as the energy needs of the region during the summer are demanding due to tourism [84], the electrical interconnection of the island with the mainland system will offer many advantages with increased possibilities of penetration of RES, which could be developed and to contribute to the energy mix [85]. This combination creates an opportunity to develop a methodological approach for the assessment of potential marine areas, aiming at the sustainable siting of OWFs.

This study examined two sub-areas of the island in the second phase, namely Agios Nikolaos, in Eastern Crete, and Gulf of Kissamos, in Western Crete, for assessing the VI of potential OWF locations. The following Figure 2.13 depicts these areas.

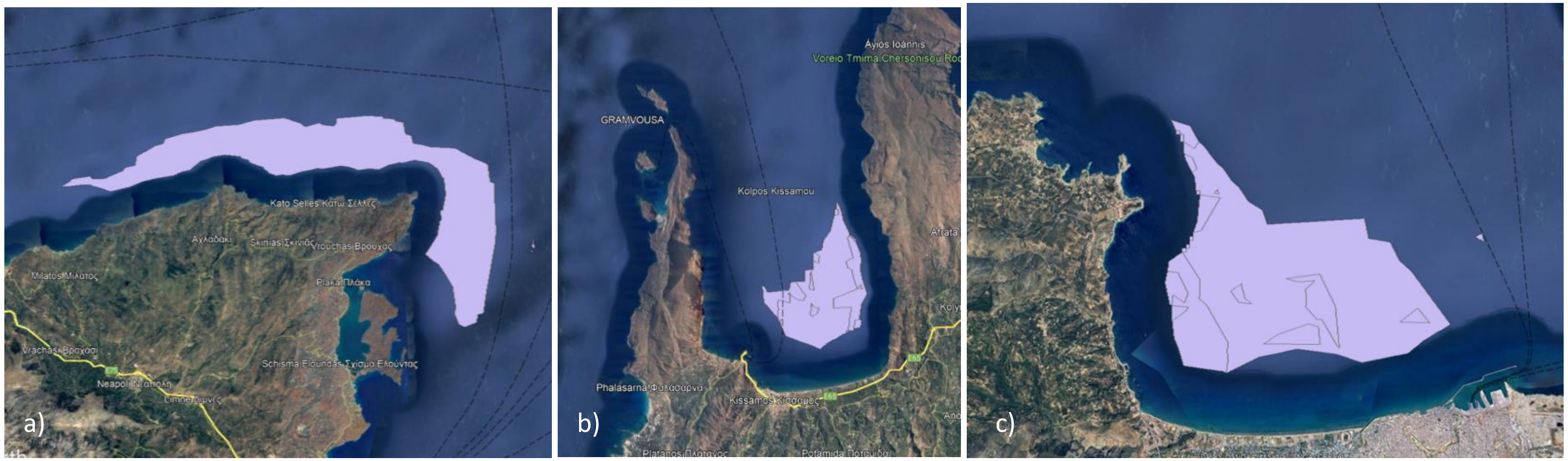


Figure 2.13: Study area, a) Agios Nikolaos, Eastern Crete and b) Gulf of Kissamos, Western Crete, c) Heraklion [86] [87]

3. State-of-the-Art

3.1 Sustainable siting of OWFs

3.1.1 Use of GIS and MCDM methods for optimal siting of renewable energy installations

Mahdy and Bahaj [88] proposed a methodology based on a more accurate identification of offshore wind energy potential sites. They combined AHP, GIS, and pairwise comparison methods. Their results showed that Egypt could "catch" the national energy targets, producing 33 GW of offshore wind power.

Vasileiou et al. [89] used a GIS-based AHP method to identify the more suitable Greek offshore areas for deploying hybrid OWFs and wave energy. Initially, they excluded the problematic marine areas based on specific criteria, and then they evaluated the remaining areas based on the AHP method. Their study resulted in really worth mentioning marine areas for siting of OWFs, in Greece and more specifically in Crete and in the north-central to the central Aegean Sea.

Similarly, Loukogeorgaki et al. [90] realised a similar study about the same type of optimal siting, but with the addition of an environmental assessment. This study showed that the criteria of wind velocity, wave energy potential and environmental performance value were the most critical in siting of hybrid OWFs and wave energy production.

Christoforaki and Tsoutsos [62] deployed a 3-step methodology, which consisted of the exclusion of inapplicable areas, the evaluation of environmental constraints, and finally, the electricity demands and the wind potential of west Crete. Finally, they suggested a sustainable example for the Mediterranean Sea area and a useful tool for policymakers to develop OWFs in Greece.

Furthermore, Giamalaki and Tsoutsos [84] demonstrated a methodology for the optimal siting of solar power plants, using GIS and AHP, introducing the relative weights from the related experts' views. As for the optimal wind siting, Hofer et al. [91], suggested an approach utilising AHP and GIS, incorporating the feature of social acceptance by calculating the relative importance from experts' opinions. These two approaches above could give a more realistic objectivity/scope to the relative weights and afterwards to the final prioritisation of criteria and the results' areas.

Similarly, Latinopoulos and Kechagia [92] developed land suitability based on different siting criteria, spatial analysis, GIS, and MCDA. The proposed decision tool could recognise the most suitable areas for WF siting, along with the provision of relevant support to potential project planners.

Additionally, Sánchez-Lozano et al. [93] used a combination of Fuzzy AHP, Fuzzy TOPSIS and GIS, in order to opt for the most appropriate location to install onshore WFs. They considered vital importance technical criteria as well as the experience of a group of experts. The study area was the coast of the Murcia Region, in the Southeast of Spain.

Moreover, Cradden et al. [94] concentrated on the site selection of offshore combined platforms, mainly in larger geographical marine areas, in Europe. They concluded that the best locations are in Northern and Western Europe due to high wind potential and "good" depths.

However, there are indeed impediments due to the difficult access and construction of installations in these marine areas.

Argin et al. [95] investigated the potential offshore wind energy potential of Turkey, due to the large surrounding marine areas of the country and in order to meet their energy targets' policies. Their emerged areas showed that the potential offshore wind power capacity was about 1,629 MW.

Concerning wave power development, Flocard et al. [96] presented a geospatial MCDM approach to indicate the most suitable sites to deploy wave energy installations farms, with a parallel target of achieving the marine co-existence of the different marine activities. All different models implemented produced a highly suitable area of 700 km2 off the coast of Portland.

3.1.2 Overview of the selected criteria of offshore wind and wave renewable energy installations

A literature review on the siting criteria has been conducted. In more cases, these criteria were grouped into two main categories, the exclusion and the evaluation. The former group targets to exclude the forbidden areas due to legislation or other unviolated factors. The latter group aimed at evaluating the remaining suitable areas from the previous step, into a range of values.

Vasileiou et al. [89] excluded the military areas, the licensed hydrocarbon areas, ones that have been planned for similar installations, the environmental areas, and the techno-economic criteria, concerning the wind speed, the depth, the wave potential, and the distance from shore. Furthermore, they evaluated the last four aforementioned techno-economic criteria and the connectivity to the electric grid, the population served, the shipping density and the distance from the ports. Wind velocity, wave energy potential and water depth acquired the highest relative importance.

Wu et al. [97] excluded four essential criteria such as the military areas, the shipping routes, the existing engineering infrastructures, and environmentally protected areas (EPA). Subsequently, they set as evaluation 22 criteria, grouped into six main categories with respect to the economy, wind resources, technical constraints, the environment, society, and construction/maintenance. Through the implementation of the proposed intuitionistic fuzzy ELECTRE-III method, they managed to eliminate the likelihood-based valued comparisons, along with the imprecise decision information.

Similarly, Wu et al. [98] defined as exclusion criteria (EXC) the military, the protected and the operation marine areas and as evaluation 18 criteria, related to the economy, the environment, society, wind potential, potential risks, and construction constraints. In the same way, they developed the PROMETHEE method under the intuitionistic fuzzy environment intending to reduce the loss of decision information.

Vagiona and Kamilakis [99] considered as EXC, the water depth, the wind velocity, the distance from protected environmental areas, and the safe distance from cities and settlements. As EVC, they considered wind velocity, population served, shipping density, and distance from protected environmental areas. Their results indicated two marine areas at a very close distance from existing onshore WFs or WFs under examination.

Loukogeorgaki et al. [90] in the first stage of their research, realised three categories of EXC concerning a) the co-existence of different marine activities, b) techno-economic constraints, and c) social constraints. Subsequently, they evaluated the wind and wave energy potential, the water depth, the distance from shore, the shipping density, the distance from ports, the grid connection, the population served, and the potential environmental impacts from the installations. The results of their study, as referred above, showed that the criteria of wind velocity, wave energy potential and environmental performance value were the most important.

Stefanakou et al., [100] excluded the four criteria described in (the Ministry of the Environment and Energy (Greece), 2010) and they also set as EVC further nine, dealing with spatial, social, techno-economic, and environmental aspects. This study proposed a tool for the decision-makers to find the most suitable areas, mainly for the siting of FWTs, but also for each marine renewable energy system in Greek marine areas, with the integration for a variety of exclusion or/and EVC.

Sourianos et al., [101] divided the siting criteria into three categories, the exclusionary, the mitigable, and the constraints. This means, for example, that an exclusionary criterion might be a constraint over or under a specific limit. On the other hand, the mitigable criteria could take different values, in accordance with the authors. Actually, they developed a software tool that could be a valuable decision support system for the relevant stakeholders and decision-makers, for the development of OWFs.

Furthermore, Kim et al. [102], evaluated the surrounding marine areas of Jeju island for installations of OWFs based on four scenarios with different combinations of siting criteria, as referred above. Kim et al. utilised the siting criteria divided into four main categories, which consisted of social and environmental constraints, wind energy, water depth, and connectivity to the electric grid. The number of candidate OWF areas was significantly smaller, in relation to the scenarios for only energy resources and economics were evaluated. This contribution could also reduce the conflicts between the competent authorities and eliminate the environmental impacts, too.

Finally, as for the study of Fetanat and Khorasaninejad [103], they focused on numerous criteria, (thirty-one), divided into six principal groups such as the characteristics of waves, the environmental constraints, the proximity to other important facilities, economic indicators, multiple technical factors and resources and, cultural aspects, related to social acceptance. The results of this study indicate the robustness of their methodology when the experts' opinions are subject to the criteria change. Also, this method could be applied to other coastal areas to promote the Integrated Coastal Management towards the goal of sustainability.

3.1.3 OWF market progress

During the last decade, 75 % of the global offshore installed wind power has been developed in Europe, as in 2019, there was installed 22 GW rated power totally, out of 29 GW worldwide. 116 wind parks have been already installed in 12 EU Member States, and 5,402 WTs have been connected to the electricity grid by 2020 [104].

The majority of installed capacity is located in the Baltic Sea, which is characterised by shallow waters. This fact allows the development of Bottom-Fixed Wind Turbine (BFWTs) in broad areas and, often, at a great distance from the coast, where the offshore wind potential is higher. However, even in shallower waters such as the Baltic Sea, there are marine areas with high wind potential, where BFWTs are difficult to be installed [105] since they have the limitation of a maximum depth of 50 m.

The technological development allows the installation of wind parks at depths > 50 m, using floating platforms. FWTs exploit the current experience of bottom-fixed WFs, along with the floating hydrocarbon extraction platforms [105].

By 2020, 62 MW of FWFs have been developed in Europe. At the same time, by 2023, it is estimated that an additional capacity of 251.5 MW will be installed. During the next decade, a total additional installed capacity of 7 GW is estimated to be installed, too [104]. These platforms are more flexible in terms of maximum installation depth, unlike BFWTs, as they can be installed at a depth of up to 1000 m.

In addition, the installation of FWFs provides reliable solutions to the lack of landing for siting onshore WFs, due to the numerous spatial constraints. Moreover, studies have shown that a major number of people questioned are in favor of the development of offshore wind energy, regarding climate change mitigation and reduction of greenhouse gases. Also, they support that the creation of new jobs will play a vital role in the local community. Finally, they consider that an OWF would have a minimum impact on the environment, tourism and generally on the whole seascape [106].

Furthermore, in relation to the fixed-bottom OWFs, FWTs also give alternatives to the problem of limited shallow waters, especially in the Mediterranean Sea. Table 1 shows the available offshore wind potential in the marine areas where FWFs could be installed.

According to NREL, in 2018, the reduced energy cost of FWFs was \$ 132/MWh for a 5.5 MW WT, while it is estimated that in 2030, the reduced energy cost will be reduced to \$ 51/MWh, due to technological development, supply chain improvement and increased competition. At the same time, the reduced energy cost for fixed-bottom offshore wind parks in 2018 was \$ 89 / MWh [107].

There are 4 different bearing floating platforms currently used, which are: Semi-Submersible, Spar Buoy, Tension Leg Platform (TLP), and Barge [104], and they are presented in Figure 2.2.

Finally, the optimal siting of FWFs is also related to the not-in-my-backyard effect Not In My Backyard (NIMBY) [108]. It is a contributor that has to be taken into account in the planning process of the project. However, the positive aspect of FWFs is that they are located far away from the coast (maybe many km in some cases), so the not-in-my-backyard effect has the minimum consequences in relation with other RET.

3.1.4 Relevant research

In Asia, Gavériaux et al. [109] considered the installation of bottom-fixed OWTs in Hong Kong Bay, using the same GIS and Multicriteria Decision Making (MCDA) methodology but also implemented different MCDA scenarios and, finally, a cost analysis. Kim et al. [110] reviewed the economic, social, and environmental restrictions in relation to the economic analysis of results of the selected areas for OWF development. Kim et al. [111] identified an OWF siting methodology and assessed eligible OWF sites in the area of Jeju Island in South Korea. They grouped the EVC into four categories. Wu et al. [40] developed an evaluation strategy for offshore wind site selection, providing a theoretical framework for the OWFs deployment in China. Besides, Obane et al. identified areas for potential offshore wind development, by dividing the areas into zones of major, moderate and minor conflict areas, according to the relevant limitations (ships, fishery, territorial waters etc). They showed that only 2 % of Japanese territorial waters are of minor conflicts [112]. Lo et al. [113] created a grey-based decision-making model for OWF site selection and made a case study on Taiwan's western coast, implementing the MCDM methodology to find the most suitable location for the development of an OWF.

In the Atlantic region, Schallenberg-Rodríguez et al. [112] examined different techno-economic scenarios and indexes using both types of OWTs (fixed-bottom and floating). Also, they used GIS software to export the relevant maps. Similarly, Laura Castro-Santos et al. [114] used the two types of OWTs. They developed a methodology of a planning tool for the installation of marine renewable energy systems, using GIS as a necessary tool/software for this purpose. In parallel, Diaz et al. [115] studied the shores of the Atlantic Ocean and, more specifically, the coasts of Portugal, Spain, and France, as well as the Madeira Islands. A similar methodology was applied in both studies based on the initial exclusion of non-suitable areas and then, based on EVC, the determination of the most suitable areas, which ultimately correspond to 0.2 % of the under-consideration area in the first case and only three eligible areas in the second study.

Cradden et al. [116] used GIS and various criteria to find optimal locations for FWF development around Europe and, more specifically, in the Atlantic and the North Sea. They also used 3 different models of wind and wave energy platforms for their scenarios.

The following study concentrated on the North Sea area, UK Continental Shelf, too. Loughney et al. [117] studied the installation of FWTs on the northern coast of Scotland, using a Multiple Attribute Decision Analysis algorithm to define the most suitable locations.

In the Baltic, according to a similar study, Ziemba et al. [118] developed a methodological framework in order to examine OWF locations in Poland, using the PROMETHEE for Sustainability Assessment (PROSA) method. The results showed that the built ranking is less sensitive to changes in criteria weights, so it is more stable in relation to the PROMETHEE method.

Additionally, the following studies examined study areas in the Mediterranean and the Black Sea. Argin et al. [119] studied the potential offshore wind energy of Turkey in the Mediterranean Sea, using MCDM methods and incorporating various environmental/technical and economic criteria. They concentrated on the use of BFWTs. Emeksiz end Demirci employed 10 multiple site selection criteria for an AHP at 31 coastal regions in Turkey with an estimated total capacity of 9 GW [120].

Several studies have been implemented in Greece. Christoforaki and Tsoutsos [62] studied the area of Chania in Crete and developed an assessment methodology and prioritisation of available areas for the installation of fixed-bottom OWFs using GIS. These areas for location were identified and then evaluated based on criteria.

A similar methodology was also followed by Gkeka-Serpetsidaki and Tsoutsos [6], who examined the territorial waters of the whole island of Crete. After identifying the available areas and during the stage of EVC, the factor of the relevant weights was introduced, which was determined by the stakeholders through MCDA. The analysis was performed based on the AHP method and was based on the completion of questionnaires by stakeholders. The addition of this parameter significantly affected the assessment.

Vasileiou et al. [121] also studied the siting of FWFs in combination with the production of wave energy. During this research, the entire Greek Exclusive Economic Zone (EEZ) was studied. Initially, areas were excluded due to limitations such as protected areas, areas for military exercises, low average wind velocity, etc. Afterwards, the remaining areas were assessed based on economic, techno-economic, and socio-political criteria. The assessment took into account relative weights for the EVC, which were determined similarly using MCDA as the research of Gkeka-Serpetsidaki and Tsoutsos [122]. Finally, the areas were classified based on their knowledge and expertise, and the most suitable area emerged between Crete and Karpathos islands.

Stefanakou et al. [123] studied the siting of FWFs in the Aegean Sea (Greece) using similarly exclusion and EVC followed by an MCDA. This study also implemented an economic evaluation for the highest-scored sites, as well as a sensitivity analysis.

Vagiona et al. [124] and Tercan et al. [125] developed a GIS-based MCDA methodology to examine the installation of BFWTs in the South Aegean in the first case and in the Ismir region (Turkey) and the Cyclades (Greece) in the second case.

Spyridonidou et al. [126] proposed a methodological framework for OWF siting, incorporating a high number of vital criteria. Their approach relied on 5 stages (with the aid of GIS): (i) definition of target, (ii) identification of suitable areas for OWF siting, (iii) decision of OWFs' layout, (iv) calculation of total investment costs and, finally (v) portfolio analysis.

It is worth noting that extensive international research has been carried out about the siting of FWFs, which could be installed in deeper waters, thus reducing the optical disturbances and the environmental impacts that they might cause.

Most of the international literature relies on GIS techniques in order to solve geospatial problems. The methodology applied internationally shows minor differences, which are found mainly in the part of EVC. Table 3.1 presents the available international literature on EVC chronologically.

Table 3.1: Current State-of-the-art

		Foundation type	Criteria								Method/tools	
			Visibility	Distance from EPA	Distance from HVG	Depth	Distance from	Distance from shoreline	Distance from	Average wind	MCDA	GIS
1	Wu et al. (2016) [40]	n/d		✓	✓	✓		✓	✓	✓	✓	
2	Cradden et al. (2016) [116]	Floating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Kim et al. (2016) [111]	Fixed	✓	✓	✓	✓	✓	✓	✓	✓		✓
4	Ziemba et al. (2017) [118]	Fixed		✓	✓	✓		✓	✓		✓	
5	Sourianos et al. (2017) [127]	Fixed		✓	✓	✓		✓	✓	✓	✓	✓
6	Vasileiou et al. (2017) [121]	Floating			✓	✓	✓	✓	✓	✓	✓	✓
7	Schallenberg-Rodríguez et al. (2018) [112]	Both		✓		✓	✓	✓	✓	✓		✓
8	Vagiona and Kamilakis (2018) [124]	Fixed		✓					✓	✓	✓	✓

9	Gavériaux, Laverrière, Wang et al (2019) [109]	Fixed			✓	✓	✓	✓		✓	✓	✓
10	Castro-Santos et al. (2019) [114]	Both		✓	✓	✓	✓		✓	✓		✓
11	Argin et al. (2019) [119]	Fixed		✓		✓		✓	✓	✓	✓	
12	Stefanakou, Nikitakos, Lilas et al. (2019) [123]	Floating		✓	✓		✓		✓	✓	✓	✓
13	Díaz, Fonseca, Soares (2019) [115]	Floating		✓	✓	✓	✓	✓	✓	✓		✓
14	Emeksiz and Demirci (2019)[128]	Fixed		✓		✓		✓	✓	✓		
15	Díaz, Guedes Soares, (2020) [115]	Floating		✓	✓	✓	✓	✓	✓	✓		✓
16	Spyridonidou et al. (2020) [126]	Floating		✓	✓	✓	✓	✓	✓	✓	✓	✓
17	Tercan, Latinopoulos et al. (2020) [125]	Fixed		✓		✓	✓	✓	✓	✓	✓	✓

18	Castro-Santos, Lamas-Galdo and Filgueira-Vizoso (2020) [129]	Floating		✓		✓	✓	✓	✓			✓
19	Loughney, Wang, Bashir et al. (2021) [117]	Floating		✓	✓	✓	✓			✓	✓	
20	Obane, Nagai and Asano (2021) [130]	Both	✓	✓	✓	✓	✓	✓	✓	✓		✓
21	Lo, Hsu, Chen et. Al (2021) [113]	Fixed			✓	✓		✓		✓	✓	
22	Gkeka-Serpetsidaki and Tsoutsos (2022) [6]	Fixed	✓	✓	✓	✓		✓	✓	✓	✓	✓

3.2 Techno-economic analysis of OWFs

3.2.1 Feasibility studies on OWFs

Several studies have addressed the techno-economic assessment of OWFs, however they tend to focus their attention on the site selection factor or use it in conjunction with this factor while assessing the efficacy of OWFs.

Using Capital Expenditure (CAPEX) and Levelized Cost of Electricity (LCOE) indicators, [131], conducted an economic analysis of offshore wind projects in the Brazilian sea, highlighting the most economically and energy-efficient regions. As a result, some emerging areas had a lower LCOE, which was around US$ 69.9/MWh, and a lower CAPEX, which was around US$ 2.34/MW.

Moreover, this study [132] was to determine whether an OWF could be developed in Turkish waters. In order to conduct a technical analysis, windPro software is used to calculate the potential AEP of the proposed project. For the selected sites, they provided details on investment cost, operations and maintenance cost, annual revenue PBP, Net Present Value (NPV), and LCOE.

Furthermore, [133] used InVEST (Integrated Valuation of Environmental Services and Tradeoffs) to assess the economic feasibility of owfs. An analysis of the NPV of a 60-MW OWF assuming a lifetime of 20 years was conducted using CAPEX for grid connection and electricity transmission, Operation and Maintenance Cost (O&M) costs, and other costs. As a result, the researchers concluded that the NPV of OWFs is significantly impacted by the distance from the nearest inland substation, which emphasizes the importance of grid connection.

A multi-objective optimization model was utilized by [112] to assess the feasibility of the sites. The five objectives of the LCC analysis were the costs associated with 1) predevelopment and consenting, 2) production and acquisition, 3) installation and commissioning, 4) operation and maintenance, and finally 5) decommissioning and disposal.

Upon selecting the site, [126] applied an economic evaluation that includes CAPEX, Operating Expenses (OPEX), and Decommissioning Cost (DECEX) during the project's life cycle, which results in the total investment costs of the portfolio.

Based on a MCDM approach, [134] choose the regions for consideration and a detailed economic feasibility analysis is conducted utilizing a discounted cash flow economic model which takes into account the major indicators NPV, LCOE, DPBP, and Internal Rate of Return (IRR) at various discount rates. As a result of the results, the radial electrical design was found to be more cost-effective than the conventional electrical design only under certain technological and economic conditions.

An economic analysis was conducted for four sites by [135], utilizing the Geske compound option model and the CAPEX and OPEX of the WF. Based on their findings, the flexibility value and uncertainty factor play a major role in the whole process.

In this study [136], seven WT models were examined, using the LCOE, where both CAPEX and OPEX were considered. The results showed that V236-15.0 MW and Siemens SWT113 had the highest and lowest wind power densities, capacity factors (CF), and power outputs across the seasons and sites, respectively.

3.2.2 Feasibility studies on floating OWFs

The data are essential elements in reducing the uncertainty in determining the profitability of a floating offshore wind farm (FOWF). There are also other uncertainties associated with the supply chain, commodities, monetary inflation, metocean conditions, which affect technical aspects and downtime, and distances between the WF location and coastal facilities. High CAPEX and OPEX are the main barriers to installing FWTs [137].

Initially, [138] analyzed floating feasibility in the European and Eastern Mediterranean with a detailed cost breakdown, focusing on semi-submersible platforms. The analysis takes into account CAPEX, the development and consent phase (D&C), the turbine and substructure, the mooring systems, electrical infrastructure, the installation phase, decommissioning operations and maintenance, and the AEP.

Subsequently, [139], in order to estimate productivity and to develop a detailed cost model, each layout is evaluated based on the levelised cost of energy, taking into account aerodynamic wakes and transmission losses. As a function of the number of WTs, the normalised optimal LCOE and CF are not significantly influenced by location and reach a maximum difference of 2–3%, suggesting that they are primarily affected by type.

Finally, LCOE was calculated for three types of floating platforms: Spar-Buoy (TELWIND), TLP (CENTEC-TLP), and Semi-Submersible (SATH), by [137]. The model evaluated floating foundations in steel and concrete. After that, a holistic life cycle analysis was conducted, starting with project development, and continuing through decommissioning, evaluating qualitative factors such as potential employment, environmental and residential impacts, as well as quantitative factors, such as IRR, ROI, NPV, PBOR PRI, B/C, CF, and LCOE. According to the results of the study, semisubmersible solutions are the most cost-effective, while tension leg foundations are the most costly due to higher installation and decommissioning expenses.

3.3 VI of OWFs

3.3.1 Chronological development of studies concerning VI of WFs

Although many scientists recognize the importance of optical nuisance from WFs, current research is still limited. There is also a small number of suggested methods that could quantify in advance the nuisance that will be felt by the population of an area from the changes in the landscape. Initially, the problem of optical nuisance from WFs began to be investigated in the late 1960s [140]. In the '60s, a study of visual disturbance was carried out mainly with the use of photographs [141]. Later, from the 1990s onwards, these studies became more extensive and more frequent. At the same time, the EU had committed its Member States to increase renewable power generation, resulting in the development of more and more WFs installations [142][143]. Thus, an increasing number of protests were held by the citizens, because of the noise produced from the WTs and the radical change in the landscape from the installation of the WFs.

Along with the development of technology, the main tool for the study of visual disturbance in Denmark, from the '90s onwards, was the GIS. They modelled the terrain of the desirable area, and afterwards, they studied the disturbance caused by WTs. [144]. In 1997, the colour differences of the objects were studied regarding how they could affect the landscape and, finally, the degree of disturbance [140].

Later, in 2000, a similar study was conducted, which, in addition to colour contrasts, also studied the size of objects at a solid angle [145]. An article was published in 2004 introducing a new method that could be used to predict the degree of visual disturbance from a WF [143] [65] (SPM). It was an innovation for its period in that they studied visual disturbance until then since, through simple variables, it offered a particular and thorough way of estimating the visual disturbance without giving any way to verify it [143]. Furthermore, Manchado et al., [146] developed a methodological framework for visibility analysis with the aid of the software MOYSES v4.0, incorporating the coefficients of the SPM. Their tool can be used during the design process of the project. Finally, in more recent studies, this method was tested and verified through questionnaires, and it was found that it assessed the nuisance caused in the study area by the WF with remarkable accuracy [147][148].

Additionally, many recent studies also used 3D visualisation (Light Detection and Ranging, Virtual Reality (VR), Photoshop, and GIS software). For example, Wróżyński et al. [149] proposed a new methodology for the assessment of the VI of a WF using GIS and 3D graphic software. They concluded that for a 150m WT, the visual assessment should be conducted at a max of 12km. Furthermore, Rafiee et al. [150] developed a new 3D real-time tool; they included variables such as noise, shadow, and visibility as well. This tool can accelerate the planning of new projects, and it can also incorporate the experts' opinions. Subsequently, Nopp-Mayr and Kunz [151] examined the visibility of rotating WTs inside woodland areas, analysing data from orthophotos and airborne laser scanning. This methodology could be used for existing or/and planned WF in forest areas. Finally, Teisl et al. [152] conducted a survey where the respondents could assess the VI of a potential OWF through VR and conventional 2D photos. They managed to better evaluate the WF through the VR representation.

Bishop [153] used GIS and Photoshop software to examine how the VI of a WF changes over time under prevailing local meteorological conditions. The results showed that the median visibility condition seems to be the best condition to be analysed and visualised. Another study by Bishop [154] also suggests that atmospheric visibility data should be examined for a possible location in terms of a more accurate visibility impact assessment.

Manchado et al. [155] developed a methodology for VI assessment by combining the Equivalent VI and High-Resolution Data. Their results concluded that the existing WF could maintain its nominal capacity with an increase of 37.25% without an extra VI. Sklenicka and Zouhar [156] examined 16 study areas, along with four European countries (Austria, Germany, Poland, and Czechia). They collected 400 questionnaires that evaluated 32 different landscapes, in each case with and without WTs. This method promotes objectivity in the planning process, because it depicts the visual preferences of the public and not only, for example, the subjectivity of an expert viewpoint. Last but not least, Alphan [157] produced Potential Visibility Models and examined the VI from 5 qualitative sceneries (residential buildings, protected areas, natural and archaeological sites, tourism development centres, roads, and coastal areas). This approach can be used for pre-project phases, as well as during the environmental licensing procedures. Finally, in this way, the optimum selection of candidate sites is achieved by minimising the potential VI and by increasing the social acceptance of the wind project.

However, throughout time, it was necessary that several changes in the method be proposed, as the wind installations evolved, coming out in larger sizes, along with the occupation of more extended polygon areas [65]. At the same time, similar interesting methods studied the nuisance as a solid angle, but also focused more on how the WFs could be seen in the surrounding area, rather than on how much annoyance the locals would experience [142][158].

The wind installations began to adopt new shapes of arrays due to their larger size and polygon areas. For this reason, OWFs may have a higher impact, if they are designed and installed arbitrarily and without respect to the observer. This fact increases the need to create a method that could calculate the inconvenience that each facility could cause, but also, due to the new features of OWFs, several modifications have to take place so that this kind of method can be developed.

A study [141] published in 2007 investigated OWF nuisance through various variables such as the size of WTs and their colour contrast with their environment. Later, in 2017, a new special method was published that used innovative factors to study VI [159]. The results of the method could not define precisely the discomfort of the observer due to the change in the landscape. Furthermore, a recent study from López-Uriarte et al. [160] suggested a new method for OWFs by introducing a new software MarRojo. This process allows developers to immediately recognise the VI value, instead of calculating the value each time the possible location of the WF changes. This method is not yet tested for actual site conditions/opinions of locals. Finally, in another very recent study was deployed a consultation tool, incorporating various criteria, for the prediction of VI, even from the pre-design process [161].

3.3.2 Overview of existing studies concerning VI on WFs

It is worth noting that there have been numerous studies on offshore wind energy concerning optimal site selection [17], using MCDM methods [162], life cycle analyses, environmental impacts [163], and technoeconomic assessments [164][165]. Although fewer studies have been conducted on the parameter of VI generally on WFs, it is rare to find information about OWFs. An overview of relevant studies that examine the VI factor is presented below.

The first attempt to quantify the VI of WFs was with the SPM, according to the literature. The so-called SPM was introduced by [143] and consists of a methodology for predicting, before construction, the VI that WFs can have on the environment. A consulting tool such as this could be used to analyze and evaluate wind projects, including public and private projects. Later, [65], developed a review of the original SPM, with updated suggestions and modifications for the five coefficients, for more accurate calculations. Furthermore, [147] used the SPM with questionnaires from the local people, in order to evaluate the VI of a WF in Crete. In this way, the public acceptance of the project could be maximized since the VI could be quantified before construction began.

Moreover, many researchers have developed different types of software to quantify the VI at a preliminary stage of such a project. [166] propose some improvements to the software tool

(MOYSES v4.0). The tool can be used during the design phase of a project. A wind park's visibility is quantified using Blender software by [149] which integrates GIS and 3D visualization. This can be used at the outset of a conversation with the locals. [160] developed a software called MarRojo©, which can assist in determining the most suitable location for an OWF by predicting the project's VI. However, they did not test it with locals' opinions.

The VI of WFs has also been studied using GIS software and 3D simulation software in order to predict and quantify the VI of WFs in several studies. [142] developed a GIS-based tool to evaluate the VI of WFs before construction and to be used as a suggestion tool for stakeholders and public administrators. By combining historical and planning data, a GIS-based model was developed for Northern Jutland by [144] to assess the VI of WTs over a long period of time between 1990 and 2010. In general, the results indicated that a reduction in the number of turbines by approximately 40% and an increase in installed capacity of about 20% would not have a significant impact on the overall VI. A 3D engine (GIS integrated platform-Falcon) was developed by [150] whereby stakeholders, through different configurations, were able to recommend a better location for a WF. Finally, the authors in this study [148] suggested a methodology that leads to quantitative and qualitative results. They used 3D computer simulations in order to assess the VI of a WF in a case study in Crete.

Many studies have investigated the VI of WFs by using images, orthophotographs, and Lidar data in order to predict and quantify the VI of WFs from various perspectives. [141] conducted an online survey, where OWTs, at three different distances (4, 8 and 12 km), in different lighting and weather conditions, were tested. Additionally, they examined photographs of moving and stationary WTs. According to the results, respondents were less negative towards 'working' WTs than those not in operation. In 1997, [140] conducted research on an Internet page, using 12 images in order to prove how the introduced objects in the landscape (for example, energy installations) are related with the environment and the observer so that the VI could be assessed. [153] collected images from an existing WF in order to examine the relationship between distance and contrast. As a result, they recommended that during public consultations, the visualisation of the WFs should include the worst-case and median condition scenarios. [151] developed a methodology to assess the visibility of rotating WTs in woodland areas. They used orthophotos and LiDAR data. In addition, this method can be used in the environmental impact assessment of a WF.

Studies have also evaluated the VI of WFs using other methods, such as VI Maps, Visibility Models, and Equivalent VI Indicators. [161] produced VI Maps that can be used during the design phase of the project to better predict the impact of an OWF on the environment. They also highlighted that there is an increasing interest in the field of optimisation of WF layouts, including noise, VI, environmental and social impact. [157] developed Potential Visibility Models and examined the VI for five qualitative scenes (residential buildings, protected areas, natural and archaeological sites, tourism development centers, roads, and coastal areas). Pre-project phases as well as environmental licensing procedures, can benefit from the use of this approach. As a result, by minimizing the potential VI and increasing the level of social acceptance of wind projects, the optimal selection of candidate sites can be achieved. Furthermore, according to the study of [156], Elevation Variation, Elevation Landmarks, and land cover (Forests, Industrial Areas, and Infrastructure Density) could have a significant impact on the VI of onshore wind parks. Additionally, [155] introduced two overall VI assessment indicators and one local VI assessment indicator, the Equivalent VI (EVI) and the need for high-resolution data was also discussed.

A few papers have also been published concerning the VI of OWFs, as well. In this study [152], the researchers compared the results of respondents when they viewed WTs in VR versus 2D photos. According to them, VR reduced the percentage of respondents who were indifferent, but also made them more negative towards them [154]. As a result, he concluded that simulations should depict the turbine's rotor at 15 degrees from the full-frontal position, as well as a reduction in the colour difference by using the extinction coefficient. [159] developed a methodology for quantifying the VI of an OWF. They introduced a new index measuring the VI in relation to the alignment of turbines, but they did not verify it through a survey. Finally, in this study [167], existing tools were tested for their ability to assess the VI of an OWF, and improvements were also suggested, when the factors did not correspond to reality.

Greece has an extremely high amount of offshore wind potential that is still untapped. Therefore, the government is doing its utmost to deploy a marine spatial plan and adopt the related framework in order to develop OWFs [168]. There was also an effort made in 2008, when a Specific Framework for Spatial Planning and Sustainable Development for RES [169] was put forward. This framework provides guidance on the planning and development of renewable energy resources. In order to achieve the goals of this framework, special criteria were introduced for the siting of WFs within the sea area, as well as on uninhabited islands. It is worth noting that, even though the minimum distances from co-existing activities (archaeology, the environment, settlements, etc.) were the same as those for onshore WFs, the distance to co-existing activities was the same. In addition, in order to ensure that the WFs would be integrated into the landscape in a seamless way, the criteria for integrating them into the landscape (both onshore and offshore) were also set to the same standard [170].

The landscape criteria that Greek legislation says should be considered for the design and construction of onshore WFs. This has also been incorporated and analysed in many environmental studies relating to onshore WFs in Greece [169]. Although it hasn't been widely tested on an OWF yet, as far as we know, it appears that this methodology has yet to be tested. In the present study, this methodology has been applied to a study area that takes place in Agios Nikolaos, Eastern Crete, for the purposes of this study Figure 2.13. A parallel survey was conducted with local residents in the nearby areas to collect questionnaires from those living in the area.

4. Materials and Methods

An overview of this Thesis's holistic approach can be seen in Figure 4.1. This Thesis begins with a literature review of the site selection processes of OWF's most suitable locations. Subsequently, two methodologies are applied in order to identify the most sustainable locations for the development of OWFs, one for the development of the floating and one for the development of the bottom-fixed OWFs. After that, those sites that are suitable are examined in terms of their VI using two methodologies. The final step is to conduct a comprehensive technological and economic assessment, which examines three different scenarios.

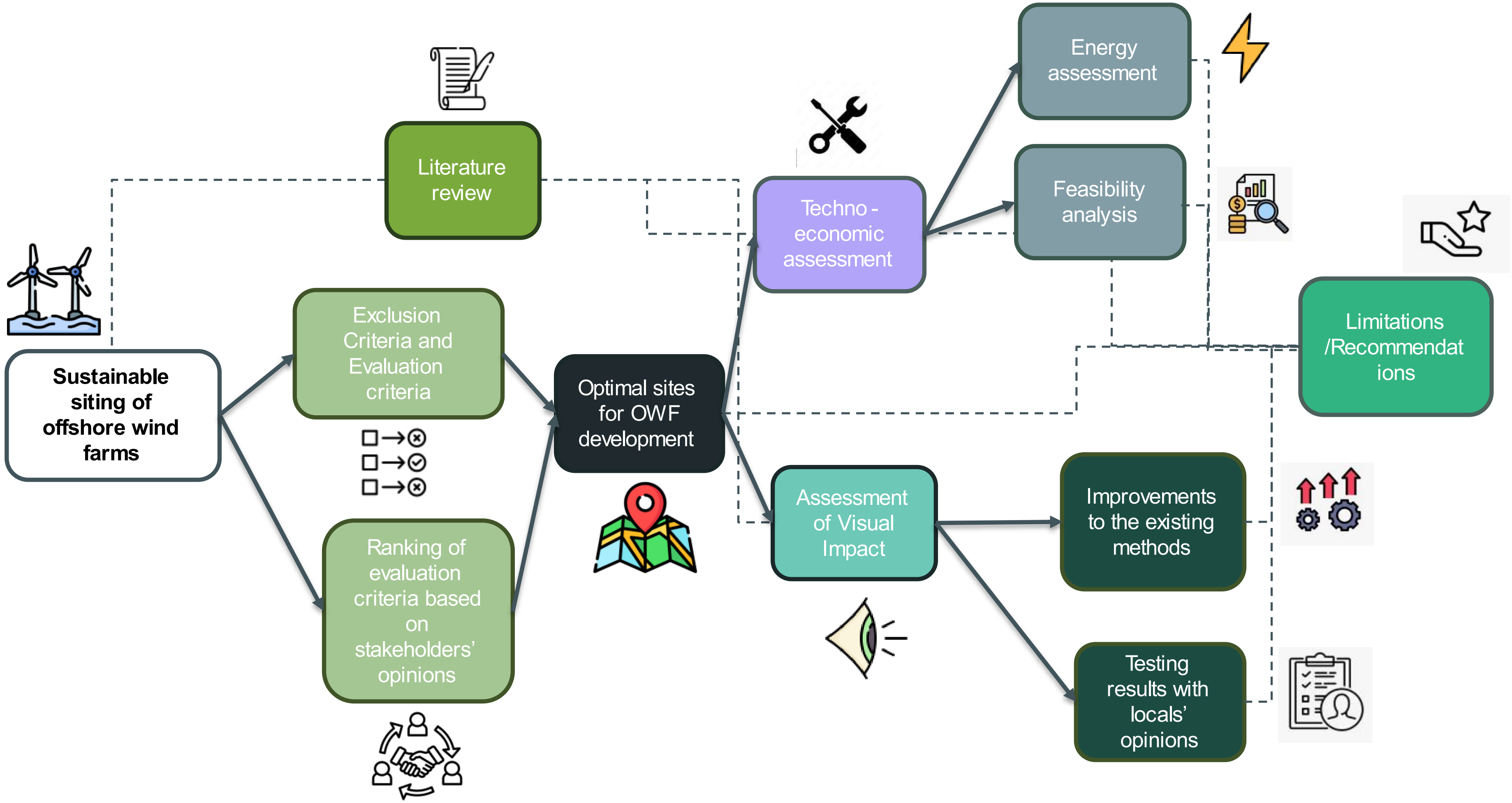


Figure 4.1: Sustainable siting of OWFs

4.1 Sustainable siting of OWFs

4.1.1 Site selection for bottom-fixed OWFs with the incorporation of relevant weights

4.1.1.1 Method definitions

In this study, initially, sixteen EVC were recognised based on the available literature. Personal interviews followed with eight categories of experts, in order that they express their preferences through the pairwise comparisons among the EVC. In this context, public acceptability of green energy solutions should integrate all different categories such as political, social, community and market [171]. Therefore, our study aims to incorporate all of the above categories of public acceptance in order to quantify the significance of this term with a dynamic tool. The eight selected categories were:

- Regional Policymakers
- Academia
- Municipalities
- Transmission and Distribution of energy
- Port Authorities
- Non-Governmental Organizations,
- Energy Production-Energy producers' associations,
- Tourism -Tourist Associations

For example, political acceptance is achieved by the groups of Regional Policymakers and Municipalities. Social acceptability is built with the opinions of Non-Governmental Organizations along with the group of Tourism -Tourist Associations. In these groups, local citizens were invited to participate, representing the general public opinion on the project. Afterwards, as for the community acceptance, the group of Port Authorities played a key role, considering that the OWFs are often located near ports or shipyards during all stages of the project (installation, operations, and maintenance, decommission). Additionally, academia helps to reinforce the knowledge and information towards the community. Finally, Energy Production-Energy producers' associations and the Transmission and Distribution of energy represent market acceptance.

As seen in Table 4.1 the experts/stakeholders were selected according to strict limitations, in order to satisfy a satisfactory representation. For example, the department that was selected the forthcoming expert had to be reliable and popular.

Table 4.1: Allocation of questionnaires per authority/department

Regional Policymakers	**Prefecture of Crete, RU of Chania**	**Prefecture of Crete, RU of Heraklion**	**Organisation for the development of Crete**	

Academia	Technical University of Crete ΑΠΘ, ELKETHE	Hellenic Mediterranean University	Aristotle University of Thessaloniki	Hellenic Centre for Marine Research
Municipalities	Municipality of Chania- Technical department	Municipality of Heraklion	Municipality of Hersonissos	Municipality of Platanias
Transmission and Distribution of energy	Independent Power Transmission Operator	Hellenic Electricity Distribution Network Operator (HEDNO)	Regularity Authority of Energy	
Port Authorities	Hellenic Coast Guard of Heraklion	Hellenic Coast Guard of Chania	Heraklion Port Authority S.A.	
Non-Governmental Organizations	Greenpeace Hellas	WWF Hellas	Natural History Museum of Crete	Local NGO “oikologiki paremvasi irakleiou”
Energy Production-Energy producers' associations	Public Power Corporation	Rokas renewables	Hellenic Wind Energy Association (HWEA)	Terna Energy
Tourism - Tourist Associations	Chania Hotels Association	Technical team of grand/popular local hotel chain	Heraklion Chamber of Commerce and Industry	

Afterwards, the relative weights were derived from the implementation of the AHP. The EXC are fourteen for our study area, so these areas were excluded with the support of GIS. Finally, the remaining marine areas were evaluated on a scale from 1 to 5, incorporating the results accruing from the experts' opinions. The final suitability map was produced, and the marine areas that got values from 3 to 5 were considered to be proper for siting.

4.1.1.2 Analytical Hierarchy Process (AHP)

AHP method analyses complex problems in a structured and hierarchical way into criteria, subcriteria, and the decision alternatives at the bottom of the hierarchy, with respect to the primordial goal of the main problem [172]. The main steps for the implementation of the AHP are [172]:

a. Definition of the main problem, including goals, criteria, subcriteria, and alternatives.
b. Pairwise comparisons amongst all criteria (one to/ by one) Table 4.2.
c. The priority vector is computed, and the consistency of the assessments is verified.

All alternative priorities are weighted.

Table 4.2: The scale of importance [173]

Intensity of importance	Interpretation
1	Equal
3	Moderate of one over another
5	Essential or strong
7	Very strong
9	Extreme
2,4,6,8	Intermediate values

A nxn matrix with the below characteristics can be created for a problem containing n elements. An example is presented in Eq. 4-1, where aij is the relative importance of the criterion ai over the criterion aj [173].

$$A = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{pmatrix}$$

Eq. 4-1

The main assumptions follow (Eq. 4-2Eq. 4-3Eq. 4-4):

$$\boldsymbol{a_{ij}} \in \boldsymbol{S} = \left\{\frac{1}{9}, \frac{1}{8}, \dots, \mathbf{1}, \dots, \mathbf{8}, \mathbf{9}\right) \forall\, \boldsymbol{i}, \boldsymbol{j}\ (\boldsymbol{Saaty\ Scale})$$

Eq. 4-2

$$a_{ij} \times a_{ji} = 1\ \forall\, i, j\ (reciprocity)$$

Eq. 4-3

$$a_{ij} = a_{ik} \times a_{kj}\ \forall\, i, j, k\ (consistency)$$

Eq. 4-4

The priority weights of the n elements can be calculated by solving the eigenvalue problem (Eq. 4-5):

$$Aw\ (A) = \lambda_{max}(A)w(A)$$

Eq. 4-5

According to the mutual judgment, if the importance of criterion ai over criterion aj is k, then the relative importance of criterion aj over criterion ai is 1/k, so in matrix A, aji=1/aij ∀ i≠j and aii=1 for i,j=1,2,3…n.

Only the upper or lower triangular part of the matrix has to be completed by the judgments. The main diagonal for (i=j) is completed with 1, and the remaining space of the table (the lower or the upper, respectively is completed automatically by the inverse number as it is described in the above matrix Eq. 4-1.

Subsequently, the process is continued with the following rules:

1. The matrix (A) completed with the judgements is normalized into a new matrix (B) by dividing the division of the column elements by the sum of the same column elements.

2. Then, a new table with the relative weights of the criteria is derived from the new normalized matrix (B), by implementing the average of each row.

A judgement will be considered as consistent if it verifies the Eq. 4-3Eq. 4-4.

The normalized eigenvector w(A) = $(w_1\ (A),\dots,\ w_n\ (A))^T$, which is assigned to the principal eigenvalue λ_{max} (A) of matrix A, represents the priority weights of the decision-maker for the n elements. If assumptions (2), (3), and (4) hold λ_{max} (A) is equal to the number of elements n and for all entries $a_{ij} = \frac{wi\ (A)}{wj\ (A)}$ is valid [174].

Assumption (4) is often violated in empirical decision situations, but according to Saaty small violations of the consistency, the constraint can be ignored, because the derived priority vectors change only slightly compared to the weight vectors derived from consistent matrices. To measure the degree of inconsistency of comparison matrices, a Consistency Index (CI) was introduced by Saaty, in order to check the degree of the inconsistency, which is measured as follows Eq. 4-6 [175]:

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

Eq. 4-6

Where:

n: the size of the matrix (n x n) and

λ_{max} (A): the maximum eigenvalue of the comparison matrix.

To make this measure comparable for different sized matrices the CI-value was related to an average Random Index RI(n) of randomly chosen reciprocal matrices of size n × n, constructed via entries the values of which were taken from the Saaty scale S (see Eq. 4-2). By solving the eigenvalue problem and determining the principal eigenvalue λmax (A), the Consistency Ratio (CR) can be determined by the Eq. 4-7 [175]:

$$CR\ (A) = \frac{CI\ (A)}{RI\ (n)}$$

Eq. 4-7

Where:

CI: Consistency Index (see Eq. 4-6)

RI: Random Index values (Table 4.3)

In this study, the matrix size was 16x16, so according to the relevant literature, the RI set to 1.597, in order for the necessary control of consistency to be implemented [176]. According to Saaty, when the CR > 0.1, the individual matrices are inconsistent. If the CR is much more than 0.1 the judgments are untrustworthy because they are too close for comfort to randomness, and the exercise is valueless or must be repeated. It is easy to make a minimum number of judgments after which the rest can be calculated to enforce a perhaps unrealistically perfect consistency [177]. So, in these cases, we apply the consistency adjustment process introduced by Saaty [178], which is based on a maximum deviation approach. This was implemented by using the online software of AHP Online System - AHP-OS.

4.1.1.3 Estimation of relative weights of the AHP

The relative weights were derived from individuals related to the energy sector, siting of OWF, etc, putting emphasis on their priorities.

Most studies internationally concentrate on exporting the relative weights via mathematical methods, depending on the literature, their knowledge, and expertise, without considering the viewpoints of local experts [88][89]. This might lead to false or misleading conclusions. For example, a local stakeholder could express the local knowledge and attitude better than anyone, so concerning our goal, it is a helpful way to test local acceptance. It is also worth mentioning that each case study is entirely different from others, so since the methodological framework applied is nearly the same, the source of the relative weights needs to be the opinions of local stakeholders and competent authorities of the study area. Finally, these experts were selected in such a way, in order to ensure that their knowledge and their experience in the field of RET, could cope with the complexion of RET site selection problem.

Subsequently, the first step was to create a sample consisting of eight (8) stakeholder groups that analytically are presented in the results session of this Thesis and the minimum amount of completed questionnaires for each group was defined to three (3) Table 5.1. Therefore, over seventy (70) questionnaires were sent to the different groups of stakeholders and the number of received completed questionnaires was finally thirty-three (33), with the limitation of at least three in each category in order to achieve the maximum objectivity of this method).

After that, the participants' priority vectors were calculated by applying the process described above. An average of every group's priority vectors was computed, and then, an Aggregation of the Individual Priorities was applied for the eight priority vectors of all the distinctive groups of experts applied by the weighted arithmetic mean of priorities based on Eq. 4-5 distinctively [84]:

$$P_g(C_j)=\sum_{i=1}^{n} w_i P_i(C_j)$$

Eq. 4-8

Where:

$P_g(C_j)$: the priority of the group of experts for the criterion j

$P_i(C_j)$: the priority vector of the individual expert i, for the criterion j

w_i : the weight of individual expert i

n: the number of experts involved in the research.

Eventually, the priority vectors deriving from the arithmetic mean method were normalized in order to ascertain that Eq. 4-6:

$$\sum_{i=1}^{n} w_i=1$$

Eq. 4-9

After the estimation of the aggregated priority vectors for each criterion j, the weighted sum aggregation was employed, in order to determine the Overall Priority Index (OPI) for each cell of the study area, based on the Eq. 4-7:

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

Eq. 4-10

In Equation (3.7), OPIi corresponds to the Overall Priority Index of the cell i,

Where:

w_j: the relative importance of the criterion j,

s_{ij}: the score of the cell i over the criterion j and

n: the total number of criteria

Afterwards, the table was completed (i) in the diagonal with one (1) and (ii) in the upper diagonal with the numbers presented in Table 4.2: 1 or 2 or 3 or 4 or 5 or 1/2 or 1/3 or 1/4 or 1/5; the lower diagonal remains empty/uncompleted.

Figure 4.2 depicts the representation of the method of AHP, incorporating the main goal of this study, the sixteen EVC that have been taken into account, as well as the site alternatives.

Table 4.3: Saaty's Random Index Values (RI) for 16x16 matrix size [176]

Matrix size (16x16)	**1**	**2**	**3**	**4**	**5**	**6**	**…**	**15**	**16**
RI	0	0	0.58	0.90	1.12	1.24	…	1.58	1.597

4.1.1.4 The general process

Two different groups of criteria (exclusion and evaluation) were selected to be applicable to the concerned study area. The first step was to exclude areas based on several constraints that might negatively impact the areas selected for the siting of OWF. The final exclusion map was combined with the evaluation map. This map represented the available sites for the siting of an (OWF), classified to the aforementioned class scale described in Table 4.2, that has been utilized. The overall methodological framework, which this job has followed is presented in Figure 4.2.

More specifically, the first step was to identify all the limitations of the study area according to the legislation, literature, and the area's particular characteristics. After that, a strict environmental framework was implemented, according to the aforementioned restrictions, so as to ensure the absolute protection of natural habitat. Subsequently, the limitations consisted of 14 GIS layers, divided into 4 main categories.

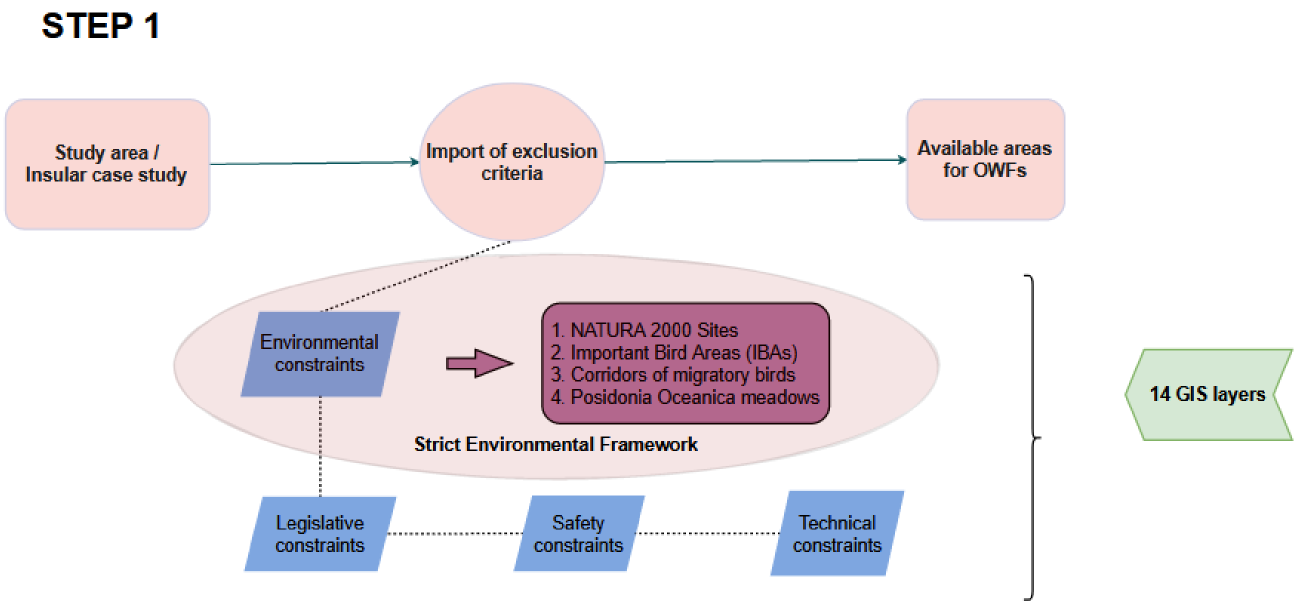
In the second step, the EVC were also selected, in order to be evaluated by the experts. They were also divided into 5 groups. They were illustrated by 16 GIS layers, too.

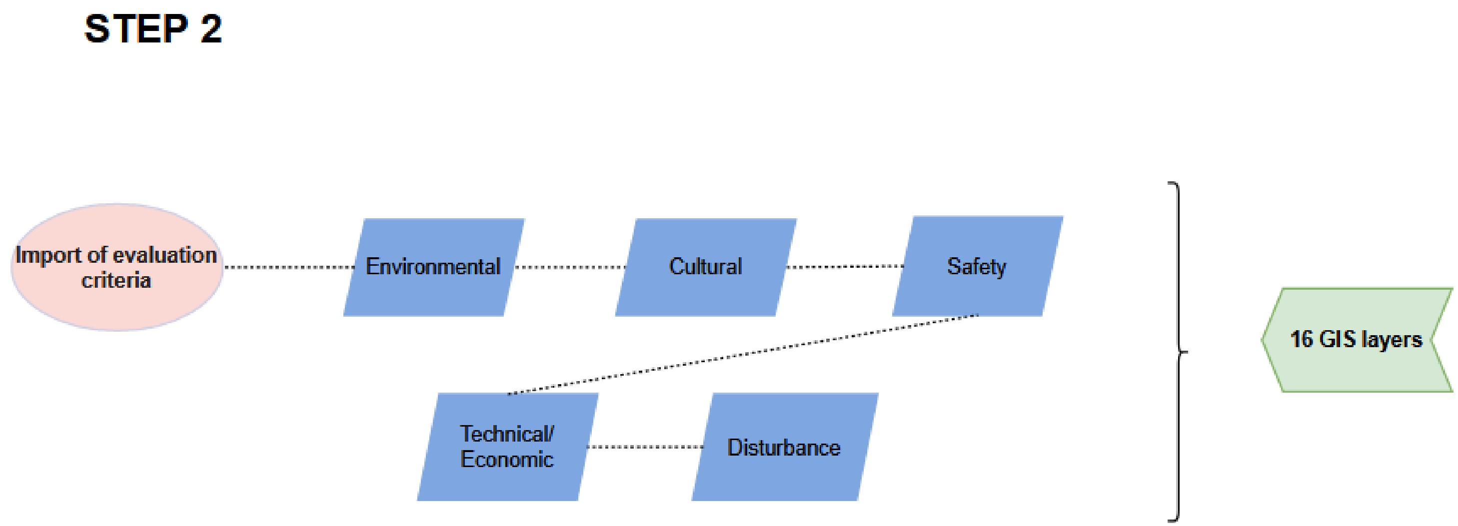
In the third step of our methodology, the AHP process is implemented according to the previous subsections 4.1.1.2 and 4.1.1.3 and the relative weights of EVC are derived.

Finally, the emerged areas are ranked according to the relative weights. Afterwards, only the highly suitable emerged areas (from a score of 3-5) are selected to be evaluated, according to the energy assessment, based on 7 different commercial OWTs models.

It has to be clear that the sample used in our survey is not statistical. Our approach relies on an explanatory basis, since it incorporates personal interviews of at least 4 representatives from each group (except for only one group we gathered 3) of stakeholders and experts (Table 5.1), in order to ‘portray’ their attitudes in terms of preliminary research [179]. For this purpose, the questionnaires gathered are a good reflection of the local community’s opinions, in relation to the characteristics of the island of Crete. The stakeholders completed a matrix table (16 x 16), like Eq. 4-1 adapted to sixteen (16) EVC (

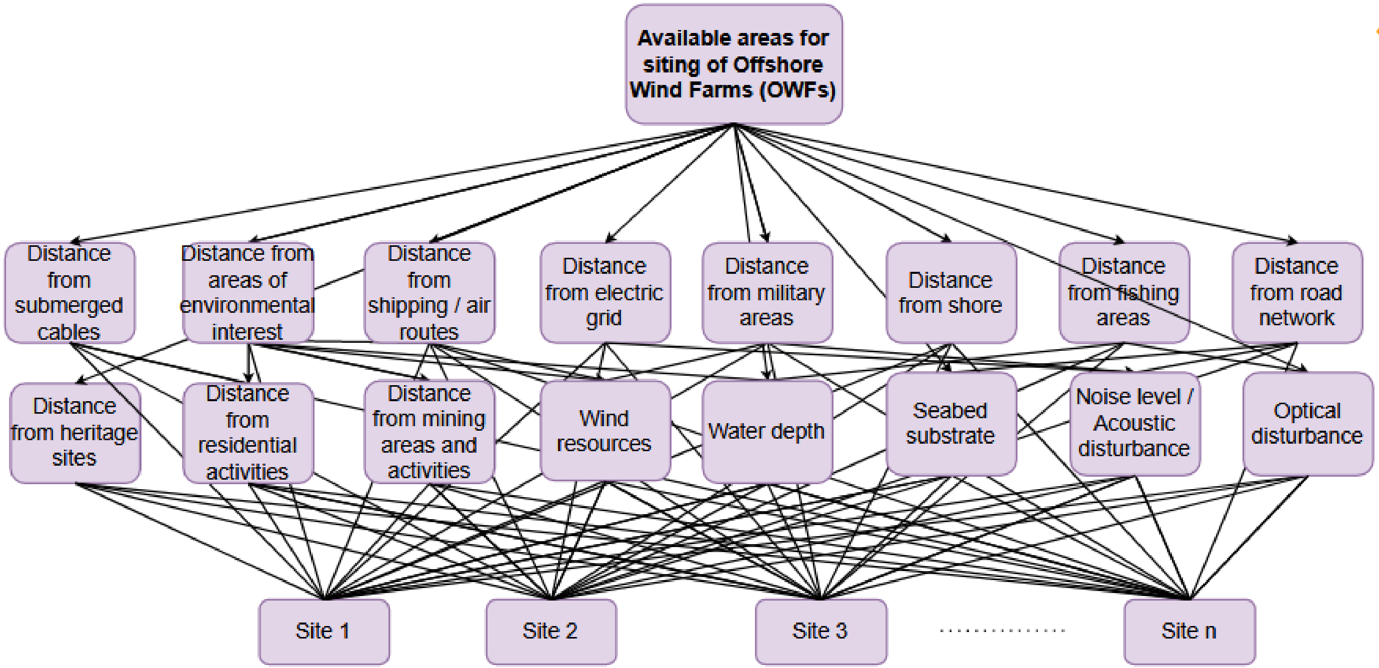
Annex B). By employing the weighted sum aggregation, the priority maps of OWFs were produced, based on the fact that after the aggregation, each cell of the study area had a score between 1 and 5, whereas 5 corresponded to higher suitability. The score of 0 represented the areas that had already been excluded in the previous step of the method. Finally, the suitability maps were created with the assistance of the software ArcGIS v. 10.5.


STEP 1
Study area / Insular case study
Import of exclusion criteria
Available areas for OWFs
Environmental constraints
1. NATURA 2000 Sites
2. Important Bird Areas (IBAs)
3. Corridors of migratory birds
4. Posidonia Oceanica meadows
Strict Environmental Framework
14 GIS layers
Legislative constraints
Safety constraints
Technical constraints


STEP 2
Import of evaluation criteria
Environmental
Cultural
Safety
Technical/ Economic
Disturbance
16 GIS layers

STEP 3

AHP's relative weights of evaluation criteria are determined by relevant groups of local stakeholders and experts



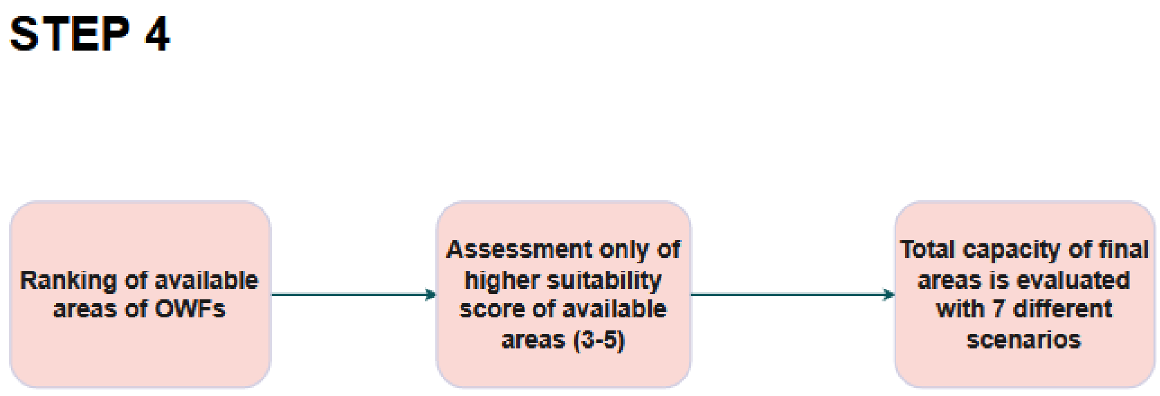


Figure 4.2: An analytical 4-step methodological framework for OWFs site selection

4.1.1.5 EXC

In order to clarify the problematic marine areas near the island of Crete, the first step was to exclude the "illegal" areas, according to the Greek legislation 2464/B/2008 Specific Framework for Spatial Planning and Sustainable Development for the RES (SFSPSD-RES) [169] and Law 3851/2010 [180]. Subsequently, additional areas were excluded, concerning a stricter framework about socio-environmental constraints. It is clarified that the developed procedure was implemented so as always to take into consideration the unique characteristics of the island of Crete. In Figure 4.3, the overall structure of EXC was depicted, divided into four basic categories.

Environmental Constraints

Areas of environmental interest: These areas were not absolutely excluded according to the national legislation (the minimum distances were determined after the decision approving the environmental conditions ('the DAEC'), but considered as critical excluding the following protected areas:

NATURA 2000: protected sites [181][182].

IBAs: Sites vital to the conservation of globally endangered, endemic or endangered bird species that depend on their habitats for survival. 208 areas exist in Greece, identified based on purely scientific criteria [183].

Posidonia oceanica meadows: It creates large meadows in the coastal zone from the sea surface up to 40 m depth (depending on the clarity of the water column, absence of high concentration of suspended particles from sediment transport, etc.) [184][185].

Corridors of migratory birds: Excluded from this survey for protection of birds' habitat [183].

Legislative Constraints

Maximum distance from road network: Defined at 10 km [169].

Distances from shore: Are strictly defined into the 6 miles (territorial waters) so the marine areas > 6 miles =11.112 km from the shore are excluded. Areas up to 1.5 km from the shore were also excluded due to the legislation, concerning the monitoring program of the bathing waters [169] and according to the preliminary procedure for the siting of OWF [186].

Forbidden fishing areas: Regions around the island that concern the prohibition of fishing due to Posidonia oceanica meadows, were also excluded at this stage of our work [184].

Distance from heritage sites: The minimum distance from world heritage monuments, archaeological and historical monuments was calculated to 3000 m according to the Law [169].

Distance from cities and settlements: This zone was selected because the limits were 1000 m from cities and settlements over and under 2000 residents, 1500m from traditional settlements, and 500m from monasteries. The distance of 1500m was considered adequate in order to satisfy all the legislative constraints [169].

Distance from mining areas and activities: A buffer zone of 500m from mining areas and activities, has to be excluded from the available sites, but it is worth noting that this distance is already overlapped by the above legislative criteria [169].

Safety Constraints

Military exercise areas: Due to safety reasons (possible collisions, unconventional activities) [186].

Areas licensed for Exploration and Exploitation of hydrocarbons: 20 marine areas for exploration and exploitation of hydrocarbons, among them and marine areas of Southern Crete [187][188].

Distance from shipping routes: A buffer zone of 926m was excluded from the principal passenger shipping routes around the island, according to government safety measures of the UK, which is a pioneer country in the offshore wind sector globally [189].

Distance from Airports: A buffer zone of 3000m was also excluded from all the civil and military airports of the island, due to firstly, the avoidance of potential collisions between aircrafts and turbines and secondly the diminution of potential interpolation to the radar systems [92].

Technical Constraints

Marine areas with water depth < -100m: Water depth is a critical constraint because advanced technology is demanded, as well as existing great economic constraints, so as to construct the foundations of an OWF into a depth greater than 50m (bottom-fixed foundations) [186][190] [191].

Marine areas with wind velocity < 6 m/s: At 100m above sea level were also excluded from the final selection because there is a lack of investment stake in these areas and there is also commercial availability for these designs of OWTs [3][192][193].

Distance from Submerged cables: A minimum distance of 500m from underwater cables such as communication and energy cables for ensuring the safety of the existing installations [194][195].

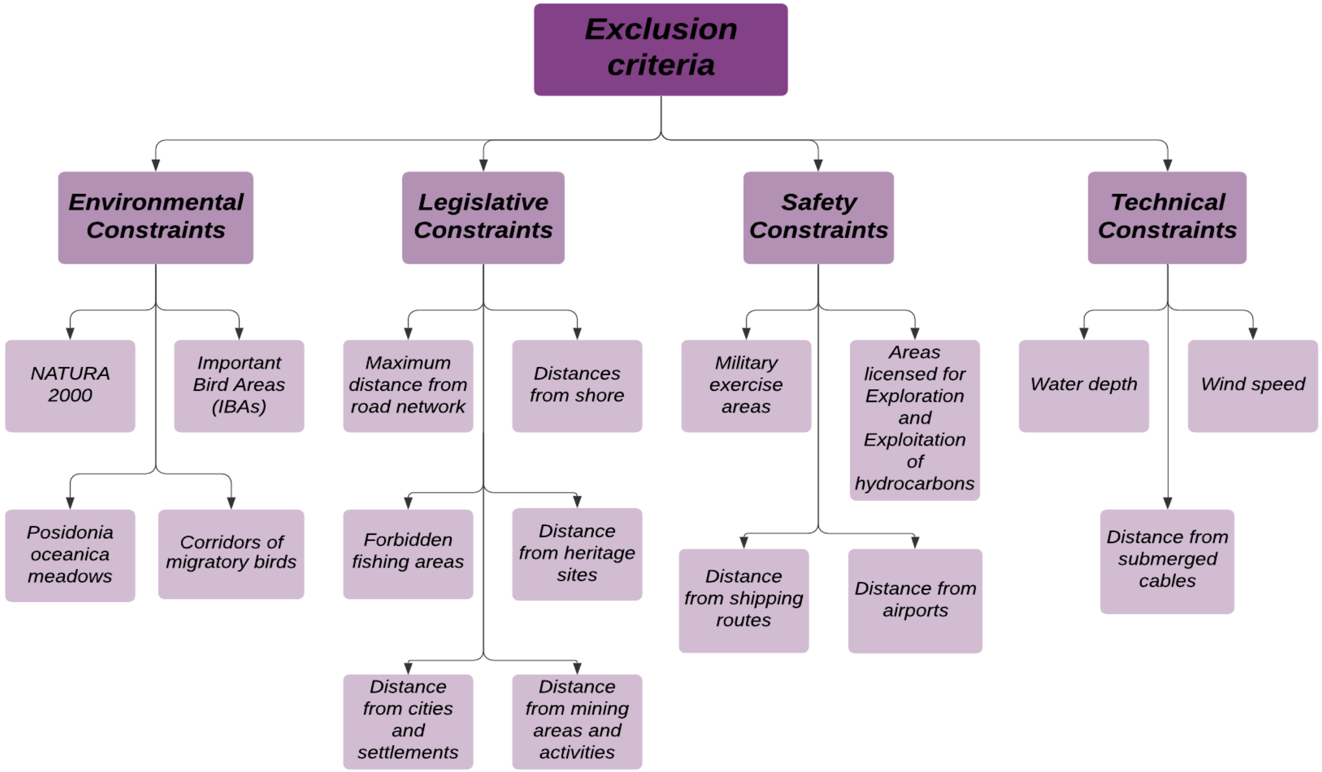


Figure 4.3: Structure of EXC

4.1.1.6 EVC

The EVC were selected based on the international literature [88][89] combined with their relationship with many environmental, techno-economic and socio-political factors that concern the island of Crete. Subsequently, the range of values of each evaluation criterion was defined. Then they were classified into five levels, where 1 represents very low suitability and 5 illustrates very high suitability In Table 4.4 the suitability scores per evaluation criterion are presented as well:

Table 4.4. In Figure 4.4, the overall structure of the EVC is depicted, divided into five important categories. Sixteen EVC were selected as follows:

Environmental

Distance from areas of Environmental Interest: The farther the installations are placed, the better suitability score these areas would acquire (in relation with those near the areas of Environmental Interest).

Distance from Fishing Areas: After excluding these areas according to the Law [184] the remaining areas were evaluated because the farther these areas from forbidden fishing areas were, the better the evaluation score they got.

Technical / Economic

Wind resources: Considering the wind speed <6m/s, at 100m height [193] as inefficient (exclusion criterion), the remaining areas were classified according to wind speeds. Namely, the higher wind speeds represented a high suitability score and inversely, the low wind speeds represented a low one.

Water Depth: Obviously, marine areas with shallower waters would be preferred to others, because of cost benefits and convenience for the installations in order to be embedded [196].

Distance from High Voltage Lines: There are available high voltage lines near OWF, so that electrical connectivity can be realised. If this is feasible, the additional costs would bear the installation cost.

Seabed substrate: The sort of seabed substrate for these installations had to be chosen with sandy layers [88]. Sandy sediments were preferred to rocky sediments for these types of structures [192].

Distance from Shoreline: The suitability score improves, as the distance from shore increases, due to the reduction of the potential optical disturbance from an observer on the shore [186] [169].

Distance from road network: The marine areas that are far away from the road network got a low suitability score [169].

Safety

Distance from Shipping/Air Routes: The upcoming OWF would not cause problems to the existing marine activities, such as to the vessel routes. As for the airplanes, the appropriate distances from the airports should also be taken into account, because there is a risk of possible collisions when the airplanes are taking off and landing [95].

Distance from submerged cables: The submarine cables can be utilised for different uses such as telecommunication cables, optical fibres for internet networks, and also for energy interconnection [95][100].

Distance from Military areas: As we have excluded the marine exercise areas for safety reasons [186].

Distance from residential activities: see 3.4.1

Distance from Mining Areas and Activities: According to the legislation [169] the minimum distance from these activities is defined at 500 m. So, as the candidate areas are departing from the Mining Areas and Activities, the suitability score rises.

Cultural

Distance from Heritage Sites: According to legislation [169], the minimum distance from heritage sites (UNESCO), archaeological sites, and historical sites were defined at 3000m.

Disturbance

Noise Level / Acoustic Disturbance: It is mentioned in the Greek legislation [169] that it must be secured on the outskirts of residential activities (cities and settlements, traditional villages, monasteries, and individual dwellings), a noise level less than 45 dB.

Optical Disturbance: In order to assess the optical disturbance from OWFs in this stage of our study, it was evaluated according to the equation of [197] and the general meaning is that when the distance between the park and the shore was amplified, the optical disturbance diminished.

*The issue of optical disturbance is considered to be a crucial one, so further research concerning this subject, will be carried out in the next step of our work.

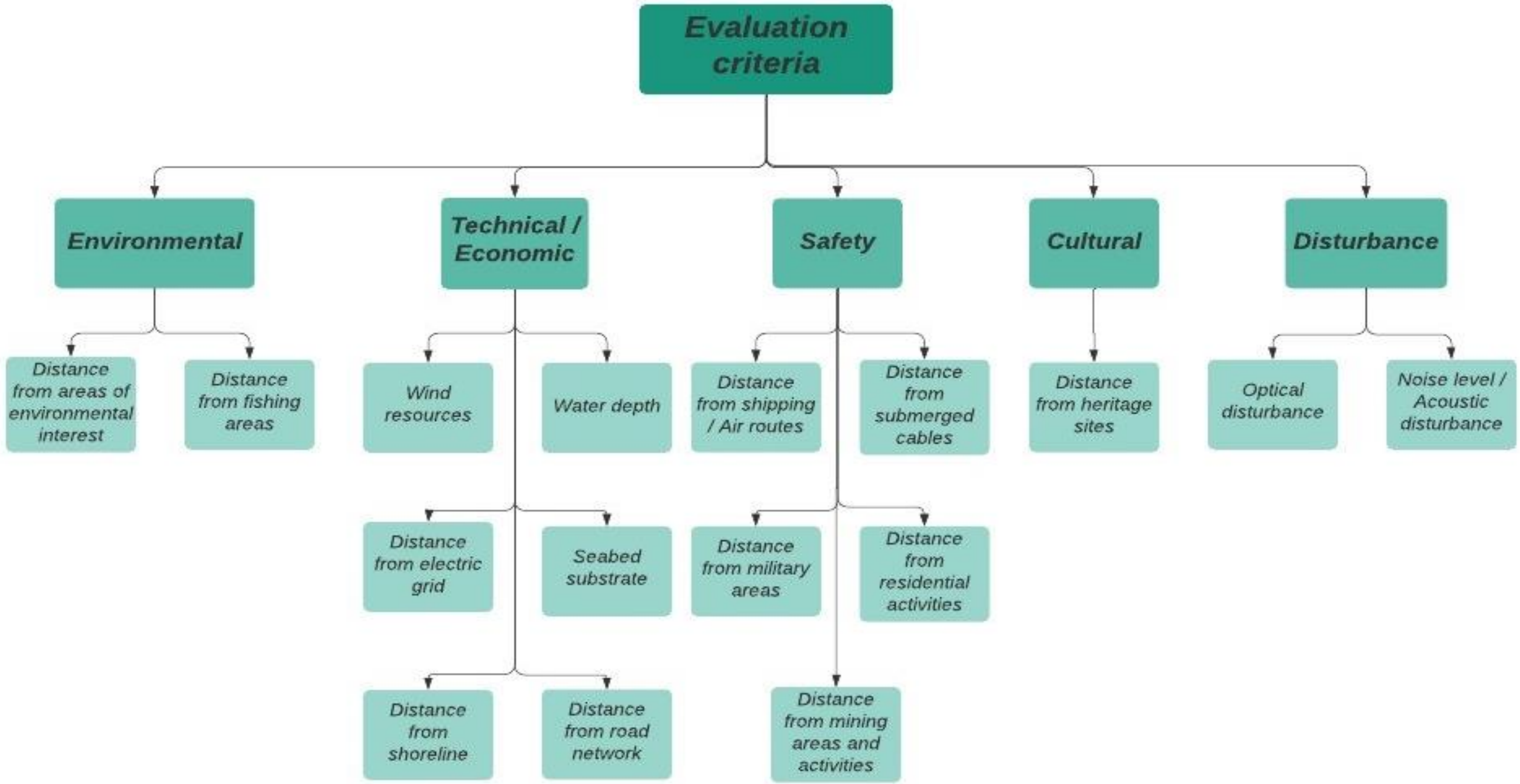


Figure 4.4: Structure of EVC

In Table 4.4 the suitability scores per evaluation criterion are presented as well:

Table 4.4: Suitability scores of EVC

Criteria	Not suitable (excluded) (0)	Very less suitable (1)	less suitable (2)	Medium suitable (3)	High suitable (4)	Very high suitable (5)	Source
Distance from submerged cables (m)*	0-500	500-838	838-1176	1176-1.514	1514-1852	>1852	[194][195]
Distance from areas of environmental interest (m)**	-	0-2000*	2000- 5000	5000-8000	8000-11,000	>11,000	[84][100]
Distance from a) shipping routes (m)*	0-926	926-2315	2315-3704	3704-5093	5093-6482	>6482	[189]
Distance from b) airports (m)*	0-3000	3000-3750	3750-4500	4500-5250	5250-6000	>6000	[92]
Distance from electric grid (km)	-	>20	15-20	10-15	5-10	0-5	***
Distance from military areas (m)**	-	0-2778	2778-5556	5556-8334	8334-11,112	>11,112	* **

Distance from shore (m)*	0-1500 & > 11,112=6nm	1500-3422	3422.4-5345	5344.8-7267	7267-9190	910-11,112	[169][186]
Distance from fishing areas (m)**	Forbidden areas	0-2778	2778-5556	5556-8334	8334-11,112	>11,112	[184]
Distance from road network (km)*	>10	8-10	6-8	4-6	2-4	0-2	[169]
Distance from heritage sites (m)*	< =3000	3000-5028	5028-7056	7056-9084	9084-11,112	>11,112	[169]
Distance from residential activities (m)*	0-1500	1500-3903	3903-6306	6306-8709	8709-11,112	>11,112	[169]
Distance from mining areas and activities (m)*	<500	500-3153	3153-5806	5806-8459	8459-11,112	>11,112	[169]
Wind resources (m/s)*	0-6	6-7	7-8	8-9	9-10	>10	[3][192][193]
Water depth (m)*	<-100	-80- -100	-60- -80	-40- -60	-20- -40	>-20	[186][192]

Seabed substrate	-	Mixed sediment	Coarse substrate	Sand	Muddy Sand/ Sandy Mud	Mud	[192][198]
Noise level / Acoustic disturbance (distance from shore to farm m)*	-	0-125	125-250	250-375	375-500	>500	[199]
Optical disturbance (distance from shore to farm km)*		0-6	6-15	15-34	34-53	53-72	[197]

* For the needs of the 5-class classification, the distances, the wind velocity, and the water depth were divided into 5 equal parts, with respect to the limits of relevant literature. The upper limit of 11,112 m = 6 Nautical Miles (n.m.) is the maximum distance from shore that an installation can be constructed, due to the limitation of territorial waters [186][169].

** The value of '0' in the columns of less suitability (1) represents the limit of restricted areas, so the classification always starts beyond the restricted areas.

***After the export of exclusion maps with available areas for siting of OWFs, the longest distance between the suitable areas and the high voltage lines, calculated at 20km.

The array of WTs was selected to be 7D x 7D, where D is the rotor diameter (RD) of the WT and this placement has proven that it is very close to the average spacing of OWFs in Europe (downwind 7.5D and crosswind 5.9D [200].

The digital data and their sources that were used in the software GIS in this study are briefly presented in the following Table 4.5.

Table 4.5: Sources of digital data used in GIS for export of maps

Data	Source
Wind Velocity (100m)	[79]
Water Depth	[201]
NATURA 2000 areas	[202]
Posidonia oceanica meadows	[203][204]
IBAs	[183]
Birds' migratory corridors	[183]
Shipping routes	[205]
Sea geology and substrates	[198]
Telecommunication submerged cables	[206]
Energy submerged cables	[207]
Areas licensed for exploration and exploitation of hydrocarbons	[187] [188]
Forbidden fishing areas	[184]
Road network, Airports, Mining areas, Military areas, Heritage sites, High voltage electricity lines, Cities and settlements	Digital data that they were provided from our lab

4.1.2 Site selection for floating OWFs without the incorporation of relevant weights

4.1.2.1 Introduction

The adopted methodology includes the identification of areas where FWTs could possibly be installed and then the assessment of these areas based on their suitability for the FWF installation. The chosen platform for the installation siting is semi-submersible, as this platform has a small draft and, therefore, could be served by the ports of Crete, while it could also be towed and installed with convenience. The platform is submerged by 2/3 of its height; therefore, its draft reaches 20 m, and its height from the sea surface is 10 m [208].

Based on the EXC, the areas where it is impossible to install a floating platform were identified and excluded. The territorial waters surrounding Crete, which remain after the exception, are the marine areas where an FWF could also be installed. These areas were then ranked according to certain EVC at a scale of 1 to 5, with the areas rated with a score of 5 being considered more appropriate according to the criterion and the areas rated with a score of 1 being considered less appropriate. These criteria were grouped into 5 categories and according to their average, their suitability is obtained and classified again at a scale from 1 to 5. The areas evaluated as 5 were considered the most suitable for siting, and those rated 1 as less appropriate Figure 4.5.

Figure 4.5: Methodological approach

4.1.2.2 EXC

The first stage of data processing is the EXC phase using ArcMap 10.7 [209]. This stage aims to identify the areas where the installation of FWFs becomes impossible. These areas were excluded from further assessment, while the remaining areas are the marine areas where it is possible to install an FWF. The exclusion of an area may be due to environmental or techno-economic factors, nuisance factors, and project safety factors. The criteria through, which the factors of the project are expressed, are presented in detail below.

EPA: EPAs include the Natura 2000 network. Installing wind parks within areas of the Natura 2000 network may adversely affect protected species. For example, noise pollution caused by a wind park may cause birds to move away from the area, and also, deaths may occur due to bird collisions with WTs. However, it has been shown that bird deaths due to collisions with WTs are significantly lower than deaths due to other causes [6][210]. In addition, mainly during the construction phase, pollutants are emitted due to the use of ships for towing WTs. During the construction phase, increased noise is produced that may impact the marine environment, too. In order to avoid this risk, the installation of a WF should take into account the breeding season of marine species [211]. For all the aforementioned reasons, the areas of the Natura 2000 network are considered unsuitable for the location of an FWF and are excluded from further assessment for reasons of environmental protection. In addition, areas located at a distance of up to 1 km from the Natura 2000 network zones were excluded from additional assessment in order to mitigate any adverse effects within these zones.

Military exercise areas (MEA): Military training areas (shooting ranges) are areas used by the military to conduct exercises with real fire [212].The installation of FWTs within the areas becomes impossible for safety reasons, and as a result, these areas were excluded from the assessment stage.

Underwater cables and pipelines: At the seabed, there are a plethora of telecommunication cables, electrical interconnections and pipelines. Electrical interconnections require the installation of high voltage (150 kV) and ultra-high voltage (400 kV) cables [85] at the bottom of the sea area. Also, gas pipelines that are going to cross the examined marine area need to be taken into consideration. Installing FWTs in the areas where the cables and pipelines are located would lead to safety problems for both the cables and the WF, mainly due to the required anchorages. Therefore, the areas where the cables and conductors are located were excluded from further assessment, as well as a protection zone of 750 m around them for safety reasons [37].

Depth: The minimum depth for the installation of a floating platform WT is 50 m. This happens due to the draft of the platform, but also because at shallower depths, it is possible to install BFWTs. This makes floating platforms economically inefficient in those waters. The maximum installation depth varies depending on the type of platform. In the case of the Spar Buoy platform, the Semi-submersible platform, and the Barge platform, the maximum depth is 1000 m [213], while in the case of the TLP platform is 350 m [214]. Therefore, areas with a depth of < 50 m and > 1000 m are considered unsuitable for the installation of a FWF.

Marine routes: In order to avoid collisions, but also possible damage to the WT anchorages, the areas that show intense mobility, as well as a safety zone of 500 m around them, were excluded for safety reasons [215]. The authors made a study assumption to protect the current shipping activity. Consequently, areas with > 80 ship routes/km^2 annually are considered unsuitable.

Airports: Areas around airports were excluded from additional assessment for safety reasons. Placing WTs near airports could cause aircraft landing and take-off problems, as well as radar interference due to the height of the WTs. Therefore, the areas within a radius of 3 km [92] around airports are considered unsuitable for installing WFs.

Marine areas designated or committed for hydrocarbon extraction: Marine areas designated or committed for hydrocarbon extraction were also assessed. The authors recommend the replacement of fossil fuel extraction with green power installations, such as FWFs.

Settlements - Coasts – Monuments: According to Greek legislation, minimum distances are defined regarding the installation of WTs. The minimum distance from settlements is set at 1000 m, the minimum distance from traditional settlements is set at 1500 m, the minimum distance from monuments and archaeologically sites is set at 3000 m, and the minimum distance from swimming shores is set at 1500 m [169]. The above restrictions are intended to reduce the audio-visual nuisance that the installation of WTs might cause. These zones, defined by Greek legislation, were exempted from additional assessment.

Average wind velocity: The average wind velocity is related to the energy and, consequently, the economic efficiency of the installation. According to the international literature, the minimum value of average annual wind speed at the height of 10 m is set at 6 m/s [121]. As a result, areas with a value < 6 m/s were considered unsuitable.

EEZ: According to the United Nations Convention on the Law of the Sea (1982) [195], each State has sovereign rights over energy production within the EEZ. However, in the case of the Greek Republic, no EEZ has been defined at present; therefore, the present investigation will be limited to Greek territorial waters, which are currently defined around Crete as 6 from the coast.

The areas listed in Table 4.6 are excluded. Areas remaining after the EXC Exemption are defined as areas where FWFs might be located.

Table 4.6: EXC

	Criterion	Exclusion zone	Protection zone	Source
Ex1	EPA (Natura 2000)	All	1000 m	[210][211][215]
Ex2	Areas of military exercise	All	-	[212]
Ex3	Underwater Cables and Pipelines	All	750 m	[206][169]
Ex4	Depth	<50 m & >1000 m	-	[215]
Ex5	Marine routes	> 80 Routes/km^2 per year	500 m	[215]
Ex6	Airports	All	3000 m	[92]
Ex7	Areas reserved for hydrocarbons extraction	All	-	
Ex8	Bathing Waters	All	1500 m	[122][169]
	Settlements	All	1000 m	
	Traditional Settlements	All	1500 m	
	Monuments	All	3000 m	
Ex9	Average wind velocity at 10 m height	<6m/s		[79][121]

4.1.2.3 EVC

Areas emerging after the exclusion process were further assessed under certain criteria and are called EVC. According to these criteria, the areas available for siting were ranked according to their suitability on a scale from 1 (less suitable) to 5 (more suitable). The selected EVC express factors of the project that could affect its implementation, such as the nuisance it could cause, environmental protection, energy and techno-economic factors, and safety factors of the project Table 4.7. Table 4.8 presents the suitability characterisation per each criterion.

Visibility: WTs are structures that due to their considerable size, often exceed 150 m in height and are usually visible from multiple points. The installation of a wind park in areas where the park would be highly visible could cause problems of social acceptance and, ultimately, the non-implementation of the project. In addition, the intense visibility of a wind park from areas with increased tourist activity might harm the tourism of the surrounding areas. The total available areas were evaluated based on the points of view from which each area is visible. The points of view are the settlements (1 viewpoint per 5000 inhabitants), the archaeological sites - monuments and the swimming shores. Areas that are visible from a small number of points of view were considered more suitable for siting, as opposed to those that are visible from a large number of points of view. The visibility assessment of the areas was performed using the Viewshed 2 command of the ArcMap 10.7, an observer height of 1.75 m, a WT height of 105 m, an altitude of 115 m (due to the height of the platform 10 m) and for a maximum distance of 10 km, as the visual nuisance of WTs even in an environment with high aesthetic value, has a minimal impact at a distance of 10 km [149].

Distance from EPA: The assessment of the distance from EPA is applied as a criterion in order to weigh the possible environmental effects that the installation of a FWF might cause. Natura 2000 sites are vulnerable ecosystems and areas of significant environmental value. The placement of WTs near these areas may affect sensitive ecosystems with adverse effects. For the above reasons, the available areas for siting had to be assessed based on their distance from the Natura 2000 area. According to the international literature [123], installing a wind park at a distance of up to 9500 m from the Natura 2000 area is likely to affect the ecosystem. The available areas were evaluated as the most suitable areas located at a great distance from areas of the Natura 2000 network and graded with 5 and considered less suitable than the areas located at a short distance from areas of the Natura 2000 network. The distance from 1000 m to 9500 m from these areas will be evaluated from 1 to 4, while the areas that are at a distance >9500 m were evaluated with 5.

Distance from the high voltage grid (HVG): The existence of an onshore HVG and its connection to it are necessary factors for the operation of an FWF. The HVG (150 kV) transfers electricity from the production points to the consumers with the lowest possible losses [207]. The cost of the grid connection is an essential techno-economic factor of the project and can be significantly affected by the site's distance from the HVG. Areas closer to the high-voltage grid provide a lower cost connection than distant ones, so areas close to the high-voltage grid were rated more positively.

Depth: The depth of the installation site could significantly affect the project cost. The installation depth varies from 50 to 1000 m depending on the type of floating platform. The installation of FWFs at great depth requires a long anchorage system, but also long underwater power cables [215], increasing the total cost of the project. For the above reasons, shallow areas were considered more economical in terms of the depth parameter and, therefore, more suitable for wind park siting.

Distance from ports: The existence of a port that will be used as a “base” is particularly important for the smooth operation of the FWF. This port will house the surveillance facilities but will also be used as a site for maintenance and small repairs of WTs. In addition to the port-“base”, it is necessary to own boats for transporting personnel to/from the installation site, as well as for towing the platform from the port to the installation site [216]. Based on the above, it is evident that the distance from the port is a techno-economic factor that significantly affects the viability of the facility. Therefore, areas that are close to ports that could be used as a port- “base” were considered more appropriate for FWF.

Distance from shoreline: The distance from the shoreline is related to the project cost. In the case of OWFs, a large part of the total cost is due to the use of submarine cables in order to connect to the mains. It is notable that in some parts of the international literature, the areas located near the coasts are excluded from additional assessment, as they are considered to be likely to cause visual or auditory disturbance [121]. In this work, the criterion of nuisance is investigated separately and not as a function of distance from the shore; therefore, the areas near the shoreline were evaluated positively for reasons of the economic viability of the facility.

Distance from marine routes: The distance from maritime routes is a criterion concerning the safety of the installation. In addition to the excluded zone of 500 m (chapter 3.1.2), the assessment of the area is applied at a distance of up to 2 n.m. (3700 m) around the diodes [48] in order to avoid collisions and damages to the anchorages. More specifically, areas at a distance from 500 m to 3700 m from marine routes were rated from 1 to 4, while areas at a distance >3700 m (2 nm) were rated at 5.

Average wind velocity: Average wind velocity is related to the energy efficiency of the installation. Areas with high annual average wind speeds are more energy efficiently and, therefore, more suitable for WF siting. The annual average wind speed at the height of 10 m is obtained in a raster format by the global wind atlas platform, whose data had been obtained from 10 years of data processing (2008–2017) of ERA5 Climate reanalysis [79].

In the areas available for siting, the annual average wind speed ranges from 6 to 8.5 m/s at 10 m. The areas with the highest average wind velocity were rated with 5, while those with the lowest with 1.

Table 4.7: EVC

	Category	Criterion	Target	Range
Ev1	Nuisance criteria	Visibility	Min	
Ev2	Environmental Criteria	Distance from EPA	Max	1000m - 9500m [123]
Ev3	Technoeconomic Criteria	Distance from HVG	Min	
Ev4		Depth	Min	50m – 1000m
Ev5		Distance from ports	Min	
Ev6		Distance from shore	Min	
Ev7	Safety criteria	Distance from marine routes	Max	0,27nm (500m) - 2 nm (3700 m)
Ev8	Energy Criteria	Average wind velocity (at the height of 10 m)	Max	

Table 4.8: Suitability characterization by evaluation criterion

	Criterion	Suitability Characterisation*[2]				
		Least Suitable (1/5)	Moderately Suitable (2/5)	Marginally Suitable (3/5)	Suitable (4/5)	Most Suitable (5/5)
Ev1	Visibility **[3]	25 - 60	10 - 25	5 - 10	2 - 5	0 - 2
Ev2	Distance from EPA	1000m – 3122m	3122m – 5248m	5248m – 7,74m	7374m – 9500m	9500m – 26,281m
Ev3	Distance from HVG	29,728m – 38,879m	22,577m – 29,728m	15,426m – 22,577m	8275m – 15,426m	1124m – 8275m
Ev4	Depth	999m – 809m	809m – 619m	619m – 429m	429m – 239m	239m – 50m
Ev5	Distance from ports	34,989m – 43,471m	26,507m – 34,989m	18,024m – 26,507m	9542m – 18024m	1059m – 9542m
Ev6	Distance from shoreline	0 – 2186m	2186m – 4373m	4373m – 6559m	6559m – 8745m	8745m – 10,932m
Ev7	Distance from marine routes	500m – 1300m	1300m – 2100m	2100m – 2900m	2900m – 3700m	3700m – 21,820m
Ev8	Average wind velocity	6 m/s – 6.5 m/s	6.5 m/s – 7 m/s	7 m/s – 7.5 m/s	7.5 m/s – 8 m/s	8 m/s – 8.5 m/s

[2] The characterisation of Ev2 to Ev8 has been made using an equal interval.

[3] The characterisation of visibility has been made using a geometrical interval.

4.1.2.4 Clustering the EVC

The Ev were then clustered into five groups depending on the factor they represent. For the clustering, the average of the Ev of each category was calculated for each raster of the map employing ArcMap 10.7. The new five clusters were:

a. Nuisance criteria: visibility criterion
b. Environmental Criteria: criterion of distance from EPAs
c. Techno-economic Criteria: distance from the HVG, depth, distance from ports and the distance from the shoreline.
d. Safety criteria: criterion of distance from marine routes.
e. Energy Criteria: criterion of average wind speed

As a next step, using the raster calculator command, the average of the values of the five categories mentioned above was calculated for each raster of the map. The areas were then rearranged, based on the values resulting from the sum of the five categories, on a scale of 1 (Less Suitable) to 5 (Most Suitable), with the areas rated at 5 being considered the most appropriate for a FWF. The assessment was performed again with the reclassify command of the ArcMap 10.7 software.

4.1.2.5 Energy Assessment

The areas rated 5 out of 5 in the suitability calculation were further evaluated in order to determine their energy characteristics. WAsP model, v. 12.6 was employed for the energy yield calculations, including the Park 2 wake model for the wake losses. Two different WT models were tested after implementing wind climate data provided by Global Wind Atlas [79], depending on the location. Wake losses also played an important role in the placement (micro-siting) of the WTs.

In each of the locations that have been rated as the most suitable, the siting of FWFs was studied, which will fully cover the available area of each area. For this purpose, locations of very small-sized areas (<1 km2) were removed, and two types of WTs with a nominal power of 8 MW and 3 MW, respectively, were examined. WTs were arranged in such a way that the minimum distance between them is 9 RD in the downwind direction and 6 RD in the crosswind direction [217], in order to mitigate the existing wake losses amongst WTs.

The platform chosen for the energy assessment was semi-submersible, as it was the best possible solution, given the relatively shallow depth of the ports of Crete, the ease of installation, and its successful application in other projects. Therefore, at the rotor height of each WT, the height of the submerged by 2/3 floating platform was taken into account. The absolute height of the semi-submersible platform is equal to 30 m, of which, as a rule, 20 m are located below sea level. Therefore, 10 m were added to the rotor height of the two types of WTs during the energy calculations [208].

The energy analysis determined the bearing capacity of the three areas in terms of installed power based on the device mentioned (9 RD X 6 RD), the AEP, the CF of each area based on wind data, and the wake losses.

In the context of energy analysis, two types of horizontal axis WTs with different maximum power outputs were examined in order to place them on a semi-submersible floating platform.

The types of WTs that examined were the WT Vestas V164 − 8 MW and the Vestas V112 Offshore − 3 MW (Table 4.9).

Table 4.9: Typical characteristics of the selected WTs[4]

WT	Vestas V164 – 8MW	Vestas V112 – 3MW
Rated power	8 MW	3MW
Cut-in wind speed	4 m/s	3 m/s
Cut-out wind speed	25 m/s	25 m/s
Rotor Height	105 m	84 m
RD	164 m	112 m
Swept area	21,124 m^2	9,852 m^2

4.2 Techno-economic analysis of OWFs

4.2.1 Theoretical background

An estimation of the lifetime cost of OWFs is based on the key drivers of wind energy economics. These factors may include CAPEX, OPEX, and DECEX, according to Figure 4.6 [207]. The CAPEX are one of the most important factors in determining the total lifetime cost of WFs. They include all the costs associated with the installation of the WF prior to its commercial operation. All costs associated with post-commercial operation, prior to decommissioning, necessary to ensure the efficient operation of the project and guarantee the performance of the WT are included in OPEX [218].

[4] Source: Vestas V112-3.0 Offshore - 3,00 MW - Wind turbine,

https://en.windturbinemodels.com/turbines/667vestas-v112-3.0-offshore

Vestas V164-8.0 - 8,00 MW - Wind turbine, https://en.wind-turbine-models.com/turbines/318-vestas-v164-8.0).

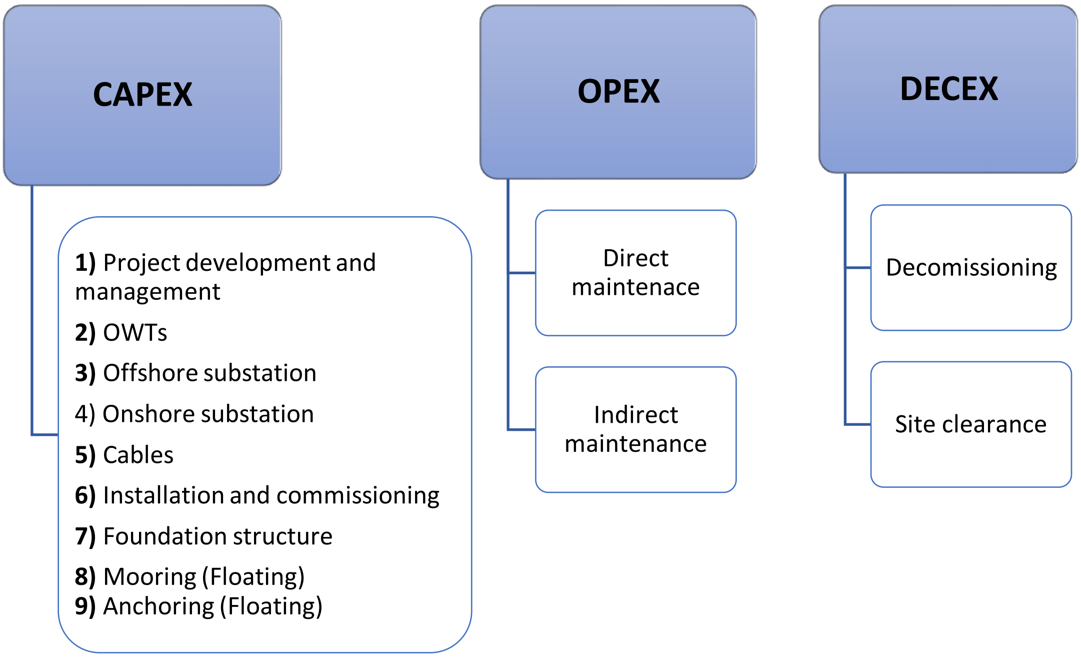


Figure 4.6: CAPEX, OPEX and DECEX breakdown of the study

Approximately 80 percent of the lifetime cost of a WF can be attributed to CAPEX, which includes the cost of the offshore WT, project development, project management, offshore substation, onshore substation, cables, moorings, installation and commissioning [219].

Approximately 20% to 30% of the total cost of a WF is devoted to operation and maintenance. Generally, O&M costs can be divided into direct and indirect costs. Direct costs include administrative expenses, security fees, network access fees, and service contracts for scheduled maintenance, whereas indirect costs include scheduled and unscheduled maintenance not covered by fixed contracts, spare parts, and other items [220].

Lastly, DECEX costs represent the last phase of the WF's lifecycle and are approximately 1-3 percent [221]. Costs associated with the cleanup and re-operation of the OWF are included. After dismantling facilities, steel and aluminum from floating platforms and electrical cables are often sold as scrap, providing a source of income. Therefore, the total cost and materials are reduced as a result of the income generated. [222]. It is also possible to recycle and reuse the metal towers and mechanical components of WTs. In spite of the challenges, research efforts and technological advancements are making progress toward recycling turbine blades in order to enhance the sustainability of WFs [223].

As shown in Figure 4.6, expenses are broken down into CAPEX, OPEX, and DECEX as a way to illustrate the relationship between the type of offshore facility and the investment required. Regardless of the method of installation, the cost of WTs, substations, and cables remains the same. The cost of supporting infrastructure for OWFs may differ significantly depending on whether they are located in shallow water or deep water. In shallow waters, monopile foundations are usually utilized, which are more economical and easier to construct. A more complex mooring system is required in deep water, on the other hand. This variation in cost is critical and illustrates the necessity of detailed analysis and understanding of the investment requirements in different locations, which reinforces the strategic significance of choosing the appropriate facility based on the location and specific requirements of each project [222].

Cost of WTs

To determine the economic value of OWTs, a number of factors must be taken into consideration, including the costs of construction, installation, grid connection, and maintenance. A number of factors influence the total cost of the project, including the technology, the location, the depth of the sea, and the distance from the coast. Considering the need for detailed analysis, offshore WT costs are divided into two main categories: floating and fixed. Offshore wind energy has its own economic surface, as each category has its own characteristics and challenges.

Bottom-Fixed

In shallow waters, BFWTs are the most common type of offshore WT. Although they are less expensive than FWTs, their application is limited by the depth of the sea. With the maturing of the technology and increased experience, fixed-site WTs are expected to have a lower life cycle cost than mobile WTs after 100 GW of installations, with the cost falling to 28 € 3/MWh after 100 GW of installations [224][225].

It is certainly true that, with the concept of "accumulated power of 1 GW and can be reduced to 33x6 €/MWh by installing 100 GW", one would need 1000 floating OWTs in order to achieve the accumulated power of 1 GW. It is estimated that the average cost to produce each MWh of energy will be approximately €123 during this initial phase. As technology advances and the installed capacity of wind power increases to 100 GW (i.e. 100,000 1 MW WTs), energy production costs per MWh decrease. Through the building and operation of more WTs, cost reductions are achieved through improvements in technology, a reduction in material costs, and an overall improvement in efficiency. As a result, energy production becomes more efficient and cost-effective as more WTs are constructed and installed [225].

Floating

In spite of the fact that floating OWTs are initially more expensive due to the complexity of their moorings and static structures, they offer a number of advantages in deep water conditions. LCOE for FWTs begins at 123 euros per MWh at a capacity of 1 GW and can be reduced to 33 euros per MWh at a capacity of 100 GW, according to a recent study [224]. As the technology matures and scale of installation increases, this technology is expected to reach cost parity with BFWTs [225].

4.2.2 Methodological framework

This chapter provides an overview of the methodology used in the research on energy production from OWTs in a case study in Crete. As described below in Figure 4.7, the methodology consists of several steps and actions.

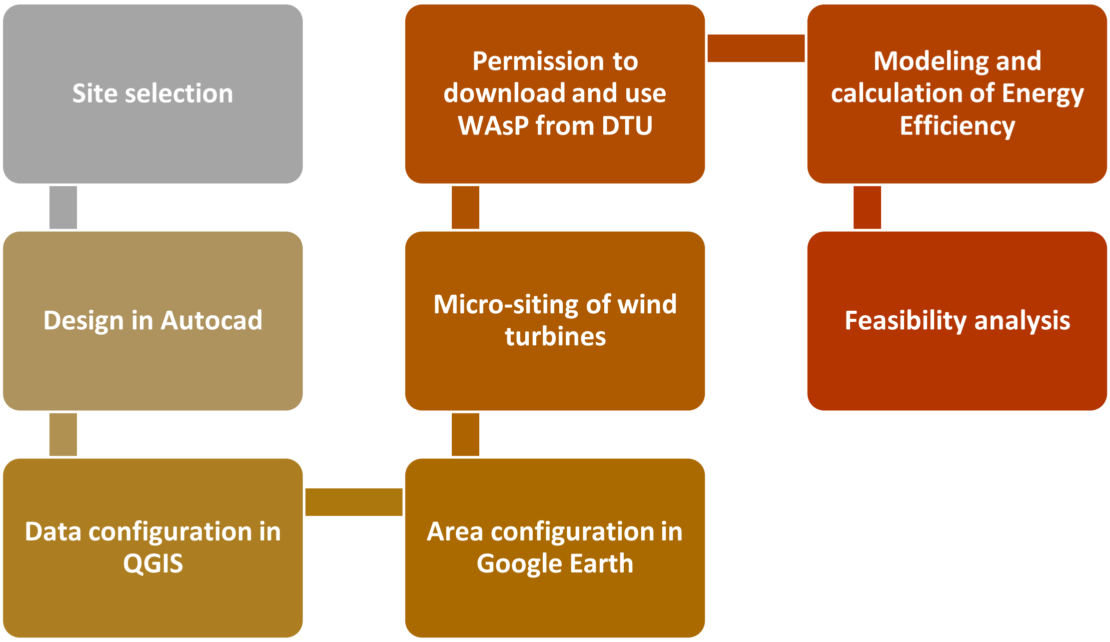


Figure 4.7: Analysis process diagram of the adopted Methodology

Site Selection: A MCDM was used during the initial phase of the methodology to select the study area. Figure 5.3 indicates that Heraklion Bay would be a suitable location for the installation of WTs to generate electricity. It should also be noted that this area was selected based on research that had already been conducted [6].

Design in Autocad: Following the selection of the area, a drawing of the area was prepared using AutoCAD software. The next step in the analysis was the creation of an accurate geographic database using AutoCAD.

Data configuration in QGIS: In order to import and format the geospatial data designed in Autocad, QGIS, a popular software program for geographical analysis, was used. In this process, geographical coordinates were mapped to their corresponding regions and the data were prepared for further analysis.

Area configuration in Google Earth: In Google Earth, a popular tool for visualizing geographical information, an OWF has been added to the study area. This step provided valuable insight into the geography of the area.

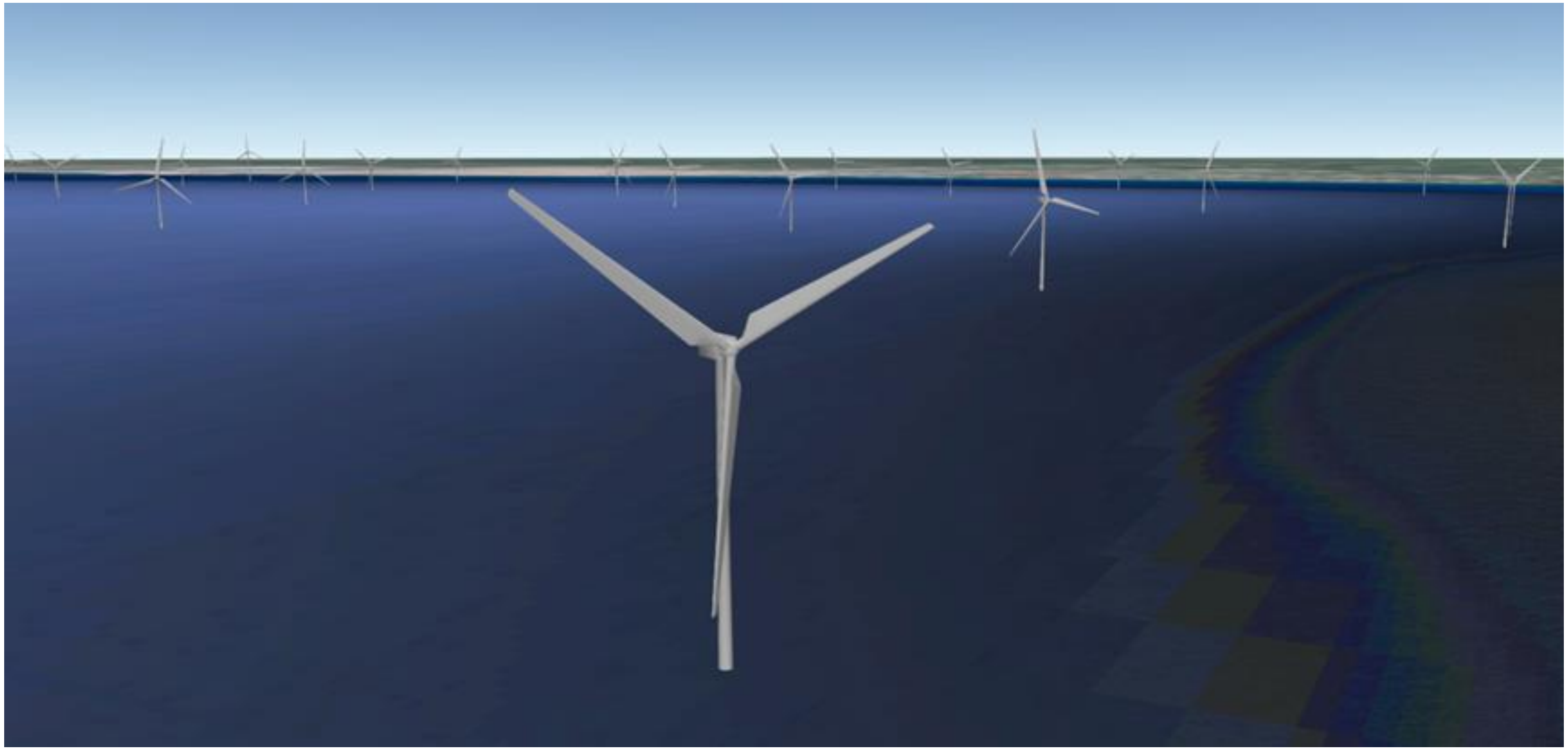


Figure 4.8: OWF Case Study Gulf of Heraklion, Crete Google earth illustration

Micro-siting of WTs: For each scenario, a calculation was conducted to determine the optimal number of WTs that would fit within the given area. The WTs are positioned so that there is a minimum distance of seven RD between them in the direction of the downwind and seven diameters in the direction of the crosswind, so as to mitigate existing losses between the WTs [226].

Permission to download and use WAsP from DTU: At this work, the energy efficiency was calculated using WAsP (Wind Atlas Analysis and Application Program). Using this software, WFs' energy production and energy efficiency can be calculated. It required a special license from the Technical University of Denmark (DTU) in order to be used in a research context. The analyses and results required for the Thesis were conducted using the WAsP software.

The Wind Atlas Analysis and Application Program (WAsP) is a program developed by the Department of Wind Energy at the Technical University of Denmark (DTU), a world leader in wind energy research. In this study, WAsP 12 was used as the latest version of the software.

Using WAsP, it is possible to predict the wind climate and wind potential of an area, as well as the amount of electricity that can be produced by wind power or WFs. Based on wind data collected from the region itself, the model is able to make accurate predictions. In addition to an advanced model to simulate airflow over a landscape with relief, there is also a model that simulates changes in terrain roughness and another that assesses the impact of obstacles near WTs on energy production.

There are several parts to the WAsP program that are dedicated to the development of different aspects of a project. The end product of the energy simulation results from the integration and combined operation of these individual components. Among the specific components of the software used are:

• WASP Map Editor

• WASP Turbine Editor

In this study, no additional software was used to analyze the climate data. Data was retrieved directly from the Global Wind Atlas platform [79]. Generalized Wind Climate (GWC) data is provided on this platform for a variety of regions. Specifically, the GWC data were collected by entering climate information into the WAsP software, which included wind information and windroses for various heights and roughness levels.

i. WASP Map Editor

The WAsP Map Editor software contains a subprogram that allows users to create maps that illustrate the surface and topography of a particular location. In order to create this map, topographical data from Crete were imported and processed through ArcGIS software. A roughness of 0.0002 m was set for the sea area, while a roughness of 0.1 m was set for the land area.

Data such as iso-elevations, which represent the height of the ground at various points, and roughness data, which indicate the resistance caused by uneven ground to air flow, have been imported into the WAsP Map Editor. WAsP usually imports this data after it has been processed through other software, such as ArcGIS, before it is imported from satellite imagery or topographic surveys.

After entering the data, the WAsP Map Editor will be able to create a detailed map that will be used to simulate airflow and assess the potential for wind energy in a particular region. Wind dispersion and power generation are calculated with the aid of this map in WAsP, which is fundamental to simulation and analysis.

The WAsP Map Editor tool allows you to edit and analyze terrain features. To define the topography and relative anomaly of the area, it imports the data generated by the WAsP Map Editor.

ii. WASP Turbine Editor

The WAsP WT Editor software part creates and parameterizes the WT model. A multitude of parameters are entered into the software, including the tower height, the RD, the starting speed and the cut-off speed, as well as the power and resistance characteristic curves. Models were developed using the WAsP Turbine Editor for Vestas V164 - 9.5 MW, Vestas V236 - 15 MW, Siemens Gamesa SG167-8 MW, and Siemens Gamesa SG154-6 MW WTs. The adopted scnarios are given in the following Table 4.10 below.

Table 4.10 Description of the scenarios

Type	1st Scenario	2nd Scenario	3rd Scenario
Model of BFWTs	Vestas V164 – 9.5MW	Vestas V236 – 15MW	Siemens Gamesa SG167-8MW
Number of BFWTs	19	11	18
Model of FWT	Siemens Gamesa SG154-6MW	Siemens Gamesa SG154-6MW	Siemens Gamesa SG154-6MW
Number FWTs	10	8	11

Modelling and calculation of Energy Efficiency: WAsP was used to create the WF model, which included geographic parameters and meteorological data from the Global Wind Atlas [79]. A calculation was then performed to determine the energy efficiency of each type of WT.

Feasibility analysis: A financial evaluation of the project was the last step in the process. On the basis of data from similar projects and scientific journals, installation costs, operating costs, retirement costs, additional energy costs, and net present value were calculated.

- Payback period

Payback period (PP) refers to the time it takes to recoup the investment. During the PP, the cost of capital is not considered (no cash flow discount is taken into account) and the cash flow generation is skipped. As a result, a project with a low PP and low long-term cash flow generation is preferred to one with a high PP and high long-term returns, which introduces a bias in the long run. Low PP contributes to the developer's acceptance of the project [137].

The PP is determined as follows Eq. 4-11:

$$Payback\ period = \frac{Total_{investment}}{Cash\ flow_{per\ period}}$$

Eq. 4-11

- NPV (Net present value)

The NPV represent the future cash flows over the entire life of a project discounted to the present. NPV is a comprehensive indicator that assesses the present value of a project's future cash flows and provides a clear picture of the expected profit or loss that will result from the investment. The NPV analysis allows investors to judge the profitability of a project and determine whether the project in question can generate positive value beyond the cost of capital. In addition, NPV is an indicative metric for comparing different investment scenarios, determining which project offers the greatest profitability under given conditions [216]. According to the NPV, a project's future cash flows are discounted to the present over its entire life span. It is necessary to discount the cash flows (i) in order to adjust for the risks associated with an investment opportunity. Investing in capital markets involves a risk that the cash flow might not materialize and (ii) the time value of money must be taken into account. Inflation and the possibility of earning money using the money in the interim are taken into consideration [137] Eq. 4-12. If NPV > 0 the investment should be carried out because it is economically feasible, otherwise not.

$$NPV = -I_0 + \sum_{i=0}^{t} \frac{CF_i}{(1+r)^i}$$

Eq. 4-12

Where:

I_0: Initial investment

r: discount rate

CF_i: Cash flow at i-period

and t: the lifetime of the project

- Internal rate of return (IRR)

A project's IRR can be defined as the discount rate that sets the project's NPV equal to zero. Over the course of a given investment period, the IRR represents the average annual return. A return on investment should be higher than that of other alternative investments with the same level of risk. IRR has some shortcomings. IRR estimates a project's annual return on investment only when interim cashflows are not generated or if these interim cashflows can be invested at the actual rate of return. When the IRR exceeds the valid reinvestment rate for interim cash flows, the measure will overestimate. During the interim cash flow period, the equation assumes that the company has a portfolio of equally attractive projects to invest in. The following applies only to investments with initial negative cash flows and with no permutations in the annual cash flows. The comparison of multiple projects with varying lengths is misleading. It is not sufficient to evaluate the best scenario solely on the basis of IRR. Combining IRR and NPV provides an excellent way to evaluate an investment's attractiveness [137].

The formula for IRR is Eq. 4-13:

$$-I_0 + \sum_{i=0}^{t} \frac{CF_i}{(1+IRR)^i} = 0$$

Eq. 4-13

Where:

I_0: Initial investment

IRR: Internal rate of return

Cf_i: Cash flow at i-period

and t: lifetime of the project

- Levelized cost of energy (LCOE)

Essentially, the Levelized Cost of Energy represents the net present value of the cost of electricity generated per unit. To compensate for the costs incurred, the LCOE measures the average price at which the energy produced over the project's lifetime must be sold. LCOE depends on CAPEX, OPEX, and DECEX, as well AEP: The LCOE can be reduced by incentives and optimized by optimizing the positioning of the system for maximum energy output [137].

The formula for LCOE is Eq. 4-18:

$$LCoE = \sum_{0}^{t} \frac{\frac{CAPEX + OPEX + DECEX}{(1+r)^i}}{\frac{AEP}{(1+r)^i}}$$

Eq. 4-14

where:

CAPEX, OPEX, DECEX:

are the capital, operating and decommissioning costs, respectively

r: discount rate

t: lifetime of the project

AEP: Annual Energy Production

4.3 Assessment of VI of OWFs

4.3.1 Methodology 1

A methodological framework is suggested to estimate the VI of an OWF Figure 4.9. The testing of the methods will be realised by comparing the results of these methods with the local inhabitants' viewpoints, with the use of questionnaires. The final target is to catch up with the potential scepticism of nearby communities, due to VI, to such a large-scale energy project. Briefly, this methodology targets to:

1. Assist the relevant policymakers in establishing policies, minimising the visual effect of OWF, in the preliminary design process of the project.

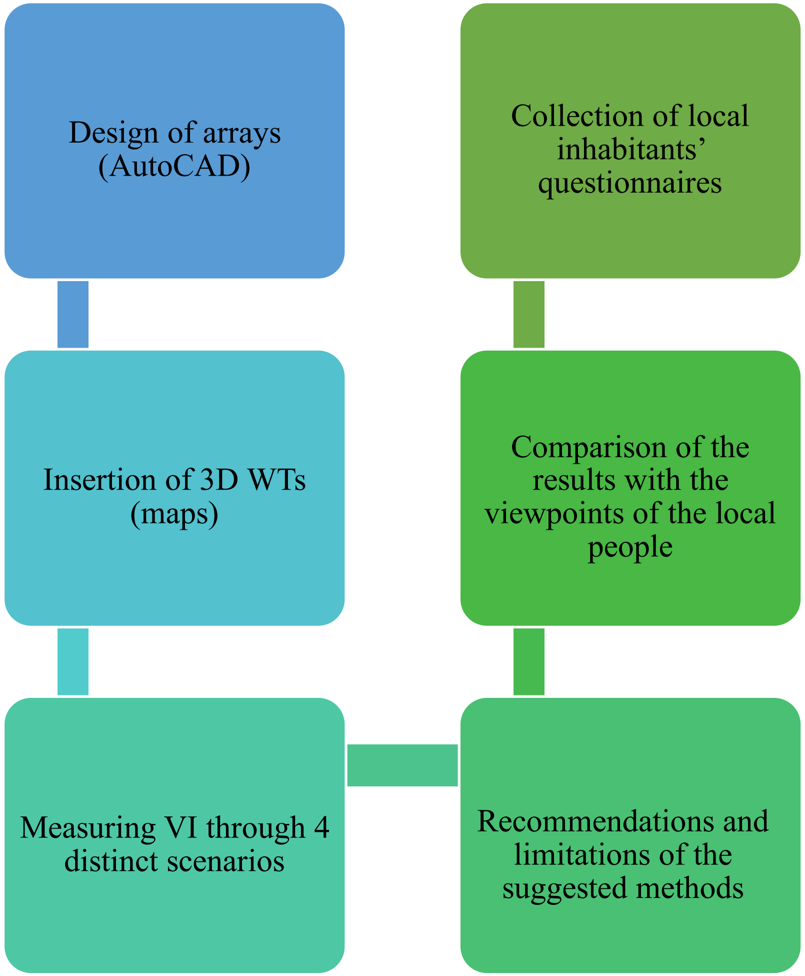
2. Increase the acceptability of these kinds of projects by the local communities.

3. Test existing tools for the assessment of the VI from an OWF.

4. Propose modifications and updates for the factors that do not correspond to reality.

Consequently, several viewpoints of observers were selected to be added to the software of ArcGIS v.10.5. The viewpoints were pinned in settlements (smaller or bigger) (coastal or not) around the potential OWF, in order to indicate all the candidate sites with a high VI from the WF. Afterwards, the visibility tool (ArcMap) was used to calculate coefficients a and b. The six main stages of the proposed methodology are briefly summarised below:

- The potential arrays of OWFs were designed with the aid of AutoCAD software, v 2018 and ArcGIS, v 2016.
- The array points were inserted in Google Earth and subsequently, the installation of 3d WTs in these points with the software Virtual 3D Animated Setup v 2.0.
- The measurement of VI was implemented in 4 distinct scenarios of 2 commercial models of OWTs.
- The acquisition of questionnaires from nearby inhabitants ensued. The attitude of the local people toward the VI of an OWF was written in an essay.
- The results from the questionnaires were compared with those of the methods.
- Recommendations to enhance the SPM, for minimising the VI of an OWF near the shore were made.


Design of arrays (AutoCAD)
Insertion of 3D WTs (maps)
Measuring VI through 4 distinct scenarios
Collection of local inhabitants' questionnaires
Comparison of the results with the viewpoints of the local people
Recommendations and limitations of the suggested methods

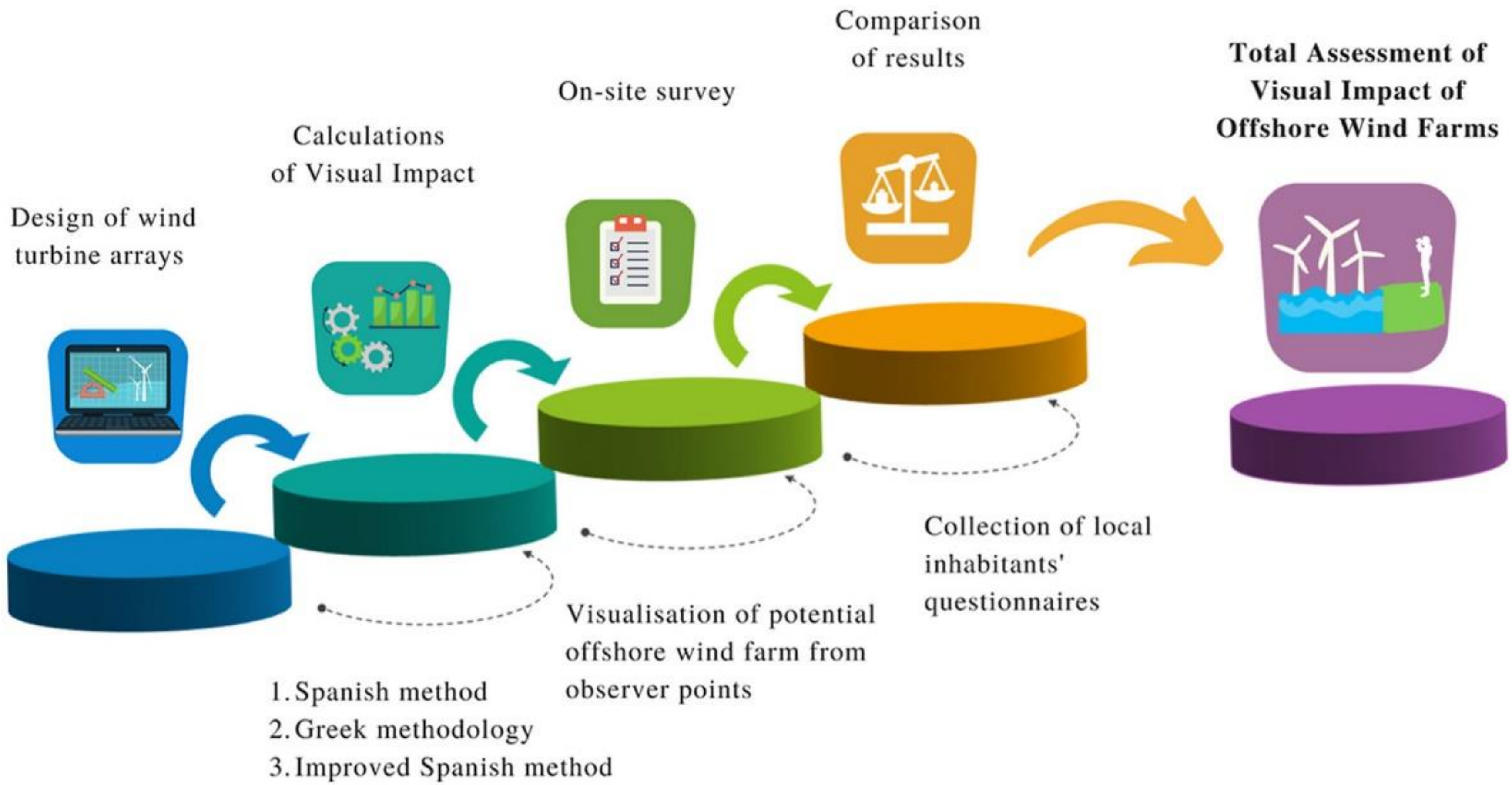


Figure 4.9: Methodological framework

4.3.1.1 VI assessment according to the Greek preliminary siting process for OWFs

To avoid the aggregation of a significant number of WTs near the shore, definition criteria for the determination of the maximum number of WTs in correlation with their size and their distance from the shore were adopted [186]:

- The height of the WT, the maximum height of the WT,
- H= height of the hub + ½ of the diameter (D) of the rotor
- The surface of the turbine (A), the maximum height (H) multiplied by the diameter (D) of the rotor.

To determine the level of visual disturbance created by a machine placed at a distance L from the observation position, the projection of the height is used, and the surface is set at a distance of 0.5m from the observation position. So, in this way, they are defined respectively, Eq. 4-15Eq. 4-16 [186]:

Visible height of the turbine:

$$H_{vis} = \frac{0.5m}{L}\ x\ H$$

Eq. 4-15

The visible surface of the turbine:

$$A_{vis} = \left(\frac{0.5m}{L}\right)^2 x\ A$$

Eq. 4-16

The overall level of the disturbance results from the sum of the above projections for all the turbines located in the area.

Therefore, a certain threshold must be set for the value of these parameters to ensure the best possible siting of the turbines. These values were defined as Eq. 4-17Eq. 4-18 [186]:

$$O_H < 0{,}6m$$

Eq. 4-17

$$O_A < 0{,}0025m^2$$

Eq. 4-18

For each WT model, two different layouts were created. One in which the WF was “against” the Greek preliminary siting process and one that was complying with it. So, in total 4 scenarios were created, which are shown in Figure 5.27 and Figure 5.28, respectively.

4.3.1.2 The SPM

The SPM was introduced by Hurtado et al. [143] and it was the first attempt to estimate the VI of a potential WF. It has several advantages to present, as well as certain deficiencies, which are presented in Table 4.11.

Table 4.11: Advantages and disadvantages of SPM

Advantages	Source	Disadvantages	Source
It introduced a condensed and prototype framework to predict and assess the VI of a WF, which did exist until then.	[65][143]	It necessitates modifications and adjustments because it is out-of-date and obsolete compared with today's data.	[143] [65] [146] [161]
It can be used as a tool by stakeholders and policymakers. (relevant authorities), during the preliminary stages of development of these kinds of projects.	[65][143][146][161]	It was created for onshore WFs and not for offshore.	[143] [148] [147] [148]
Easy to use.	[65]	It was tested for WTs that were much smaller in size, in comparison with current ones.	[143] [148] [147] [148]
It can quantify the VI of WFs in some manner.	[143][146][161]	It was designed mainly for linear arrays and not for more complicated ones.	[143] [65] [146]
It can be programmed.	[65][143][146]	t does not take into consideration variables like colour differences and weather conditions	[143] [65]

It is applied to a regional or local level.	[65][143]	There are some misunderstandings concerning the calculation of the variables of the coefficients a, b, c, d, and e which need to be updated, as well. (e.g. coefficient c does not consider the case, where only a limited number of WTs can be seen from the village).	[143] [65]
It can support the comparison of different scenarios.	[65][143]		

The original SPM is analysed further below, consisting of five (5) coefficients and three (3) equations, calculating the VI. The method's coefficients of a, b, c, d, and e are briefly described in Eq. 4-19-Eq. 4-27 [148]:

$$a = \frac{\sum_{i=1}^{n} \frac{x_i}{WM}}{n}$$

Eq. 4-19

Where:

n: number of areas inside the village with different views of the WP,

Xi: number of WTs visible from area i and

WM: total number of WTs in the WF.

$$b = Number\ of\ houses\ visible\ from\ the\ wind\ farm / Total\ number\ of\ houses\ in\ the\ village.$$

Eq. 4-20

The coefficient c is the result of the multiplication of n and v, which are estimated according to Table 4.12 and Table 4.13, respectively. Also, the cubic faces of the installation are represented in Figure 4.10.

$$c = n * v$$

Eq. 4-21

Table 4.12: Correction factor function of the number of WTs

Number of WTs	n
1-3	0.50
4-10	0.90
11-20	1.00
21-30	1.05
>30	1.10

Table 4.13: Correction factor function of the situation

Aspect of view	v
Frontal	1.00
Diagonal	0.50
Longitudinal	0.20

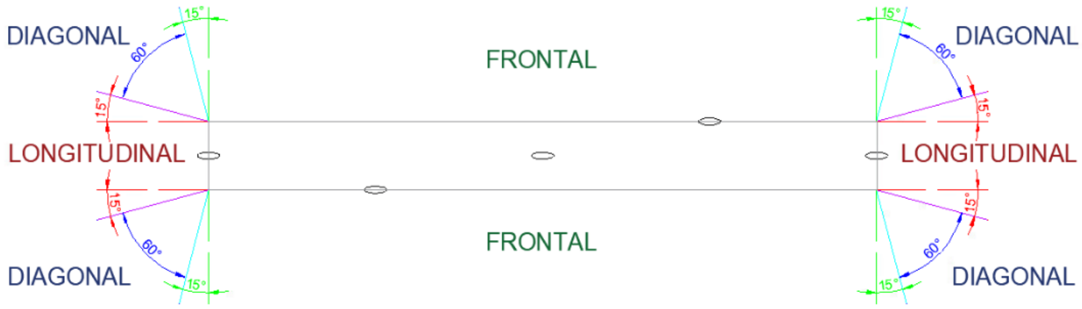


Figure 4.10: Cubic faces of the installation, modified from [65]

The coefficient d assesses the distance between the WF and the village (observer viewpoint) as follows (Eq. 4-22-Eq. 4-24):

$d = 1$, if x < 500m

Eq. 4-22

$d = 1.05 - 0.0002 * x$, if 500m < x < 6000m

Eq. 4-23

$d = 0.10$, if x>6000m (and WT is visible)

Eq. 4-24

The last coefficient e refers to the population of the selected village (point) and is estimated using Table 4.14.

Table 4.14: The coefficient function of the number of people

Number of habitats	e
>300	1
100-300	0.90
50-100	0.60
20-50	0.45
5-20	0.35
1-5	0.20
0	0

Finally, Partial Assessment 1 (PA1), Partial Assessment 2 (PA2), and the total assessment are computed with Eq. 4-25Eq. 4-26Eq. 4-27. Furthermore, the determination of the whole VI is estimated according to Table 4.15.

$$PA1 = a * b * c * d$$

Eq. 4-25

$$PA2 = a * b * c * d * e$$

Eq. 4-26

$$C = \sum_{i=1}^{m} \frac{a*b*NHm}{NTHE}$$

Eq. 4-27

Where:

C: total coefficient of affected people,

NHm: population of village m,

NTHE: total number of people in the area analysed

a: (see Eq. 4-19)

b: (see Eq. 4-20)

Table 4.15: Determination of the impact level

Assessment	Impact level
0.00-0.10	Minimum
0.10-0.30	Light
0.30-0.50	Medium
0.50-0.70	Serious
0.70-0.90	Very serious
0.90-1.00	Deep

4.3.1.3 Improvements in the coefficients of SPM

A more accurate process to evaluate the VI of OWFs is proposed, adapted to the new present data. A transformation would be attempted to the factors v, c, and d [65]. Coefficients a, b and e are calculated as the aforementioned process in sub-session 4.3.1.2.

Modified factor v according to SPM II (SPMII)

In the first part of the SPM, factor c was considered and more specifically, factor v (Eq. 7). It is observed that in the case of the alignment of the WTs in a row, the further the observation progresses from the front to the side, the less impact it has on the observer. However, the same cannot be said in the case of alignment in several parallel rows of WTs, since the maximum impact in a rectangular installation will be obtained from the diagonal side [65].

As a WF could acquire different sizes and dimensions, its cube could also acquire equally different sizes and dimensions. Thus, a value table such as Table 4.13 that has constant values could not satisfy the wide range of cases that may exist. Taking into consideration the following modification/suggestion from the relevant literature [65], Table 4.13 resulted in Table 4.16, in which L is the length of the rectangular cube of the installation, W is the width, and D is the diagonal. For each of the 4 scenarios this variant was tested, and the results were compared with the original.

Table 4.16: Corrections on factor v according to the reference [65]

Aspect of view	v
Frontal	L/D
Diagonal	1
Longitudinal	W/D

Modified factor v without the use of cuboids

The interest then turned to the rectangular cubes themselves. It has been observed that using these cubes, parts of extra area/volume are added, which do not belong to reality. This becomes more apparent in Figure 5.27 concerning scenarios 1 and 2, in which the shape is more specific.

The use of only three designations (front, diagonal and side view) is no longer enough in many cases to cover all the different visual aspects that an installation may acquire. To prevent this irregularity, the use of cuboids for the factor v is abandoned.

So, we do not consider the area as a cuboid, but we concluded the following steps to better describe the factor (v). Thus, the technique created for calculating the factor v is the following:

1. Measuring the maximum distance between the two WTs on the end of the array (Lmax) (Figure 4.11a).

2. Drawing two lines from the observation point that connect these two WTs (Figure 4.11b).

3. Drawing a line that connects these two WTs (red line), and then drawing a line from the observation point, passing through the middle of that line (purple line) (Figure 4.11c).

4. Drawing parallel lines to the purple line of step 3 (blue lines), passing again from the two external WTs. The vertical distance between these two lines is the distance Li (Figure 4.11d) (yellow line).

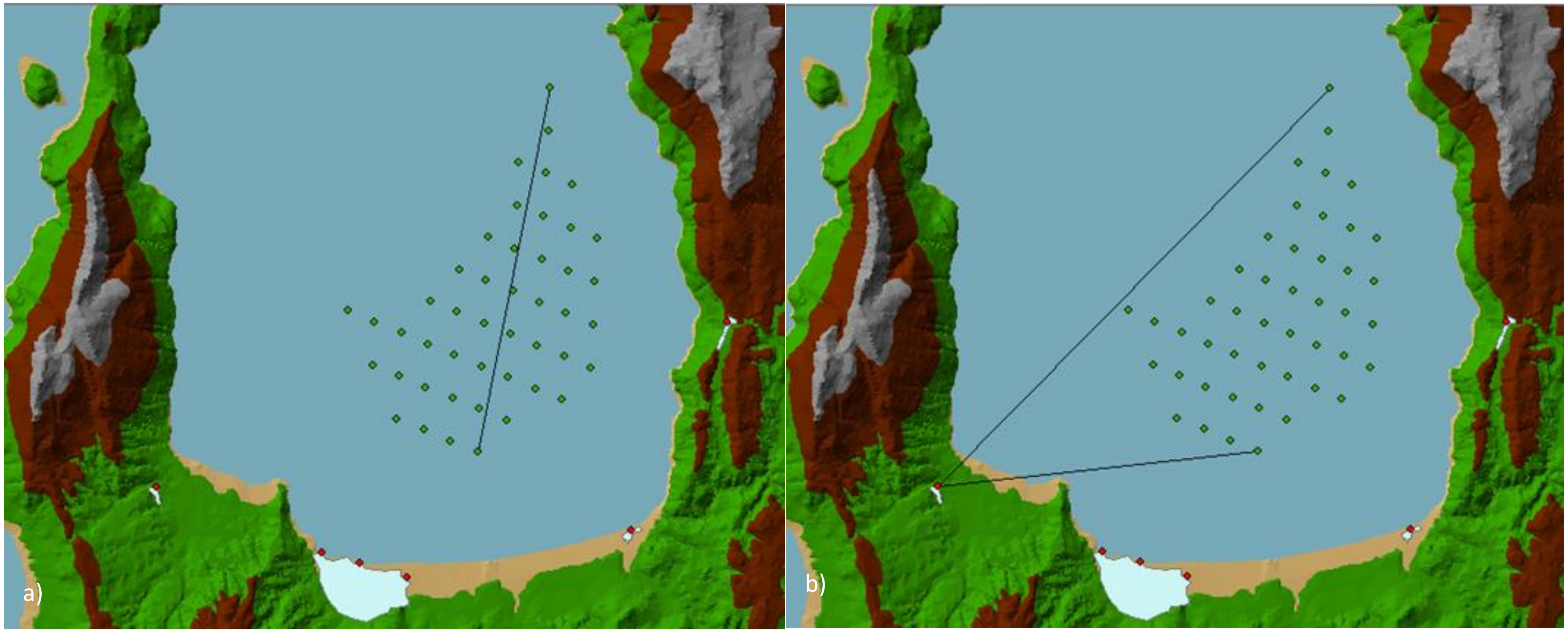
5. The factor v is equal to:

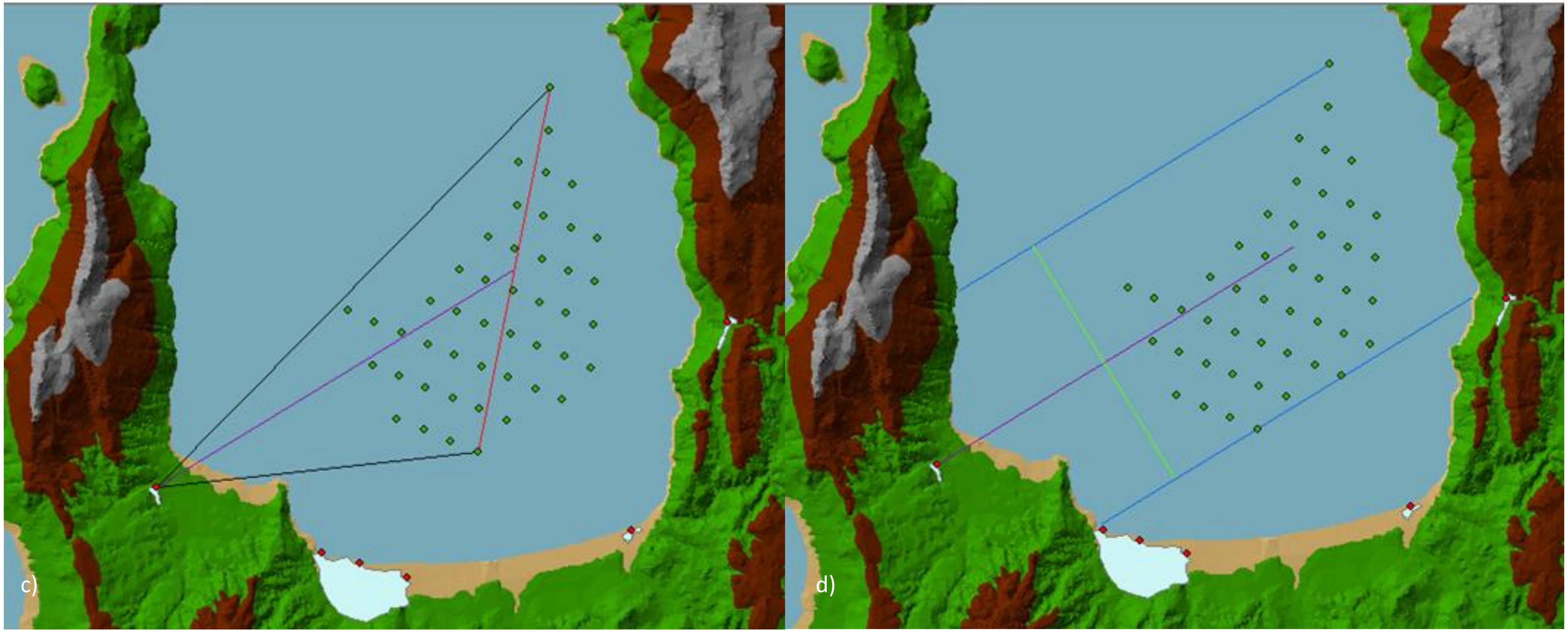
$$v = \frac{Li}{Lmax}$$

Eq. 4-28

Special case

If in step 4 there are WTs outside the blue lines (Figure 4.11e), then we identify the WT that is farthest from the nearest parallel and take it as one of the external WTs, and we start the process from step 3 (Figure 4.11f). The new vertical distance between these two parallel lines is Li. In case the same problem is met again, the same process is repeated until it stops.


a)
b)


c)
d)

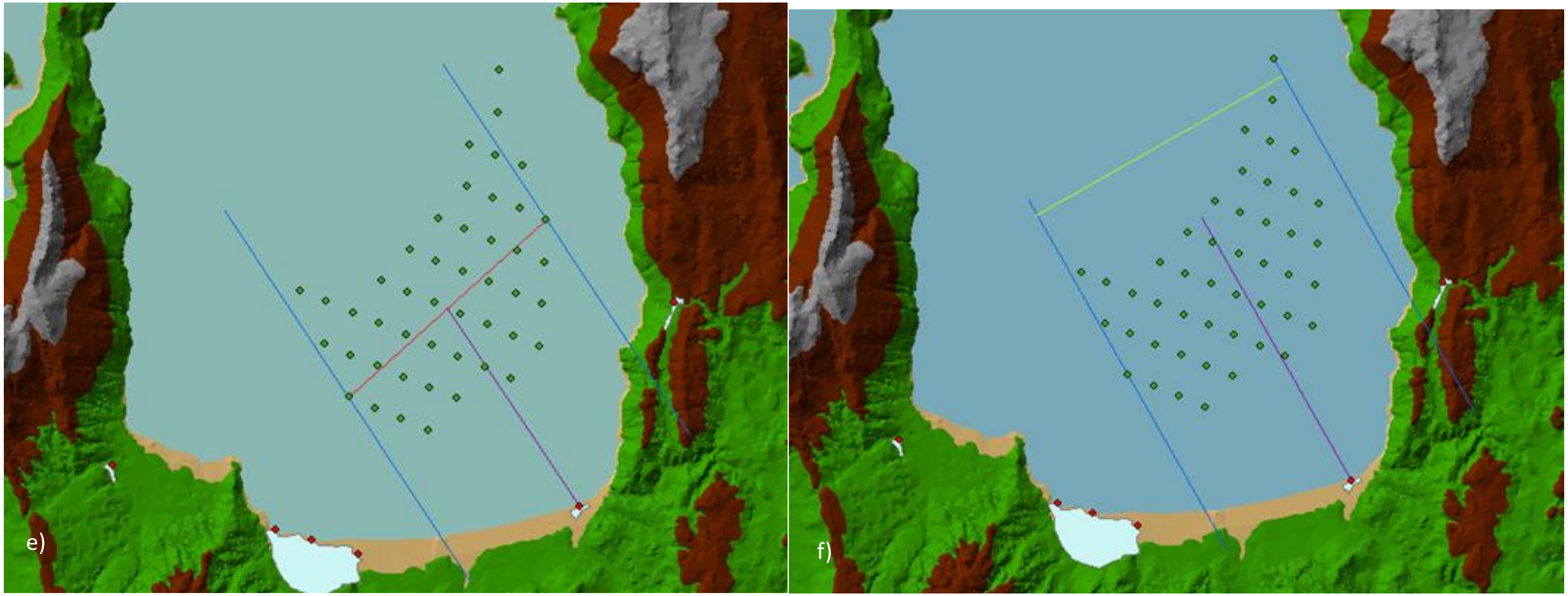


Figure 4.11: Calculation of factor v: The different steps of the process

Modified coefficient d according to SPMII

The last part where modifications were tested was at coefficient d. Since the creation of the SPM, the size of WTs has increased dramatically; thus, current WTs can be perceived from much greater distances in relation to the previous ones [65]. As it was not possible to find additional information on what values the coefficient d should take, the values of the literature were used [65]. This case concerned WTs with a height of 140m, where according to this, the distance up to 8 km from the observation point could take the value of d to be equal to 1.

Proposed modification for coefficient d

Another variant tested at coefficient d was the transformation of Eq. 4-22-Eq. 4-24, in a way that corresponds to more giant WTs. According to previous studies [147][148], in which the SPM had a reasonably satisfactory reality simulation for the onshore WTs of that time, in its original form, it was considered that Eq. 4-22-Eq. 4-24 effectively simulates the change of nuisance as a function of the distance for the WTs of that time. Thus, considering as l the ratio of the D and Hhub products of the WTs studied to that of the WTs used in 2005 (when the SPM was created), linear interpolation will be used to create a table representing the most modern WTs of interest (Table 4.17).

Table 4.17: Adaptation of coefficient d

x (km)	d
< 0.5*l	1.00
0.5*l - 6*l	a + b*x
> 6*l	0.10

Where:

l: a correction factor equals the ratio between the projection of the WT parallelogram used in our case and those of WTs in 2004 when the SPM was created [143]. A study found that the typical dimensions of a WT in 2005 were rotor height 80 m and RD 80 m [227].

a,b: a and b values will be calculated by linear interpolation.

The use of linear interpolation also solves another issue that has the original panel. More specifically, if the limit conditions in Eq. 4-23 for 500-6000 m are tested, they disagree with the other values in Eq. 4-22-Eq. 4-24. In the first case, it comes out 0.95, and in the second case, it comes out -0.15, since for the 6000 m the coefficient is 0.1.

Factor ψ and coefficient ψf

Factor ψ and coefficient ψf are a new addition to the method, which was considered correct, after processing the results from the questionnaires distributed. Factor ψ is an essential factor that measures the sample's view of RET and coefficient ψf examines how it affects the degree of the impact on the observers. The calculations of factor ψ and coefficient ψf are described in subsection 5.3.1.5 "Questionnaires’ results".

4.3.1.4 Questionnaires from the observation areas

Creation

To verify the above changes, questionnaires were distributed in the study areas, which showed images from each area, with the wind installations arrays studied. To create these images, the landscape, as it was seen from the observation points was first photographed. The programs used to create the questionnaire images were Google Earth and the Virtual 3D Animated WT. The former provided a realistic depiction of the landscape, while the latter was used to integrate WTs into the landscape. Finally, the photos taken from the observation areas were used to calibrate the image shown by Google Earth, adjusting the zoom in/out, so that the image from Google Earth coincides with that of the photos from the observation points.

Structure

In the questionnaires, the respondents were asked to fill in their degree of annoyance from the change in the landscape for each of the images they observed. The five answers that they could give for each of them were "Little / Not at All", "Little", "Moderate", "Very" and "Very Much". The questionnaire also collected demographics and, more specifically, gender, age group, and educational level. Finally, respondents were asked to answer the question "What is your point of view about RET?", and the possible answers were "Very Poor", "Poor", "Neutral", "Good" and "Very Good". Respondents were also allowed to make their free comments optionally in terms of the survey.

Questionnaires' results

The possible answers for each photo of the questionnaire correspond to a specific PA[5] value as shown below:

- Little / Not at All: PA = 0
- Little: PA = 0.25
- Moderate: PA = 0.5
- Very: PA = 0.75
- Very Much: PA = 1

Then, the answers were converted to PA, the average (average) PA was found for each scenario at each observation point and it was compared with the variants tested in the SPM. This comparison was made through the deviation of the PA of each method, with the corresponding of the questionnaires Eq. 4-29.

$$\varepsilon = \frac{|PA_{res} - PA_{meth}|}{PA_{res}}$$

Eq. 4-29

Where:

PAres: PA from respondents

PAmeth: PA from the methodology

[5] PA is assessed as PA1 (Table 4.15).

A similar process was used to create the factor ψ. The answers to the question "What is your view on RET?" were converted/translated to ψ value, as shown below:

- Very Poor: ψ = - 1
- Poor: ψ = - 0.5
- Neutral: ψ = 0
- Good: ψ = 0.5
- Very Good: ψ = 1

Then, for each of the five categories, the average of PA was calculated and a diagram f (ψ) = PA was created. From the trend line of this diagram, which is the most appropriate relation (linear, polynomial, etc.) that describes the change of pa based on the coefficient ψ was found. To verify this, the correlation coefficient R2 was used, which is used to show the existence of a correlation between an independent variable (ψ) and a dependent one (PA). The coefficient takes values between 0 and 1. When the value of the coefficient is 0, then it is considered that there is no correlation between the two variables, while when the coefficient value is 1, it means that there is a perfect correlation. The threshold beyond which a strong correlation is considered is subjective and depends on what analysis is performed each time. This value usually ranges between 0.8 and 0.9, so in this work, it considered that for R2 values greater than 0.9, there was a strong correlation between ψ and PA. Excel (v 2016) was used to calculate this factor [143].

The value of the factor ψ for the sample was then calculated, as the average of the various values ψ given by the sample. At the same time, from the trend line of diagram f (ψ) = PA, the ratio f(1)/f(0) was calculated, which shows how much lower the value of PA would be for an observer with a very good view of RES, compared to an observer with a neutral point of view. Thus, from the ratio f(1)/f (0), the kind of relationship that connects the factor ψ and PA and from the value of factor ψ, it is possible to calculate the value of coefficient ψf, which when multiplied by the value of PA given by SPM, gives the degree of impact that the population will feel depending on their view of RES technologies. In more detail, in the case of linear interpolation, Eq. 4-30 applies.

$$PA = PA_{neu} + \psi \, x \, \frac{PA_{neu} - PA_{vg}}{\psi_{neu} - \psi_{vg}}$$

Eq. 4-30

Where:

PA_{neu}: The degree of annoyance felt by observers who have a neutral view on RES technologies. At the same time, it is the PA given by the SPM.

PA_{vg}: The degree of annoyance felt by observers who have a very good opinion on RES technologies.

ψ_{neu}: The coefficient ψ corresponds to the sample which has a neutral opinion on RES technologies.

ψ_{vg}: The coefficient ψ that corresponds to the sample, which has a very good opinion on RES technologies.

Subsequently, with the addition of the two following Eq. 4-31Eq. 4-32, we have:

$$PA = PA_{neu} \; x \; \psi_f$$

Eq. 4-31

$$PA_{vg} = \frac{f(1)}{f(0)} \; x \; PA_{neu}$$

Eq. 4-32

Afterwards, by replacing the aforementioned Eq. 4-31Eq. 4-32 to Eq. 4-30, we get the Eq. 4-33, which represents the value of the coefficient ψf.

$$\psi_f = 1 \; - \; \psi \; x \left(1 - \frac{f(1)}{f(0)}\right)$$

Eq. 4-33

Finally, the coefficient ψ was multiplied by the values given by the SPM and the modifications made to it and a comparison was made with the results of the questionnaires. The new deviations were compared with the deviations without the coefficient ψ to show how they affected the results.

4.3.2 Methodology 2

A methodological framework is proposed to assess the VI of OWFs (Figure 4.12). Firstly, the suggested method based on Greek legislation is tested [169]. In order to apply this method, two basic criteria must be considered; the density of WTs in km2 and the percentage of the observer's visual horizon that is covered by WTs. It is significant to note that these criteria are applicable to a wide variety of points of interest (settlements, archaeological sites, traditional settlements, National Parks, and tourist areas). Also, there are specific limitations to each of the aforementioned criteria, which can result in some conclusions regarding how much VI is generated by an installation. The second approach was to conduct a site survey within the study area as a second step in the analysis process. There was a large number of questionnaires collected from the local people. These were used to determine whether a potential OWF in their region would be visually annoying to them, as well as in which grade. Finally, the results from the first methodology (concerning settlements) are compared with those from the inhabitants. The methodology adopted in this study is discussed in more detail below.

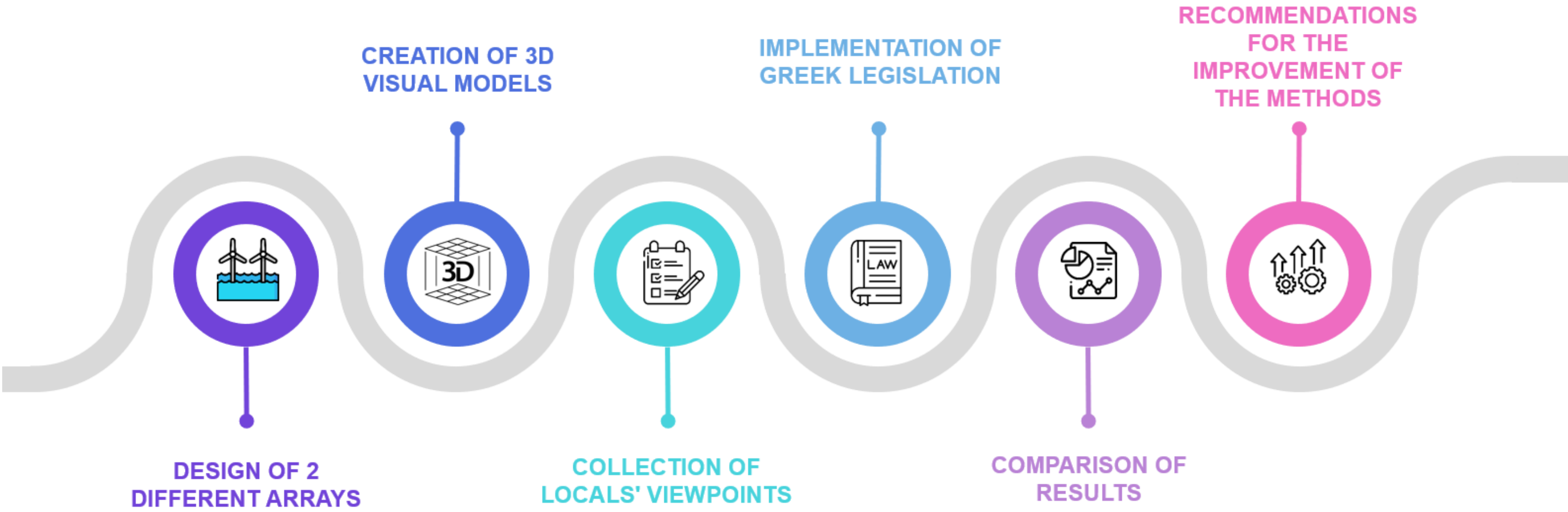


Figure 4.12: Methodological process

4.3.2.1 Landscape integration criteria for OWFs

First of all, there are many factors that may influence the integration of a WF into a landscape, such as the height of the turbines, the colour of the turbines, the distance from the point of interest, etc. Researchers have also taken a variety of approaches to this topic, as discussed in the introduction and state-of-the-art section. The study selected two criteria in accordance with the national law (Criterion 1- Maximum number of WTs per km^2, Criterion 2- Weighted factors of optical coverage angles, see subsection 5.3.2.1), and they were tested based on the opinions of local residents.

As a result of previous research, the most suitable areas were identified. Afterwards, it was calculated how many turbines (2 different models were selected) could be located within the polygons based on 7x5 RD and predominant wind directions (see subsections 5.3.2.1 and 0). As a result, buffer zones from villages were established in order to determine whether WTs are located inside these zones. In subsection 5.3.2.3, the results of the analysis are presented.

The concentric zones A, B, and C are defined according to Table 4.19 and are determined for each special interest point. The maximum number of WTs per zone is determined according to Table 3 (Greek legislation). From both an economic and an environmental point of view, the concentration of WFs in areas of high wind potential is desirable, however, the density of WTs around existing sites of particular interest in these areas should be limited within predefined limits. The visual horizon of points of special interest should be limited if the density exceeds this limit. Moreover, the impact of each WT on the landscape depends on its actual distance from the area of interest. In order to quantify the above, two requirements-criteria are provided, according to which the WF is controlled and conformed.

The second criterion for assessing the VI of WTs is examined when the first criterion has not been met, and it is concerned with the percentage of the observer's visual horizon that is covered by the WTs, which revolve 360 degrees around themselves. As long as the first criterion has been met, the second does not require further investigation. For the purpose of estimating this criterion, WTs whose actual distance from each other is not more than 500 m are joined by imaginary straight sections. The angles (in degrees) between these sections are then calculated. Using the centre of the points of special interest and passing the sides through the ends of the imaginary parts mentioned above, angles are generated.

A WF's VI on the landscape is determined by a circle defined by a centre and a radius that varies according to the importance and quality of the point of "special interest" in the landscape. This circle symbolizes the visual interference from the WF from this point. Table 4.18 presents the points of "special interest" and the maximum distance from the WF, which has to be checked in relation to the points of "special interest".

WTs located outside the circle or whose shaft has no visual contact with the point are not included in the calculation. This is because their shafts are not visible from the point. In general, any existing points of particular interest in the vicinity of WTs should be restricted within prescribed limits with regard to the density of WTs around those points. When the density threshold for covering points of particular interest is exceeded, there should be a restriction on the coverage of the visual horizon of those points of particular interest. As a result, each WT's impact on the landscape from a particular point varies based on the actual distance from that particular point from which the turbine is located.

Table 4.18: Distance examined per point of special interest [169]

Point of special interest	**Maximum distance from WF (km)**
	Sea area
The closest limit of inscribed in the list of World Heritage and other major monuments, archaeological sites and historical sites of par. 5. Section bb) of article 50 of Law 3028/02.	6.0
The nearest limit of absolute protection zone (Zone A ') of other archaeological sites	6.0
The nearest limit of an institutionalized core of a National Park, a monument of nature, an aesthetic forest of par. 3 and 4 of article 19 of law 1650/86.	0.8
The nearest border of an institutionalized traditional settlement	6.0
The nearest borders of cities or settlements	2.0
The nearest border of an institutionalized or landscaped tourist area tourist accommodation of medium and large size, special tourist infrastructures, tourist ports	2.0

It is intended that the WF is controlled in order to provide an unbiased evaluation of the VI under the following conditions-criteria that it must adhere to in order to determine whether it will have an impact on the landscape [169]:

- The first criterion relates to the total number of WTs in each area. The radius of the circle is the maximum distance from the point of particular interest, and the center of the circle is at the point of special interest (Table 4.18). It is necessary that the shaft of the turbine has visual contact with the point. In order to test this, the viewshed tool in Google Earth Pro software was used. To account for the actual distance between the WTs and the point, the circular surface is divided into three total concentric sections (zones), A', B', and C', wherein the maximum density that can be accommodated is different in each of the three zones.

- The second criterion in assessing wind power is not applicable if the first criterion has been met, since it is concerned with the percentage of the observer's visual horizon that is covered by the WTs, which rotate 3600 around themselves. For the purpose of estimating this criterion, WTs whose actual distance from each other is not more than 500 m are joined by imaginary straight sections, and the angles (in degrees) between these sections are then calculated. Using the centre of the point of special interest and passing the sides through the ends of the imaginary parts mentioned above, the angles are generated.

As an examination of the criterion, it is necessary to take into account only those WTs which are located in circles with the centre at each of the points of particular interest and with a radius of a maximum distance above that point and which have a shaft with visual contact with that point. To take into account the actual distance between the WT and the point, the circle can also be divided into three totally concentric zones, A', B', and C', in which each of the three zones contains a differently weighted coefficient for the sum of the angles enclosing the imaginary segments corresponding to the respective zones. It is not taken into account that certain parts of WFs are taken out of consideration; the angle of view from the point of special interest is already covered by other WFs which are closer to it, and therefore, their angle of view has already been taken into consideration in the overall calculation (angular overlap).

Typically, if a WF meets the first criterion, then it means that the WTs are located sparsely enough around and near the point of particular interest, even if they are likely to expand to several areas of the horizon around the point of particular interest. The first criterion must be met for a WF, but even if it does not meet that criterion, it must also be met for a WF that has at least one or a few WTs situated around a point of particular interest, even if the WTs are positioned in a minimum of one of these directions.

There is a commonality in the concentric zones for both criteria and horizon regardless of the significance of the point of interest where the WF in question is located, as shown in Table 4.19, depending on the importance of the point of interest:

Table 4.19: Points of special interest and radius zones from examined WF [169]

Point of special interest	**Zone radius (km)**
	Sea area

	A’	B’	C’
Limits of the inscribed in the list of World Heritage and other major monuments, archaeological sites and historical sites of par. 5. Subsection bb) of article 50 of Law 3028/02.	3.0	4.5	6.0
Absolute protection zone boundaries (Zone A ') of other archaeological sites	0.5	3.0	6.0
Boundaries of an institutionalized core of a National Park, a monument of nature, an aesthetic forest of par. 3 and 4 of article 19 of law 1650/86.	0.2	0.8	-
Boundaries of an institutionalized traditional settlement	1.5	3.0	6.0
Limits of cities or settlements> 2000 inhabitants and limits of settlements <2000 inhabitants classified as tourist or remarkable	1.0	2.0	-
‘Settlement boundaries <2000 inhabitants that are not classified as tourist or remarkable	0.5	1.0	2.0
Boundaries of institutionalized or landscaped tourist area medium and large tourist accommodations, special tourist infrastructures, tourist ports	1.0	1.5	2.0

Table 4.20 presents the maximum density of WTs per zone for the purposes of applying the first criterion, which can be seen as follows:

Table 4.20: Criterion 1, Maximum density of WTs (number of WTs/km^2) and Optical coverage weighted angles for the application of criterion 2 [169]

Zone	Criterion 1 (Sea area) Maximum number of WTs/km^2	Criterion 2 (Sea area) Weighted factors of optical coverage angles
A’	0.0	1.0

B’	4.0	0.5
C’	7.0	0.3

It is important to note that the above number pertains to WTs that have blade diameters of 85m or larger (standard WT). Depending on the RD, the number is adjusted to the nearest larger integer if the RD is different from the stated diameter.

It is essential that the second criterion of "optical coverage" is met in addition to the first criterion of "density" if the first criterion of "density" is exceeded. This second criterion can be calculated by applying the weighted coefficients per zone to the sum of the angles that are within the respective zone, including the imaginary parts located within that zone (such as pre-existing installations), as shown in Table 4.20.

Finally, for the purpose of the application of the second criterion, a threshold is determined regarding the ratio between the weighted sums of the defined angles (with the coefficients identified above) and the whole circle (360°). At this point, a 30% limit has been set for the area of sea space.

Since the above values (maximum density of WT installation, weighted coefficients of the optical coverage angles, and visual coverage percentages) are differentiated, they correspond to spatial objectives that are geared toward enhancing the efficiency of the wind potential in areas where it is most exploitable, such as the seaside region, while also taking into consideration the unique characteristics of the insular region. Nevertheless, the restriction of not allowing WTs to be erected within zone A must never be enforced.

A detailed example of how criterion 2 is calculated can be seen below in Figure 4.13 and

Table 4.21, which demonstrate how it is calculated.

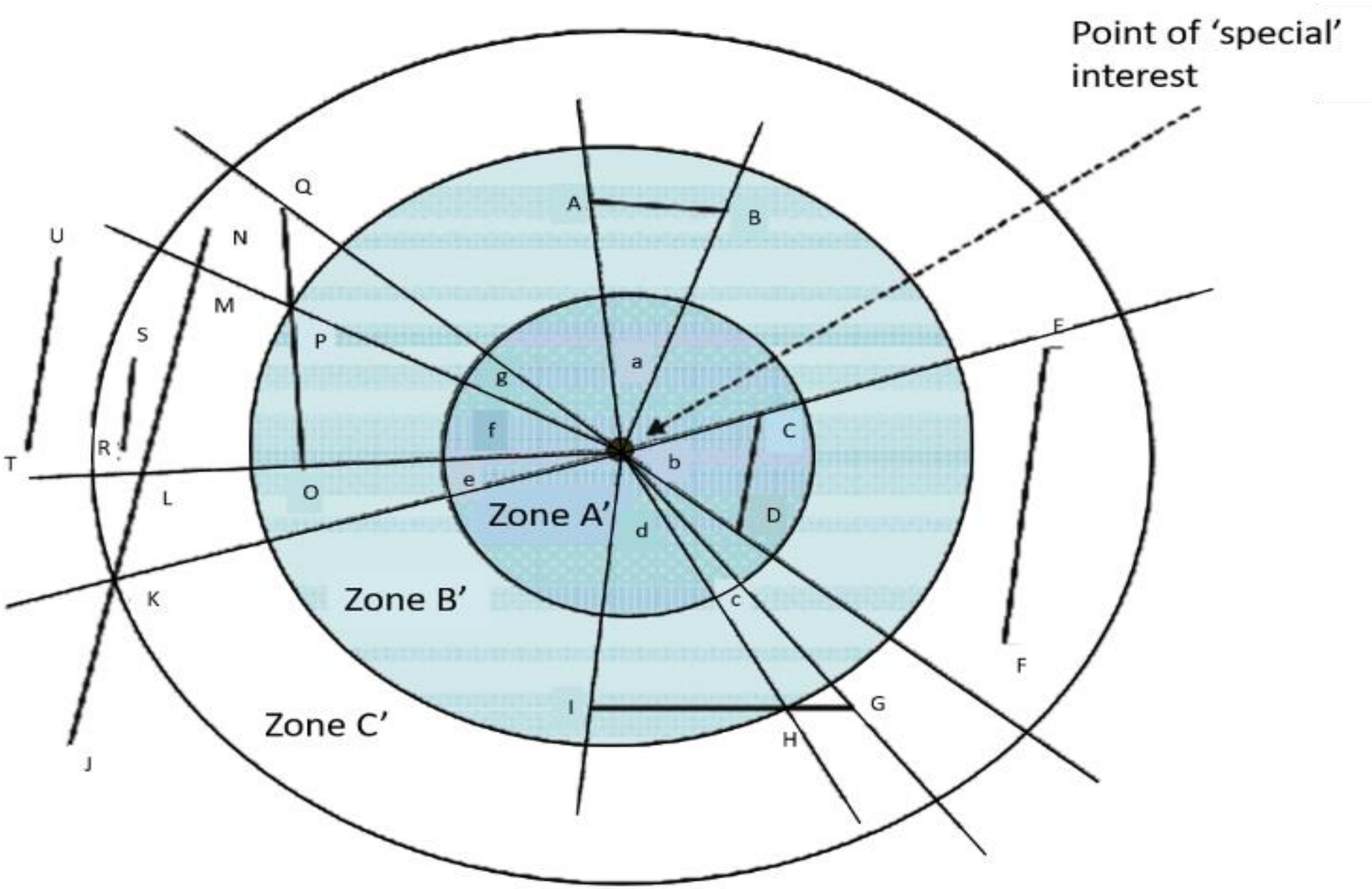


Figure 4.13: Example of calculation of criterion 2: Percentage of coverage. Modified from [169]

Table 4.21: Example of calculation of criterion 2: Percentage of coverage [169]

Angles	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**Sum**	**Weights**	**Weighted sum**
Straight sections	AB	CD	GH	HI	LK	OP	PQ			
Overlapping sections		EF				LM, RS, TU	MN			
Zone A’		25						25	1.0	25.0
Zone B’	25			30		25		80	0.5	40.0
Zone C’			10		15		20	45	0.3	13.5
Sum										78.5
Percentage										**21.81 %**

4.3.2.2 Questionnaires from locals

The objective of this study was to conduct site surveys, as well as conduct personal interviews with local inhabitants. This was in order to investigate the potential VI that an OWF might have on the local environment [86]. The objective was to create images of OWFs in their region. This was to show how it could be seen from the nearest villages or points within their region. Personal interviews have been shown to be an effective tool in smoothing the situation with regard to these themes (social acceptance).

A respondent was asked to observe two different pictures in the first questionnaire. After this, the individual was asked to assess the level of the optical disturbance they were experiencing. A five-scale response was given, in which the respondent replied: "Little / Not at All", "Little", "Moderate", "Very" and "Very Much" Table 4.22. As part of the second part of the process, respondents were required to provide some demographic information, such as their gender, age, and level of education. As part of the third part of the interview, the interviewers asked the interviewees to rate their general opinions about RET (PV, WFs) on a five-point scale (Table 4.23). The participants were also given the opportunity to make some comments and suggestions regarding the future of the renewable energy industry.

Table 4.22 presents the explanation of possible answers in the questionnaires about the optical disturbance of the two pictures. Furthermore, Table 4.23 explains the possible answers to the questionnaires about general viewpoints on renewable energy.

Table 4.22: Interpretation of possible answers in the questionnaires about the optical disturbance of the two pictures

Little/Not at all	**1**
Little	2
Moderate	3
Very	4
Very much	5

Table 4.23: Interpretation of possible answers in the questionnaires about the general viewpoints on renewables

Very bad	**5**
Bad	4
Moderate	3

Good	2
Very good	1
Other/Not answer	6

5. Results and Discussion

5.1 Results from the sustainable siting of OWFs

5.1.1 Results from site selection for bottom-fixed OWFs with the incorporation of relevant weights

5.1.1.1 Results from the stakeholders' questionnaires / relative weights of AHP

In this subsection 5.1.1.1, the results of our survey are presented, followed by the relevant diagrams and tables. First of all, a total number of 33 experts/stakeholders (out of the 71 questionnaires that were finally sent) were employed voluntarily and responded to our invitation. The allocation per category is also analytically presented in Table 5.1.

In Table 5.1 (see also Table 4.1), the panel was consisted of stakeholders and experts, who could potentially be involved in the preliminary process for a sustainable siting of an OWF in the study area. The environmental criterion was "represented" from the category of non-governmental organizations. These organisations were exclusively related to the protection of the marine environment, for example, the protection of birds, turtles, seals, etc. Specifically, in this category, experts from national organizations were also selected for a more holistic approach to the siting problem.

Additionally, it is worth mentioning that this number of responses is not negligible in terms of this kind of study. The relevant studies managed to collect a smaller number of experts or/and they relied on their own experience and knowledge to produce the relevant results.

Notably, they acted in their own interest with different moral principles, as was analysed in chapter 4.1.1 of this work. Additionally, all the names are confidential, and they were only utilized for this study.

Table 5.1: Allocation of the responses per Stakeholders' group

Categories of Stakeholders' groups	**Number of questionnaires/groups**
1) Regional Policymakers	4
2) Academia	4
3) Municipalities	5
4) Transmission and Distribution of energy	5
5) Port Authorities	4
6) Non-Governmental Organizations	4
7) Energy production-Energy producers' associations	4

8) Tourism -Tourist Associations	3
Total	**33**

Moreover, the local experts completed the questionnaires, and more specifically, the pairwise comparison part, and it was found that 19 out of 33 matrices had a CR > 0.1, so they had to be adjusted, in order they do not violate the condition of CR<0,1 [91]. All the details about the limitations and details of the method used AHP are analytically presented in the methodology subsection 4.1.1.2. The procedure was realized with the assistance of the online AHP Online System - AHP-OS [228].

The adjusted relative weights of the selected criteria are presented in Table 5.2 per expert/stakeholder group. In order to come up with these numbers, the average of relative weights per criterion and group was also calculated.

All the participants fulfilled the relevant questionnaires according to the principles of theory in subchapter 4.1.1.2. Subsequently, all the calculations required were implemented as described in subchapter 4.1.1.3 of the methodology. Finally, the whole process which has been followed was described in subchapter 4.1.1.4, and it synchronically was illustrated by Figure 4.2, in terms of a more holistic comprehension.

Table 5.2: The adjusted relative importance of the selected criteria per stakeholder group

Criterion	Regional Policy makers	Academia	Municipalities	Energy Transmission & Distribution	Port Authorities	Non-Governmental Organisations	Energy producers & associations	Tourism - Tourist Associations	Average / Aggregation of individual properties
Distance from Submerged cables	0.04	0.07	0.09	0.04	0.08	0.03	0.04	0.06	0.06
Distance from Areas of environmental interest	0.10	0.13	0.08	0.10	0.09	0.16	0.12	0.11	0.11
Distance from Shipping / Air routes	0.04	0.05	0.06	0.05	0.09	0.04	0.06	0.05	0.06
Distance from electric grid	0.04	0.09	0.06	0.03	0.08	0.04	0.05	0.06	0.06
Distance from military areas	0.13	0.05	0.06	0.09	0.11	0.04	0.08	0.03	0.07

Distance from shore	0.06	0.05	0.03	0.06	0.05	0.06	0.06	0.04	0.05
Distance from fishing areas	0.07	0.07	0.05	0.05	0.03	0.06	0.05	0.07	0.06
Distance from road network	0.03	0.04	0.05	0.03	0.08	0.03	0.03	0.06	0.04
Distance from heritage sites	0.11	0.08	0.09	0.12	0.08	0.12	0.07	0.14	0.10
Distance from residential activities	0.08	0.07	0.05	0.07	0.03	0.06	0.04	0.07	0.06
Distance from mining areas and activities	0.02	0.04	0.09	0.07	0.03	0.02	0.03	0.02	0.04
Wind resources	0.08	0.11	0.07	0.07	0.05	0.06	0.12	0.07	0.08
Water depth	0.05	0.06	0.04	0.04	0.03	0.06	0.07	0.03	0.05
Seabed substrate	0.05	0.03	0.03	0.04	0.03	0.10	0.06	0.03	0.05
Noise level/ Acoustic disturbance	0.03	0.02	0.07	0.07	0.07	0.06	0.06	0.07	0.06
Optical disturbance	0.08	0.03	0.08	0.06	0.07	0.07	0.07	0.09	0.07

								Sum=	1.00

Subsequently, in Table 5.3, the sixteen EVC and the percentage of their relative importance are shown. These numbers resulted from the average of relative weights of the preferences from each group, per criterion was implemented, so as to calculate the relative importance of each evaluation criterion.

It is also noticed that the criterion of Distance from Areas of environmental interest and the criterion of Distance from heritage sites acquired the most significant/highest relative importance. This observation led us to the conclusion that the most asked people considered as priorities the protection of nature, as well as the heritage sites. It is also worth noting that the wind resource criterion (the most significant-in terms of economic viability-for an installation came to the third position. Maybe, it is an indication that the people nowadays-regardless of what they represent-agree that the protection of nature and the preservation of ancient civilisations are above all the interests-or they have already realised that this is our common interest.

Table 5.3: Relative importance of the selected EVC

Criterion	Relative Importance (%)
Distance from Submerged cables	6
Distance from Areas of environmental interest	11
Distance from Shipping / Air routes	6
Distance from electrical grid	6
Distance from military areas	7
Distance from shore	5
Distance from fishing areas	6
Distance from road network	4
Distance from heritage sites	10
Distance from residential activities	6
Distance from mining areas and activities	4
Wind resources	8
Water depth	5
Seabed substrate	5
Noise level/ Acoustic disturbance	6
Optical disturbance	7

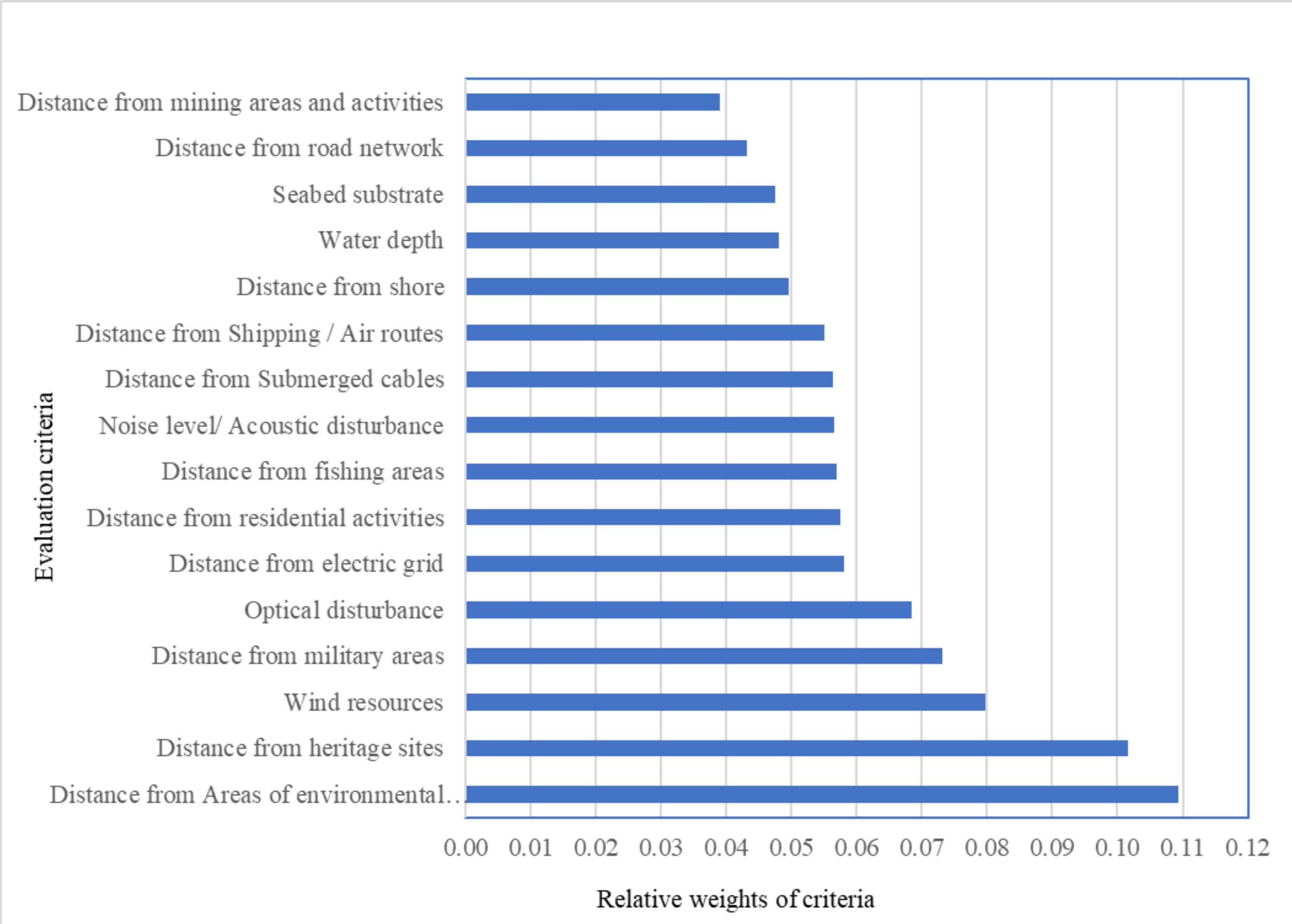


Figure 5.1: Increasing order of adjusted aggregate relative weights per each evaluation criterion

Figure 5.1 shows the differences between the first relative weights and the adjusted ones. Consequently, it is notable that the first five criteria and their weights do not have any notable change. The criterion of distance from areas of environmental interest acquired a higher relative weight (0.11), as shown in Figure 5.1, meaning that it is a crucial constraint for each group of experts, so it should be taken into consideration from the very start of planning the selection of the site for an OWF. Furthermore, the criterion of distance from heritage sites is assessed with a high score, by the majority of experts, so this criterion is also crucial for the initial planning of an OWF.

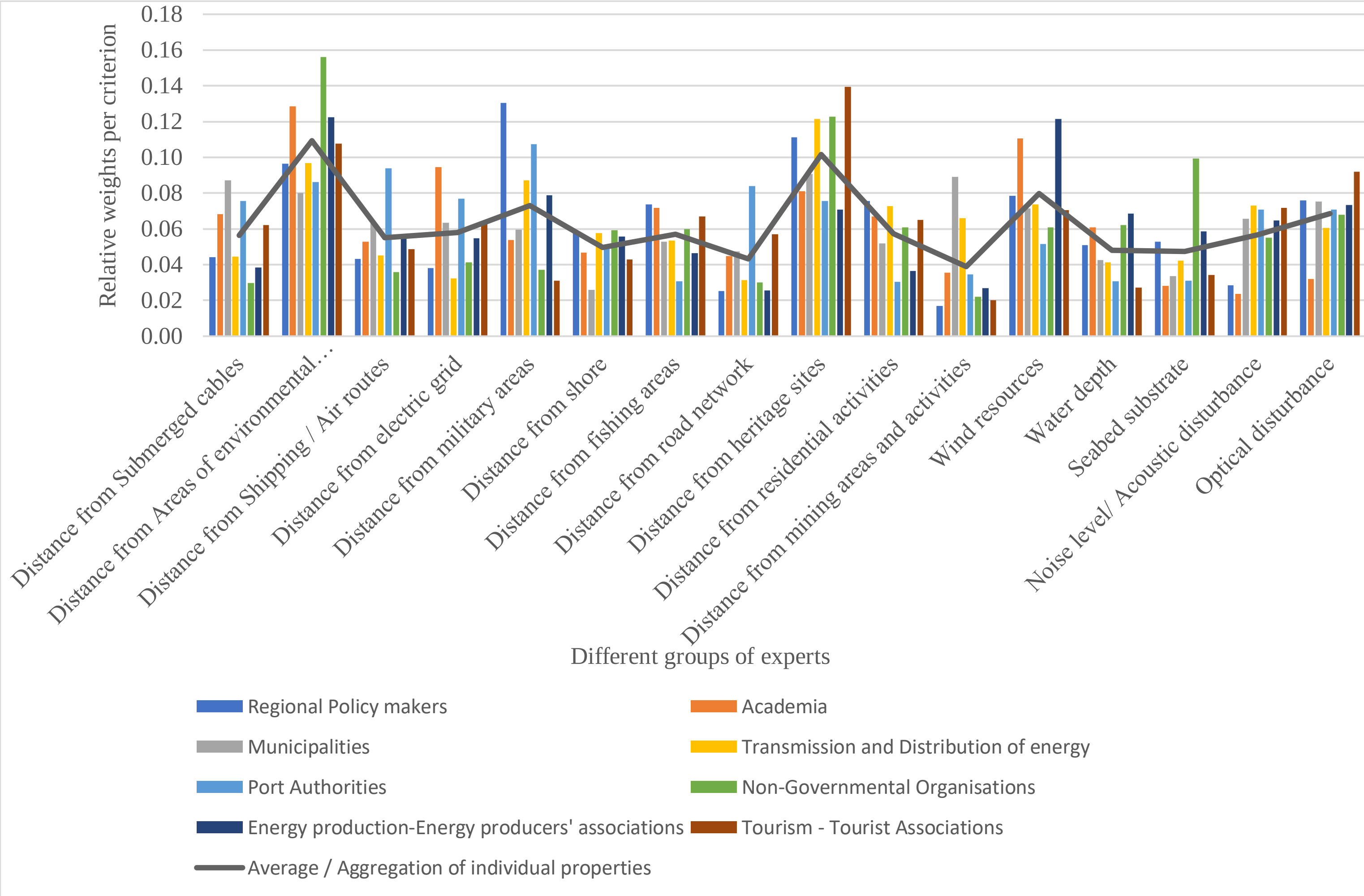


Figure 5.2: A graph of grouped columns for the comparison of different groups

In Figure 5.2, the results of questionnaires per group are presented. For example, the non-governmental organisations preferred the distance from areas of environmental interest with a high weight of nearly 0.16, whereas the energy producers selected wind resources as the most important criterion for them. Finally, all the preferences per group and per criterion could be noticed and compared in Figure 5.2. So, it is important to see that they preferred to prioritize the criteria related to their expertise/work sector.

Besides, in Figure 5.2, it is noticed from the second match of graphs that all the groups prioritised the environmental criterion. Additionally, as was expected, the environmental non-governmental organisations gave the highest priority, in relation with all other groups, to the criterion distance from areas of environmental interest.

It is also worth mentioning that the environmental criteria are usually common for all countries, for example, NATURA 2000 sites, which are a directive from EU. Meanwhile, for every local region, there is a possibility that supplementary environmental limitations and rules could exist, in order to protect the special and endangered species of fauna and flora of this region.

5.1.1.2 Exclusion of unsuitable marine areas

In Figure 5.3, the available marine areas for siting an OWF are depicted, after excluding restricted areas (with the aid of the cell statistics tool, (ArcGIS) (subsection 4.1.1.4) for the island of Crete. The light green areas could meet the requirements for a sustainable siting.

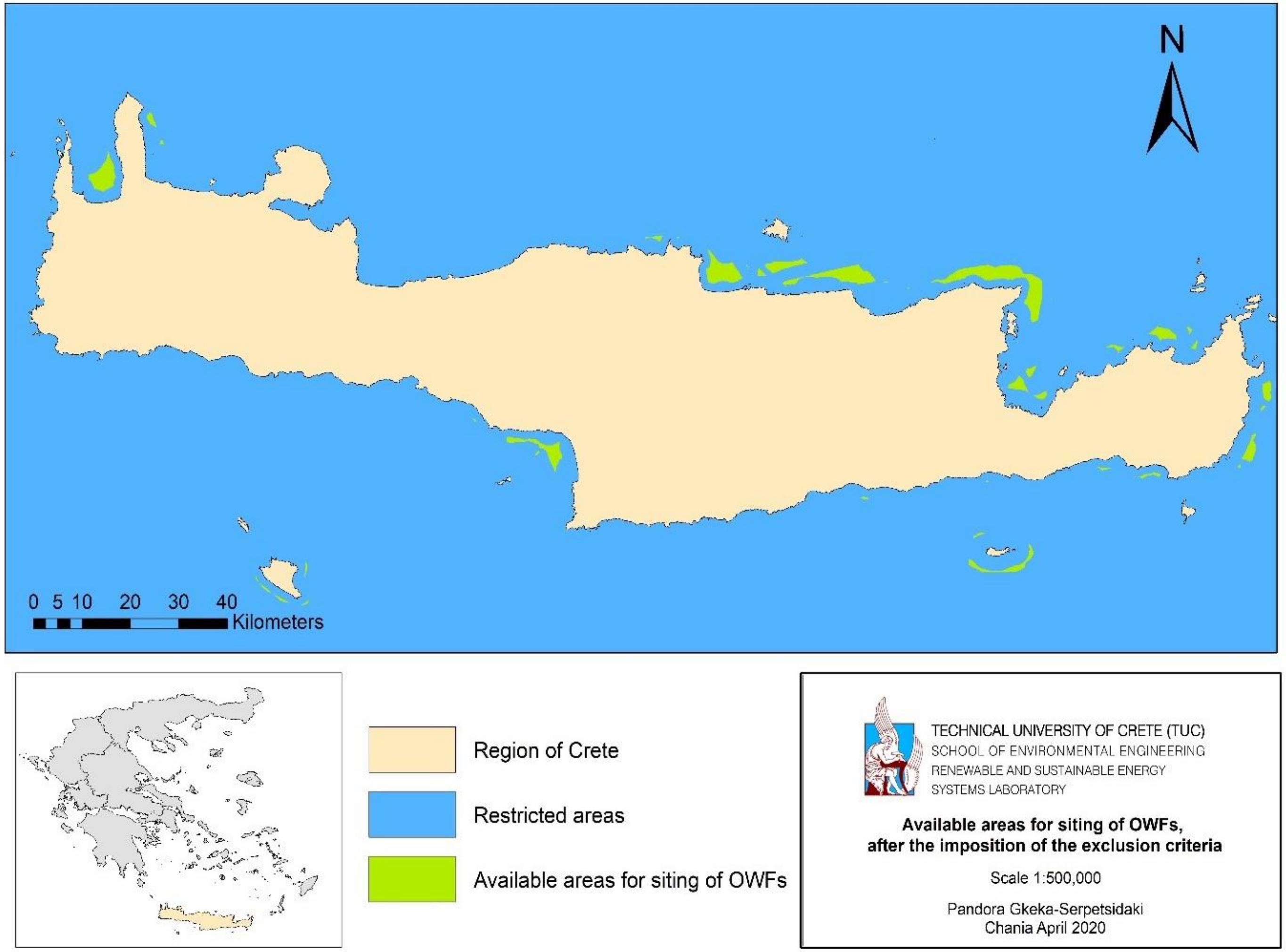


Figure 5.3: Available areas for siting of OWFs, after the imposition of the EXC

5.1.1.3 Evaluation maps and ranking of suitable areas

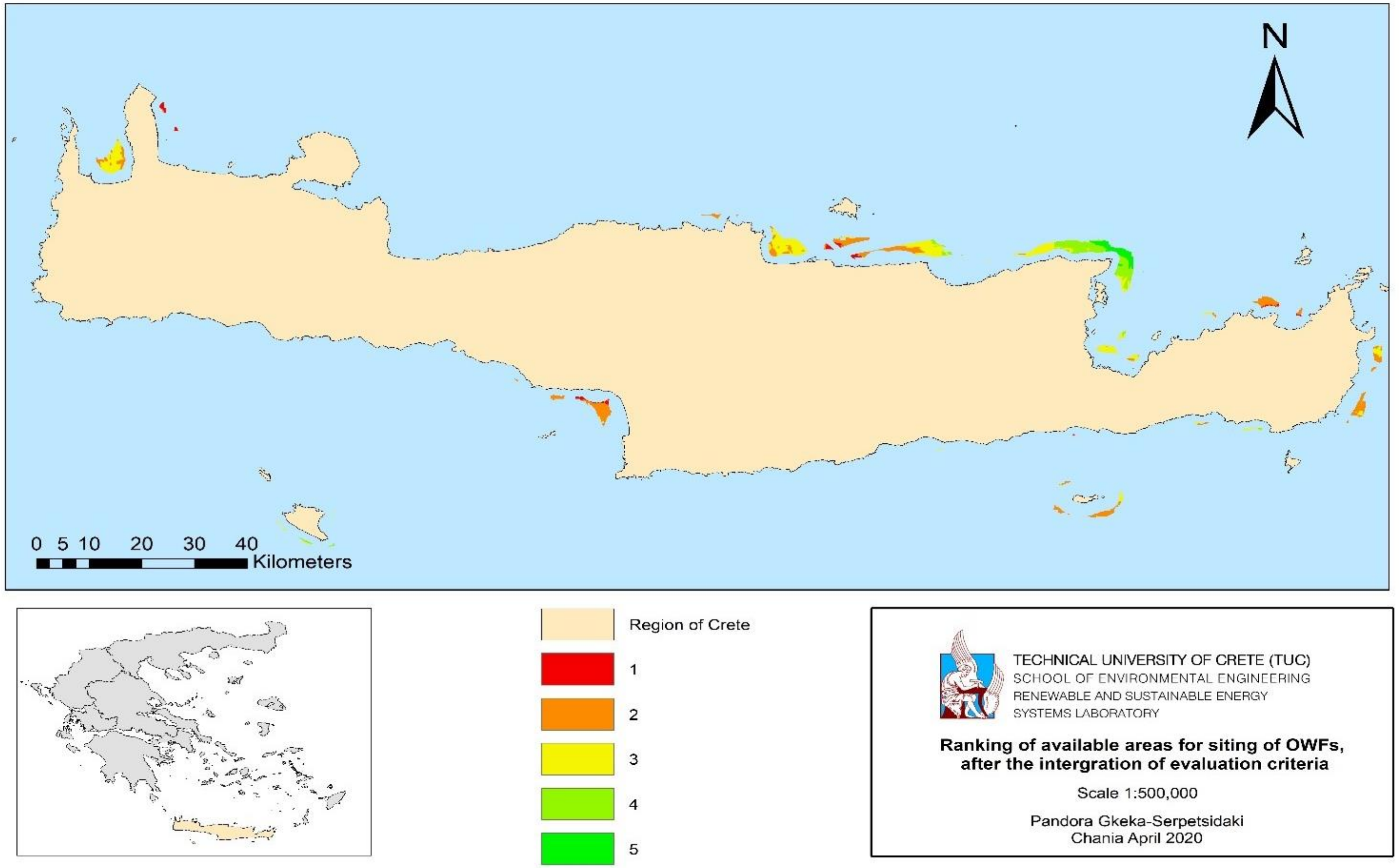


Figure 5.4: Ranking of available areas for siting of OWFs

In Figure 5.4, the same available areas (as in Figure 5.3) are shown but then categorized on a scale from 1 to 5, 5 being the highest score. These results have been derived after implementing the weighted sum overlay analysis (GIS), incorporating the relative weights of the EVC, resulting from our survey with the experts/stakeholders.

According to Figure 5.4, the dark green area has been characterized by number 5, which is very highly suitable. This matching has also come up according to subchapter 4.1.1.3.

The completion of questionnaires of the experts from 1-5 (1 Very less suitable (1) less suitable (2) Medium suitable (3) High suitable (4) Very high suitable (5) has led to the relevant results of suitable areas, when the weighted overlay was implemented through GIS.

The final available marine areas for siting of OWFs are about 205.5 km2, around the island of Crete, where 8.42 km2 are very less suitable, 67.45 km2 less suitable, 81.68 km2 medium suitable, 35.55 km2 are highly suitable and finally 12.4 km2 are very high suitable.

The criteria for choosing a WF are not universal, they depend on each region, each country, and each cultural context of such a society. The sustainable siting of an OWP is strongly associated with the local particular characteristics, additionally to the national legislation and spatial planning.

Summarising, from these two relevant studies in the Greek Sea area [100][121], it is verified that the island of Crete always comprises an excellent solution for the siting of OWFs. This occurs firstly due to the efficient wind potential of the area, secondly due to the proximity of candidate areas from the high voltage lines, as well as with the minimisation of costs because of the small distances from the shore.

There are some differences regarding the emerged suitable areas around Crete, but this is because of the different water depths that these two studies examined. They assessed areas with great depths, in order to install FWTs. In our case, there was a limitation of water depth, which is why some regions are not so similar.

Also, as already discussed above, there is a similar study for the island of Crete, only for the Chania RU. Our results concerning western Crete agree with some results from this study, concluding that the gulf of Kissamos is a candidate area for OWF siting.

Generally, several studies conclude that Crete is a “key-stone” in terms of offshore wind energy development of the island, and for the whole country (with the implementation of interconnection). In agreement with all the previous aforementioned studies, we conclude that our results are very similar to those, so they are accurate and concise.

5.1.1.4 Energy assessment of highly suitable areas

Eventually, in Table 5.4, the available marine areas (km2) for the installation of OWFs around the island of Crete are presented, but only those with a suitability score of 3-5 were selected for a stricter scenario. Additionally, the next columns show the number of WTs and MW, respectively, which each available area could receive. Four commercial models were selected by Vestas and three by Siemens Gamesa Renewable Energy (SGRE), as these two companies are the most experienced in the offshore wind energy sector and the two leading manufacturers with 90% of the market share in Europe [191]. The supplementary Table 5.5

explains the code numbers 1-7 (Table 5.4), which describe the WT models, MW, and the RD selected for each scenario.

Table 5.4: List of available siting areas for OWFs, adapting seven scenarios of different commercial models of OWTs with the number and MW supported, respectively

Geographical region	Suitability (range)	Total area (km²)	WTS (1) (2) (3)	MW (1)	MW (2)	MW (3)	WTS (4)	MW (4)	WTS (5)	MW (5)	WTS (6)	MW (6)	WTS (7)	MW (7)
Kissamos	3	15.82	12	114.0	120	100.8	23	96.6	13	91	11	88	8	80
Heraklion (a)	3	20.28	15	142.5	150	126.0	30	126.0	17	119	14	112	11	110
Heraklion (b)	3-4	15.91	12	114.0	120	100.8	23	96.6	13	91	11	88	8	80
Agios Nikolaos (a)	3-4-5	57.47	43	408.5	430	361.2	85	357.0	49	343	42	336	31	310
Sum (1)		**109.48**	**82**	**779**	**820**	**688.8**	**161**	**676.2**	**92**	**644**	**78**	**624**	**58**	**580**

Agios Nikolaos (b)	3-4	4.64	3	28.5	30	25.2	6	25.2	3	21	3	24	2	20
Agios Nikolaos (bi)	3-4	1.49	1	9.5	10	8.4	2	8.4	1	7	1	8	0	0
Agios Nikolaos (bii)	3	1.55	1	9.5	10	8.4	2	8.4	1	7	1	8	0	0
Agios Nikolaos (c)	3	0.47	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0
Siteia (a)	3	2.56	1	9.5	10	8.4	3	12.6	2	14	1	8	1	10
Siteia (b)	3	0.96	0	0.0	0	0.0	1	4.2	0	0	0	0	0	0
Ierapetra (a)	3-4	1.08	0	0.0	0	0.0	1	4.2	0	0	0	0	0	0
Ierapetra (b)	3	0.34	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0

Ierapetra (c)	3	0.13	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0
Xrisi	3	1.57	1	9.5	10	8.4	2	8.4	1	7	1	8	0	0
Gavdos	3-4	1.98	1	9.5	10	8.4	2	8.4	1	7	1	8	1	10
Sum (2)		**126.25**	**90**	**855**	**900**	**756**	**180**	**756**	**101**	**707**	**86**	**688**	**62**	**620**

A total amount of 126.25 km2 of marine areas totally, with a suitability score (≥3) 3, 4, or 5 could actually be utilised for the development of OWFs (see Table 5.4, Sum (2)). Furthermore, following a consultation with local experts, Eastern Crete is regarded as a privileged area, satisfying many of the selected criteria sufficiently. It is worth mentioning that according to Regulatory Authority for Energy (RAE, Greece) [229], there are already several onshore wind parks in this region.

It is noticed that the first four optimal locations (Kissamos, Heraklion (a), Heraklion (b), and Agios Nikolaos (a)) could cover the energy demand of the island with the first four scenarios (1), (2), (3) and (4) of WTs (Table 5.4, Figure 5.4).

So, as it seems from Sum (1) the optimal scenario is the selection of the second alternative (2, see Table 5.4), wherein 109.48 km2 of marine areas, 82 OWTs could be embedded, with a 164m RD and 10MW rated capacity, achieving a total installed capacity of 820 MW. Eventually, the findings from Table 5.4 show that the annual energy demands of the island could easily be overcovered by OWFs.

Table 5.5: Supplementary to Table 5.4 with the relevant definitions

Code	WT model, MW and RD	References
1	Vestas V164-9.5 MW (MHI VESTAS), 164m	[191][230]
2	Vestas v164-10 MW (MHI VESTAS), 164m	[191][230]
3	Vestas v164-8.4 MW (MHI VESTAS), 164m	[191][230]
4	Vestas v117-4.2 MW (MHI VESTAS), 117 m	[191][230]
5	SGRE WTs swt-7.0-154, 154 m	[191][231]
6	SGRE WTs sg 8.0-167 dd, 167 m	[191][231]
7	SGRE WTs sg 193-10 MW, 193m	[191][231]

5.1.1.5 Comparison of results with equal weights assessment

A total increase of 32.8% of high suitability areas had derived when the equal weights of criteria were calculated (Table 5.5, Table 5.6). For example, in the case of Kissamos, it is noticed that an increase of 36.16% [(21.54/15.82)-1]*100 high suitability areas (3,4,5) had occurred, when the equal weights of criteria were implemented. Since there are many EPA around Kissamos (Figure 5.5) and the relative importance of this criterion is the highest, according to experts (Table 5.3), it is clear why there is a decreased amount of highly suitable areas in this area. This fact led us to verify that our methodological approach is stricter and more enhanced in relation to the equal-weighted approach.

Table 5.6: Comparison of high suitability areas, incorporating experts' opinions and equal weights, respectively

Geographical region	Experts' weights Total area (km²)	Suitability (range)	Equal weights Total area (km²)	Suitability (range)
Kissamos	15.82	3	21.54	3,4
Heraklion (a)	20.28	3	26.57	3,4
Heraklion (b)	15.91	3,4	23.34	3,4
Heraklion (c)*	_	_	1.63	3
Agios Nikolaos (a)	57.47	3,4,5	57.22	3,4,5
Agios Nikolaos (b)	4.64	3,4	5.41	3,4
agios (bi)	1.49	3,4	1.95	3,4
agios (bii)	1.55	3	2.47	3
Agios Nikolaos (c)	0.47	3	0.71	3
Siteia (a)	2.56	3	2.43	3
Siteia (b)	0.96	3	2.27	3
Ierapetra (a)	1.08	3,4	1.31	3,4
Ierapetra (b)	0.34	3	1.67	3
Ierapetra (c)	0.13	3	_	_
Xrisi	1.57	3	8.13	3
Messara*	_	_	2.65	3
Gavdos	1.98	3,4	8.36	3,4,5
Sum	**126.25**		**167.66**	

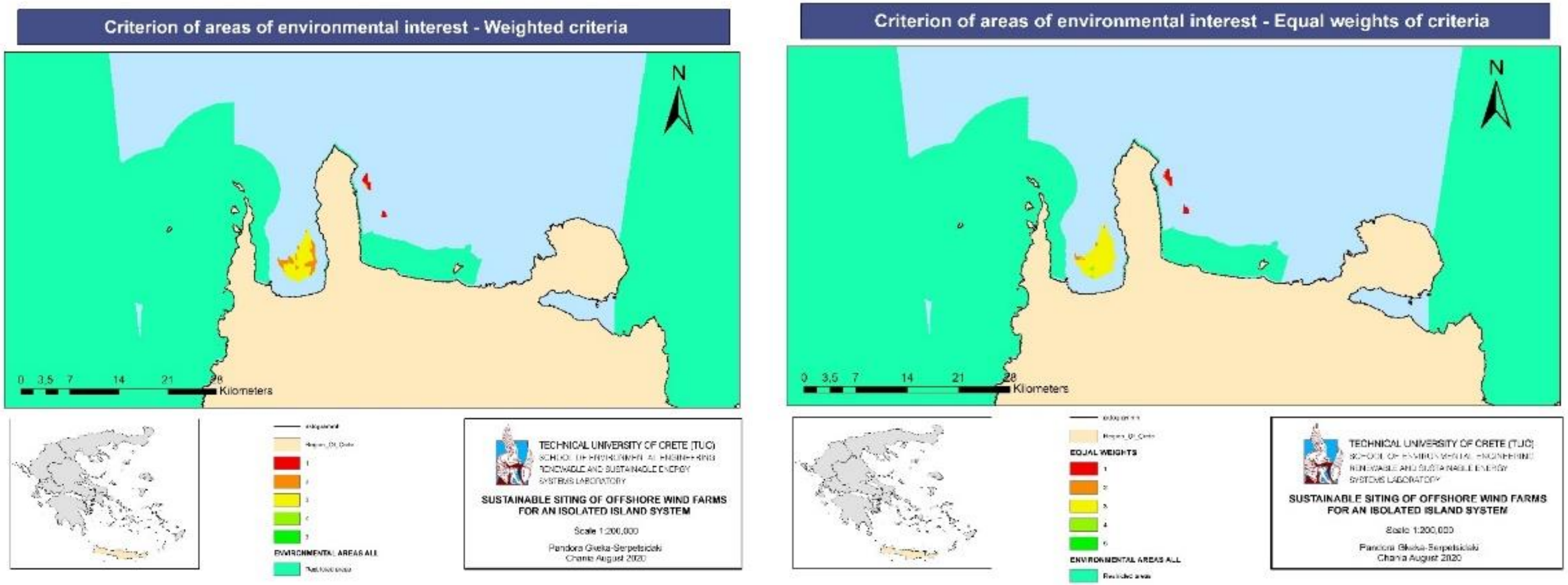


Figure 5.5: Example of the criterion of «areas of environmental interest» in relation with experts' weights and equal weights

5.1.2 Results from site selection for floating OWFs without the incorporation of relevant weights

5.1.2.1 Results and Discussion

The criteria presented in Chapter 4.1.2 were combined with the aim of defining first the areas where it is possible to site and then the most suitable areas for siting in the marine area of Crete. The classification of the areas was implemented on a scale from 1 to 5. Finally, in the areas that have been judged as the most suitable, an energy assessment was carried out in order to determine their energy characteristics.

5.1.2.2 EXC results

In the areas combined in Figure 5.6, FWTs cannot be installed and are, therefore, excluded. As a next step, the areas where an FWF could be installed emerged.

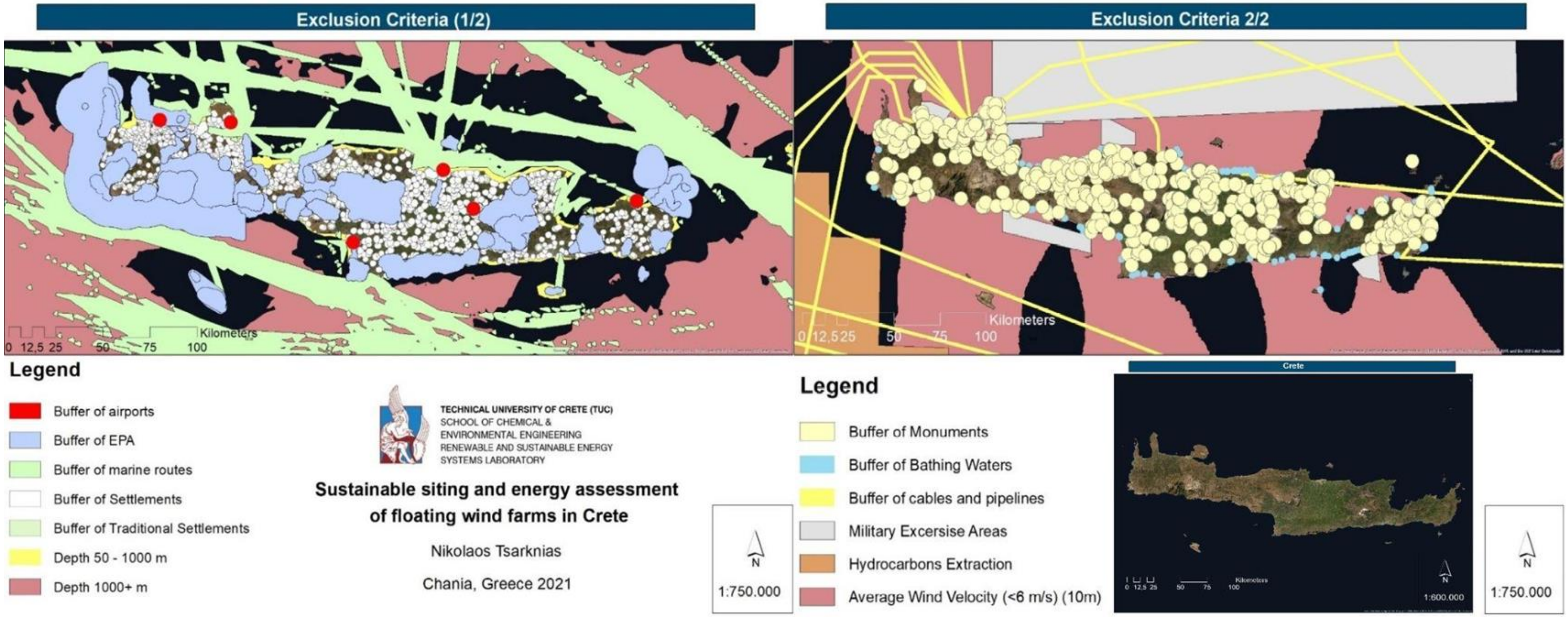


Figure 5.6: EXC (2/2) (ArcMap 10.7)

After excluding all the areas presented in Figure 5.6 (EXC), the areas where an FWF can be located within the Greek territorial waters (6 n.m.) are presented in Figure 5.7.

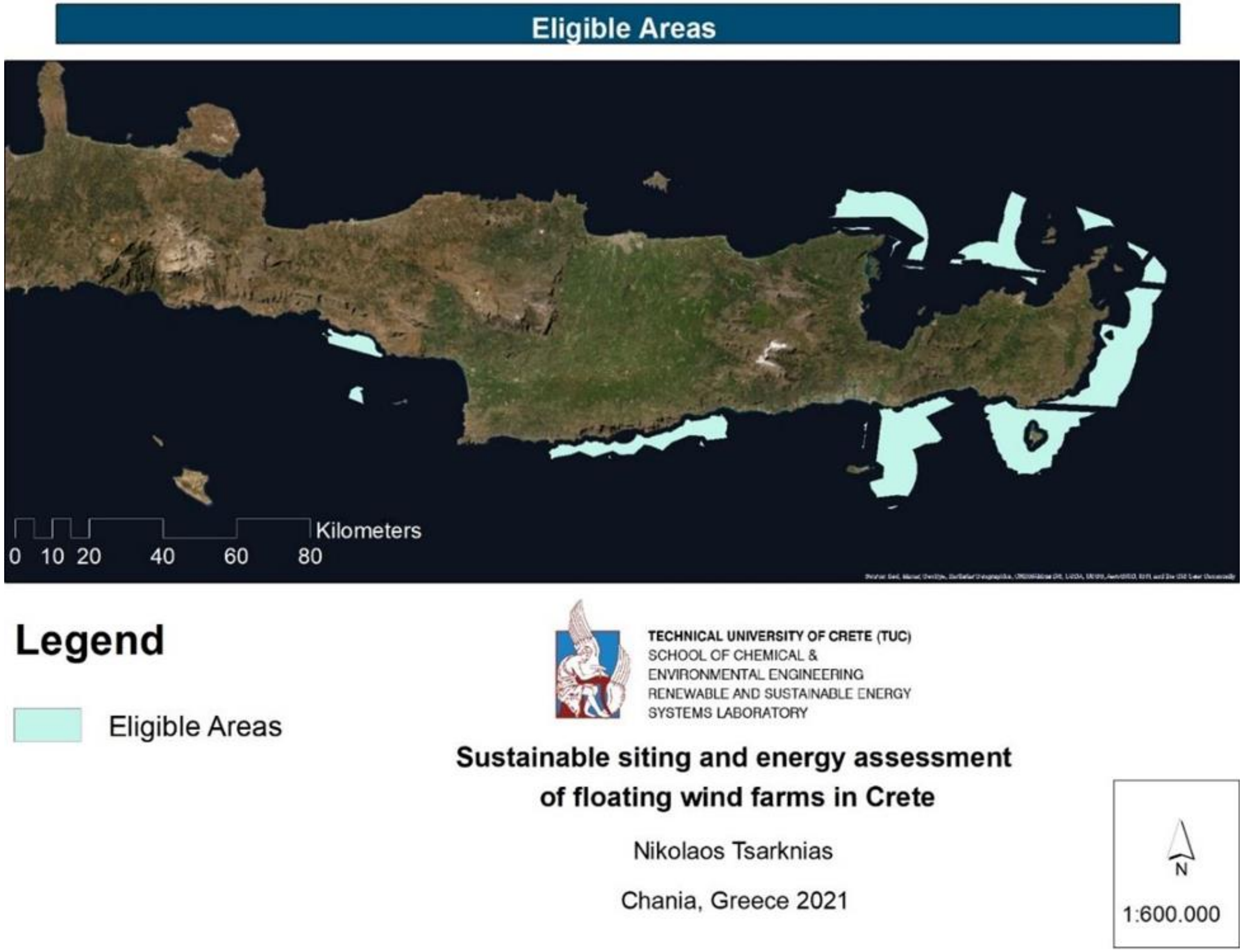


Figure 5.7: Eligible areas (ArcMap 10.7)

The available areas per RU are presented in Table 5.7:

Table 5.7: Available areas per RU

RU	Area (km^2)	Percentage (%)
Chania	0	0
Rethymno	62.54	3.99
Heraklion	170.95	10.90
Lassithi	1334.74	85.11
Total	**1568.23**	**100**

5.1.2.3 Results of EVC

Eligible areas that have arisen as a result of the EXC implementation were further assessed based on EVC in order to define the suitability of every eligible location and determine the most suitable sites for the installation of FWFs in Crete. The ports based on the assessment that was carried out are the following: Souda, Rethymno, Heraklion, Kissamos, Agios Nikolaos, Sitia, Ierapetra, Kaloi Limenes, Sfakia, Paleochora, Atherinolakkos.

It is worth noting that in all of the above ports, port dredging interventions are required in order to tow the platform within it, as well as extensions in order to create a repair and maintenance area for WTs. The additional figures concerning the findings of this work are included in the Annex C.

5.1.2.4 Suitability of eligible areas

The suitability of the eligible locations for FWFs installation, as a result of the EVC, is presented in Figure 5.8.

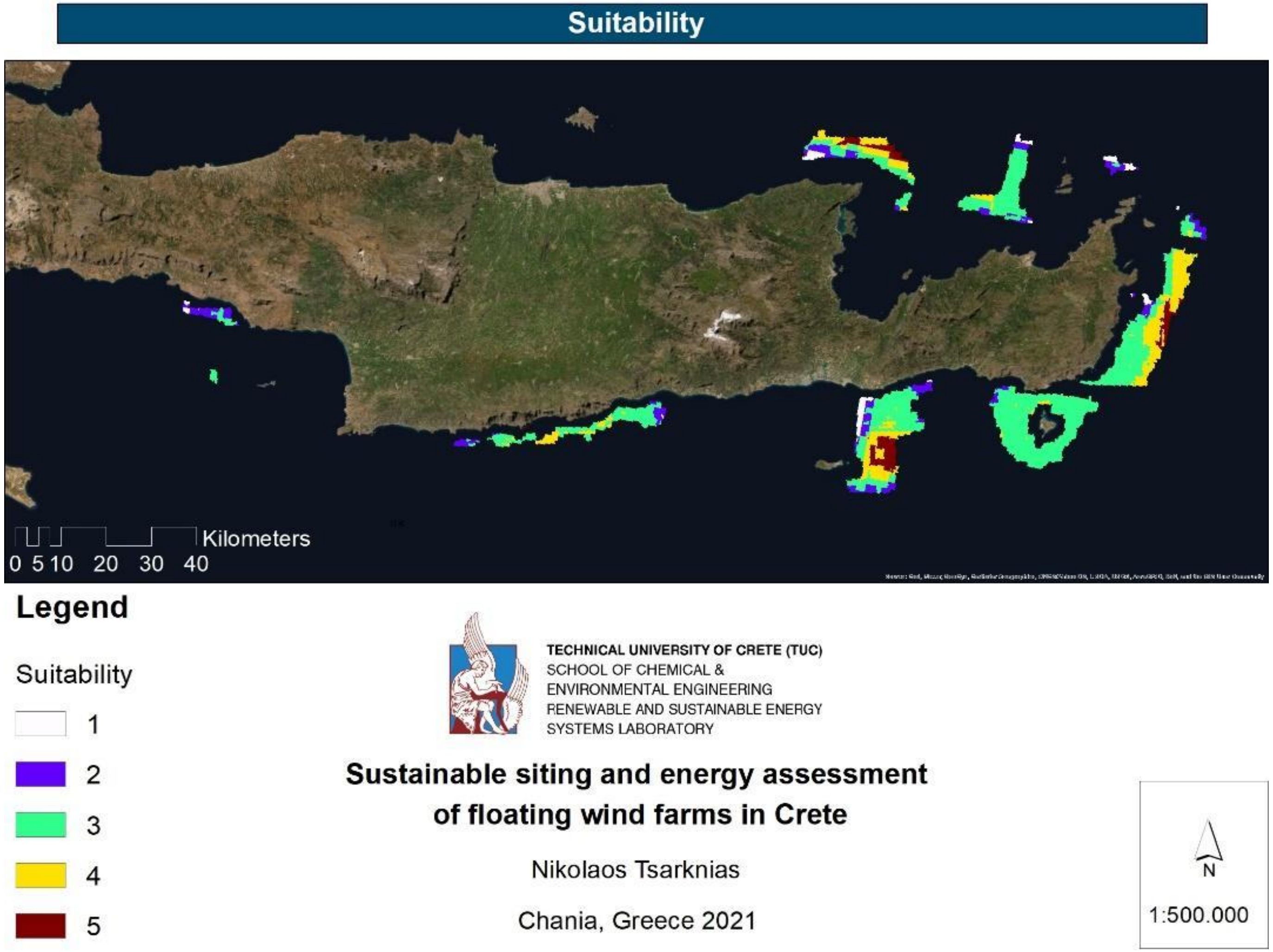


Figure 5.8: Suitability of eligible areas (ArcMap 10.7)

All of the areas rated as “most suitable” are located in the Lassithi RU (Table 5.8).

Table 5.8: Most suitable areas and their wind velocity sensitivity analysis

	Most suitable areas	**Initial case**	**Case 1 (+20% Relevant Weight for Ev8)**	**Case 1 (-20% Relevant Weight for Ev8)**
Location	Area (km^2)			
Elounta	12.89	5/5	5/5	5/5
Zakros	10.71	5/5	5/5	5/5
Chrisi	21.20	5/5	5/5	4/5

A sensitivity analysis has been conducted regarding the relevant weight of the average wind velocity (Ev8). During the analysis, an increased (+20 %) and a decreased (-20 %) relevant weight is considered. Based on Table 5.8, there was no major change in the suitability of the selected areas.

5.1.2.5 Results of energy assessment

An energy assessment was carried out in the most suitable areas (Zakros, Elounta, Chrisi) in order to define the energy characteristics of those locations. The aim of this assessment was the determination of the most energy-efficient areas, not the exact calculation of those energy characteristics.

Two cases were examined relating to the rated power of the WTs. In case 1, Vestas V112 – 3 MW WT was implemented, and in case 2, Vestas V164 – 8 MW was used. The typical layout of a 9 X 6 RD was considered for all the locations. Because of the flat terrain of the sea that was examined, the climate data [52] used will be the same for WTs located in sites that have been rated as similarly suitable according to the energy criteria. A 10 m additional to the turbine hub height was considered because of the spar-buoy platform height.

The location that presents the largest CF in both cases is “Zakros”, the second most efficient is “Elounta”, while “Chrisi” has the smallest CF. In terms of AEP “Chrisi” presents the largest number in case 1 (3 MW turbines), mostly because of its size, which allows more turbines to be installed. In case 2 (8 MW turbines) “Elounda” is the location which produces the most energy annually, followed by “Chrisi”. In both cases, “Zakros” presents the smallest energy production, as a result of its small size, that does not allow the installation of a large, rated capacity WF.

In case 1, the three “most suitable” areas combined can produce 1,144.271 GWh of electricity, while in case 1,585.224 GWh can be produced annually. Taking into account that the energy production demand of Crete in 2020 was 2813.316 GWh and the peak power demand was 605.10 MW [55], in case 1, only the “most suitable” sites can cover 41 % of the island’s annual electricity demand, while in case 2, 56 % of the demand can be covered. This way, the RES penetration in the electricity mix could reach 65 % in case 1 and 80 % in case 2.

The largest portion of the eligible areas is located in the Lassithi RU, with 85.11 % of the eligible areas, followed by the Heraklion RU with 10.90 %, while the Rethymno RU contains 3.99 % Table 5.7. None of the eligible locations lies in the Chania RU. Additionally, only 2.8 % of the eligible areas have been rated as “most suitable”, while all of the “most suitable” areas are located in the Lassithi RU.

The exploitation of only the three “most suitable” areas could provide electricity that would cover up to 56 % of the island’s demand and provide electricity for 396,000 dwellings per year (4 MWh per household annually [57]). That would raise the clean energy’s share to 80 % of the total demand and would save up to 1.5 million tons of CO2 eq. annually (Table 5.9).

Table 5.9: Energy assessment results

	Case 1 (Vestas V112 – 3MW)			Case 2 (Vestas V164 – 8 MW)		
Location	**Chrisi**	**Elounta**	**Zakros**	**Chrisi**	**Elounta**	**Zakros**
Installed Capacity (MW)	114	84	66	160	128	104
Number of WT	38	28	22	20	16	13
Area (km^2)	21.20	12.89	10.71	21.20	12.89	10.71
Density (MW/km^2)	5.38	6.52	6.16	7.55	9.93	9.71
CF (%)	43.4	57.9	62.3	40.1	52.2	58.2
AEP per WT (GWh)	11.415	15.219	16.396	28.131	36.626	40.830
Gross AEP (GWh)	433.758	426.127	360.720	562.611	586.016	530.795
Wake Losses	4.84%	5.41%	2.48%	4.17%	4.77 %	1.97%
Availability Factor	98%	98%	98%	98%	98%	98%
Net AEP (GWh)	404.519	395.006	344.746	528.373	546.919	509.932

5.2 Results from Techno-economic analysis of OWFs

5.2.1 Results of the Energy Study of the WF in WAsP

The creation of the model Vestas V164 – 9.5MW profile is presented in the WT Editor in the following Figure 5.9. The power curve of the Vestas V164 – 9.5 MW WT, which was configured in the WAsP WT Generator is shown in Figure 5.10. This turbine has a nominal power of 9.5 MW and an RD of 164 m. In the power curve, the relationship between wind speed and electrical power generated is shown. It begins to generate power at 3.5 m/s and reaches its rated power at 14 m/s, while the maximum wind speed it can withstand before turning off (cut-out) is 25 m/s [220]. A description of the relevant creation of profiles and power curves for the other three WT models is provided in Annex D, Figure D.1, Figure D.2, Figure D.3.

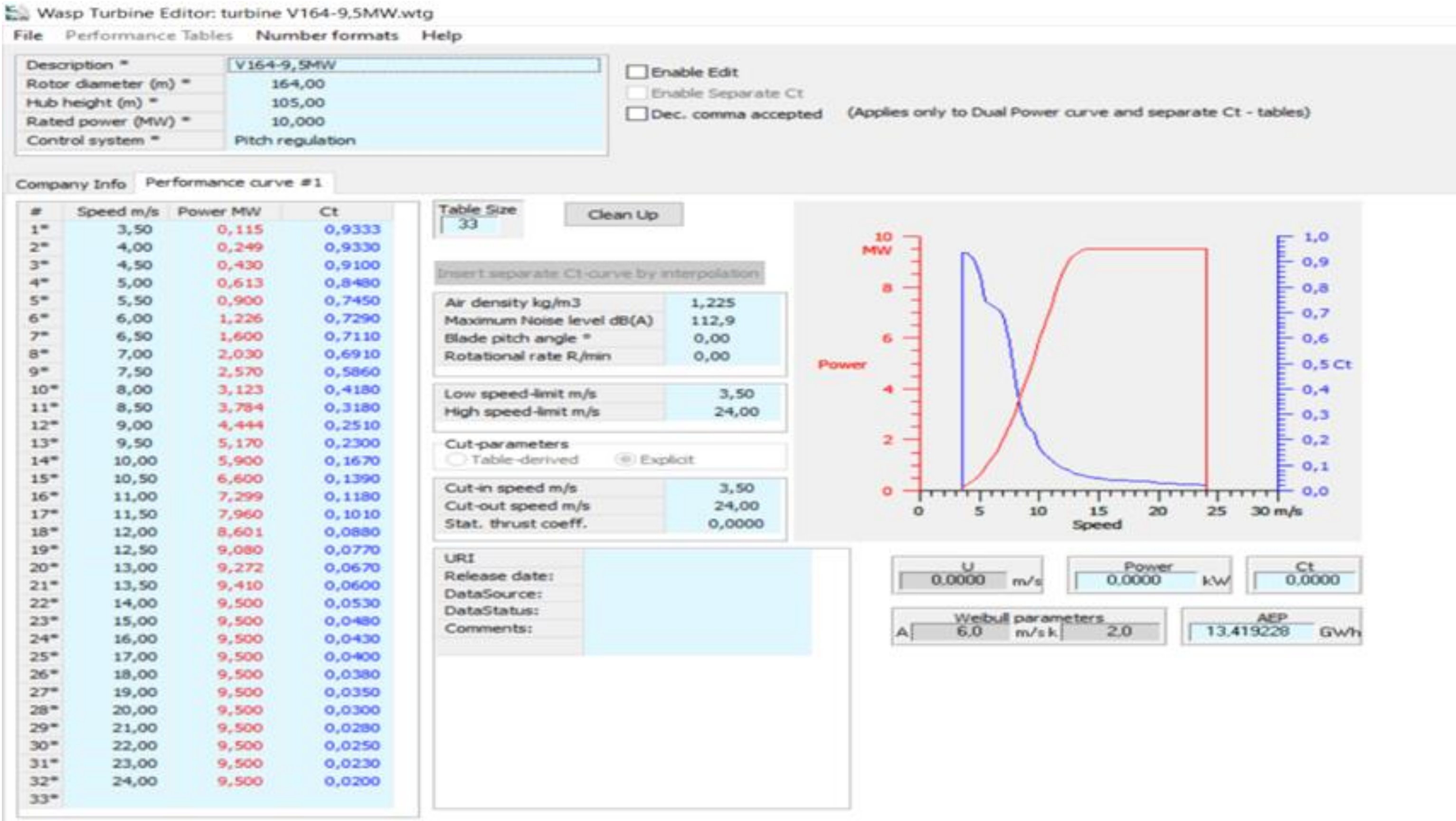


Figure 5.9: Creation of Vestas V164 – 9.5MW profile in the WT Editor

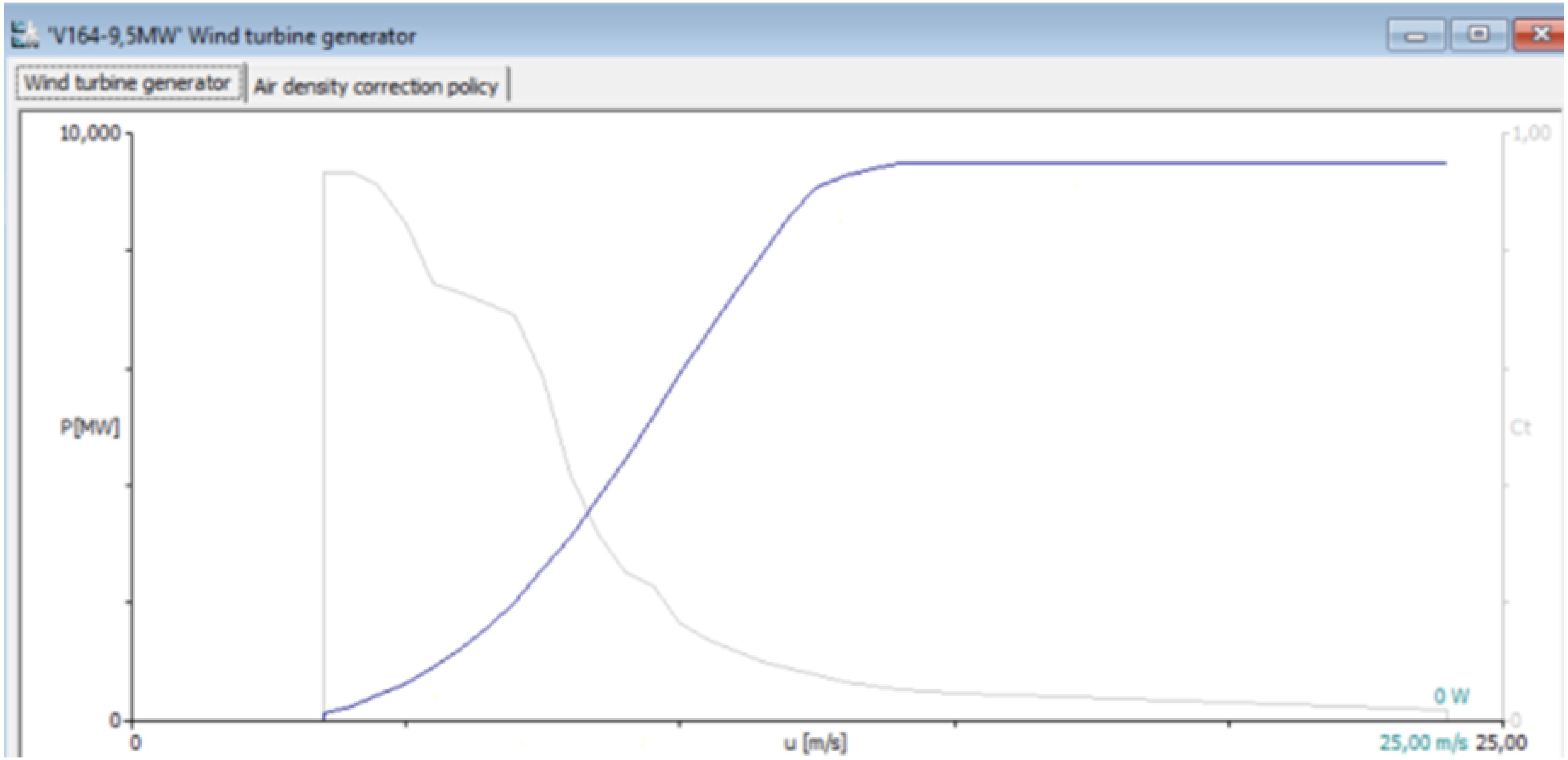


Figure 5.10: Power curve of Vestas V164– 9.5 MW (WAsP 12.6.)

In the WAsP program, individual applications as well as meteorological data obtained from the Global Wind Atlas website are registered. As part of this framework, these data are analyzed using the Terrain Analysis and WF toolkits, with the ultimate goal of accurately estimating the WF's energy parameters.

A total of four WTs will be examined as part of the energy analysis, including Vestas V164 - 9.5MW, Vestas V236 - 15MW, Siemens Gamesa SG167-8MW, which are bottom- fixed, and the Siemens Gamesa SG154-6MW, which has a floating base. The characteristics of the WTs are presented in Table 5.10.

Table 5.10: Comparative Table of Technical Characteristics of selected WT Models

Characteristics of WTs	Vestas V164 – 9,5MW	Siemens Gamesa SG 8.0-167DD	Vestas V236 –15MW	Siemens Gamesa SG6.0-154DD
Nominal power	9.5 MW	8 MW	15 MW	6 MW
Cut-in wind speed (m/sec)	3	3	3	4
Cut-out wind speed (m/sec)	25	25	31	25
Hub height (m)	105	92	150	101
RD (m)	164	167	236	154
Swept area (m^2)	21,124	21,900	43,742	18,600
Type	Bottom-Fixed	Bottom-Fixed	Bottom-Fixed	Floating

Hierarchical structure of a project in WAsP

The next step after the analysis of the various subprograms required to produce an energy analysis of a WF is to synthesize the main program within the WAsP environment. As a result of the previous stages, the various components will be incorporated into the main program as inputs. It is critical for the proper functioning of the software to adhere to an organizational structure that defines the relationships between its various components. Also, the WAsP User Guide provides guidance on how to establish these connections.

Workspace

WAsP allows users to create WFs within a Workspace, where the project components are arranged in a hierarchical manner as illustrated in Figure 5.11. A Project is first defined within the Workspace, which will collect and manage the remaining sub-modules.

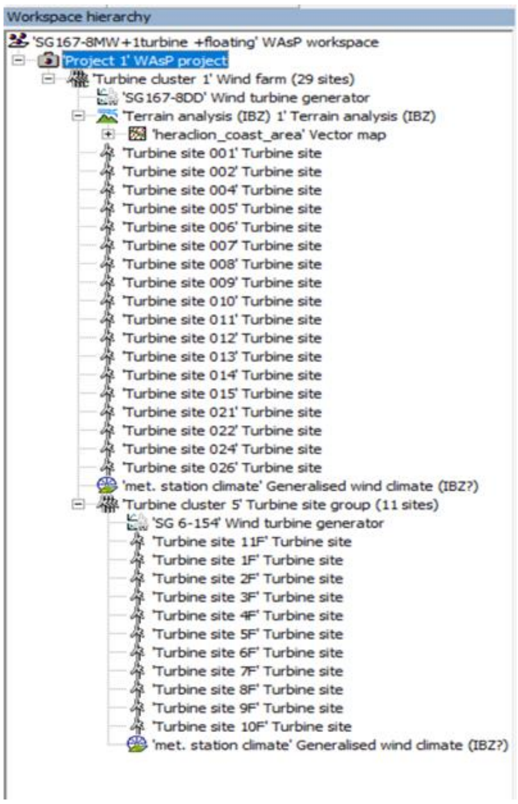


Figure 5.11: Sample of Worspace of Wasp

Terrain analysis

A map of the study area is added to the Project defined in WAsP, providing the software with the necessary information about the relief and surface roughness of the area. A terrain analysis, known as Terrainanalysis (IBZ), is performed in order to accomplish this goal. A map incorporating the generated data is shown in Figure 5.12. WAsP provides two types of soil analysis: IBZ and CFD. The IBZ method, which is applied in the present study, follows the traditional models of the previous versions of WAsP, where the roughness change is based on the internal boundary layer theory and linearized BZ flow model, the core of WAsP since its original creation in 1987. On the other hand, the CFD option is a more recent integration, which uses computational fluid dynamics to calculate ground roughness.

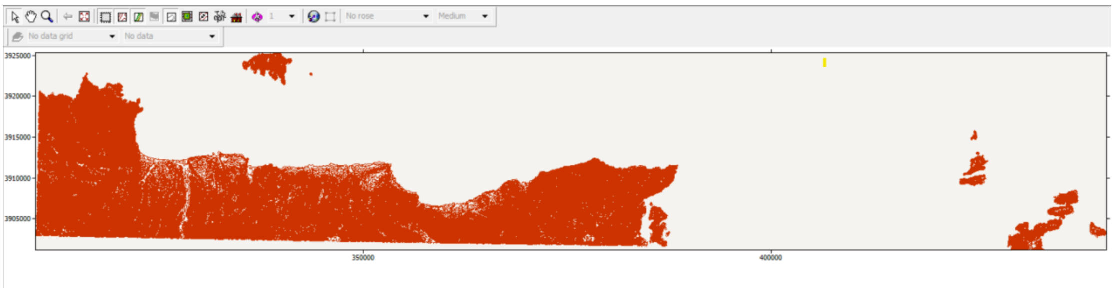


Figure 5.12: Development of 3D visualization of landforms through WAsP

GWC

The Global Wind Atlas online platform was used to obtain the climatological data, which did not require the use of specialized software [79]. The data are available in the form of GWC for the specific area of interest and are reproduced by integrating climate data into WAsP. Wind data information as well as wind diagrams for various heights and roughness lengths are included in this dataset.

Micro-siting of WTs

In each scenario, the WTs are positioned facing the main wind direction, namely northwest. A Vestas V164 - 9.5MW BFWT has a RD of 7 RD in the main wind direction, equalling 1148 m, and 7 RD perpendicular to the main wind direction, equalling 1148 m. The Siemens Gamesa SG154-6MW FWT has a distance of 1078 m in the main wind direction and 7 m in the direction perpendicular to the wind direction. According to the specific arrangement, a total of 29 WTs can be installed: 19 WTs of 9.5 MW bottom-fixed base and 10 WTs of 6 MW floating base. As mentioned above, the circles in the image represent the limiting radius for the distance between them. Figure 5.13 illustrates the layout within the "Gulf of Heraklion" area.

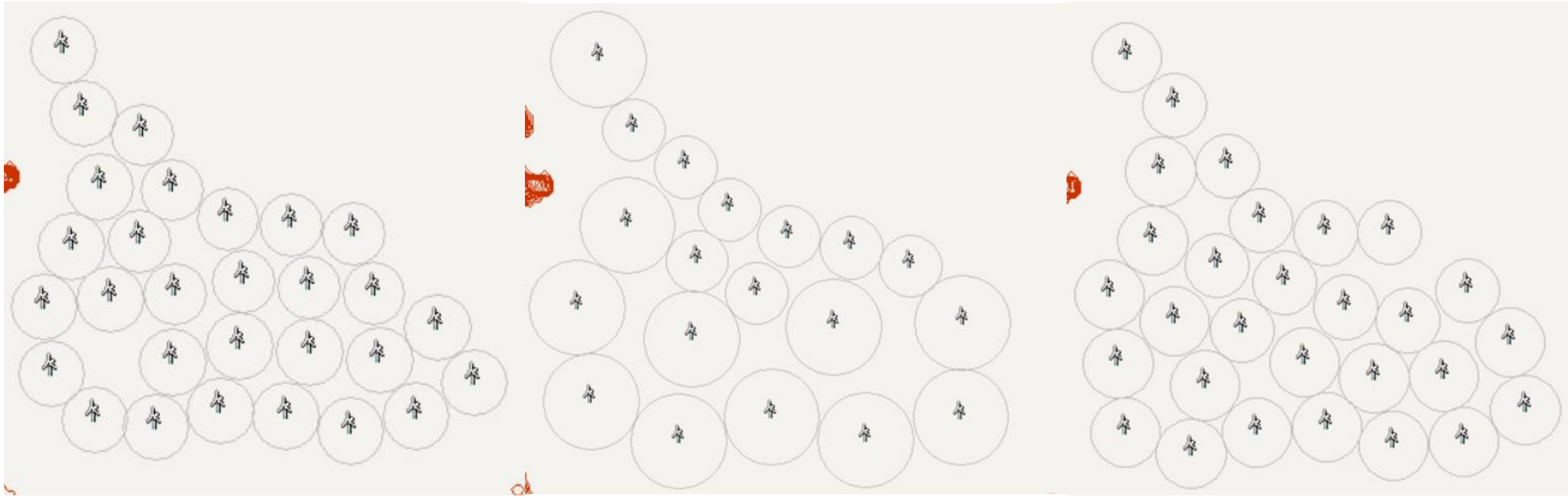


Figure 5.13: Micro siting of WTs-1st Scenario, 2nd and 3rd Scenario

WF

The WF's exact location and model will be determined as a result of this process. By entering the coordinates and locations of the WTs (Figure 5.14) this can be accomplished. The WTs are then placed on the map once the profile, coordinates, and climate data have been entered. Scenario 1, Figure 5.15, is illustrated in the following image.

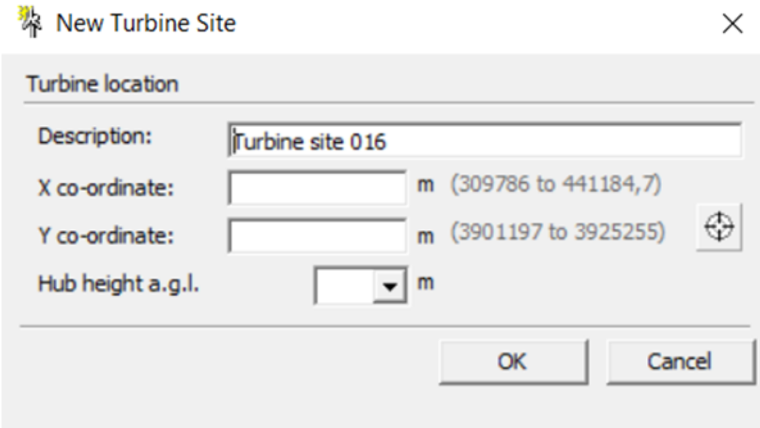


Figure 5.14: Data entry environment for WT placement in the WAsP workspace

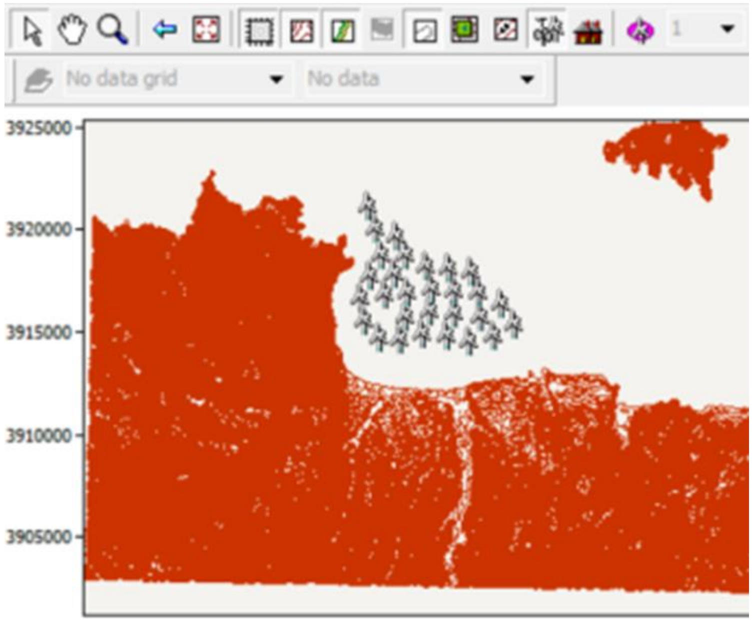


Figure 5.15: Placement of WTs in Scenario 1 WAsP

Obstacles

WAsP offers the option of modeling physical barriers which may reduce the wind potential available for exploitation in a given area. WT shading losses are caused by the mutual effect they have on each other, which reduces the speed of the wind reaching the blades. As a result of these losses, minimum distances between WTs were defined in the preliminary study. To reduce losses resulting from WT interaction, Figure 5.16, was applied to all scenarios where a minimum distance of seven RD was required between the WTs in the downwind direction and seven RD in the crosswind wind direction.

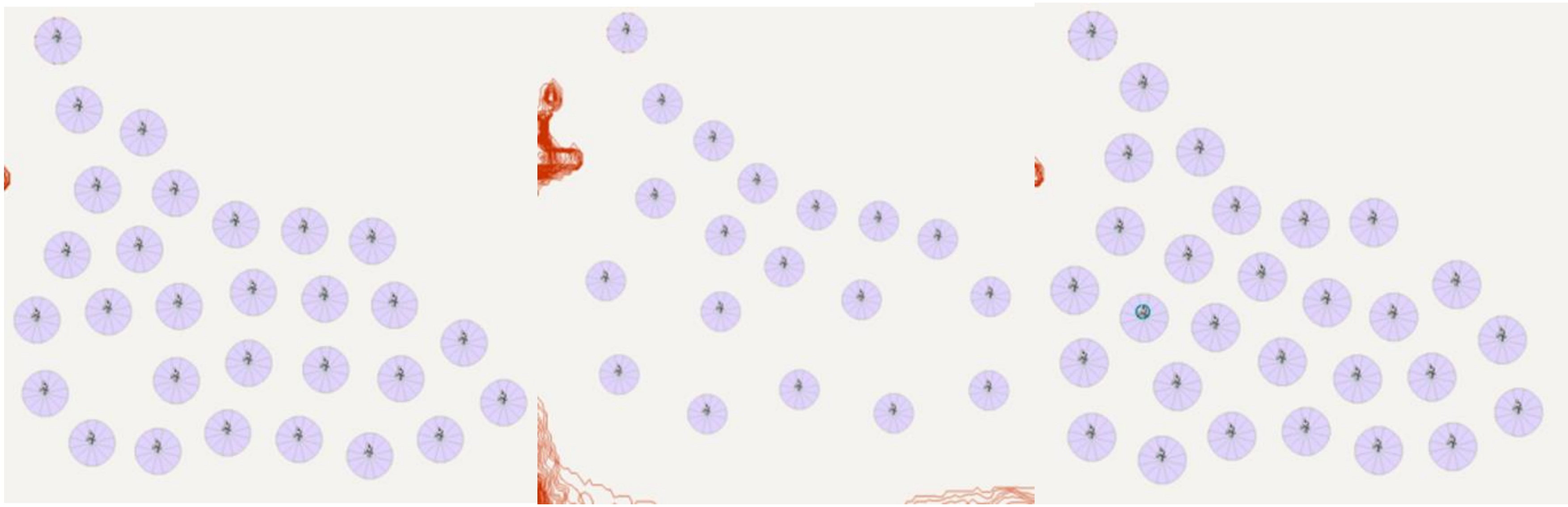


Figure 5.16: Obstacles: Scenario 1 V164-9.5MW & SG154-6MW, Scenario 2: V236-15MW & SG154-6MW, Scenario 3: SG167-8MW & SG154-6MW

5.2.2 Results from the energy analysis

The illustrated Table 5.11 provides an extensive analysis of the wind conditions related to Scenario 1, in which two different models of BFWTs (Vestas V164 - 9.5 MW and Siemens Gamesa SG154 - 6 MW) are considered. In the table, the angles indicate the directions in which the wind comes from, expressed in degrees. The 'Frequency' column gives an indication of the frequency of wind blowing from each direction.

It is important to note that the Weibull-A and Weibull-k parameters are important components of the Weibull distribution, which is widely used to simulate wind speed and estimate the energy production from WTs. In relation to the average wind speed, the Weibull-A factor corresponds to the scale of the distribution. Weibull-A values that are higher indicate a generally higher wind speed in an area, which is beneficial for wind power generation.

As a measure of the stability of the wind speed, the Weibull-k factor corresponds to the shape of the distribution. An increased Weibull-k value indicates more stable wind conditions, with less variation in wind speed, while a lower Weibull-k indicates greater uncertainty and more dispersion in wind speed. Based on the Weibull-k values from the wind data table, we observe that the highest Weibull-k values correspond to narrower wind speed distributions in the 270° and 300° directions, respectively, with values of 3.15 and 2.96. As a measure of wind speed stability, the Weibull-k factor corresponds to the distribution shape. Weibull-k values that are higher indicate more stable wind conditions, with less variation in wind speed, whereas Weibull-k values that are lower indicate more uncertainty and dispersion in wind speed. Using the wind data table, we observe that the highest Weibull-k values correspond to narrower wind speed distributions in the 270° and 300° directions with values of 3.15 and 2.96, respectively.

Average Wind Speed shows the average wind speed in m/s for each given direction. It is a fundamental datum for the analysis of wind performance, as the wind speed is a key factor in predicting the amount of energy produced by a WT.

Table 5.11: Scenario 1 wind data (V164 – 9.5MW &SG154-6MW) (WAsP 12.6)

Angle [°]	Frequency [%]	Weibull-A [m/s]	Weibull-k	Average wind speed [m/s]
0°	2.7	4	1.36	3.7
30	1.4	2.5	1.19	2.32
60	1.2	2.9	1.26	2.65
90	1.1	3.6	1.36	3.29
120	1.5	2.8	1.33	2.58
150	3.3	4.3	0.95	4.36

180	13.4	9.8	1.56	8.85
210	3.6	3.7	0.94	3.79
240	2	3.2	1.02	3.14
270	**21.9**	9.7	**3.15**	8.68
300	**38.8**	8.4	**2.96**	7.54
330	9.2	6.7	1.84	5.94
Sum				7.13

An example of a windrose is presented in Figure 5.17, which illustrates the distribution of wind frequency and direction for a given location, in this case Heraklion Bay, Crete. As can be seen in this diagram, the different angles correspond to the directions in which the winds blow, and the radial distance from the center represents the frequency with which those winds occur.

The blue patterns indicate the direction intervals with the highest frequency, which provide a visual representation of the dispersion of winds in the study area. In the chart, the main wind directions are around 270° and 300°, which indicates that the winds are usually from the west to the northwest.

As WT efficiency directly depends on the direction and frequency of the winds, this type of analysis is essential for the design and placement of WTs. In order to optimize wind energy utilization in a particular area, an understanding of the wind profile is essential, and the wind pattern is an ideal tool for providing this information.

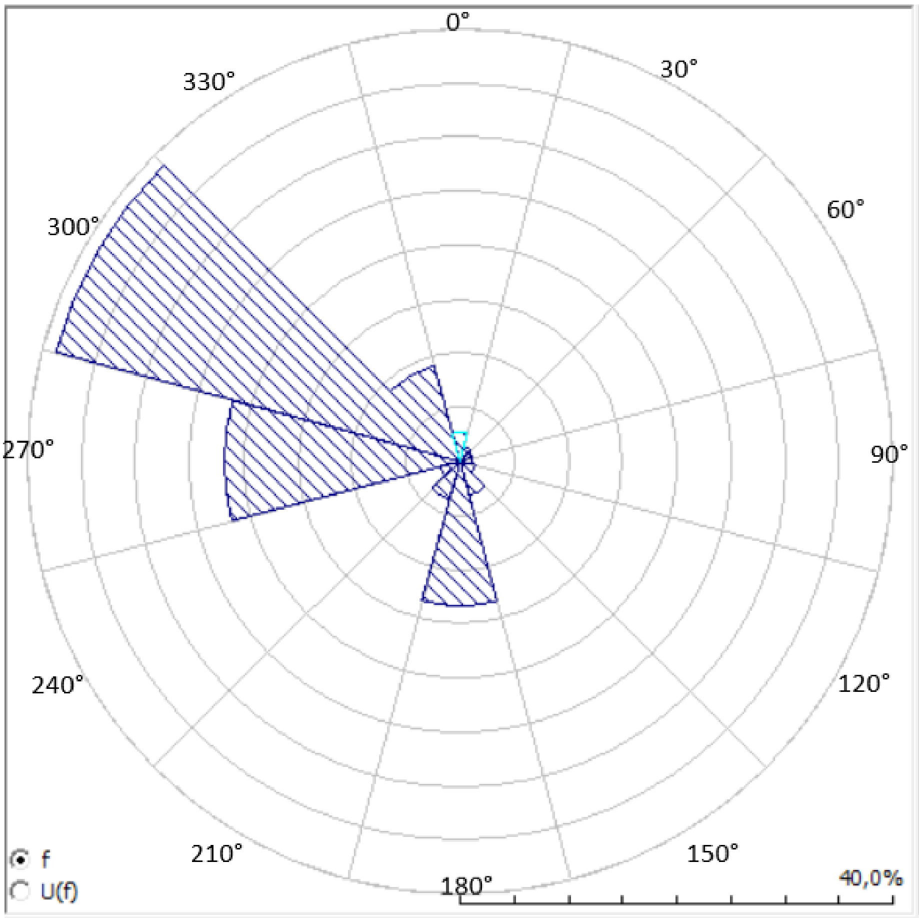


Figure 5.17: Wind rose representing the distribution and frequency of prevailing wind directions for Scenario 1

The software provides the possibility of analyzing the wind data for each direction, beginning from the north axis, as indicated and illustrated in the diagrams below for one of the WTs of the wind park, specifically for turbine site 001 which is bottom-fixed for scenario 1, Figure 5.18, Figure 5.19.

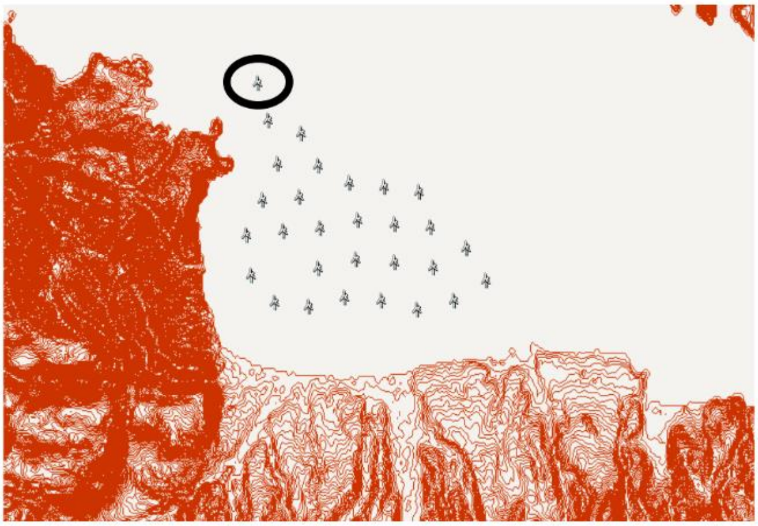
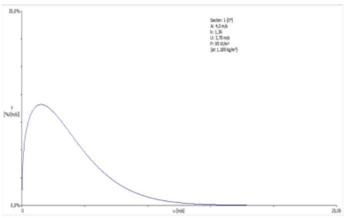
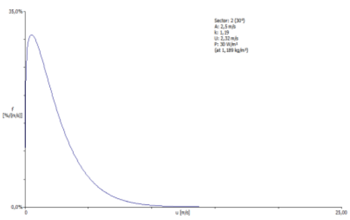
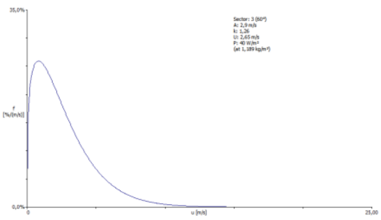


Figure 5.18: WT WT 001

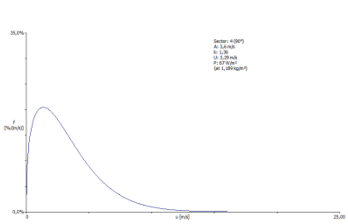
0° 30° 60°

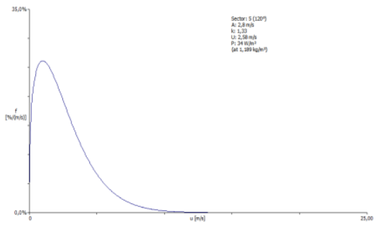


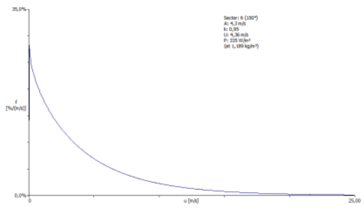




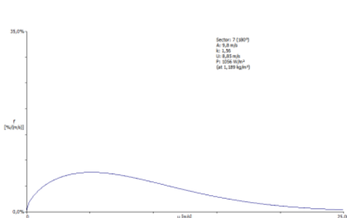
90° 120° 150°

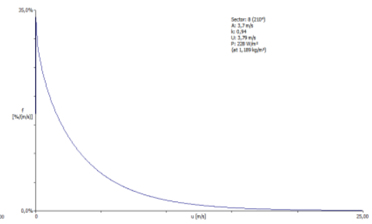


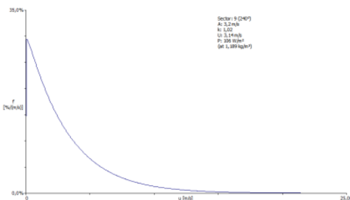




180° 210° 240°







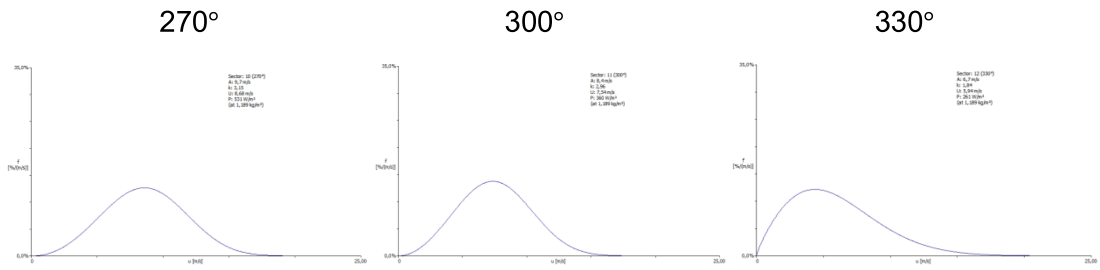


Figure 5.19: Wind Frequency Charts Per Direction for Various Measurement Angles Turbine site 001 scenario 1

The following Table 5.12 illustrates the overall results of the energy production analysis of Scenario 1. There are two WTs included in this project: the Siemens Gamesa SG154-6MW FWTs and the Vestas V164-9.5MW BFWTs. This analysis provides information on the total number of WTs as well as statistics such as projected net and gross energy output in GWh.

In particular, the table shows the total gross energy production (Total gross AEP), the total net energy production (Total net AEP) including losses caused by the tornado (wake loss), as well as their corresponding minimum and maximum values. Furthermore, the CF, wake-reduced average wind speed, air density, power density, and RIX index are included.

In order to evaluate the viability of wind energy investment in the area in question, it is necessary to obtain this information in order to estimate the overall performance of the WTs. In order to make an informed decision regarding the potential development of the WF, the present analysis provides a comprehensive picture of the expected energy performance.

An energy CF is a measure of the actual energy produced by a WF compared to the ideal, theoretical production if the WTs were continuously operating at their maximum power. In the present WF, the value of the CF is 27.7%, which is considered competitive for the wind industry and indicates a stable and reliable wind generation during operation [232].

The total gross energy production (Total gross AEP) for the WF amounts to 635,447 GWh and represents the volume of energy produced before any losses are applied. Taking into account this value is important for evaluating the overall energy efficiency and contribution of the park to the energy grid.

Unlike gross energy production, total net energy production (Total net AEP) reflects the amount of energy actually available for use after excluding all operational losses. The wind farm recorded net energy production of 607.945 GWh, indicating high levels of efficiency with relatively low losses. In order to understand the real energy supply of a park and to assess its impact on the energy market, this indicator is essential.

Table 5.12: Results from the energy production analysis of Scenario 1

FWTs	Siemens Gamesa SG154-6MW	10		
BFWTs	Vestas V164-9.5MW	19		

Sum of WTs		29		
Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	635.45	21.91	15.24	26.35
Total net AEP [GWh]	607.95	20.96	14.22	26.21
Proportional wake loss [%]	4.33	-	0.33	7.65
CF [%]	27.7	-	26.9	29.9
Mean speed [m/s]	-	7.02	6.86	7.13
Mean speed (wake-reduced) [m/s]	-	6.84	6.71	7.11
Air density [kg/m³]	-	1.19	1.19	1.19
Power density [W/m²]	-	432	409	447
RIX [%]	-	-	0	5.1

Results from the 2nd and 3rd scenarios are presented in detail in Annex D, Table D.1, Table D.2, Table D.3, Table D.4.

Based on WAsP 12.6 software, the following images illustrate windroses of gross energy produced and shading losses for three different scenarios.

According to scenario 1, shading losses range from 0.33% to 7.65% and total 4.33% (Table 5). It is noteworthy that the maximum value does not exceed 8%, which indicates that the WTs have been designed in a manner that limits shading losses to an acceptable level.

Shade losses are slightly increased in Scenario 2, ranging from 0.37% to 8.65% with a total loss of 4.56% (Table 7), with the average loss percentage increasing compared to Scenario 1. The layout of the WTs or the topography of the area may contribute to greater shading losses in this scenario.

As a final point, Scenario 3 presents shading losses between 0.25% and 8.08% with a total loss of 4.47%, similar to Scenario 1 (Table 9). As a result, Scenario 3 has a similar efficiency in terms of limiting shading losses as Scenario 1.

Overall, Scenarios 1 and 3 seem to have similar effects on shading losses, while Scenario 2 has slightly higher losses. There may be differences in the layout and models of the WTs as a result of their layout and models. It is important for WFs to analyze shading losses in order to optimize their performance and reliability.

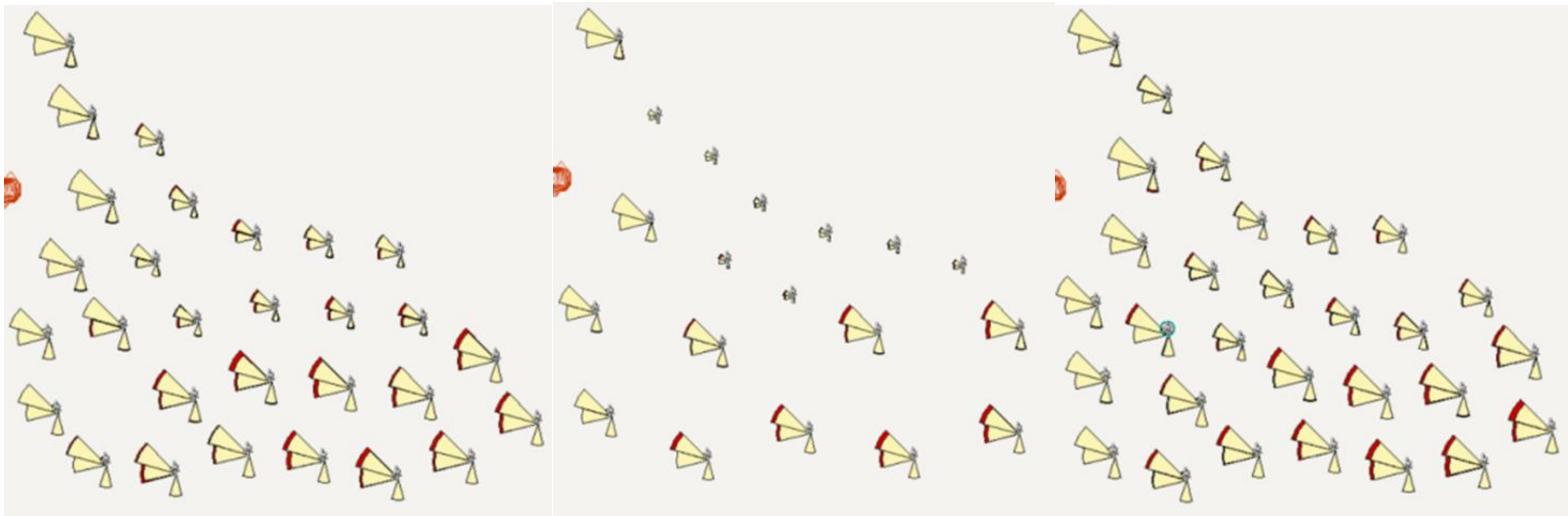


Figure 5.20: Shading loss in energy production windrose- Scenario 1, 2, 3

Figure 5.21 depicts the windrose of a wind scenario using Google Earth's interactive platform. The geometric figures show the generated energy yields and shadow losses per WT, thus providing a comprehensive analysis of the design's efficiency.

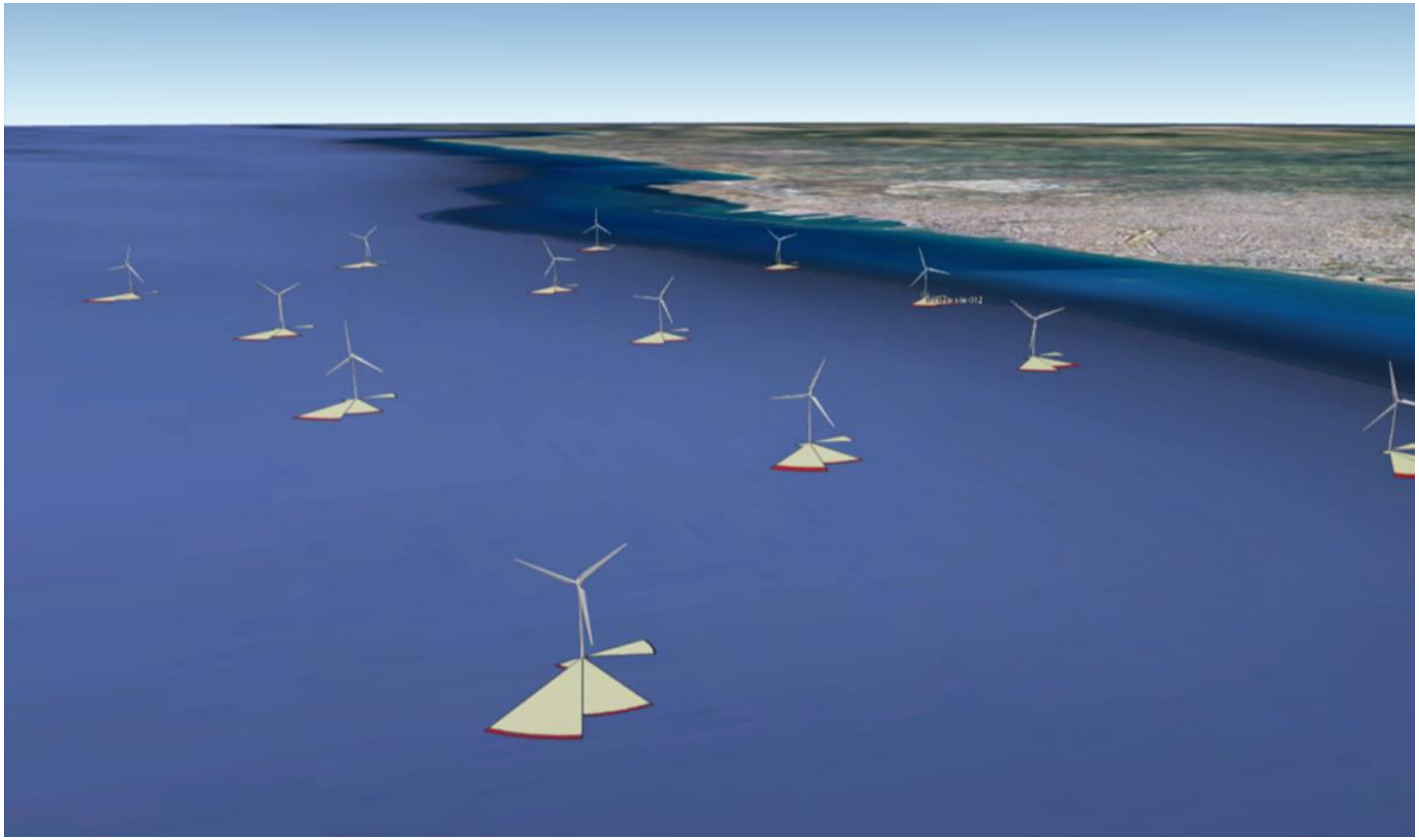


Figure 5.21: Illustration of shading loss windroses

A comprehensive WT data set is described in

Table 5.13 below, illustrating the complexity of WF performance analysis. In addition to serving as a key benchmark, the RIX rate also provides insight into the operational efficiency and reliability of each WT. GWh values for gross and net AEP provide a meaningful comparison of theoretical and actual energy yields. It is particularly interesting to note the percentage Wake Loss value, which quantifies the extent to which aerodynamic interference between WTs reduces WF efficiency. A second critical value is the CF percentage, which provides an insight into the actual performance of WTs in relation to their maximum output. Collectively, these metrics facilitate a nuanced understanding of WF dynamics, which is critical for optimizing renewable energy resources. As for the other two scenarios, data are provided in Table D.5, Table D.6.

Table 5.13: Complete data per WT Scenario 1

	Site description	X-location [m]	Y-location [m]	RIX [%]	Height [m]	Gross [GWh]	Net AEP [GWh]	Wake Loss [%]	CF [%]
Bottom-Fixed	**WT 001**	323680	3920600	0.6	105	26.35	26.207	0.54	31.5
	WT 002	324023	3919502	0.9	105	26.013	25.582	1.66	30.7
	WT 004	324309	3918232	1.5	105	25.527	25.302	0.88	30.4
	WT 005	323823	3917196	3.3	105	24.824	24.545	1.13	29.5
	WT 006	323340	3916150	5.1	105	24.029	23.804	0.94	28.6
	WT 007	323476	3914993	4.5	105	23.954	23.876	0.33	28.7
	WT 008	324215	3914199	2	105	24.387	23.959	1.75	28.8
	WT 009	325276	3914068	0.2	105	24.919	23.959	3.85	28.8
	WT 010	326391	3914350	0	105	25.28	24.412	3.43	29.3
	WT 011	327535	3914259	0	105	25.419	23.574	7.26	28.3
	WT 012	328653	3913997	0	105	25.477	23.679	7.06	28.4
	WT 013	329786	3914253	0	105	25.66	24.216	5.63	29.1

	WT 014	330788	3914834	0	105	25.843	24.272	6.08	29.1
	WT 015	330158	3915797	0	105	25.943	24.356	6.12	29.2
	WT 022	327947	3915368	0	105	25.686	23.891	6.99	28.7
	WT 020	329154	3915227	0	105	25.783	24.463	5.12	29.4
	WT 023	326727	3915470	0	105	25.557	23.724	7.17	28.5
	WT 025	325569	3915190	0	105	25.291	24.172	4.42	29
	WT 027	324491	3916289	2	105	25.098	24.248	3.39	29.1
Floating	**WT 2F**	325619	3916374	0	101	15.24	14.23	6.63	27.1
	WT 3F	326797	3916597	0	101	15.398	14.221	7.65	27
	WT 4F	326525	3917679	0	101	15.474	14.633	5.44	27.8
	WT 5F	324982	3917287	1.1	101	15.247	14.709	3.53	28
	WT 6F	327939	3916489	0	101	15.46	14.279	7.64	27.1
	WT 7F	329053	3916392	0	101	15.5	14.315	7.65	27.2
	WT 8F	328698	3917418	0	101	15.579	14.861	4.61	28.3

	WT 9F	327616	3917574	0	101	15.527	14.779	4.82	28.1
	WT 10F	325552	3918179	0.2	101	15.454	14.799	4.24	28.1
	WT 11F	325049	3919132	0.4	101	15.528	14.882	4.16	28.3

5.2.3 Results from the economic analysis

An economic analysis of three scenarios for the development of an OWF is presented in this section. Using metrics such as PP, net present value, IRR, and LCOE, the analysis examines CAPEX, OPEX, DECEX, and return on investment. The discount rate (r) and was set equal to 6% [233]. From the time of predevelopment to decommissioning, the project has a lifespan of 35 years. The AEP is calculated in MWh. In the following calculation of the economic indicators, the average and maximum energy values have been taken into account.

Analyses are based on WAsP data as well as cost estimates derived from [193] and other reliable sources. According to the Energy Regulatory Authority (RAE), the average energy price for September 2023 is €101.96/MWh, and the maximum energy price is €1288/MWh. For the assessment, it was recommended to use these prices from the Next Day market, which reflects "wholesale" electricity transactions through RES for Greece [234].

The CAPEX was calculated based on the data provided in [193], along with the following detailed cost categories. The Table 5.14 and Figure 5.22 present a detailed breakdown of the CAPEX for the development of an OWF, featuring two types of turbines V164-9.5MW and SG154-6MW. Various categories of costs are recognized, from the development and management of the project to the installation of the equipment.

Development and permitting services, environmental impact assessments, and other work related to project development and management are included in the project development and management category. Therefore, offshore turbine prices are influenced by the market for physical units, with BFWT costing less per MW than floating turbines. Infrastructure costs, such as those associated with offshore and onshore substations, as well as cables, are also significant. Achieving power delivery from the turbines to the grid requires the presence of these elements. Last but not least, installation and commissioning represent a significant portion of the cost, with the installation of foundations and cables playing a particularly important role.

As part of the process of calculating the total CAPEX for the installation of the floating base, a detailed analysis of component costs was required. The floating base was constructed using a TLP type steel structure, which formed the basis of the cost estimation study. Additionally, mooring systems were analyzed, including the cost of moorings, synthetic rope, chain, wire rope, and anchors. Based on [235], this analysis was reinforced and supported, providing a solid scientific basis for understanding and applying CAPEX estimation best practices. As a result of this approach, an accurate cost estimate can be made, taking into consideration important parameters such as the average distance from the coast (2000 m) and the average depth to which the FWTs are installed (90 m), as well as their distribution along the coast in order to ensure that the project will perform optimally and function effectively.

CAPEX plays an important role in the financial analysis of OWF development because it provides a holistic view of the costs involved in building and operating the WF. Based on the study of Spyridonidou et al. (2020) [126], OPEX were calculated to be 3% of the total investment cost. Approximately 2% of the total investment cost was estimated to be the withdrawal cost (DECEX) [236].

Based on the exchange rate (03.2024), 1 British Pound is equal to 1.17 Euros, so for each scenario, the economic data of the study was converted from British Pounds to Euros.

Table 5.14: CAPEX Calculation Data Scenario 1 [193][237]

Project development and management	**120,000**	**£/MW**	**£28,860,000**
Development and licensing services	50,000	£/MW	£12,025,000
(i) Environmental studies (=4000£) (ii) Assessment of resources (=4000£) (iii) Geological and hydrological studies (=4000£) (iv) Engineering and consultancy (=4000£)	8,000	£/MW	£3,848,000
Other (includes developer staff hours and other subcontracted work)	42,000	£/MW	£12,987,000
OWTs (Nacelle, rotor, tower, etc)			
10 BFWTs	1,000,000	£/MW	£180,500,000
19 FWTs	1,300,000	£/MW	£78,000,000
Offshore substation (electrical system, facilities, structure)	120,000	£/MW	£28,860,000
Onshore substation (Buildings, access and security, other)	30,000	£/MW	£7,215,000
Cables (Extract & Type & Anchor & Protect)	170,000	£/MW	£40,885,000
Installation and commissioning	650,000	£/MW	£156,325,000

Foundation installation	100,000	£/MW	£24,050,000
Offshore substation installation	35,000	£/MW	£8,417,500
Construction of onshore substation	25,000	£/MW	£6,012,500
Onshore installation of export cables	5,000	£/MW	£1,202,500
Offshore cable installation	220,000	£/MW	£52,910,000
WT installation	50,000	£/MW	£9,025,000
Offshore logistics	3,000	£/MW	£541,500
Other	212,000	£/MW	£38,266,000
Installation Floating type TLP (steel)	108,663	£/MW	£6,519,767
Anchorages			£481,395
Synthetic rope	1860	M£	£334,884
Chain	698	M£	£125,581
Wire rope	116	M£	£20,930
Anchor	132,558	M£	£265,116

TOTAL CAPEX	3,390,000	£/MW	£488,911,279
	3,941,860	**€/MW**	**568,501,487€**

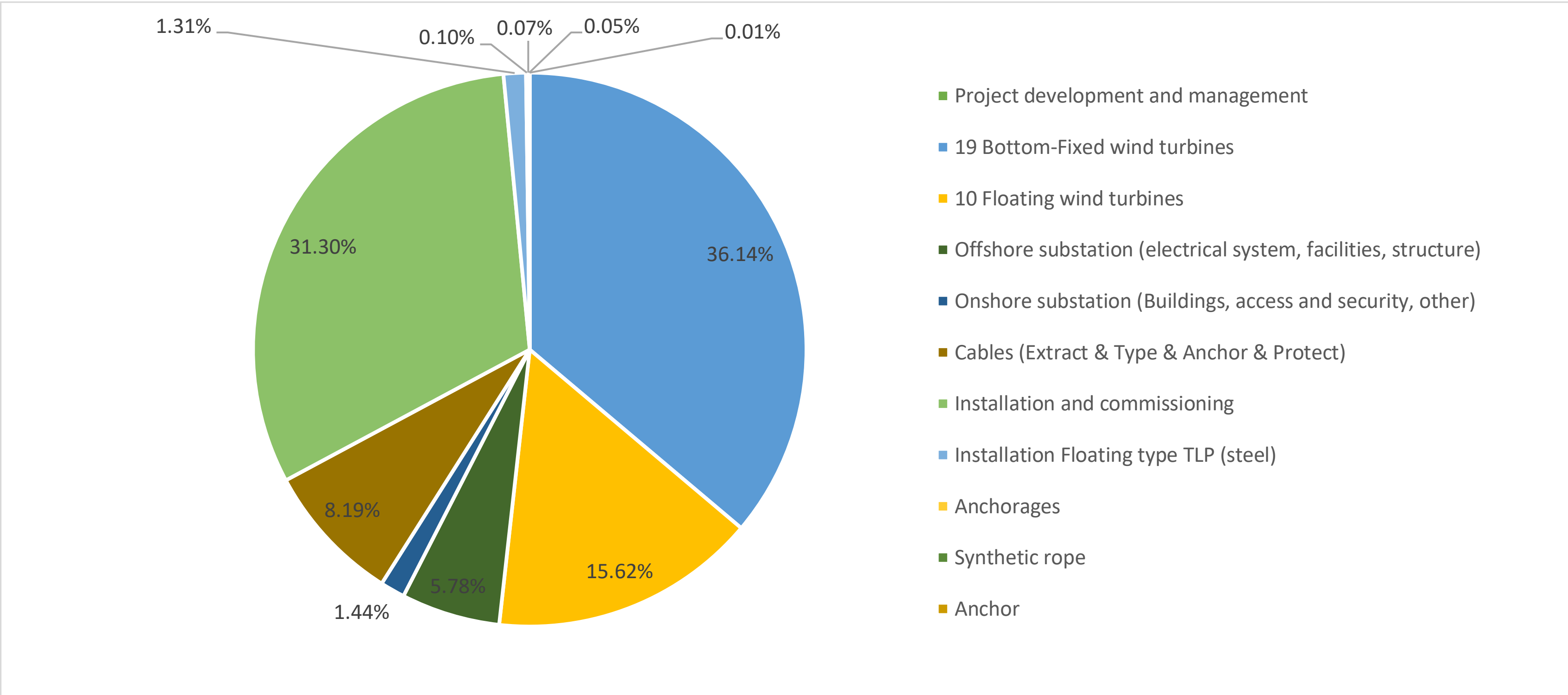


Figure 5.22: Cost breakdown of Scenario 1

Table 5.15: Results of Economic Analysis of Scenario 1

Index	Years	Cost
CAPEX	8	568,501,487€
OPEX	25	546,278,191 €
DECEX	3	22,295,594 €
Sum (CAPEX+OPEX+DECEX)	36	1,137,075,272 €
Average Energy Price Net Cash Flows	36	412,424,547 €
Maximum Energy Price Net Cash Flows	36	821,723,518 €
AEP (MWh)	25	15,198,625
NPV Average Energy Price	36	-119,076,472 €
NPV Maximum Energy Price	36	20,112,388 €

In scenario 1, the following financial parameters are presented: Total CAPEX of €568,501,487, OPEX of €546,278,191, and DECEX of €22,295,594 making up a total cost of €1,137,075,272 (

Table 5.15). Accordingly, the NPV for the average energy price is -€119,076,472, making the investment economically unattractive, and the NPV for the maximum energy price is €20,112,388. Approximately 15,198,625 MWh of energy is produced annually, generating annual revenues of €1,549,499,819 at the average energy price and €1,958,798,790 at the maximum energy price.

As for Scenario 2, the financial data are as follows: CAPEX amounts to €505,037,588, OPEX amounts to €485,295,159, and DECEX amounts to €19,806,655, resulting in a Total Cost of €1,010,139,402. There is a NPV of €12,298,372 for the average energy price, and a NPV of €167,140,297 for the maximum energy price. As a result, scenario 2 offers greater economic efficiency regardless of the prevailing energy price, making it a more desirable investment option. Due to the significantly higher NPV in scenario 2, the investment would be able to withstand even higher energy costs, increasing its attractiveness. It is estimated that 16,907,850 MWh of energy is produced each year, generating revenues of €1,723,755,308 at the average energy price and €2,179,083,708 at the maximum energy price. As a result of the average energy price of €713,615,905 and the maximum energy price of €1,168,944,306, the net cash flows are €713,615,905.

The following financial parameters are presented in scenario 3: Total CAPEX 492,695,646 €, OPEX 473,435,677 €, and DECEX 19,322,626 €, for a total cost of 985,453,949 €. Accordingly, the NPV for the average energy price is -94,166,631, making the investment economically unattractive, while the NPV for the maximum energy price is €28,848,073. The annual production of energy is reported at 13,432,500 MWh, which generates revenues of €1,369,443,375 based on the average energy price and €1,731,180,600 based on the maximum energy price.

Analytical data for scenarios 2 and 3 can be found in Annex D, Table D.7, Table D.8, Table D.9, Table D.10.

Payback period

There is a growing need for reliable indicators to evaluate the performance of energy investments in the complex and dynamic energy market. PP is one such indicator, which provides an estimate of the time required to recoup the investment. In the following Table 5.16, the PP and the IRR are presented for the 3 scenarios, for average and maximum energy price.

Table 5.16: PP and IRR of each scenario for average and maximum energy price

Scenario	PP for average energy price (years)	Last negative value (€)	First positive value (€)	PP for maximum energy price (years)	Last negative value (€)	First positive value (€)
1º	Between	-13,135,291	26,782,183	Between	-29,699,546	28,270,048

	13th -14th			9th -10th		
	$IRR_{average}$	3.74%		$IRR_{maximum}$	6.33%	
2º	Between 9th -10th	-32,279,298	18,563,915	Between 7th -8th	-7,531,926	62,227,539
	$IRR_{average}$	6.23%		$IRR_{maximum}$	8.78%	
3º	Between 12th -13th	-33,605,173	2,426,846	Between 9th -10th	-13,652,519	37,930,198
	$IRR_{average}$	3.97%		$IRR_{maximum}$	6.55%	

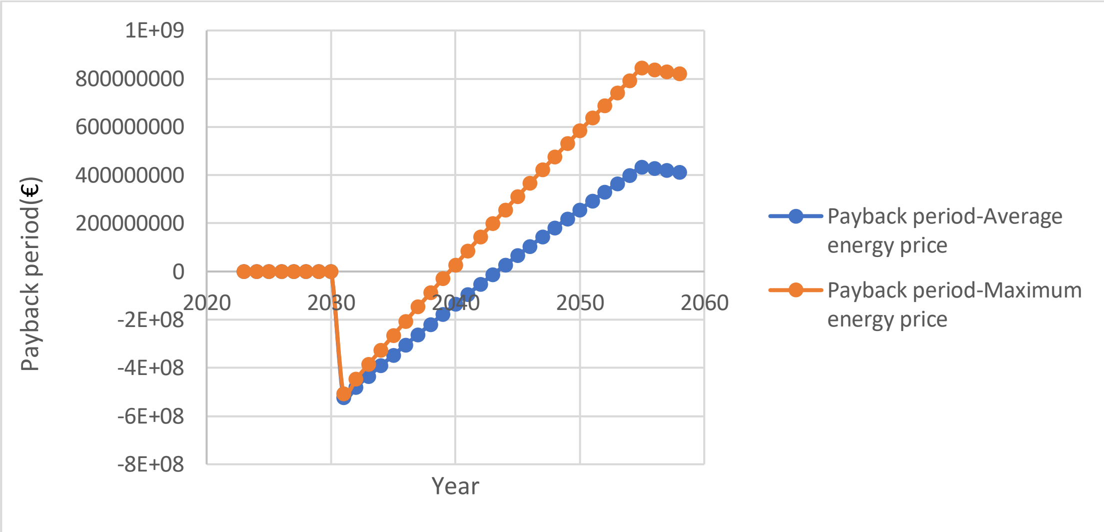


Figure 5.23: Average and Maximum Energy Price PP compared to Investment Time Scenario 1

For the average energy price, for the first scenario, the PP becomes positive between the 13th and 14th year. In particular, the last negative value is -€13,135,291 while the first positive value is €26,782,183. Thus, the PP will be somewhere between the 13th and the 14th year.

The PP for the maximum energy price also becomes positive between the 9th and 10th year. The last negative value is -€29,699,546 and the first positive value is €28,270,048, indicating a 9-year PP.

As can be seen in the second scenario, the PP becomes positive between years 9 and 10. In particular, the last negative value is -32,279,298 and the first positive value is 18,563,915. This implies that the PP is somewhere in the ninth year.

The PP becomes positive between the 7th and 8th year for the maximum energy price. There is a negative value of -€7,531,926 and a positive value of €62,227,539, which indicates that the PP will last somewhere around seven years.

The PP becomes positive between the 12th and 13th year for the average energy price in the third scenario. The last negative value is -€33,605,173 while the first positive value is €2,426,846. As a result, the PP is approximately 12 years.

Between the ninth and tenth year of the maximum energy price, the PP also becomes positive. The last negative value is -€13,652,519, while the first positive value is €37,930,198, indicating that the PP is somewhere in the 9th year.

As part of

Annex B

Questionnaire

Table B.1: Pairwise comparisons for EVC, concerning a sustainable siting of OWFs

		Distance from:															
		Submerged cables	**Areas of environmental interest**	**Shipping / Air routes**	**Electrical grid**	**Military areas**	**Shore**	**Fishing areas**	**Road network**	**Heritage sites**	**Residential activities**	**Mining areas and activities**	**Wind resources**	**Water depth**	**Seabed substrate**	**Noise level/ Acoustic disturbance**	**Optical disturbance**
Distance from:	**Submerged cables**	**1**															
	Areas of environmental interest		**1**														
	Shipping / Air routes			**1**													

	Electrical grid				1												
	Military areas					1											
	Shore						1										
	Fishing areas							1									
	Road network								1								
	Heritage sites									1							
	Residenti al activities										1						

Mining areas and activities											1					
Wind resources												1				
Water depth													1			
Seabed substrate														1		
Noise level/ Acoustic disturban ce															1	
Optical disturban ce																1

Exclusion maps

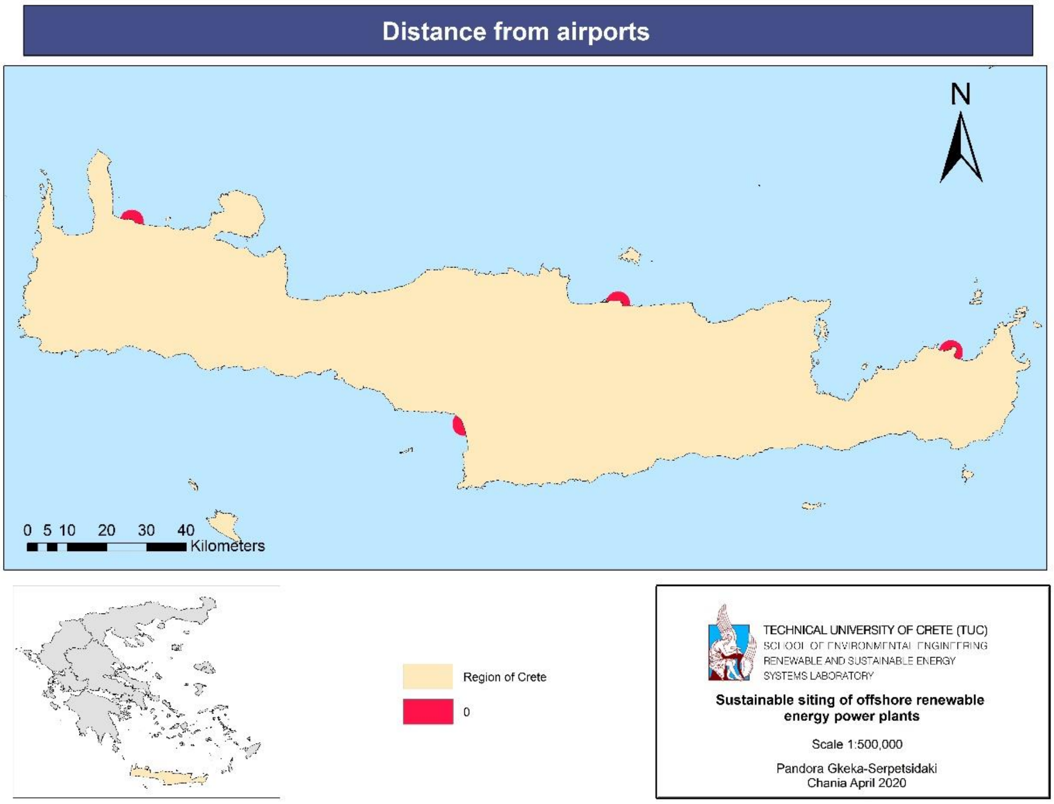


Figure B.1: Exclusion map: Distance from airports

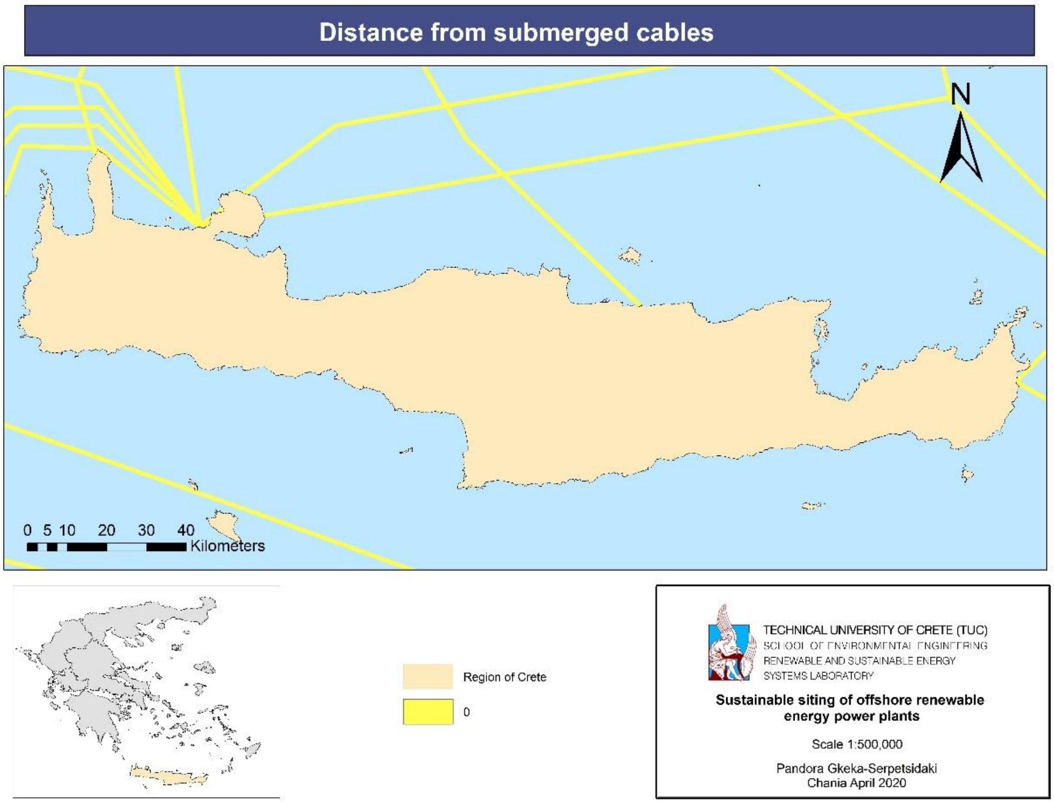


Figure B.2: Exclusion map: Distance from submerged cables

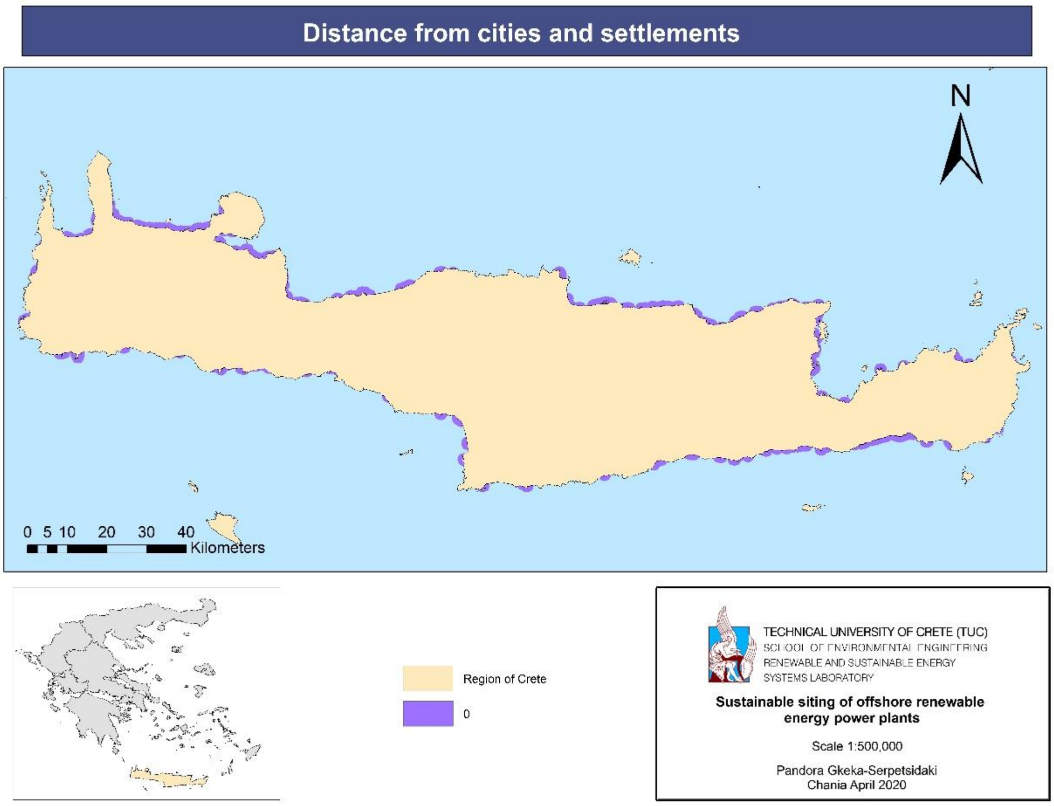


Figure B.3: Exclusion map: Distance from cities and settlements

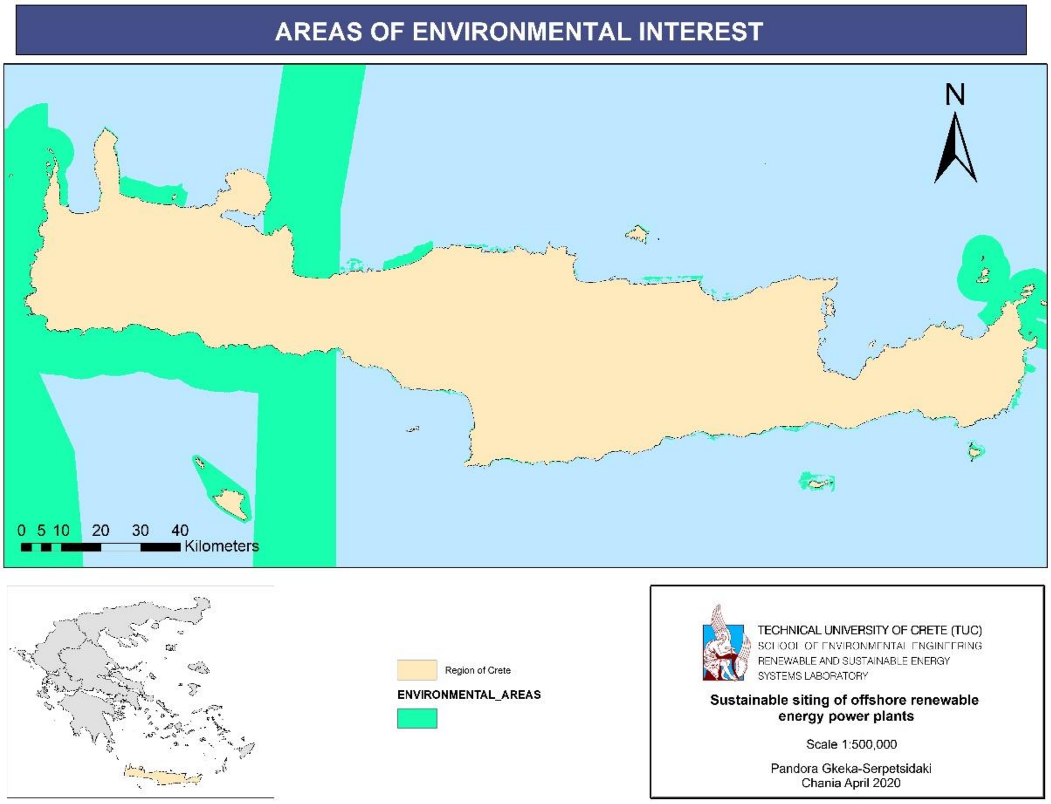


Figure B.4: Exclusion map: Distance from areas of environmental interest

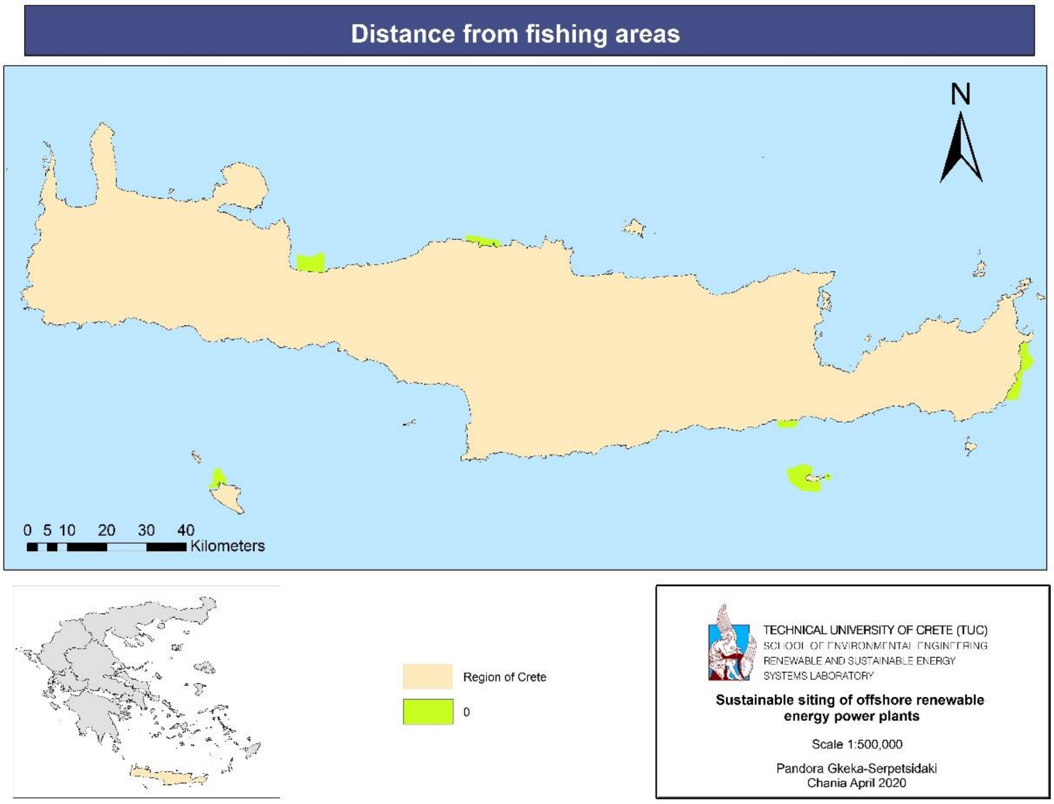


Figure B.5: Exclusion map: Distance from fishing areas

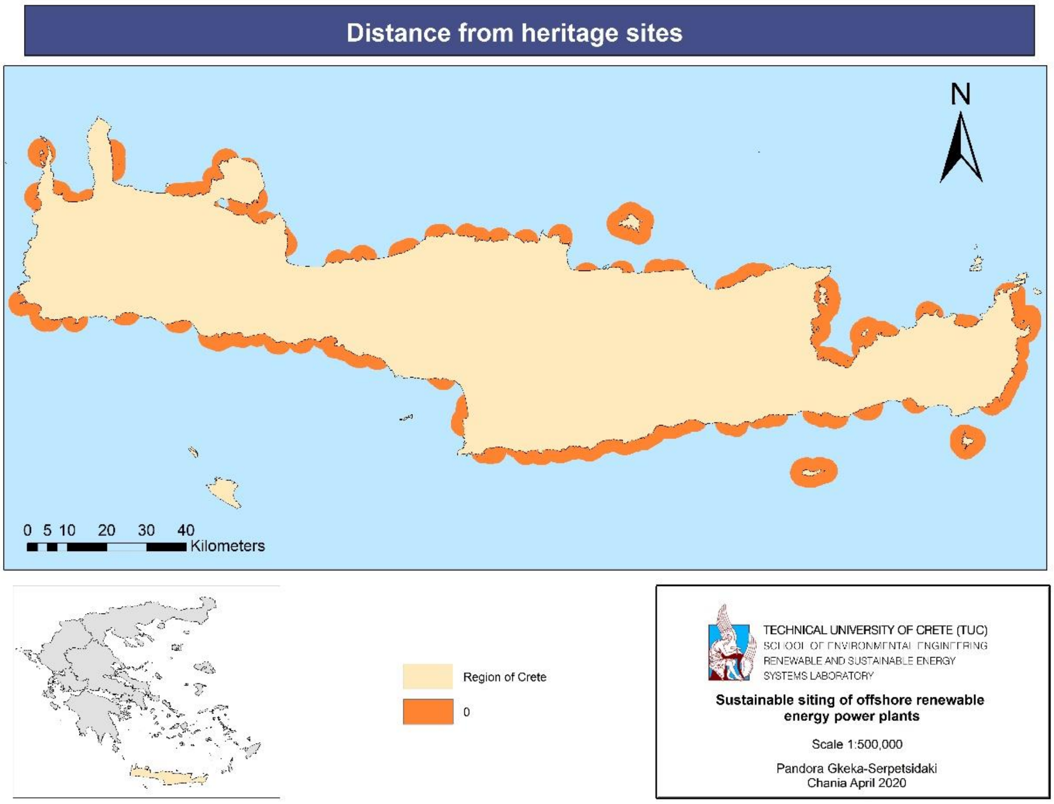


Figure B.6: Exclusion map: Distance from heritage sites

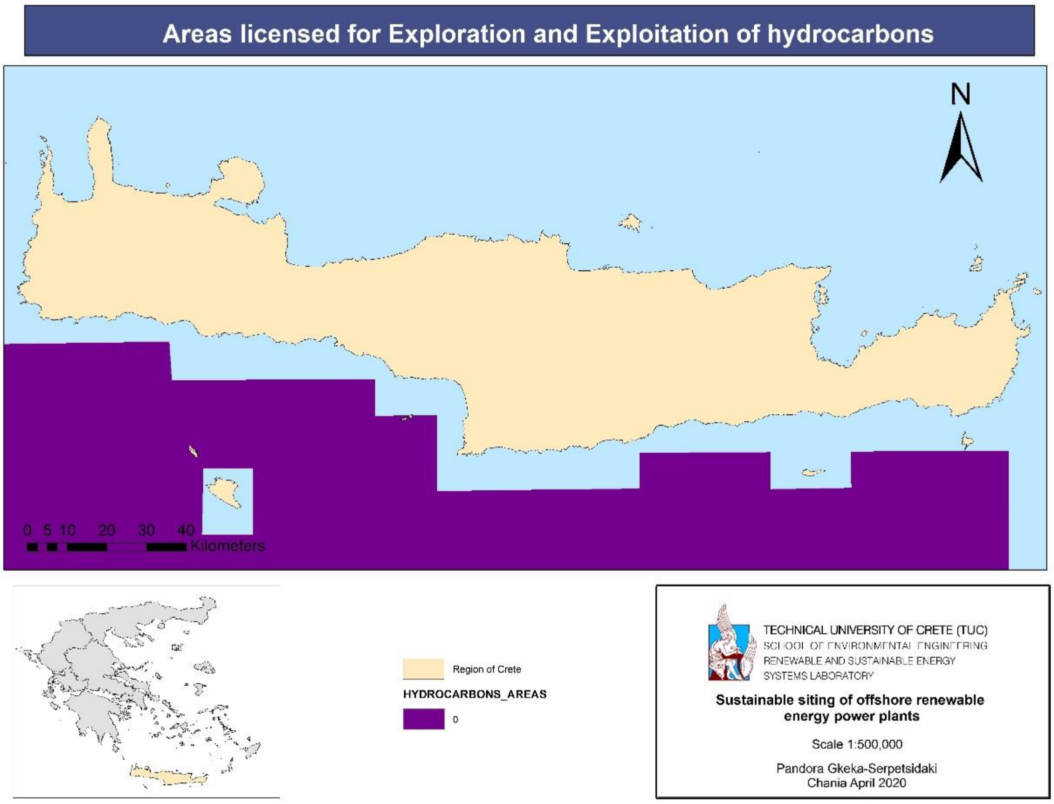


Figure B.7: Exclusion map: Areas licensed for exploration and exploitation of hydrocarbons

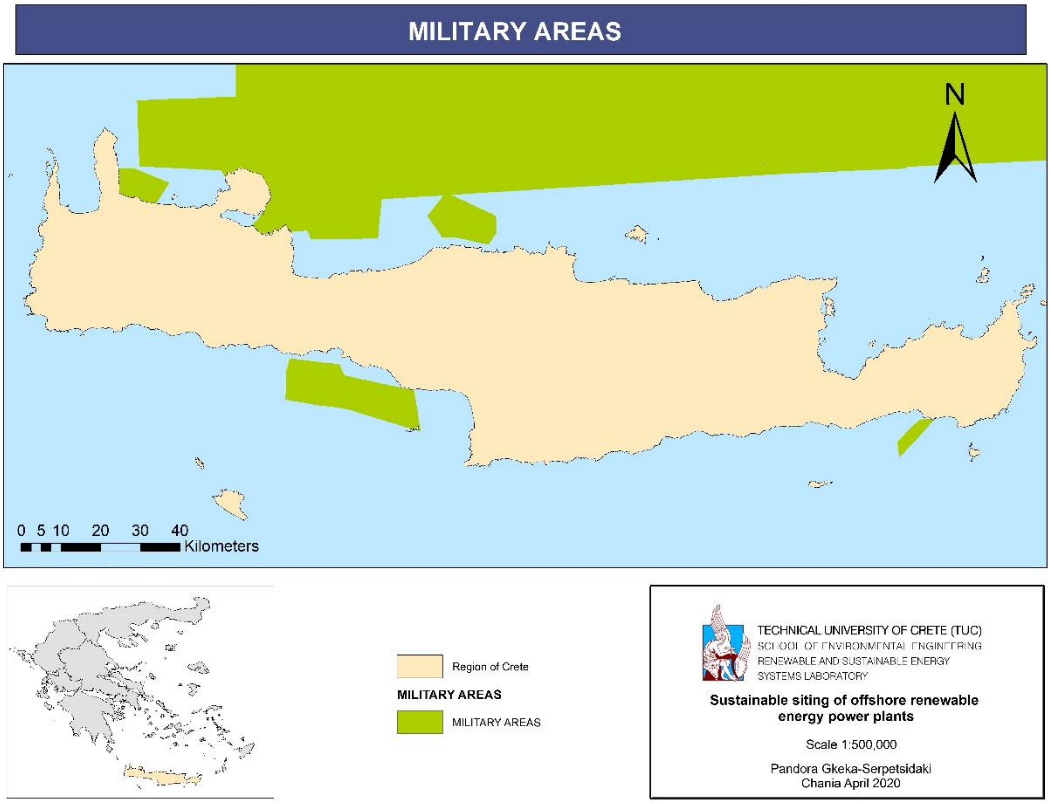


Figure B.8: Exclusion map: Military areas

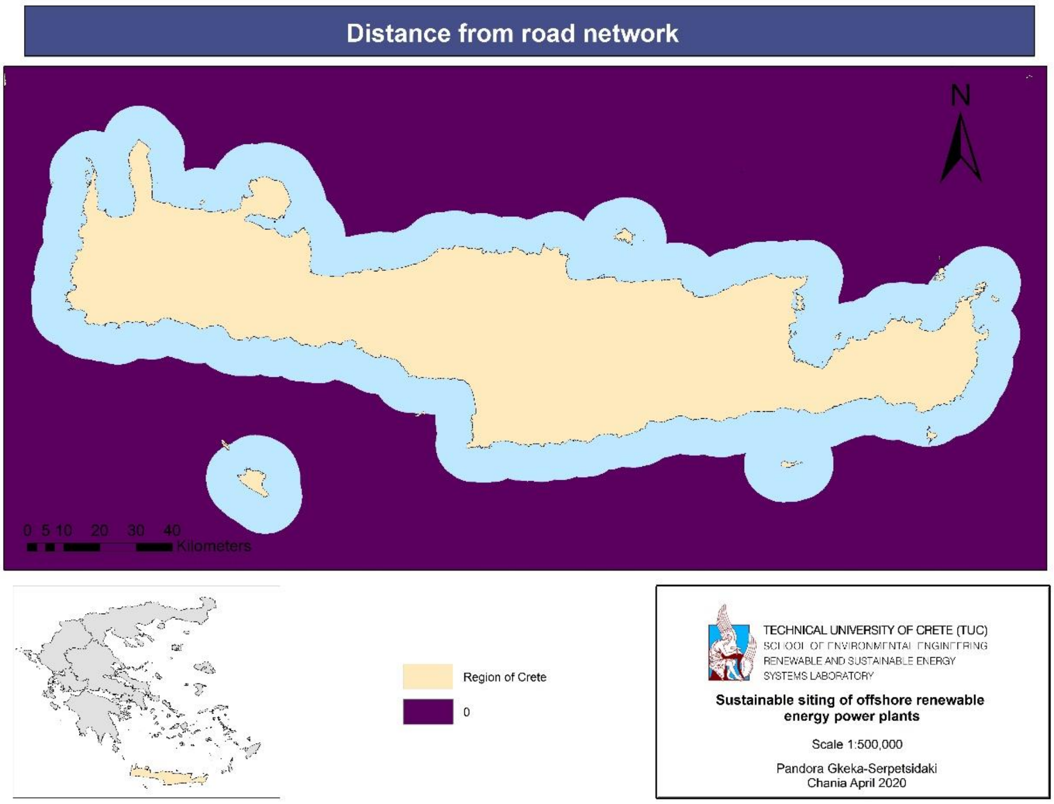


Figure B.9: Exclusion map: Distance from road network

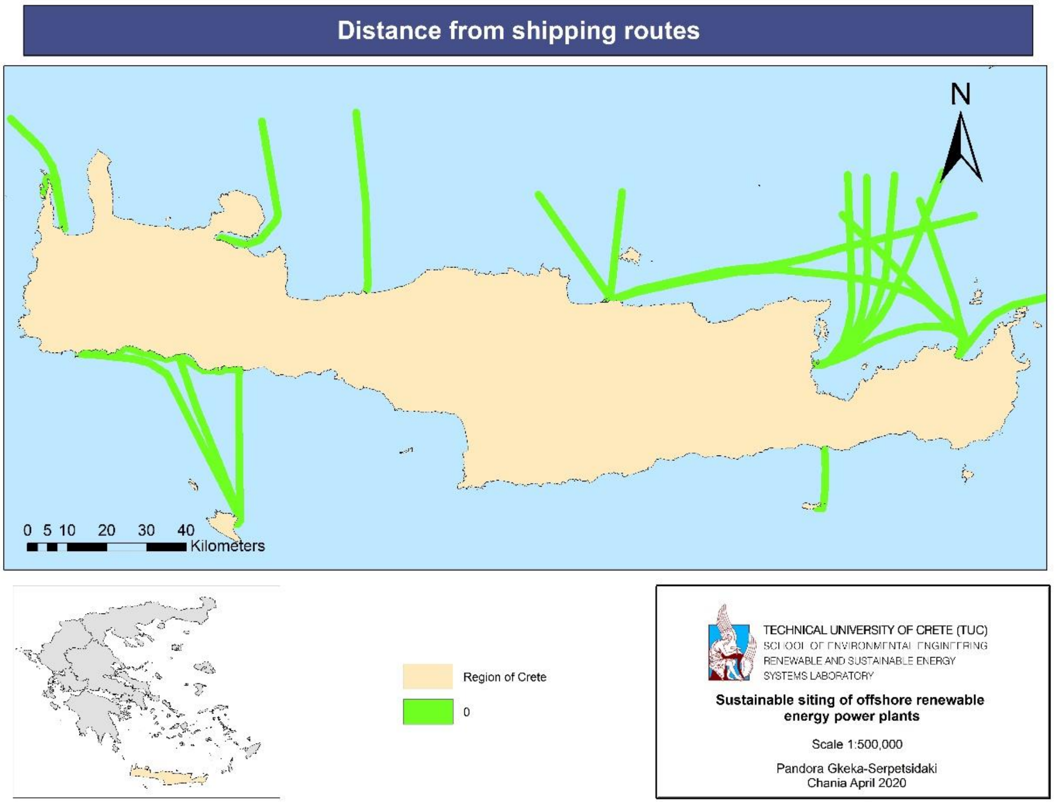


Figure B.10: Exclusion map: Distance from shipping routes

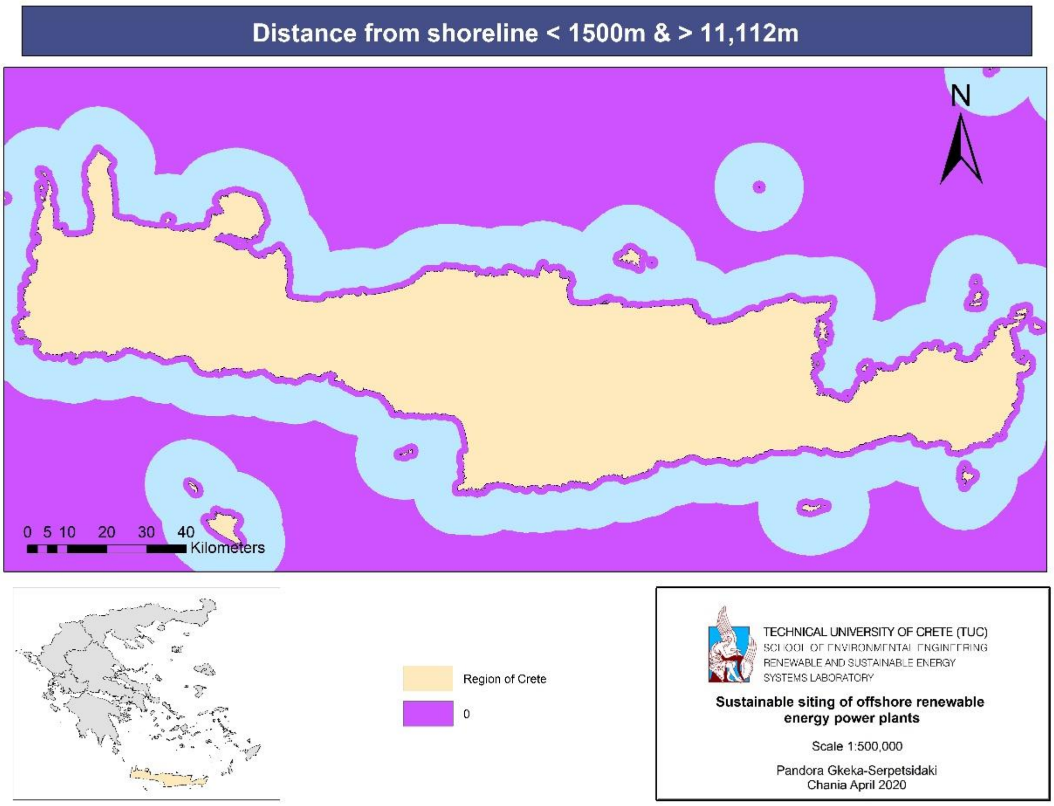


Figure B.11: Exclusion map: Distance from shoreline

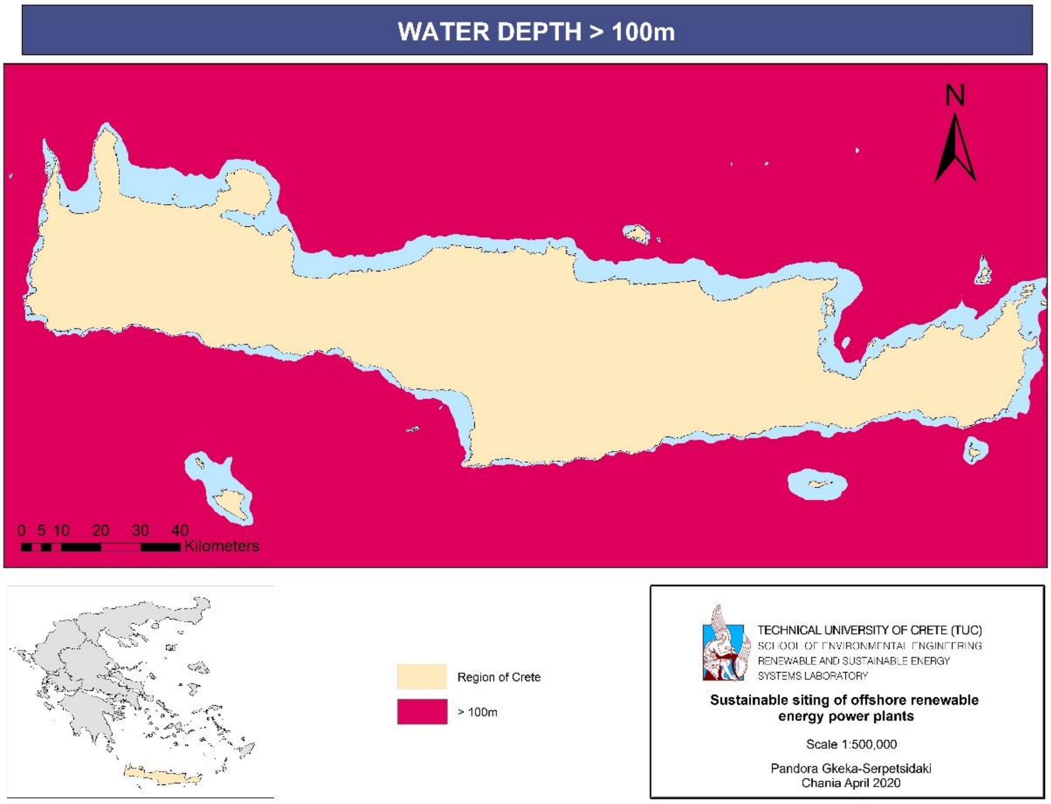


Figure B.12 : Exclusion map: Water depth

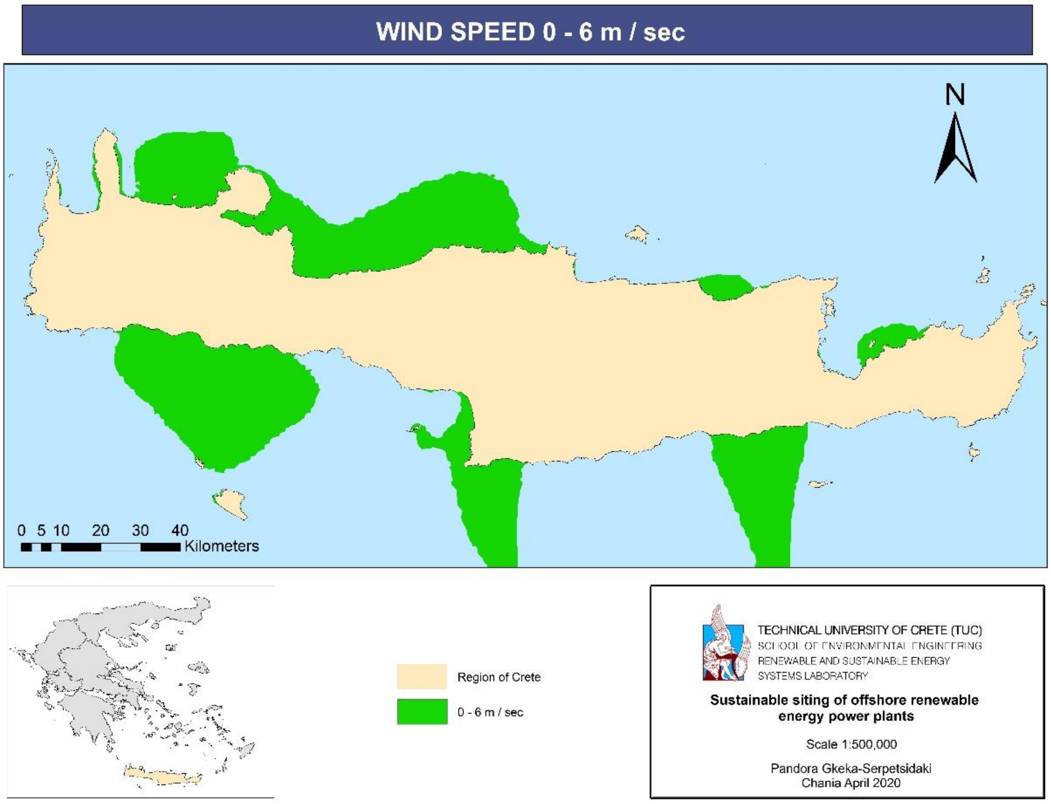


Figure B.13: Exclusion map: Wind speed

Evaluation maps

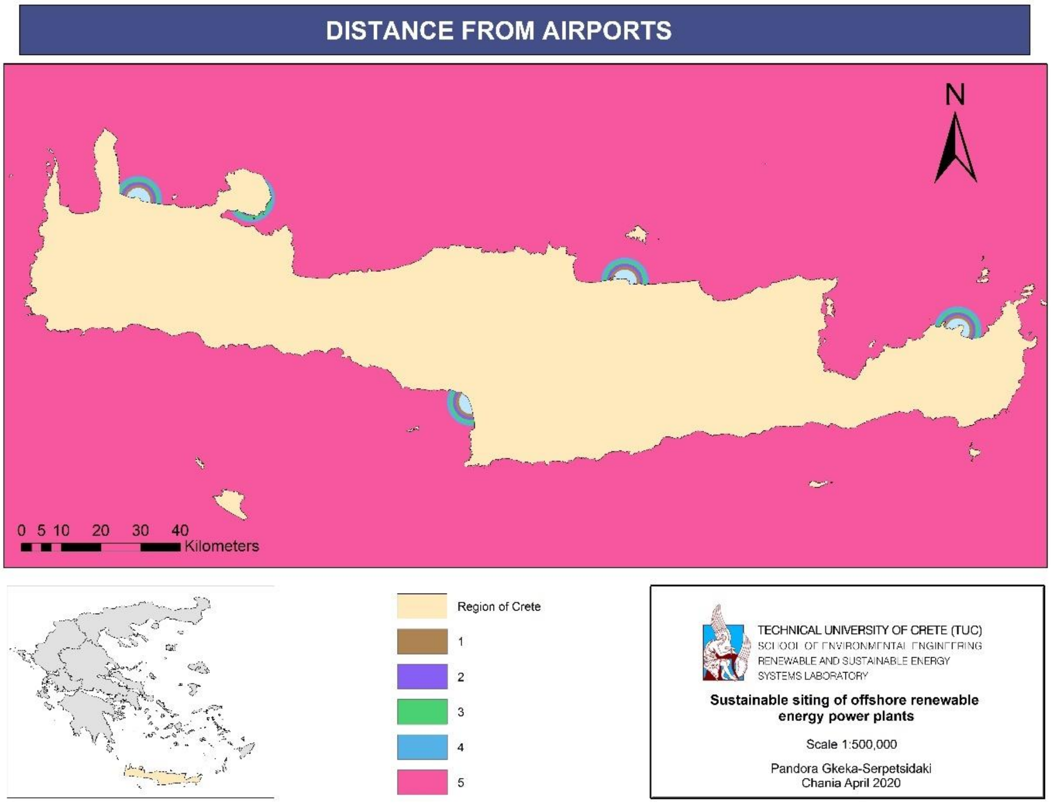


Figure B.14: Evaluation map: Distance from airports

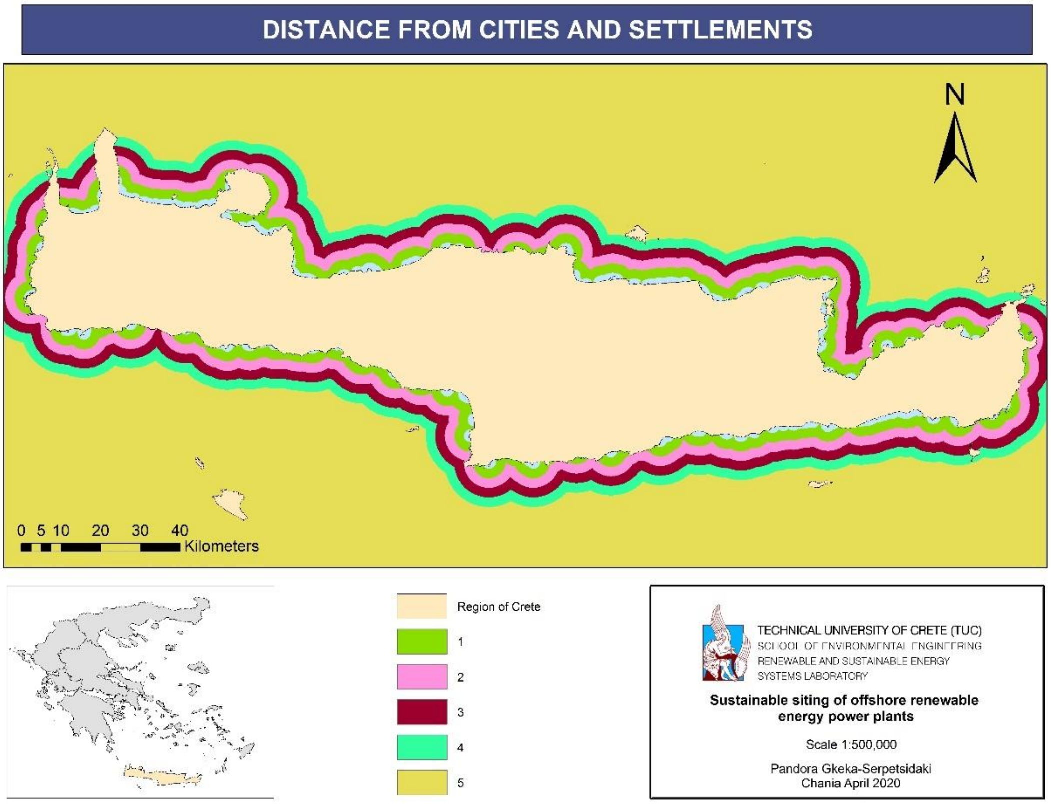


Figure B.15: Evaluation map: Distance from cities and settlements

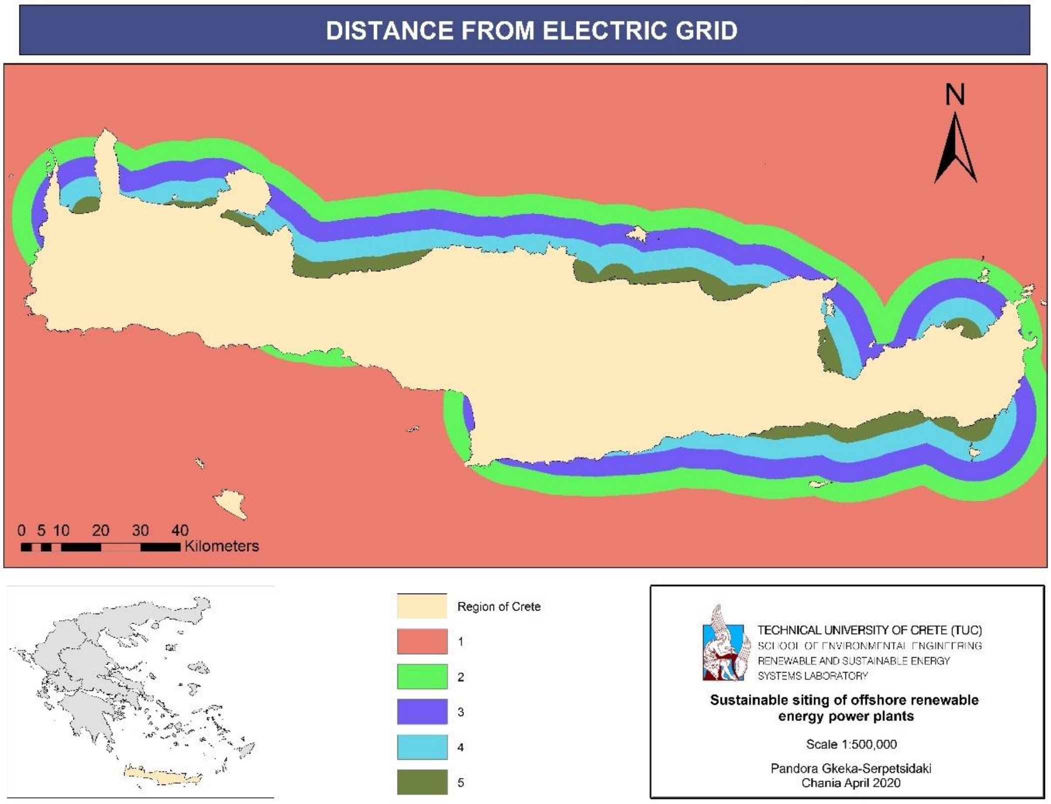


Figure B.16: Evaluation map: Distance from electric grid

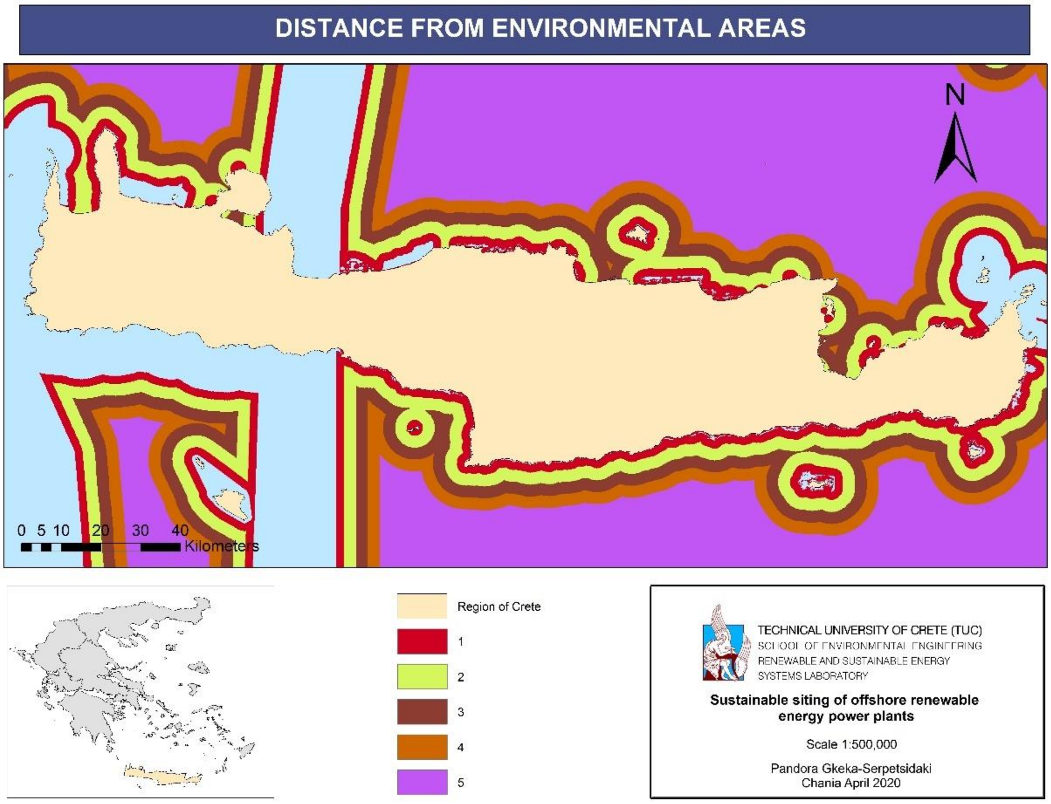


Figure B.17: Evaluation map: Distance from environmental areas

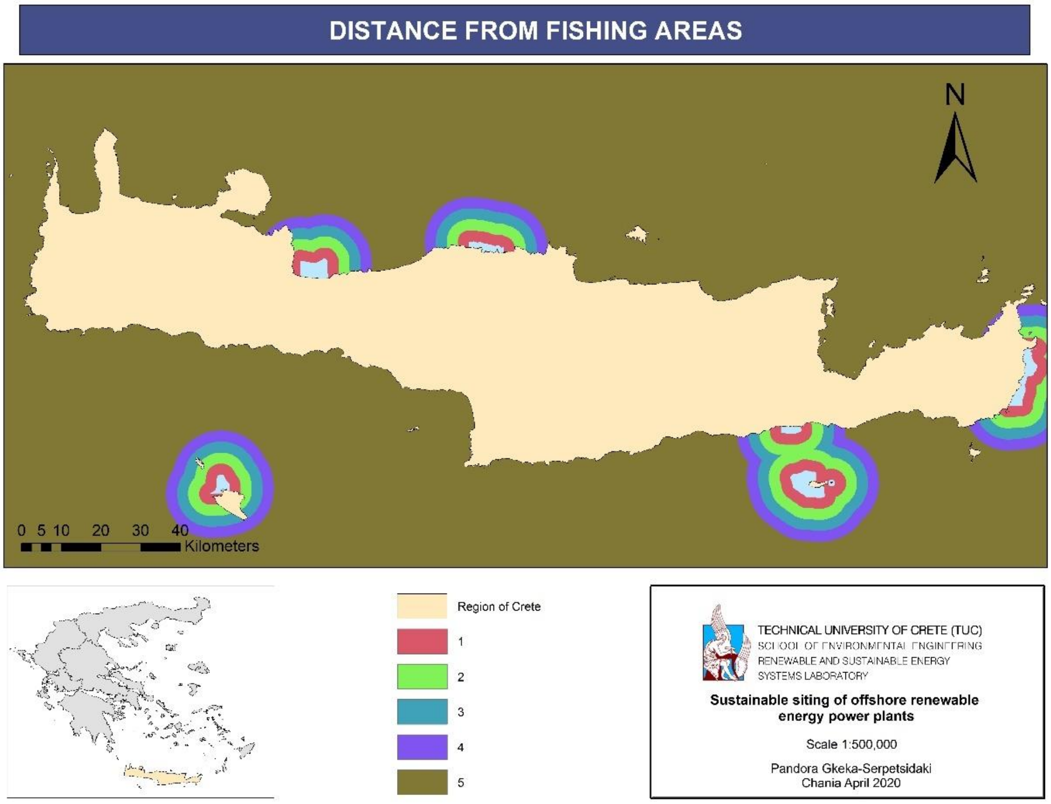


Figure B.18: Evaluation map: Distance from fishing areas

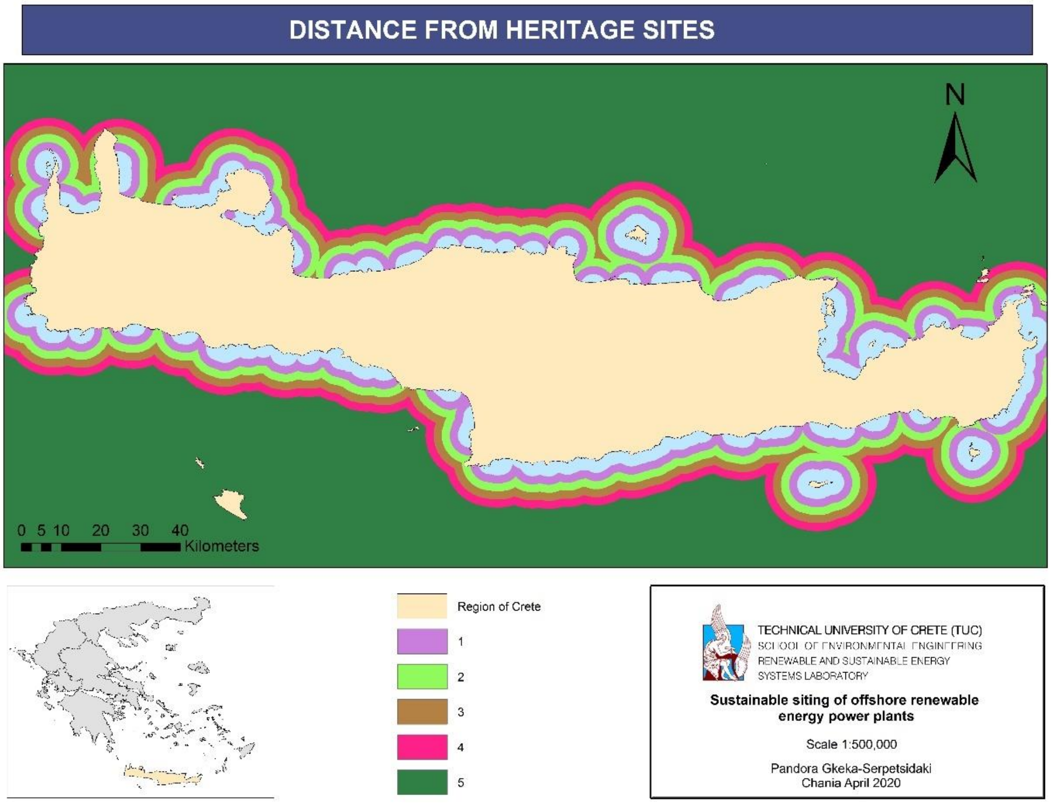


Figure B.19: Evaluation map: Distance from heritage sites

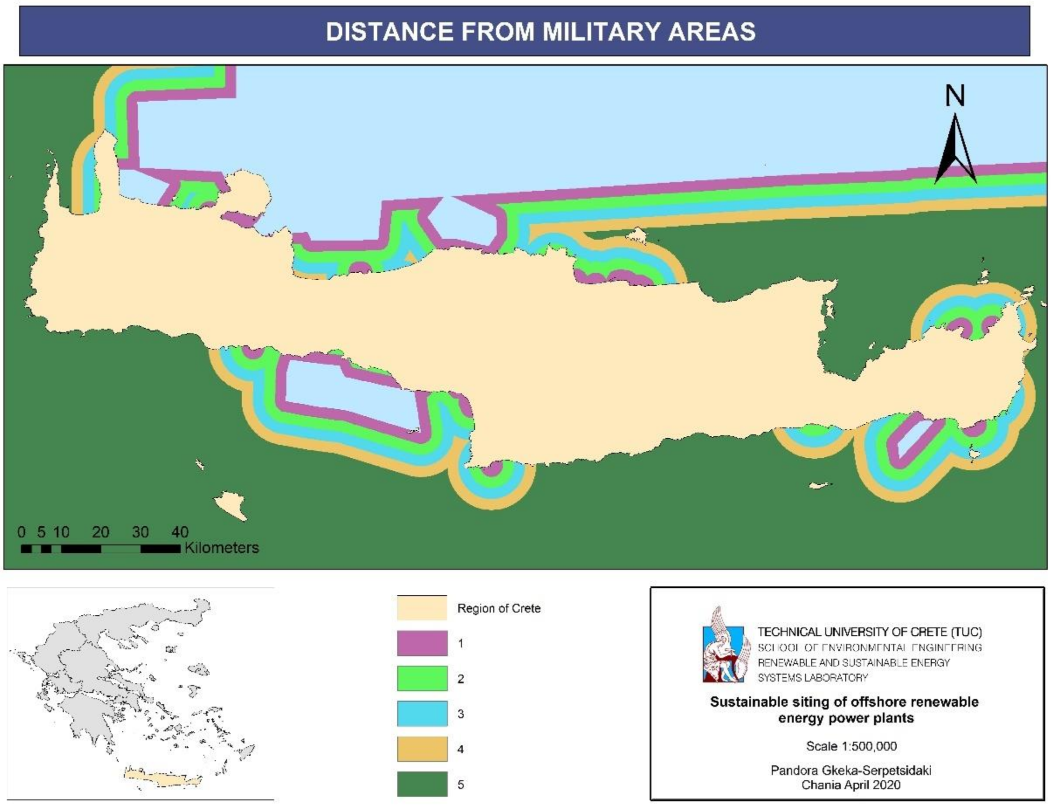


Figure B.20: Evaluation map: Distance from military areas

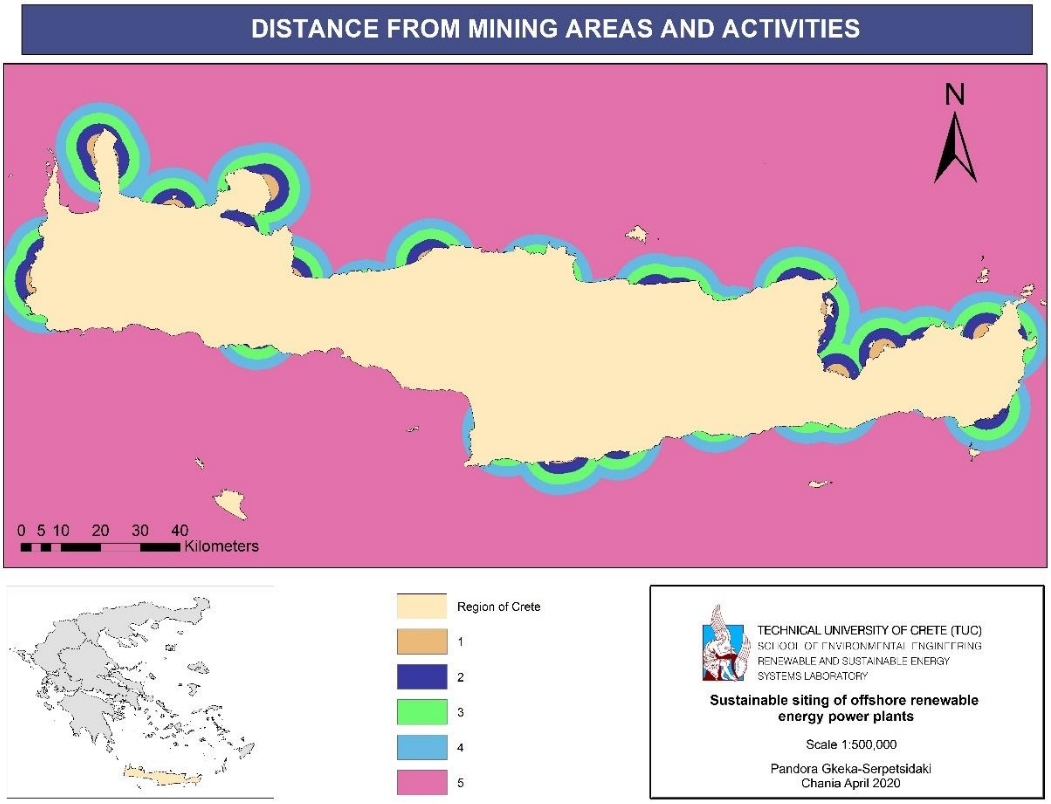


Figure B.21: Evaluation map: Distance from mining areas and activities

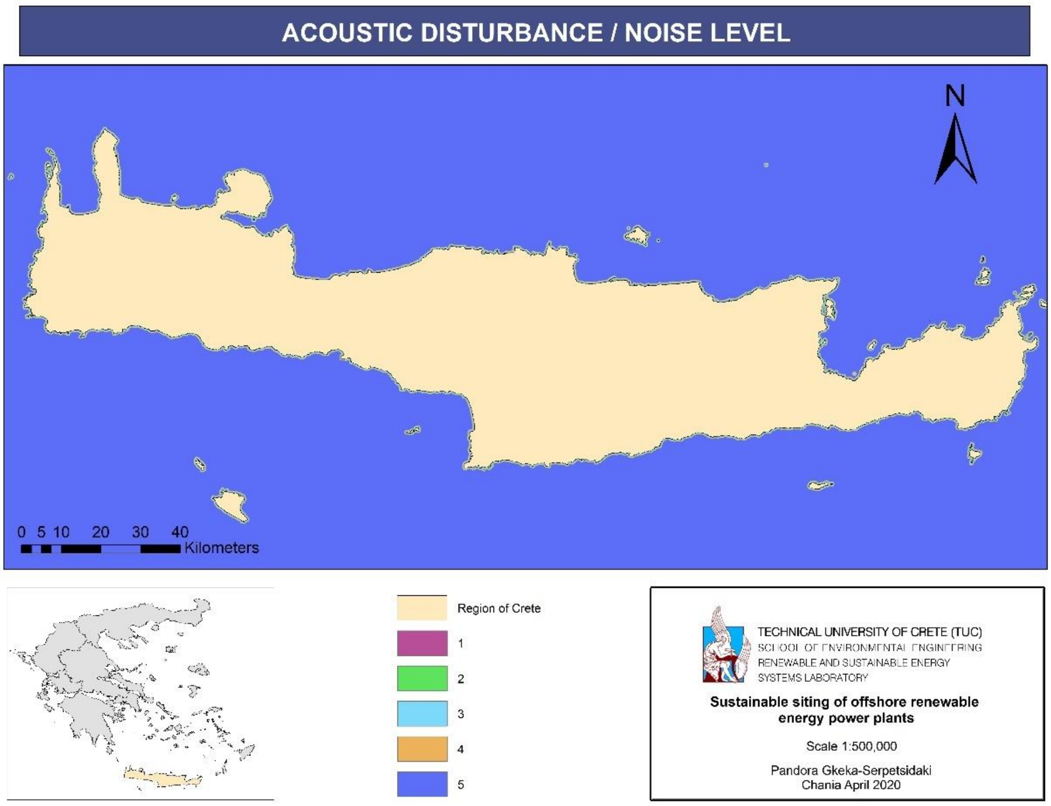


Figure B.22: Evaluation map: Acoustic disturbance/Noise level

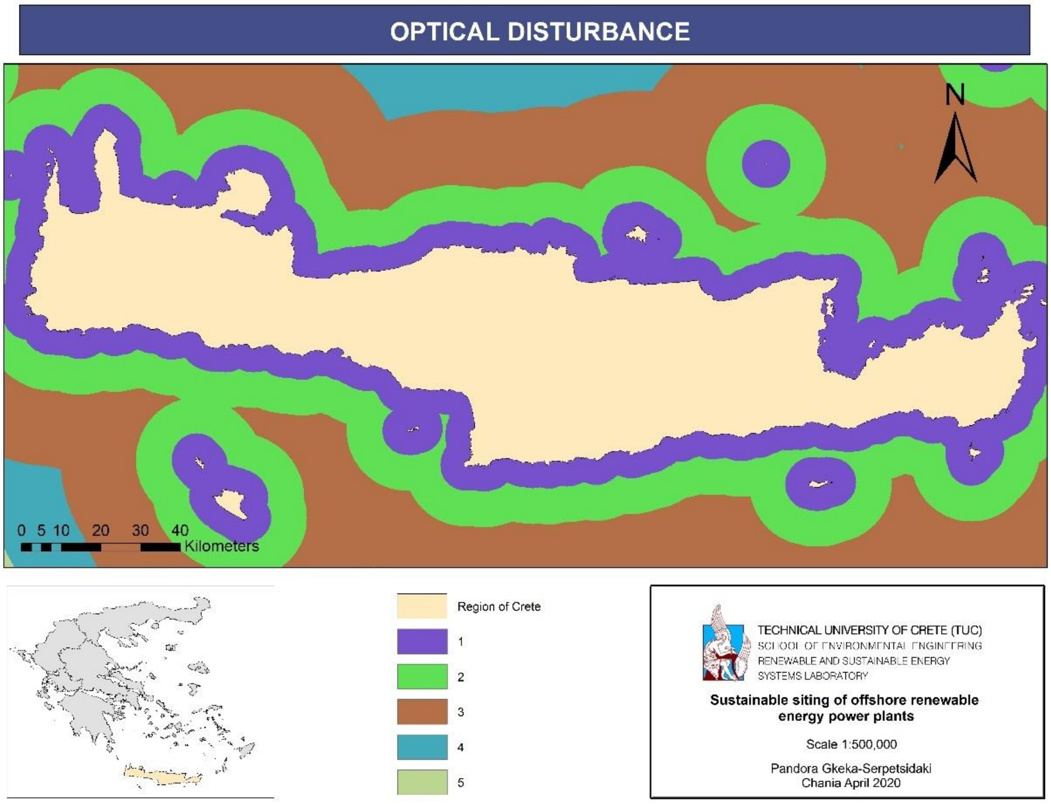


Figure B.23: Evaluation map: Optical disturbance

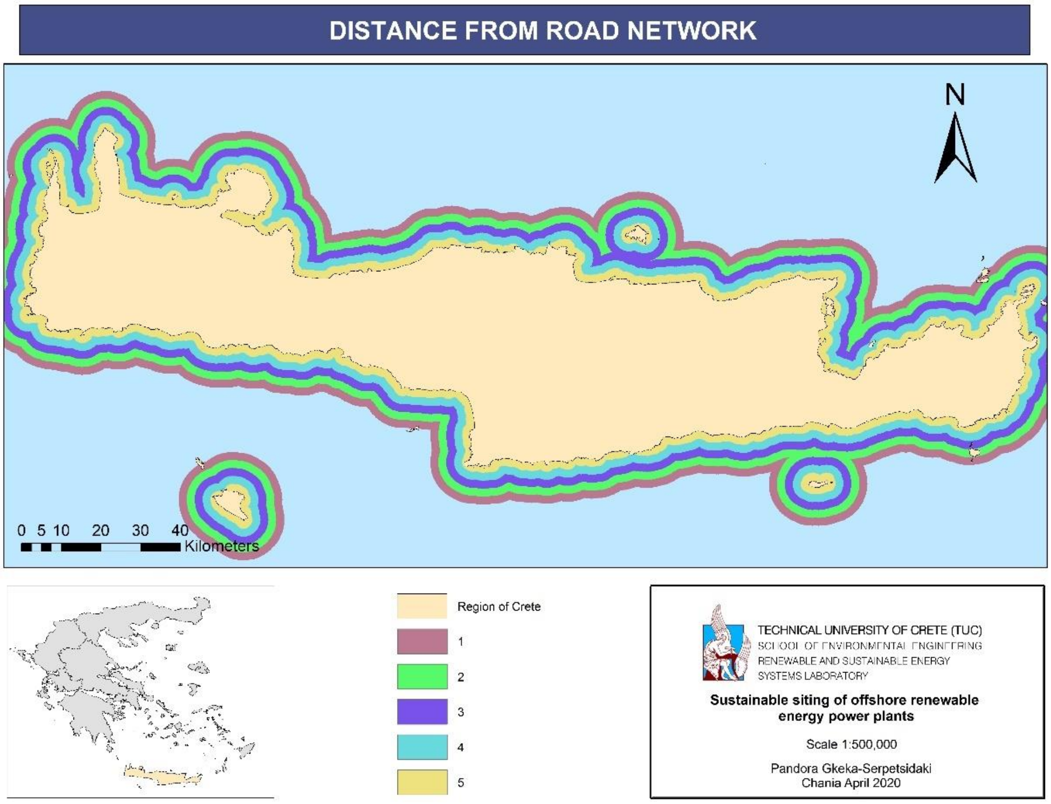


Figure B.24: Evaluation map: Distance from road network

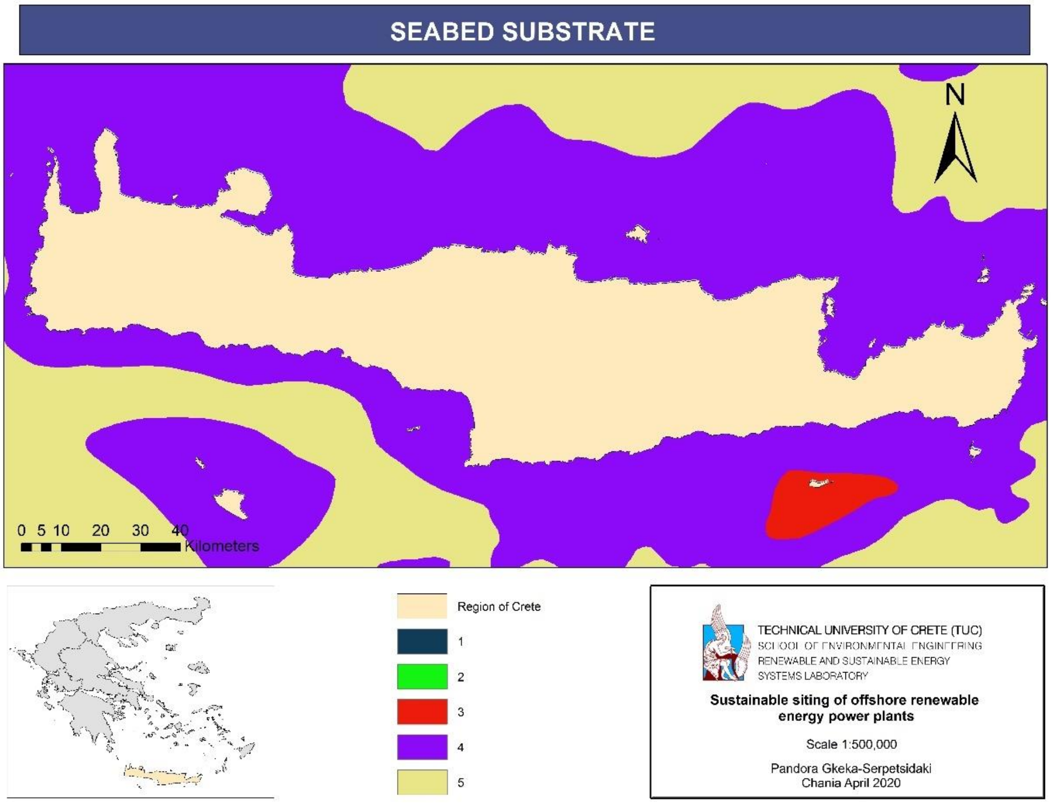


Figure B.25: Evaluation map: Seabed substrate

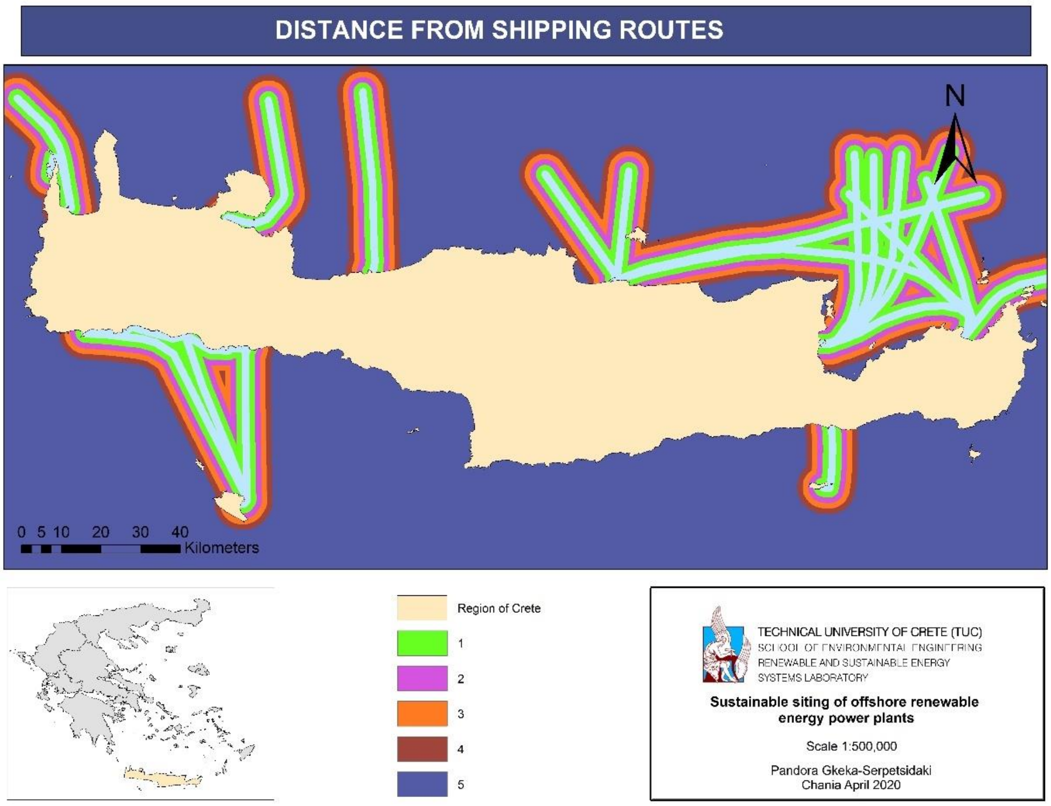


Figure B.26: Evaluation map: Distance from shipping routes

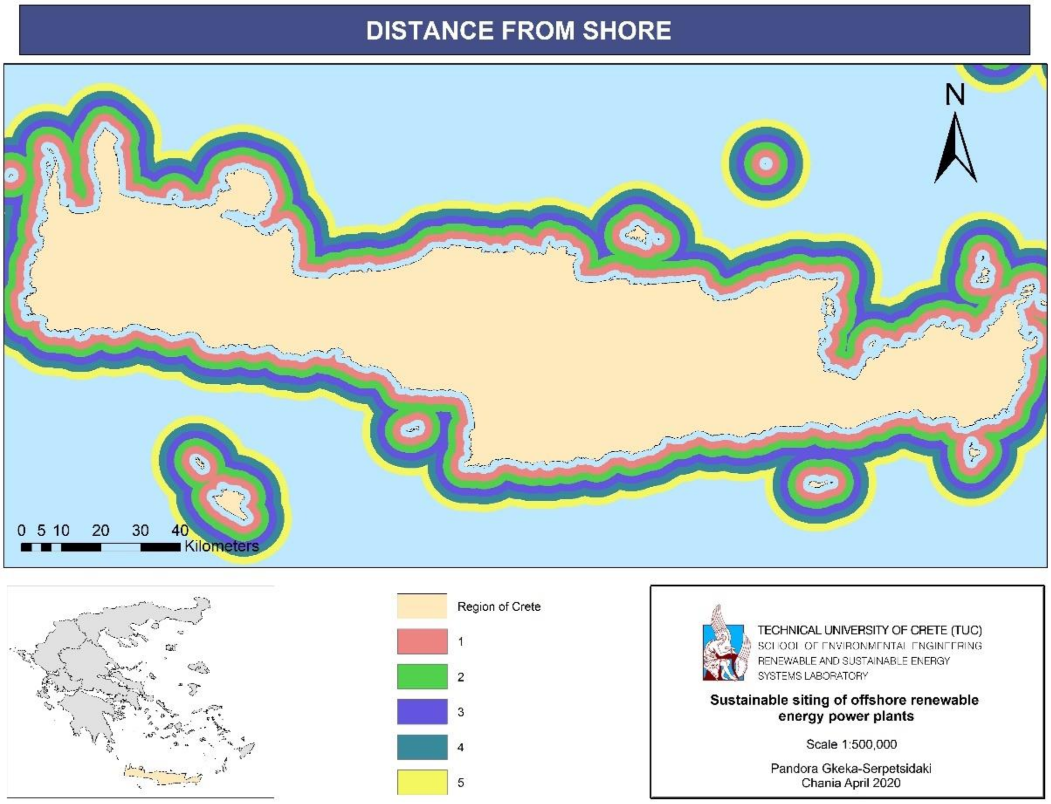


Figure B.27: Evaluation map: Distance from shore

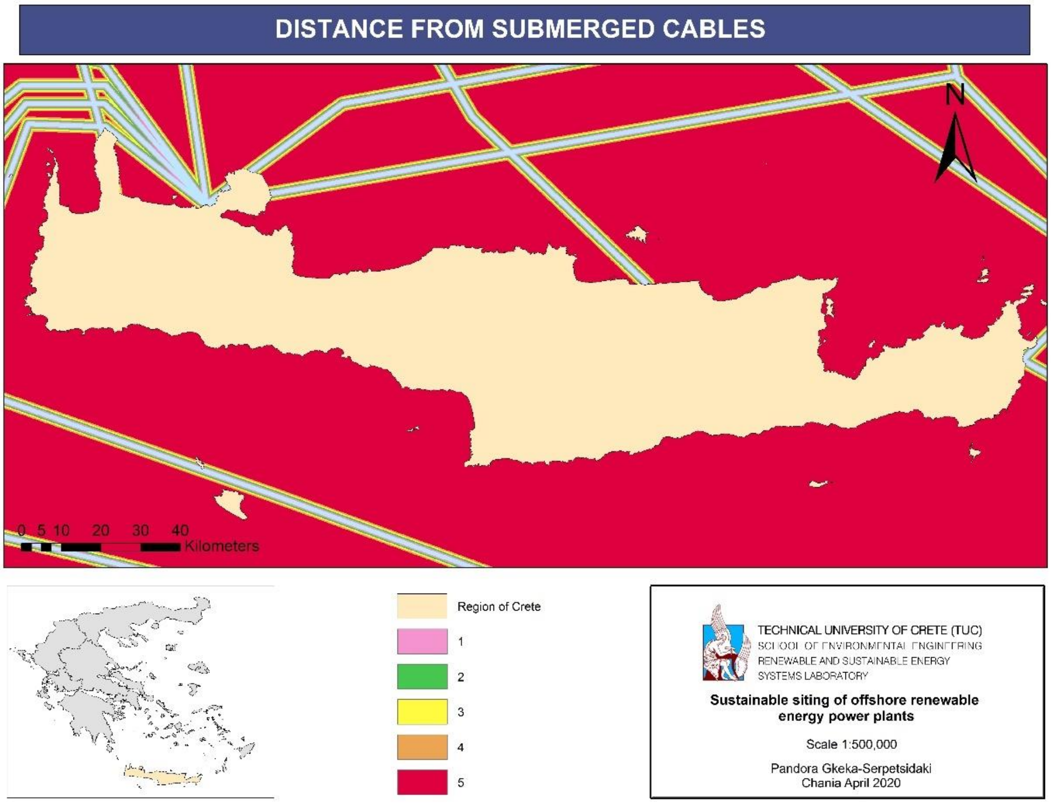


Figure B.28: Evaluation map: Distance from submerged cables

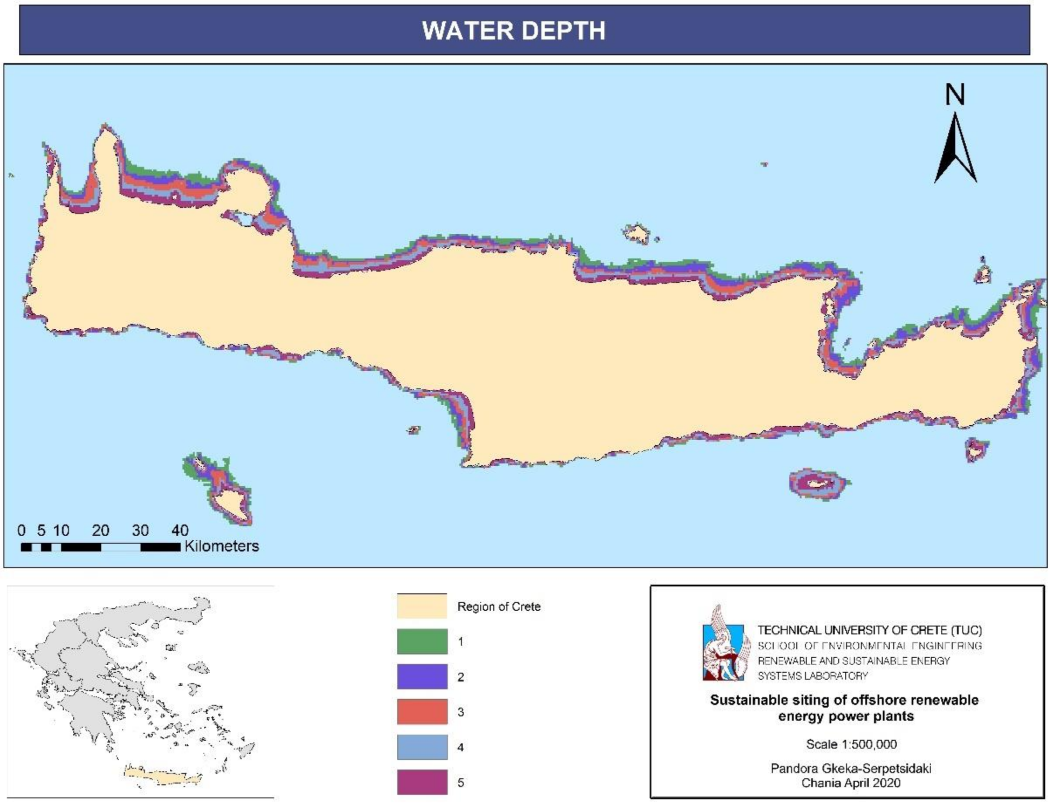


Figure B.29: Evaluation map: Water depth

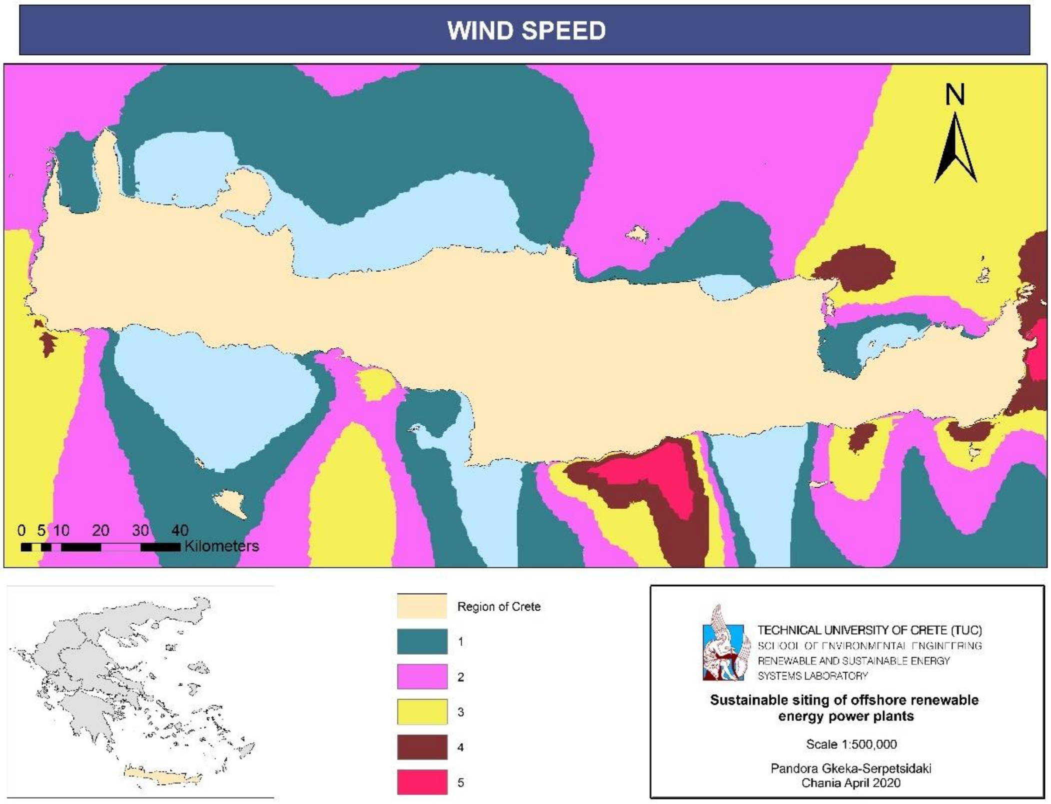


Figure B.30: Evaluation map: Wind speed

A. Annex C

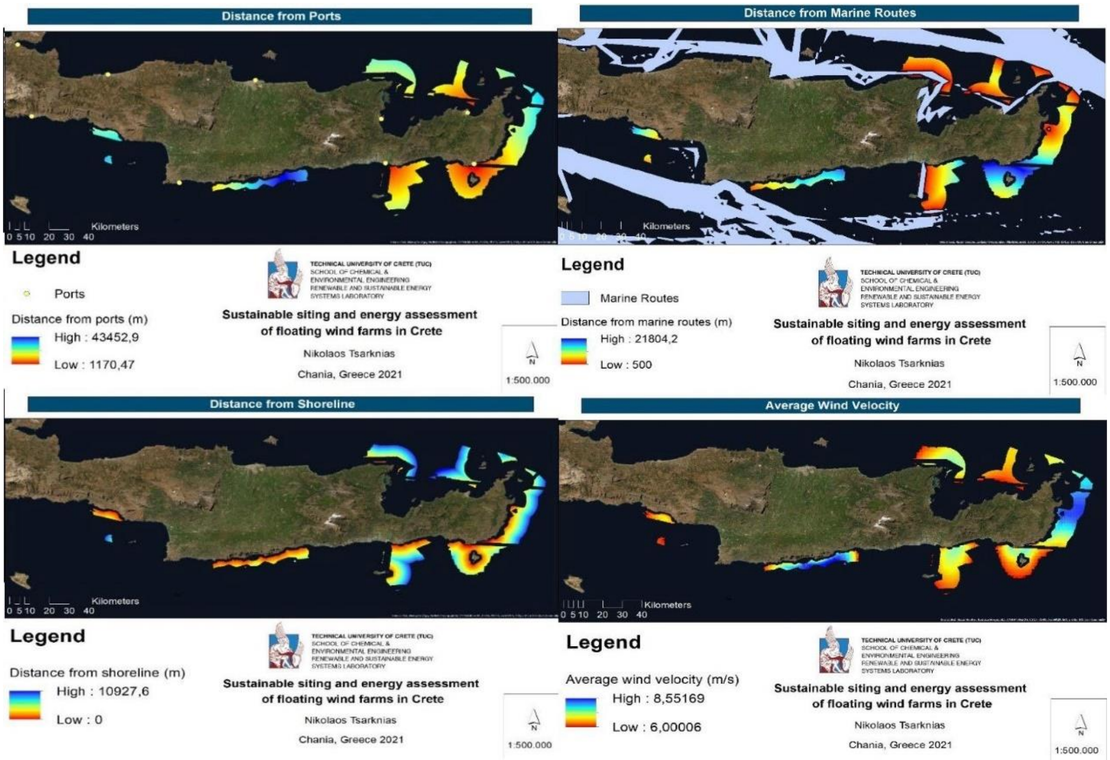


Figure C.1: EVC (1/2)

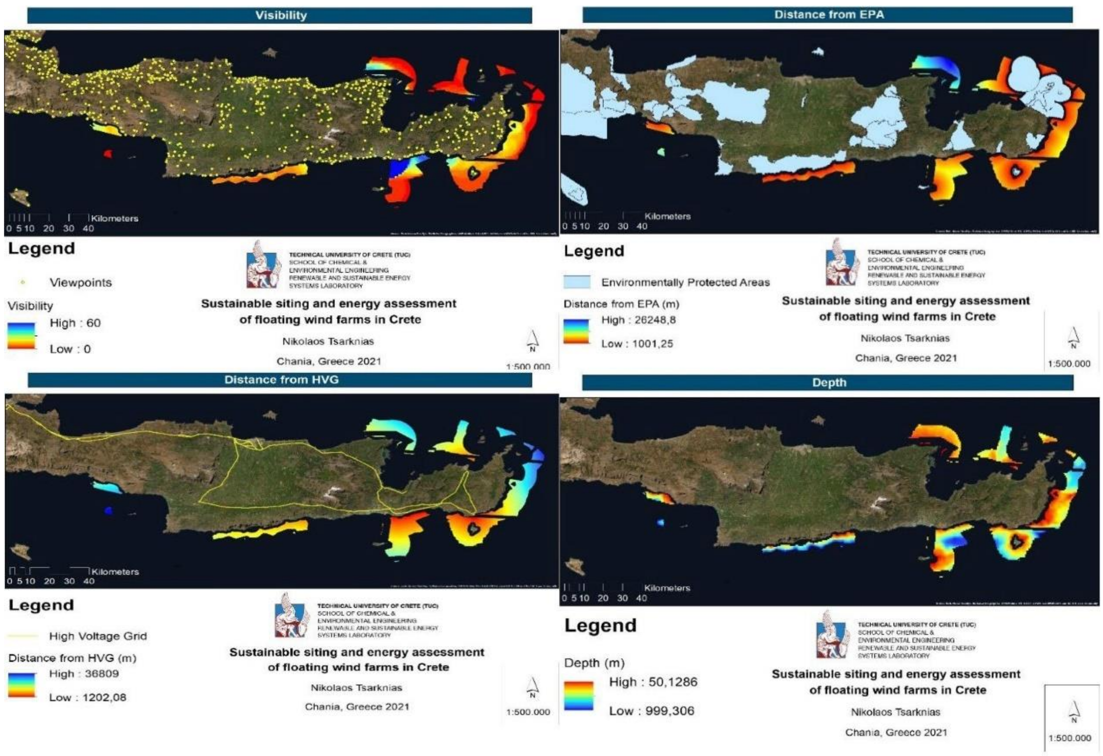


Figure A2:Evaluation Criteria (2/2) (ArcMap 10.7)

Figure C.2: EVC (2/2)

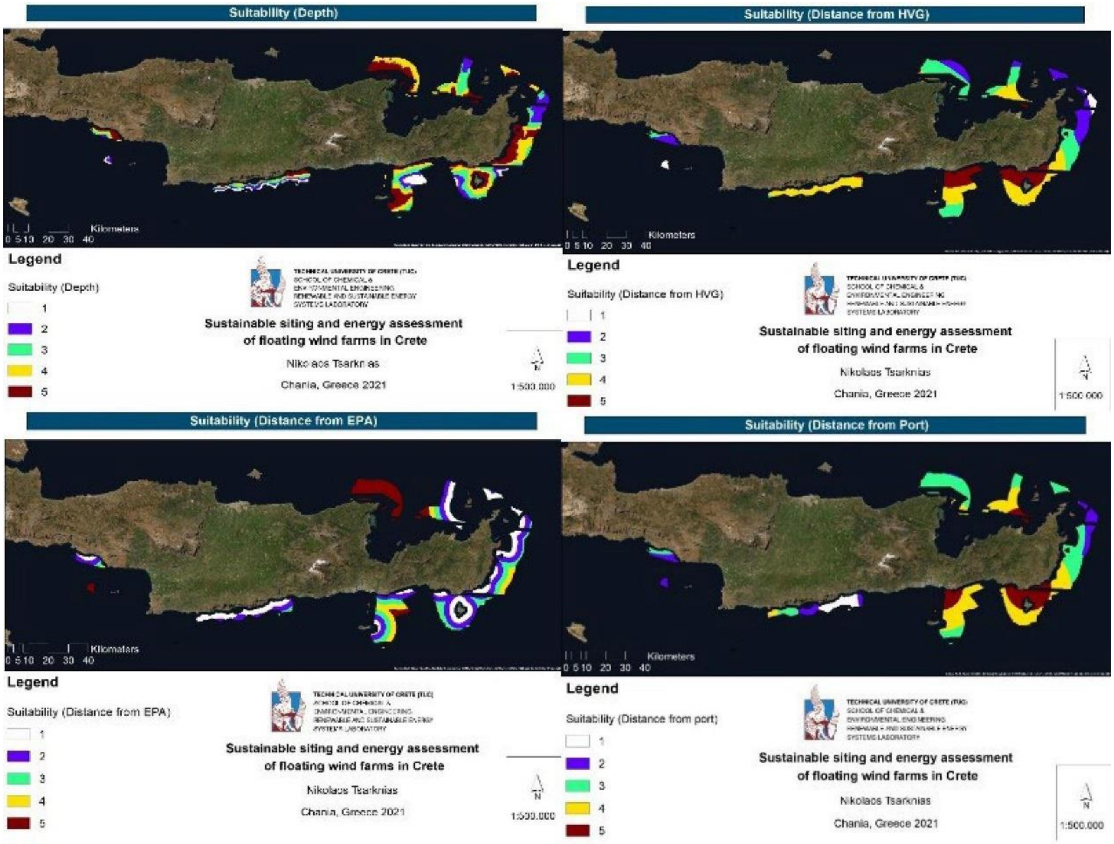


Figure C.3: Suitability of EVC (1/2)

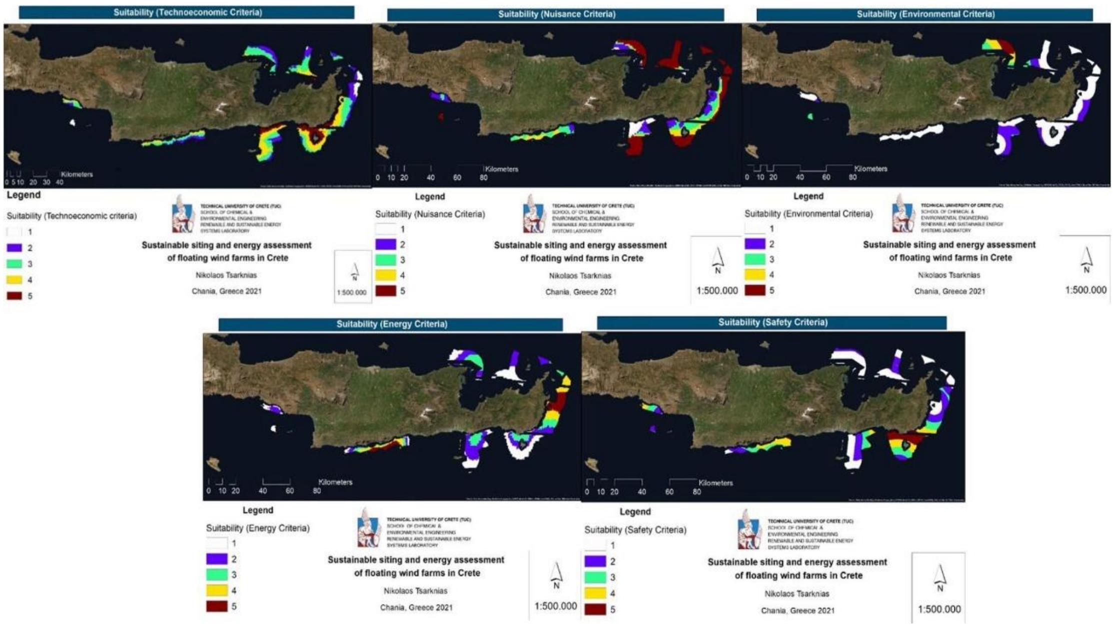


Figure C.4: Suitability of EVC (2/2)

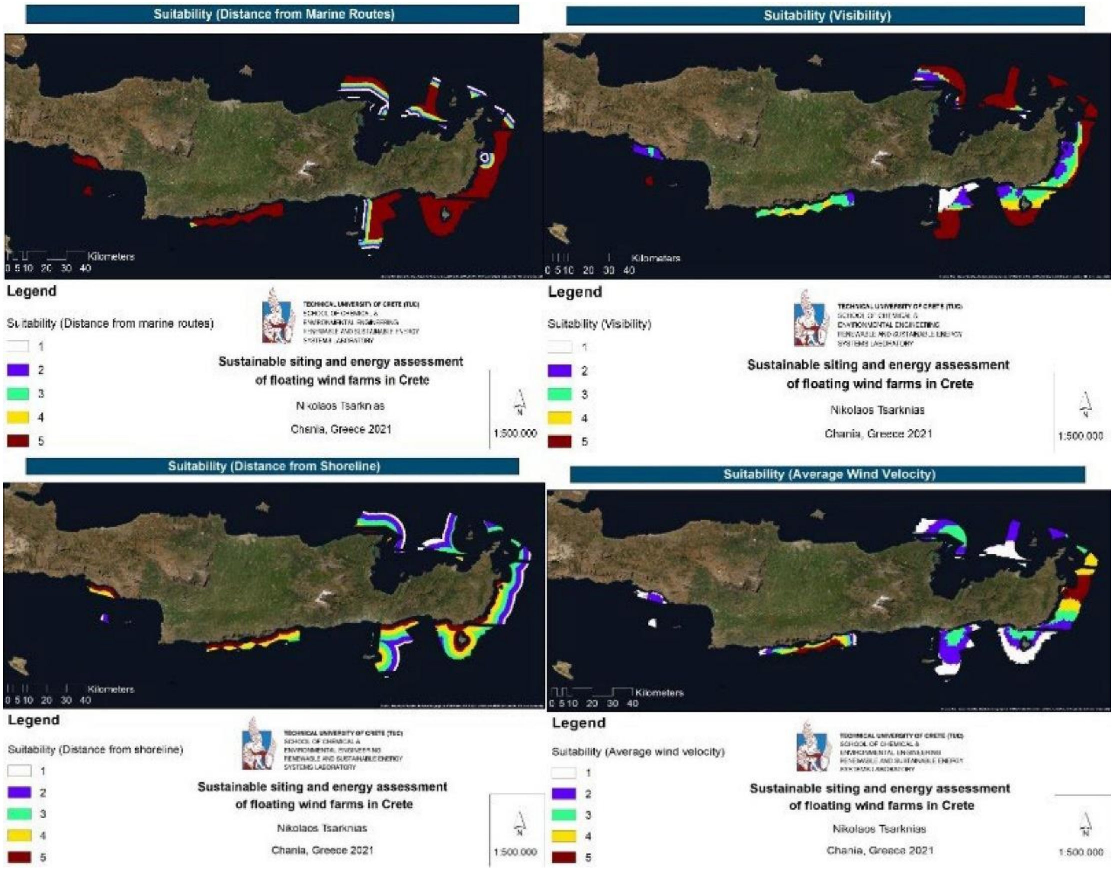


Figure C.5: Suitability of categorized criteria

, Figure E.4, Figure E.5, the relevant charts for the second and third scenarios are included.

The analysis of the PP for average and peak energy prices in three different scenarios indicates that there are significant variations that have an impact on the financial viability and return on investment. As shown in the first scenario, the PP differ significantly between the average and peak energy prices, with the peak price offering a faster PP. As a result, this pattern is repeated in the following scenarios, with scenario 2 showing the fastest payback for the maximum energy price and scenario 3 showing a balanced picture between the two price categories.

Based on this analysis, scenario 2 appears to be the most attractive, owing to a faster return on investment, especially in the case of a maximum energy price. Due to its slower PP, scenario 1 is considered less attractive, while scenario 3 offers a balanced perspective, making it an intermediate choice. Investors should determine their preferred scenario based on their preference for quick returns on investment versus long-term financial security, their expectations for energy price fluctuations, and their risk tolerance.

For each of the three scenarios, the IRR values reflect different projections of investment performance. For both the average and maximum price of energy, scenario 2 has the highest IRR, making it particularly attractive from a financial standpoint. As a result of the higher return, this scenario is likely to generate a greater return per euro invested than the other two scenarios. The IRRs for scenarios 1 and 3 are lower, indicating a more conservative approach and a lower expected return.

Levelised Cost of Electricity (LCoE)

The following are three different scenarios regarding the LCoE during the assumed operational period of 2031 to 2055. As part of the evaluation of a project's financial viability, these scenarios are intended to attract potential investors.

Each scenario is illustrated in Figure A.1, illustrating the reduction in the cost of electricity during park operation, and the main parameters and developments impacting the cost of electricity will also be discussed. In this analysis, we will be able to obtain valuable information about the financial performance of the project and will be able to make informed decisions regarding the investment [238].

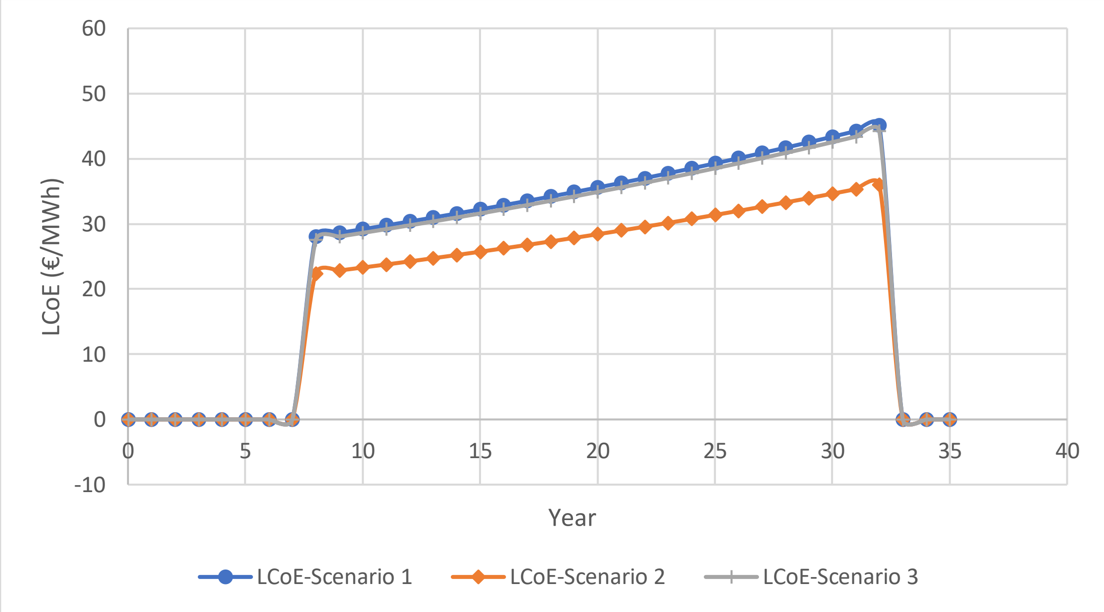


Figure A.1: Comparison of LCOE over lifetime of project for each scenario

The discounted energy costs provided for three scenarios over a 36-year horizon demonstrate distinct economic dynamics, which are integral to determining the most sustainable and cost-effective strategy for wind energy development.

Based on scenario 1, the discounted energy cost starts in year 8 at €28.05/MWh, rises steadily to a peak of €45.12/MWh, and then decreases to zero. There may be a transition from a phase of investment to a phase of operation without additional costs, perhaps as a result of the return on investment or the termination of financial obligations. It appears that the initial capital outlay will gradually be recovered over time.

The scenario 2 appears to be the most economically viable, starting with a lower discounted energy cost of €22.40/MWh, increasing to €36.03/MWh, and finally decreasing to zero. Compared to scenario 1, lower start and end points indicate superior cost efficiency and potentially lower financial risk.

Scenario 3 is a middle ground between scenarios 1 and 2, starting at €27.51/MWh and scaling up to €44.25/MWh. Despite its intermediate placement, scenario 2 remains less favorable due to its higher cost profile.

Net Present Value

As a result of the analysis, Table A.1 and Figure A.2 shows the total NPV values for the average and maximum energy prices according to the estimates of the Energy Regulatory Authority (RAE) [234].

Table A.1: Total Net Present Value results of each scenario for average and maximum energy price

Scenario	NPV average energy price (€)	NPV maximum energy price (€)

1	-119,076,472 €	20,112,388 €
2	12,298,372 €	167,140,297 €
3	-94,166,631 €	28,848,073 €

According to the first scenario, the average price of energy is -119,076,472, indicating a negative NPV, while the maximum price is €20,112,380. Even though the peak value is high, the negative average value may indicate that there are periods or conditions that are high risk.

In the second scenario, the average value is positive and reaches €12,298,372, with a maximum value also positive and high (€167,140,297), indicating stable profits and high returns.

In the third scenario, the average NPV is -94,166,631, which is negative, while the maximum is €28,848,073. Although the maximum value is positive, the average value is negative, which indicates a risk of loss.

Comparing the average and maximum energy values from each scenario, it appears that the second scenario is the most attractive, since it has the highest average NPV, which is positive, and the highest maximum value. As a result, this scenario offers the best balance between risk and return, making it a more attractive investment opportunity.

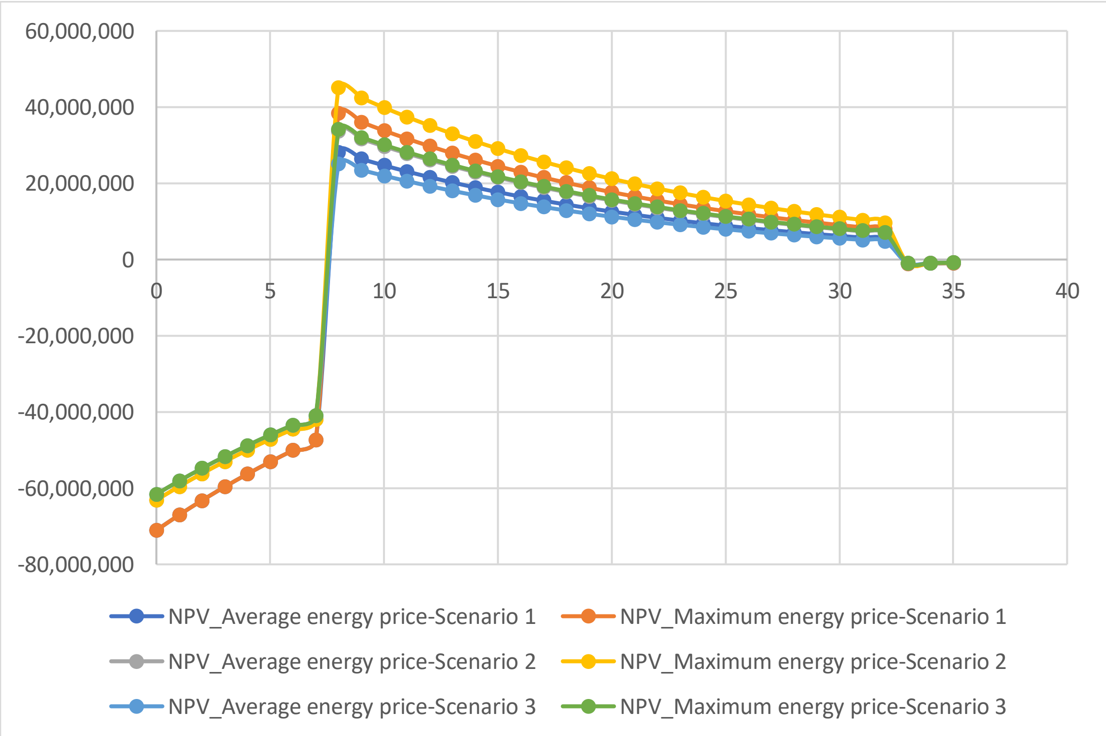


Figure A.2: Comparison of Net Present Value of average and peak energy price scenarios with time of investment

5.2.4 Discussion section

As shown in scenario 1, the total CAPEX is €568,501,487, the OPEX are €546,278,191 and the DECEX are €22,295,594, resulting in a total cost of €1,137,075,272. For the average energy price, the NPV is negative -€119,076,472, making the investment economically unattractive. Nevertheless, under ideal conditions, the NPV for the maximum energy price amounts to €20,112,388, which makes the project economically attractive. Due to this, the economic viability of Scenario 1 is highly dependent on the fluctuations in energy prices. A gradual transfer of costs from the initial investment to the operational phase is reflected in the gradual increase in reduced energy costs from €28.05/MWh to €45.12/MWh. It is important to note that the final reduction to zero signifies the completion of the project's PP, marking a critical point in its profitability.

Scenario 2 presents a lower total cost than Scenario 1, with CAPEX of €505,037,588, OPEX of €485,295,159, and DECEX of €19,806,655. In Scenario 2, the total NPV is positive €12,298,372, and for the maximum energy price it increases by €167,140,297, which makes it extremely attractive for investors. According to this analysis, Scenario 2 offers the greatest economic efficiency, regardless of the price of energy. Starting with a lower reduced energy cost of €22.40/MWh, then gradually increasing to €36.03/MWh, before reducing to zero, suggests higher initial economic efficiency and a faster payback, making Scenario 2 more economically attractive.

Scenario 3 shows the lowest CAPEX (€492,695,646) of the three scenarios, with OPEX of €473,435,677 and DECEX of €19,322,626. Although the NPV for the average energy price is negative - €94,166,631, the NPV for the maximum energy price is €28,848,073, which indicates a moderate economic attractiveness under ideal circumstances. As a result of this scenario, the reduced energy cost starts at €27.51/MWh and reaches €44.25/MWh, demonstrating a compromise between cost and efficiency.

The analysis of the three scenarios indicates that Scenario 2 offers the most economic efficiency and the quickest PP, making it the preferred investment option. Both scenarios 1 and 3 present greater risk due to negative NPVs at average energy prices, although scenario 3 offers an intermediate solution with less cost and moderate economic attractiveness at maximum energy prices. There is no doubt that scenario 2 is the most viable and cost-effective solution, offering the best balance between cost, performance, and risk. Due to the lower start and higher end LCOE, along with the higher and positive NPV, Scenario 2 is the preferred option for investors seeking maximum returns with a minimum level of risk. While scenario 1 and 3 have potential, they are more risky and require more careful analysis and management.

By adding two more years of margin to the present analysis, the focus shifts to exploiting technological innovations, adapting to changing energy markets, and utilizing opportunities arising from new energy policies. As a result of integrating advanced technologies, CAPEX and OPEX can be reduced, increasing the economic attractiveness of each scenario. In addition, a more detailed assessment of energy prices and the ability to adapt to new energy policies and regulations may increase the NPV, increasing the financial viability of an investment. Risk management and exploitation of opportunities arising from the energy market and energy policies can maximize investment returns, making it more attractive to investors.

As well as improving the project's adaptability and resilience to market fluctuations, increasing the time margin can also facilitate improved risk management.

Assume that a 20% reduction in wind energy production results in a corresponding reduction in energy production. In Scenario 1, the annual production is 15,198,625 MWh. By reducing 20%, the new output will be 80% of the original, i.e. it is calculated that 15.198.625 MWh*0.8=12.158.900 MWh.

There will be a direct impact on Net Cash Flows and NPV as a result of this reduction in production. Based on the assumption that a reduction in production will have a commensurate impact on Net Cash Flows, this would result in the following:

According to the average energy price, the initial Net Cash Flows are €412,424,547. As a result of a 20% reduction, it will be as follows: €412,424,547*0.8=€329,939,638

Based on the maximum energy price, the initial Net Cash Flows are €821,723,518. Taking a 20% reduction into account, the amount will be: €821,723,518*0.8=€657,378,814

The decrease in Net Cash Flows will have a negative impact on investment for scenario 1, as well as for other scenarios. The best way to deal with unexpected scenarios, such as a significant reduction in wind speed by 20%, would be to provide funding or subsidies to the project. The financial support provided by this program can ensure the viability of the project, allowing for adaptation to adverse conditions and ensuring its continuation. In order to enhance economic attractiveness and reduce investor risk, direct financing or tax incentives and subsidies can play a key role. As a result, renewable energy projects are able to achieve ecological and energy goals while still being financially viable.

5.3 Results from the assessment of VI of OWFs

5.3.1 Results from Methodology 1

5.3.1.1 Case study area

The study area was identified in terms of previous research [86] [239]. It was held on the island of Crete, concerning a sustainable siting of OWFs and the emerging marine area is presented in the white polygon area (Figure A.3).

In the first step, the villages that were mostly affected by the view of the WF were identified, so they were defined as the observer points. The names of the villages are presented below, as well as their population according to the population census (2011).

1. Kaliviani (136)

2. Kissamos (4236)

3. Nopigeia (63)

4. Ravdoucha (107)

Subsequently, it was observed that Kissamos town was too large, and it also extended to a wide coastline area, to be consisted of only one viewpoint. So, in terms of the more accurate quantification of VI, it was decided that it had to be divided into 3 points (Kissamos 1, Kissamos 2, Kissamos 3, relevant to 2, 3, 4, respectively (Figure A.3)).

Finally, it has to be noted that the first evaluation, according to Greek legislation (subsection 0) was implemented for all of the six observer points which are presented as follows (Figure A.3):

1. Kaliviani

2. Kissamos 1

3. Kissamos 2

4. Kissamos 3

5. Nopigeia

6. Ravdoucha

However, since the samples of the questionnaires were supposed to be too small, unreliable results might arise, thus, the three smaller (in population) villages (Kaliviani, Nopigeia, and Ravdoucha) were exempted from the further evaluation processes. So, the following scenarios were only considered for the three points of Kissamos.

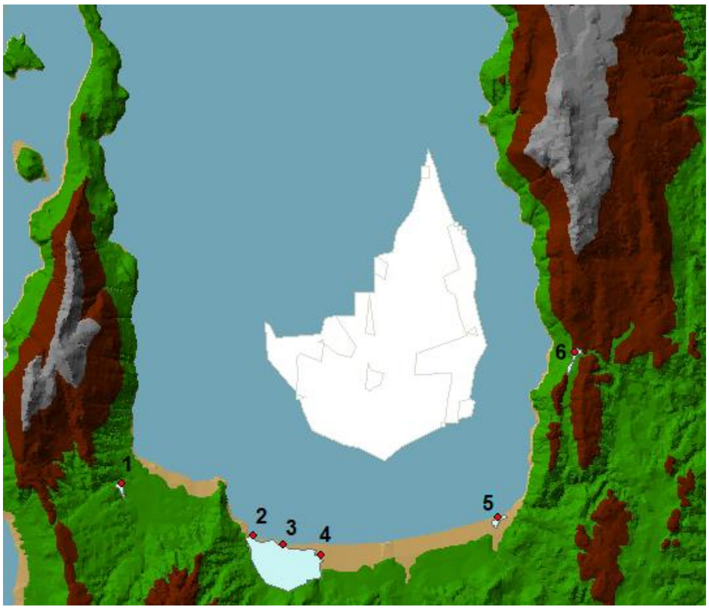


Figure A.3: Area of interest and observer points

After that, the arrays of OWT were designed with the aid of AutoCAD. In this Thesis, two models of OWT were selected, 1. Vestas V117-4.2 MW (MHI), 117 m and 2. Vestas V164-9.5 MW (MHI), 164m [230]. As it is shown in Figure 5.27, according to this study, in the first case were used smaller and more WT, whereas in the second case were used larger and fewer WT in the same polygon area.

It is also worth mentioning that concerning the distances between the turbines, the practice of 7x5 RD adopted downwind and crosswind, respectively [240]. The whole array is also oriented to the predominant wind direction (N-NE). After importing these arrays to ArcMap, the WFs results are shown in Figure 5.27. The WF of Figure 5.27a is the model of 117 m RD, and it will be the first scenario (1). The wind array in Figure 5.27b is a 164 m rotor in diameter, and it will be the second scenario (2).

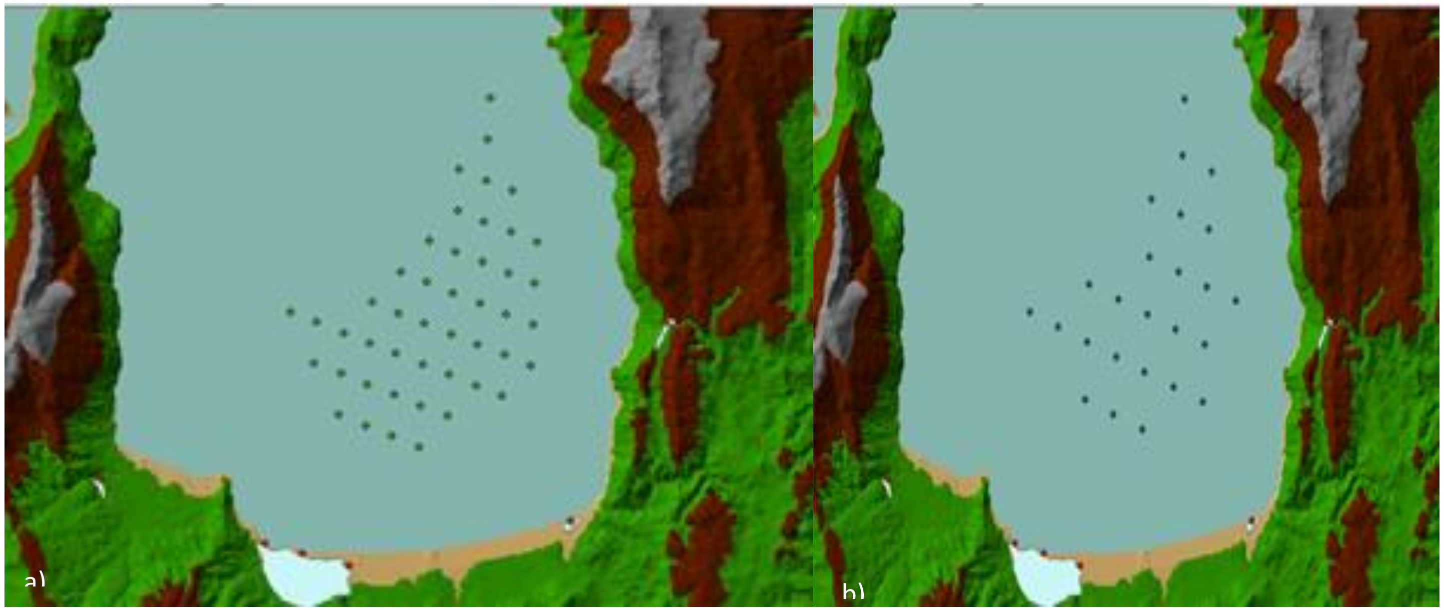


Figure 5.27: a) Scenario 1. WTs with 117m RD. b) Scenario 2. WTs with 164m RD

5.3.1.2 Results of VI according to the Greek legislation

The scenarios above were tested with the Greek ministry guidelines, and the results are demonstrated in Table A.2. The bold numbers in these tables indicate that the value of the coefficient has exceeded the limit.

Table A.2: Application of the Greek law for scenarios 1 and 2

Model	**WTs Number**	V.P	Distance Range (km)	H_{vis} Range (cm)	ΣH_{vis} (cm)	A_{vis} Range (cm^2)	ΣA_{vis} (cm^2)
V117	46	1	5.04 – 11.39	0.66 – 1.49	46.00	0.34 – 1.73	**37.75**
		2	3.10 – 10.47	0.72 – 2.42	**61.66**	0.40 – 4.56	**70.83**
		3	2.99 – 10.36	0.72 – 2.51	**64.38**	0.41 – 4.90	**77.81**
		4	2.89 – 1.32	0.73 – 2.59	**65.69**	0.41 – 5.24	**81.08**
		5	2.98 – 9.09	0.83 – 2.51	**67.77**	0.53 – 4.93	**83.35**
		6	2.65 – 7.61	0.99 – 2.83	**75.40**	0.76 – 6.23	**104.05**
164	25	1	5.21 – 11.30	0.83 – 1.80	30.43	0.60 – 2.83	**34.12**
		2	3.35 – 10.41	0.90 – 2.64	39.66	0.71 – 6.10	**59.83**
		3	3.42 – 10.30	0.91 – 2.74	41.29	0.72 – 6.57	**65.26**
		4	3.33 – 10.27	0.91 – 2.91	42.12	0.73 – 6.92	**68.16**
		5	2.84 – 9.10	1.03 – 3.29	45.00	0.93 – 9.51	**77.29**
		6	2.36 – 7.74	1.21 – 3.97	51.21	1.28 – 13.80	**100.10**

By observing the above tables, we conclude that every scenario contains observer points in which the impact is higher than the upper limit proposed by the Greek Ministry. Firstly, the WTs that seemed to generate the highest VI of all the selected observer points were removed. Then, two new WF arrays were created where the two coefficients, OH and OA (Eq.3 and Eq.4, respectively) were below the limit, for each observer point. This is also examined according to the maximum power capacity of the WTs. Thus, in this way, the other two scenarios (3) and (4) were created, and they are represented accordingly in the following Figure 5.28a, Figure 5.28b

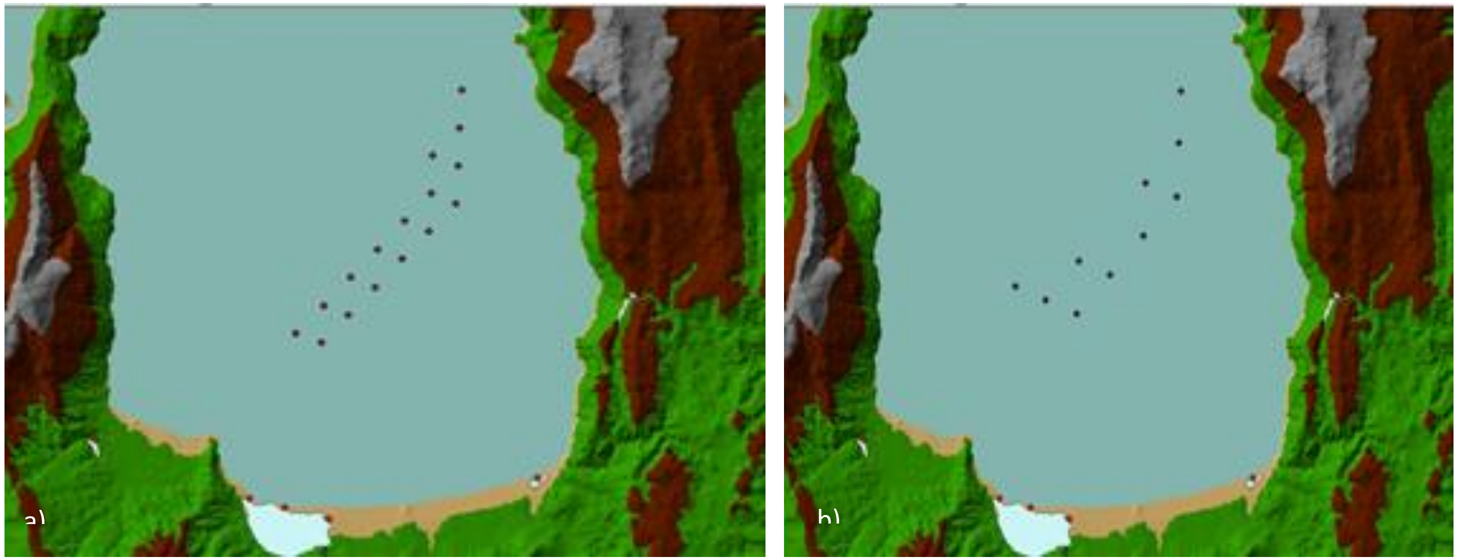


Figure 5.28: a) Scenario 3. WTs with 117m RD, complying with the Greek Ministry sitting process, b) Scenario 4. WTs with 164m RD, complying with the Greek Ministry sitting process

5.3.1.3 Application of improvements on the coefficients of SPM – Testing results of different scenarios and questionnaires

Subsequently, after the creation of the 4 scenarios, the process will continue with the application of the original SPM, following the 8 sequences of calculations, indicated by the relevant code numbers below:

0: Original SPM

1: Replacement of factor v with the suggested one from SPMII [65] (subsection 0)

2: Replacement of factor v with the new one which does not use cuboids (subsection 0)

3: Replacement of coefficient d with the suggested one from SPMII [65] (subsection 2.1.1.1.1)

4: Combination of 1 and 3

5: Combination of 2 and 3

6: Replacement of coefficient d with the modified suggested one (subsection 0)

7: Combination of 1 and 6

8: Combination of 2 and 6

Subsequently, after the application of these scenarios, the results from the questionnaires from the 6 observer points were gathered and processed. As mentioned already, due to the small population of the villages of Kaliviani, Ravdoucha, and Nopigeia, it was not possible to gather enough source material for a trustworthy analysis. So, the questionnaire results were analysed only from the 42 collected questionnaires from the three observer points in Kissamos town (2,3,4). The results from the original SPM, the different scenarios, and the questionnaires are displayed in Table A.3. In the first column, the first number indicates the observer point in Kissamos town, and the second number is the current scenario.

Table A.3: Comparison of the results from the methods and the results from the Questionnaires

	$(PA)_0$	$(PA)_1$	$(PA)_2$	$(PA)_3$	$(PA)_4$	$(PA)_5$	$(PA)_6$	$(PA)_7$	$(PA)_8$	$(PA)_{Questionnaires}$
2.1	0.094	0.262	0.296	0.220	0.611	0.690	0.171	0.476	0.537	0.571
2.2	0.072	0.215	0.239	0.210	0.631	0.702	0.182	0.546	0.609	0.631
2.3	0.053	0.050	0.067	0.200	0.192	0.255	0.139	0.134	0.178	0.542
2.4	0.021	0.036	0.051	0.180	0.302	0.430	0.144	0.242	0.344	0.536
3.1	0.099	0.276	0.325	0.200	0.611	0.718	0.174	0.482	0.567	0.679
3.2	0.075	0.226	0.261	0.210	0.631	0.730	0.183	0.550	0.636	0.619

3.3	0.055	0.055	0.093	0.200	0.192	0.336	0.141	0.135	0.236	0.595
3.4	0.058	0.117	0.062	0.450	0.900	0.478	0.361	0.722	0.383	0.560
4.1	0.104	0.288	0.348	0.200	0.611	0.738	0.176	0.488	0.589	0.696
4.2	0.081	0.242	0.297	0.210	0.631	0.774	0.185	0.555	0.681	0.661
4.3	0.118	0.235	0.102	0.500	1.000	0.432	0.342	0.684	0.295	0.583
4.4	0.046	0.091	0.055	0.450	0.900	0.542	0.357	0.714	0.430	0.548

It is evident that there is a considerable difference between the results from the original SPM and the results from the 8 sequences. First of all, although the original SPM indicates that there is a “Minimum” to “Light” VI (Table 4.15), all the other methods show that the VI is much worse, even up to “Very Serious” values. However, the results from the questionnaires also indicate that there is a “Serious” impact in every observation point in Kissamos. Equally notable is the fact that both scenarios 3 and 4, which fully complied with the Greek Ministry suggestions, turned out to have a severe VI, even though they were supposed to have “Minimum” or at least “Little” impact. This fact shows that the proposed methodology from the Greek Ministry is inefficient and, in some way, problematic.

5.3.1.4 Deviations compared to the results of the questionnaires

Consequently, to evaluate which method is closer to reality, Table A.4 was used to figure out which method had the smallest deviation from the Questionnaires. By observing the deviations of each method from the questionnaires, it is clear that of all the methods used, the original SPM is the one that gives the results that are farther from reality. With an average deviation of 88.0%, it is easy to realise that its use for calculating the size of the VI should be prohibitive, at least for the VI from OWFs. After, examining the sequences which followed, it is clear that the deviations are much smaller, especially for the cases where changing the factor v was combined with changing the coefficient c. The 3 sequences which had the lower deviations were:

- Sequence 5, where factor v was replaced with the new one, which does not use cuboids, and coefficient d was replaced with the suggested one from SPMII [65]. This method gave the lowest deviation of all, at a percentage of 19.7%.
- Sequence 8, where factor v was replaced with the new one, which does not use cuboids, and coefficient d was replaced with the suggested one (Table 4.17). This method gave the second lowest deviation, at a percentage of 26.1%.
- Sequence 7, where factor v was replaced with the suggested one from SPMII [65] and coefficient d was replaced with the suggested one (Table 4.17). This method gave a deviation of a percentage of 31.6%.

Notably, the change of factor v with the version which does not use cuboids was a part of the 2 more efficient methods, indicating the superiority of this new factor compared to the previous ones. As for coefficient d, it is not clear enough which one is the more suitable, but at a first glance, it seems that coefficient d from the SPMII [65] is the most appropriate one.

After a closer observation of Table 10, it was also found that for scenarios 1 and 2, the average1 deviation was much lower than the average2 deviation in scenarios 3 and 4.

Table A.4: Deviation % from the sequences of results in relation with ones from the Questionnaires, separately for Scenarios 1, 2, and Scenarios 3, 4

	$(PA)_0$	$(PA)_1$	$(PA)_2$	$(PA)_3$	$(PA)_4$	$(PA)_5$	$(PA)_6$	$(PA)_7$	$(PA)_8$
2.1	83.6	54.2	48.2	61.5	6.9	20.8	70.1	16.7	6.0
2.2	88.6	65.9	62.1	66.7	0.0	11.3	71.2	13.5	3.5
3.1	85.4	59.3	52.1	70.5	10.0	5.8	74.4	29.0	16.4
3.2	87.9	63.5	57.8	66.1	1.9	17.9	70.4	11.2	2.7
4.1	85.1	58.6	50.0	71.3	12.3	6.0	74.7	29.9	15.4
4.2	87.7	63.4	55.0	68.2	4.5	17.1	72.0	16.0	3.1
average1	86.4	60.8	54.2	67.4	5.9	13.1	72.1	19.4	7.9
2.3	90.3	90.8	87.6	63.1	64.6	52.9	74.3	75.3	67.1
2.4	96.1	93.3	90.5	66.4	43.6	19.7	73.1	54.8	35.8
3.3	90.7	90.8	84.4	66.4	67.7	43.6	76.3	77.3	60.4
3.4	89.6	79.1	88.9	19.6	60.9	14.6	35.5	29.0	31.5
4.3	79.8	59.7	82.5	14.3	71.4	25.9	41.4	17.3	49.4
4.4	91.6	83.4	90.0	17.9	64.2	1.1	34.9	30.3	21.5
average2	89.7	82.8	87.3	41.3	62.1	26.3	55.9	47.3	44.3
Total average	88.0	70.7	70.8	54.3	36.0	19.7	64.0	31.6	26.1

After a closer observation of Table A.4, it was also found that for scenarios 1 and 2, the average1 deviation was much lower than the average2 deviation in scenarios 3 and 4.

In the cases where the WFs were too large to comply with the Greek law (Scenarios 1 and 2), the tested sequences seemed to present a great value on the generated VI, showing average deviations at just 5.9% for sequence 4, 7.1% for sequence 8 and 13.1% for sequence 5, respectively. On the other hand, it has been shown that for scenarios 3 and 4, where they were much smaller in size, the deviations are much higher, with the lowest value being 26.3 % and the rest being higher than 41.3%, making it clear that the methods are not enough sufficient for the assessment of these smaller in size WFs.

This huge difference between the assessment of the larger WFs and the smaller WFs led to the conclusion that the method requires improvement and that it also has to be modified concerning the function n, which is responsible for assessing the impact judging from the size of the WF. What is unclear is the new form that function n should take, since WTs are not placed linearly, but the array could take various schemes/arrays. Another issue that could be further investigated is that instead of using the number of WTs to calculate factor n, the area of the WF could also be measured or the density of the WTs inside the WF polygon area.

5.3.1.5 The results of the questionnaires in relation with coefficients ψ and ψf

Finally, this research focused on how the opinion of a person about RET could affect the way they would be influenced by their sight. By categorising the sample according to their opinion and then calculating the average PA for each category, the diagram from Figure A.6 was created.

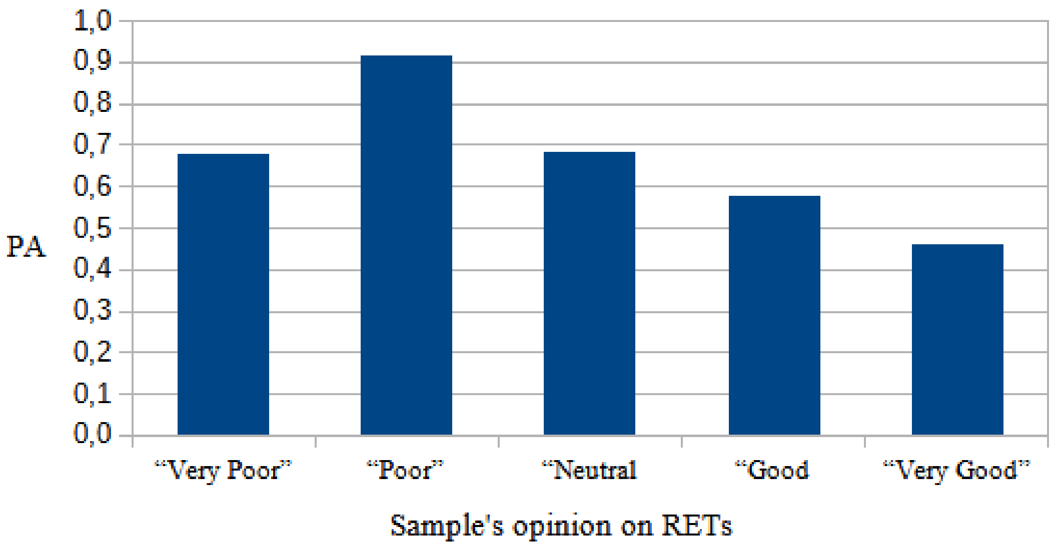


Figure A.6: PA value depends on the opinion of the sample on RET

It is visible from this diagram that one's opinion has a great impact on how one is affected by the sight of a WF. It is also notable that generally, the more positive their opinion is, the less they are affected by their sight. For the rest of the process, only average of “Neutral”, “Good” and “Very Good” categories were used. The other two categories were not used due to their composition of only one or two individuals; hence they were considered to be unreliable. From the three mentioned average categories, a f(ψ) = PA diagram was created using a linear trendline, as shown in Figure A.7 (subsection 0). In this diagram, it is also possible to observe the coefficient of determination R2 of the trendline.

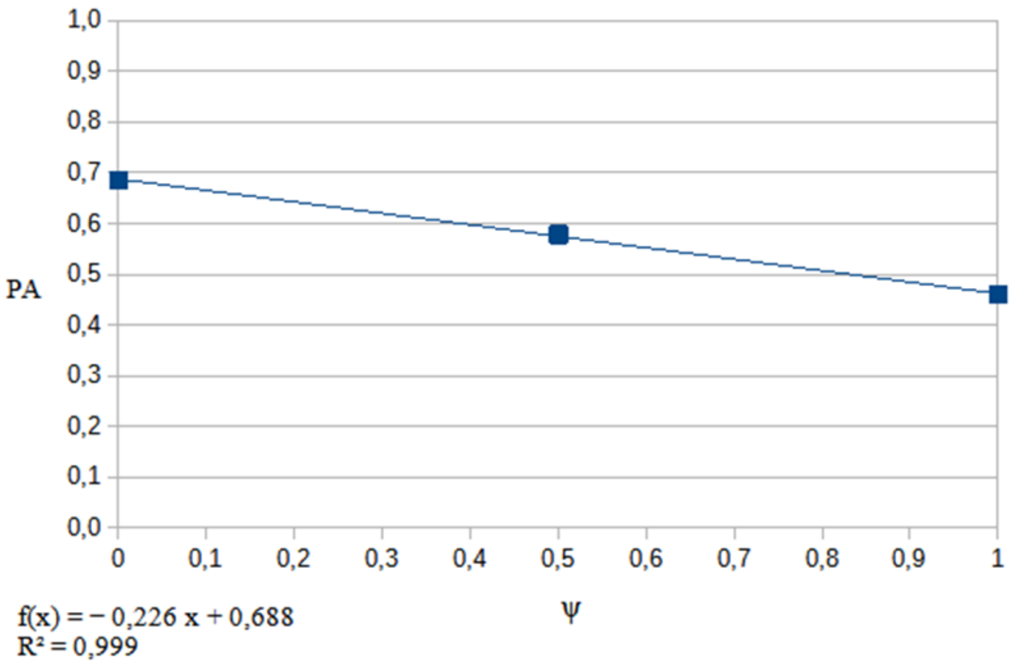


Figure A.7: f(ψ) = PA Diagram

The determination coefficient has a value of 0.999, almost equal to 1. Thus, it is considered "safe" to conclude that there is a remarkable correlation between factor ψ and coefficient PA. Following the methodology, it was found that ψ was equal to 0.321, f(1)/f(0) was equal to 0.662 for the examined sample of the response. Subsequently, applying Eq.17, it was found that ψf was equal to 0.891. Finally, by implementing Eq.15, Table A.5 was created, which shows the PA values according to the inhabitants' opinions.

Additionally, Table A.6 was also created to highlight the deviation of these scenarios in relation to the results of the questionnaires. Hence, the differences in the values of PA with and without the use of the coefficient ψf are presented in Table A.6.

Table A.5: Comparison of the results from the methods after the addition of coefficient ψf

	$(PA)_{0+\psi f}$	$(PA)_{1+\psi f}$	$(PA)_{2+\psi f}$	$(PA)_{3+\psi f}$	$(PA)_{4+\psi f}$	$(PA)_{5+\psi f}$	$(PA)_{6+\psi f}$	$(PA)_{7+\psi f}$	$(PA)_{8+\psi f}$
2.1	0.084	0.234	0.264	0.196	0.545	0.615	0.152	0.424	0.479
2.2	0.064	0.192	0.213	0.187	0.562	0.626	0.162	0.487	0.543
2.3	0.047	0.045	0.060	0.178	0.171	0.227	0.124	0.119	0.159
2.4	0.019	0.096	0.045	0.160	0.802	0.383	0.128	0.641	0.307
3.1	0.088	0.246	0.290	0.178	0.545	0.640	0.155	0.430	0.505
3.2	0.067	0.201	0.233	0.187	0.562	0.651	0.163	0.490	0.567
3.3	0.049	0.049	0.083	0.178	0.171	0.299	0.126	0.120	0.210

3.4	0.052	0.104	0.055	0.401	0.802	0.426	0.322	0.644	0.341
4.1	0.093	0.257	0.310	0.178	0.545	0.658	0.157	0.435	0.525
4.2	0.072	0.216	0.265	0.187	0.562	0.690	0.165	0.495	0.607
4.3	0.105	0.209	0.091	0.446	0.891	0.385	0.305	0.610	0.263
4.4	0.041	0.081	0.049	0.401	0.802	0.483	0.318	0.636	0.383

Table A.6: Deviation % from the sequences of results in relation with ones from the Questionnaires with the addition of coefficient ψf

	$(PA)_{0+\psi f}$	$(PA)_{1+\psi f}$	$(PA)_{2+\psi f}$	$(PA)_{3+\psi f}$	$(PA)_{4+\psi f}$	$(PA)_{5+\psi f}$	$(PA)_{6+\psi f}$	$(PA)_{7+\psi f}$	$(PA)_{8+\psi f}$
2.1	85.3	59.1	53.8	65.7	4.7	7.6	73.3	25.7	16.2
2.2	89.8	69.6	66.2	70.3	10.9	0.8	74.3	22.9	14.0
2.3	91.4	91.8	89.0	67.1	68.4	58.0	77.1	77.9	70.7
2.4	96.5	82.1	91.5	70.1	49.7	28.5	76.0	19.7	42.8
3.1	87.0	63.7	57.3	73.7	19.7	5.7	77.1	36.7	25.5
3.2	89.2	67.5	62.4	69.8	9.1	5.1	73.6	20.8	8.4
3.3	91.7	91.8	86.1	70.1	71.2	49.7	78.9	79.8	64.7
3.4	90.8	81.4	90.1	28.3	43.4	23.9	42.5	15.0	39.0
4.1	86.7	63.1	55.5	74.4	21.8	5.5	77.5	37.5	24.6
4.2	89.1	67.4	59.9	71.7	14.9	4.4	75.0	25.1	8.1
4.3	82.0	64.1	84.4	23.6	52.8	34.0	47.7	4.5	54.9
4.4	92.5	85.2	91.1	26.8	46.4	11.8	41.9	16.1	30.1
$average_{\psi f}$	89.3	73.9	73.9	59.3	34.4	19.6	67.9	31.8	33.2
$average_{\psi f}$ - average	1.3	3.2	3.2	5.0	-1.6	-0.1	3.9	0.2	7.2

Concerning the calculations of average ψf – average (Table A.6), it is evident that the addition of the coefficient ψf was beneficial for some case scenarios but also inefficient for some other scenarios. This finding was predictable, as it was proven that most of the existing methods tend to undervalue the real dimension of the VI.

In any case, the addition of factor ψ and the coefficient ψf in the assessment obtained by the SPM, is highly advisable, as it was proven that the "quantity" of the VI that a person feels is highly related to its opinion on the RET.

5.3.1.6 Discussion section

From the date which the SPM was suggested (2004), until today (2022), there have been many changes. For example, the size of the WTs has dramatically evolved, along with the size and shape of the siting arrays, especially those of OWFs. This fact has led us to the conclusion that SPM requires updates and modifications to keep up with today's data. According to our research, it was found that the original SPM had an 88.0% deviation compared to the results of the questionnaires. This was achieved by following a similar approach as Kokologos et al, [148] along with the combination of the initial SPM and the 3D simulation, suggested by Tsoutsos et al. [11], and by using questionnaires as a means of verification [147]. Finally, the results verified that the original SPM is outdated and not applicable on OWFs.

Our findings also follow the study of Manchado et al. [9], where they suggest that the original SPM needs improvements; they suggested that the evolution in size of WTs was indisputable, so the original SPM was obsolete. They also proposed a more synchronous SPM by modifying the five coefficients of the original one (SPMII). However, this methodology was not tested to prove its validity in some way. In our research, we initially tested some of their suggested improvements, along with the addition of some other original ones. The results of their and our suggestions compared with the viewpoints of the local inhabitants showed that there was an increased accuracy concerning the original SPM, with potential for additional improvements.

More specifically, sequence 5, which was the combination of our improvement in parameter v and the improvement in coefficient suggested by SPMII [65], showed that the minimum average deviation compared with the results of the questionnaires at a percentage of just 19.7% (Table A.3). On the other hand, the original SPM (sequence 0) proved to be the method with the greatest deviation from those of the questionnaires. In addition to this, it was found that the three most suitable sequences (sequences 5,8 and 7) had a much smaller deviation concerning the scenarios with the larger size of WFs (1 and 2) compared to the scenarios with the smaller ones (3 and 4), on an average (Table A.4).

The aforementioned finding led us to the conclusion that one of the main coefficients of the method that still needs improvements is parameter n, which measures the impact according to the size of the WF. Future studies could study this parameter and possibly could also change its form. This could be realised by measuring the area of the WF or the density of the WTs across the polygon area of the WF or something similar, instead of counting the number of WTs. It could also be a combination of the aforementioned practices.

Furthermore, the question of how someone's perception of RET can affect the way he perceives the VI from a WF was another aspect that was examined in our study. As shown in

Figure A.6, there is a relation between the VI and the opinion of a person about RET. For the categories “Very Poor” and “Poor” the sample was too small (just 2 individuals in the first category and 1 in the second one), so these opinions were not counted, as they could give reliable conclusions. But for the rest of the samples, it seemed that there was a very close relation and from the relevant Figure A.7 it was found that there was a very strong linear connection between the factor ψ which measures the people’s perception of RET and PA, which measures the VI that could be felt by the people. This led to the conclusion that a sixth coefficient ψf has to be added to the equation of PA to assess the impact based on people’s perception of RET. However, this finding indicates that a VI assessment would require the opinions of the local people according to their beliefs based on RET (use of questionnaires). In addition, further research has to be made on different locations to assure how a different civilisation could influence the results and the relevant Figure A.7. The remaining of results of the methods are presented in Annex E.

Apart from SPM, the Greek Ministry guidelines have also proven to be insufficient, as it was demonstrated that the WFs, which were acceptable by the limits of the method, ended up being unacceptable by the citizens, in terms of real VI.

To the best of our knowledge, compared to the relevant existing studies, our study appears to combine many advantages, such as the assessment of the VI of OWFs, the combination of 3 software tools (AutoCAD, GIS, and Google Earth Pro), the proposed modifications on the SPM, the addition of the suggested methodology by the Greek Ministry, the comparison of the results of the different scenarios, the examination of four different OWF arrays’ scenarios and the incorporation of local people’s viewpoints.

5.3.2 Results from Methodology 2

5.3.2.1 Case Study area

Agios Nikolaos was chosen as the case study area based on previous research that was conducted on the island of Crete concerning the sustainable siting of OWFs [6]. It can be easily observed from the global wind atlas data (Figure A.9a, Annex F) that the mean wind speed in the area appears to be high at 100m height, which is 9.67 m/s, as evidenced by the data from the global wind atlas. In order to identify which villages, the largest annoyances would occur in the future, the viewshed tool from Google Earth Pro was run on various villages. This was done in order to identify which sites would cause the most problems. In this study, the number of observer points selected was eight (8) (Table A.8, Figure A.8):


Katw Selles
Vlichadia
Αγ. Νικόλαος
Paralia Milatou
Selles
Vrouhas
Milatos
Μίλατος
Sissi
Σίσι
Plaka
Πλάκα
Σχίσμα Ελούντας
Νεάπολη
Λίμνες
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

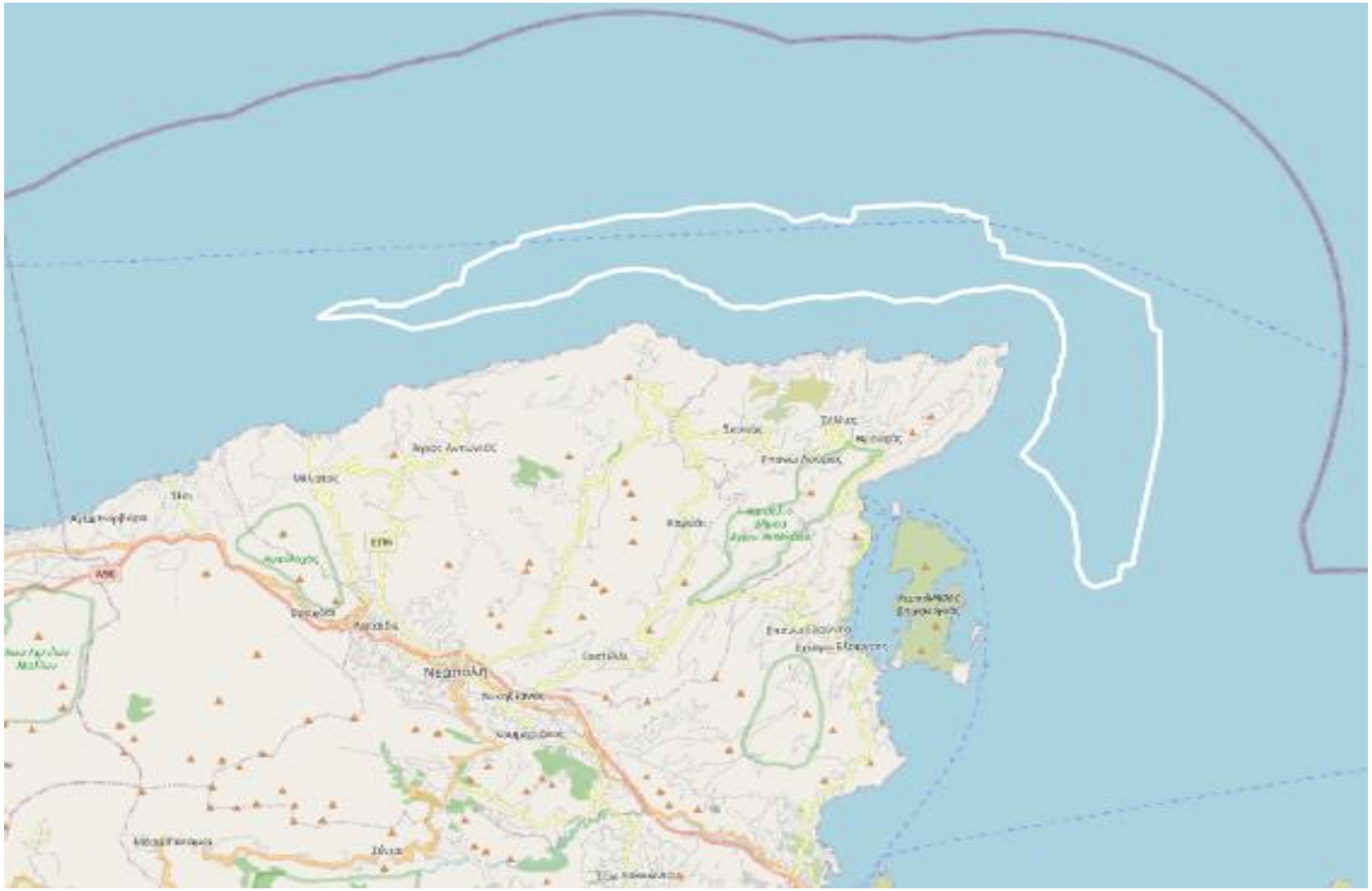
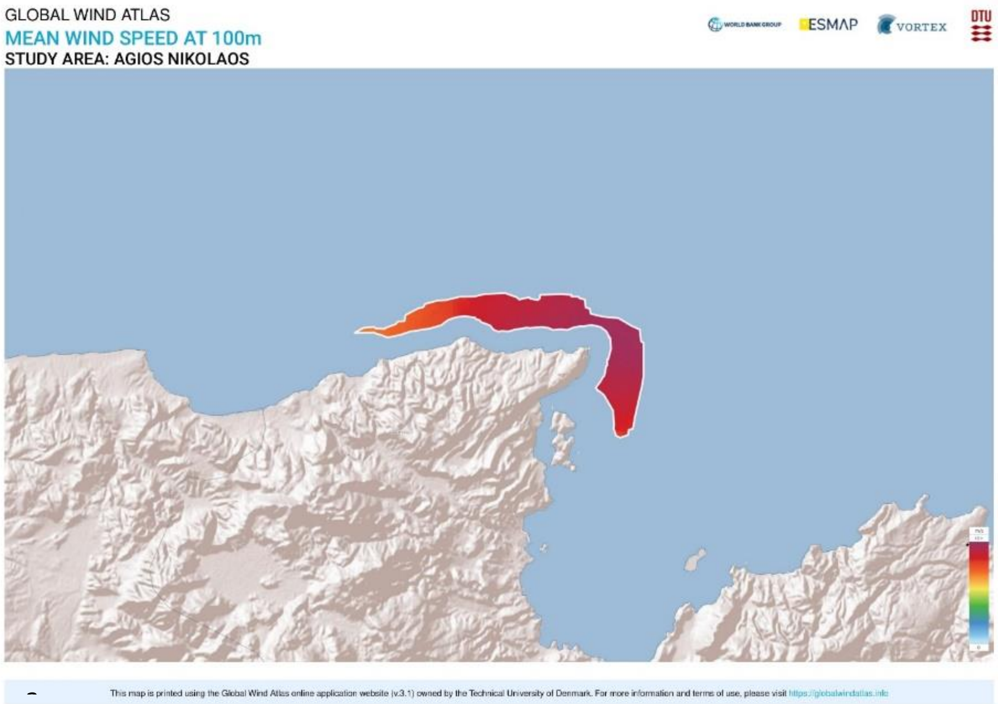


Figure A.8: Observer points in Google Earth

5.3.2.2 Micro-siting of WTs

There were two different micro-siting arrays of OWTs that were chosen for the purpose of this study. This application evaluates two models: (1) the Vestas V117-4.2 MW (MHI), 117 m, and (2) the Vestas V164-10 MW (MHI), 164 m [230]. In selecting these two rotors, it was due to the fact that their RD vary greatly. Thus, in the first case, in the same polygon, there would be a large number of smaller WTs. In the second case, the number of larger WTs would be much smaller. It was speculated that this fact could have a definite impact on the level of annoyance based on the VI of the concept. The practice of measuring the distances between the turbines was implemented based on 7x5 RD downwind and crosswind, respectively [240]. In conclusion, it was determined that the WTs should be placed westward in the area, that being the predominant direction of the wind (Figure A.9a,Figure A.9b). A number of offshore WT arrays were designed with the help of the software AutoCAD, which can be seen in Figure A.10a, Figure A.10b).



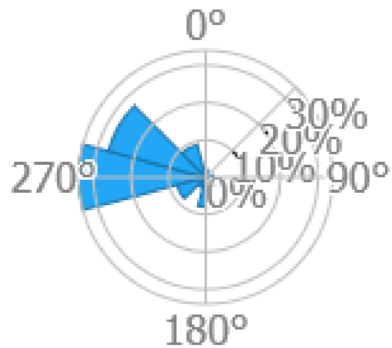


Figure A.9: a) Mean wind speed and b) predominant wind direction [79]

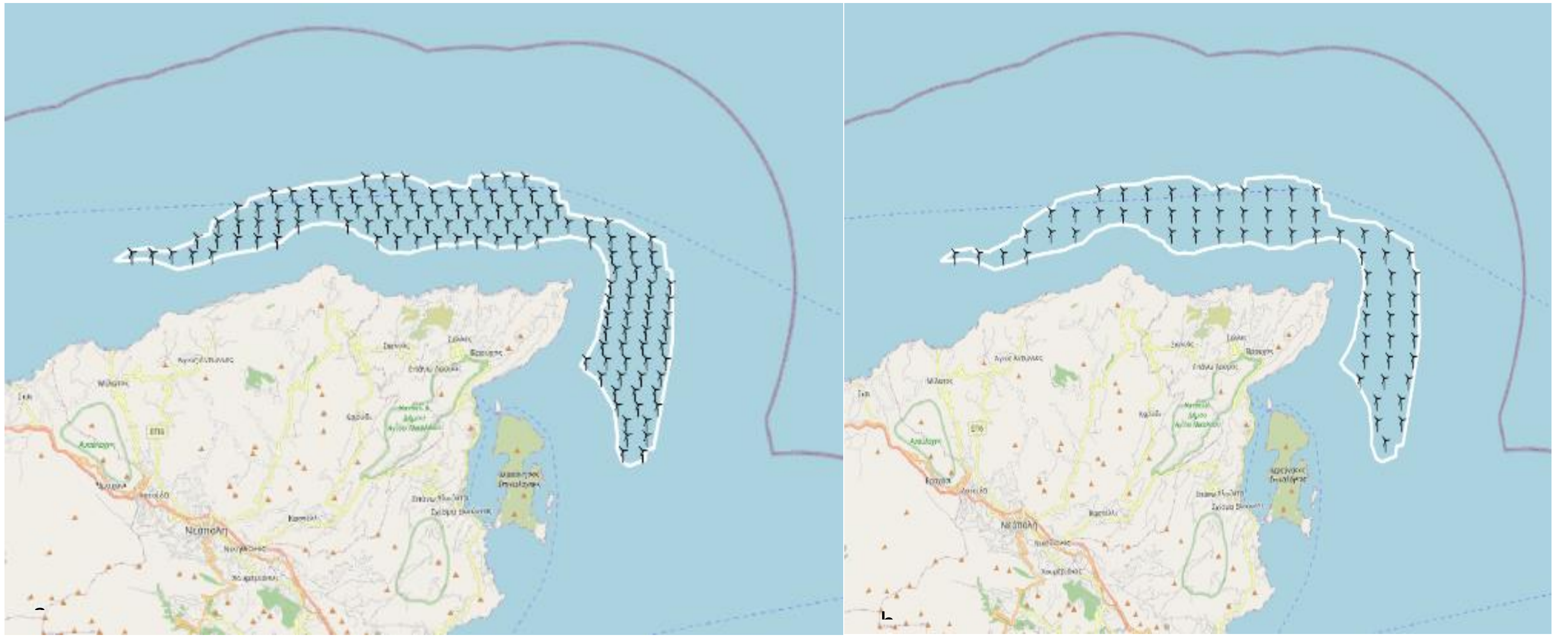


Figure A.10: Micro-siting array of WTs. a) 117 RD b) 164 RD

5.3.2.3 Results from the application of Greek legislation

The methodology suggested by the Greek Ministry was applied to our case study area, which is Agios Nikolaos on the island of Crete. This was done in order to evaluate the potential VI on the area that an OWF could have in the area, as we mentioned earlier. In the following Figure A.11, you can see the results which came out as a result of using the software QGIS to render the data.

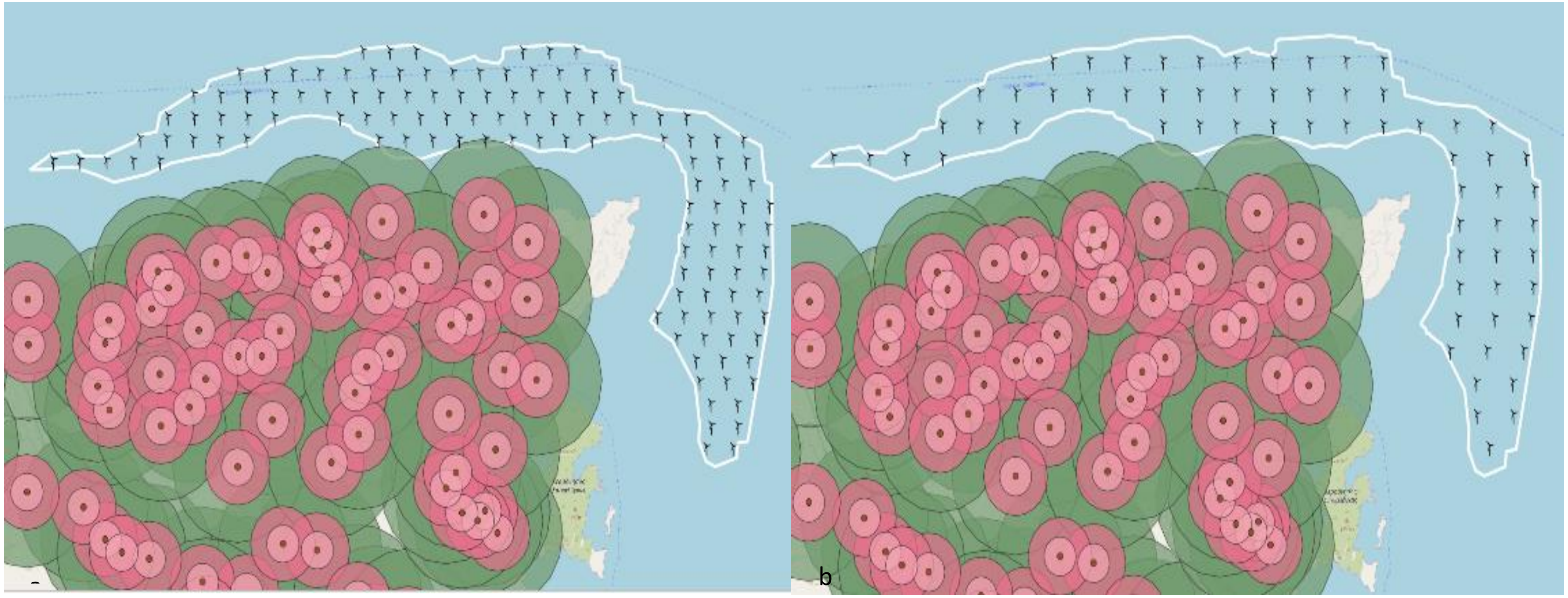


Figure A.11: Buffer zones of settlements under 2000 inhabitants, 500m, 1000m and 2000m, respectively. a) scenario of 117 RD WT b) scenario of 164 RD WT

According to Figure A.11, the first scenario (Figure A.11a) shows only one WT location inside the 2km buffer zone (Zone C'), whereas, in the second scenario (Figure A.11b), there should be no WTs anywhere within the 2km buffer zone of settlements (Zone C'), as we can observe from Figure A.11.

As a further reference, Table A.7 provides the related calculations that were made as a result of this study.

Table A.7: Results from observer points/settlements for the two different scenarios

Observer points/Points of settlements/villages in the area		**Scenario 1:117 RD WT**	**Scenario 2:164 RD wind RD turbine**
Number of WTs per zone	Zone A'	0	0
	Zone B'	0	0
	Zone C'	1*1.376[6]= 1.376	0
Area km^2	Zone A'	0.785	0.785
	Zone B'	2.355	2.355
	Zone C'	9.420	9.420
Density of WTs=Number of WTs/km^2	**Zone A'**	**0**	**0**
	Zone B'	**0**	**0**
	Zone C'	**0.146**	**0**

According to Table A.7, for the first scenario, the first criterion is examined, and the results from the three zones (0,0,0.146) are within the limits of Table 4.20 (0,4,7). In addition, the second criterion does not need to be considered since the first criterion has been satisfied. For the second scenario, the results are (0,0,0) for the three zones, thus, the limits are satisfied, and therefore, the second criterion need not be considered. It is important to note that in both scenarios, as long as the first limitation is met, there is no or minimal VI.

Furthermore, with more powerful WTs, we can observe that the impact on the visual environment is less pronounced. This is because their sparse placement, according to the methodology referred to above, is also less evident. In any case, it appears that there is no significant impact on the visual environment of the surrounding villages.

[6] According to Greek legislation, the proposed RD (117m for the 1st scenario, or 164m for the 2nd scenario) should be divided by the typical RD (85m, according to Greek legislation).

5.3.2.4 Results from questionnaires

During July-August 2021, a questionnaire survey was conducted in Crete (Agios Nikolaos region). According to each observer point (village) and its population, the following Table A.8 shows how questionnaires were allocated. For the sake of brevity, the questionnaires are included in the relevant Annex F. In addition, the village of Selles was excluded from further analysis due to the absence of respondents/residents.

Table A.8: Observation points/villages their population, and the number of collected questionnaires

Observer point/village	Population (2011)	Collected questionnaires
Vlichadia	7	3
Vrouhas	135	8
Katw Selles	1	1
Milatos	178	12
Paralia Milatou	157	10
Plaka	94	4
Selles	25	0
Sissi	1003	40
Sum		**78**

The results of the questionnaire collected in the village of Sissi are presented below in Figure A.12, to provide a picture of the results. In the first columns of the diagram, the response percentages are depicted according to the first image (scenario 1-117 RD WT), and in the second columns of the diagram, the response percentages are displayed according to the second image (scenario 2- RD 164 WT). The responses that we collected were extrapolated based on the real population.

According to the survey results, the respondents (32% and 42%, respectively) replied that they would not experience any optical disturbance from an OWF in their region if such a facility were built in their region, in both scenarios. As a result of the sparse siting of the devices in the second scenario, there is a noteworthy conclusion that will result in a minimised VI in that scenario. According to the findings from the survey, it appears that the methodology described above can be verified by the results.

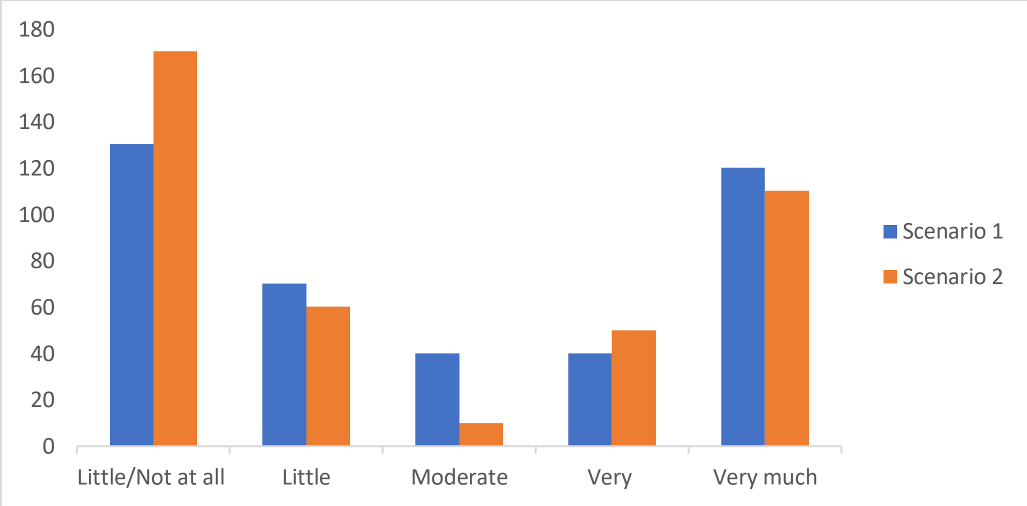


Figure A.12: Responses from the locals' questionnaires concerning their answers about the two pictures, a) 1st and b) 2nd scenario, respectively

The following Figure A.13 is an example of a questionnaire from the village of Sissi, concerning the first and second scenarios, respectively. The images were produced using Google Earth Pro and the software Virtual 3D Animated WT [241]. The remaining images are included in Annex F, along with a description of the other villages/observation points.


Σίσσυ
Google Earth

Figure A.13: Sample of questionnaires, village of Sisi

Table A.9: Answers from the locals' questionnaires concerning the answers about their general opinion on renewables

Percentage of respondents (%)	Answers about opinion on renewables
25	Very good
39	Good
25	Moderate
3	Bad
8	Very bad

Table A.9 illustrates the responses of the respondents based on their overall opinion of renewable energy. In the diagram, it can be seen that a large percentage of respondents (64%) are positive or very positive toward renewable energy. Meanwhile, only 11% (negative or very negative) of respondents are completely opposed to the use of RES.

A percentage of 10% of women had a very positive view of renewable energy and a percentage of 7% were completely opposed to it. Compared to the women, 36% of the men had a very positive view of renewable energy, and only 9% of the men were totally opposed to the concept.

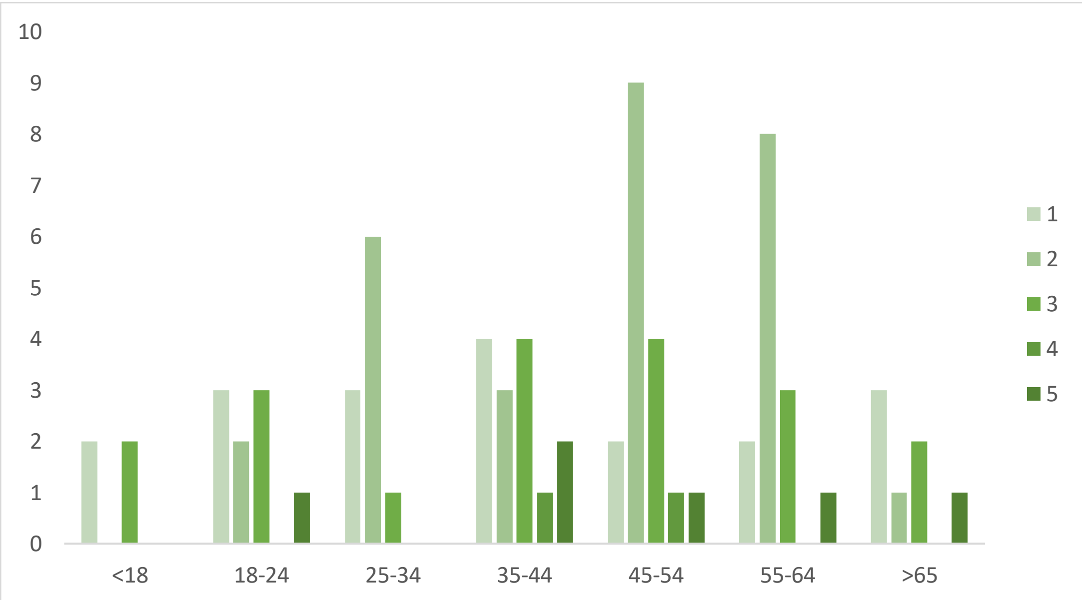


Figure A.14: Diagrams from the locals' questionnaires concerning the answers about their general opinion on renewables, according to their age group

It is important to note that the results apply to all observer points. According to the diagram in Figure A.14, a large percentage of people in the 35-44, 45-54, 55-64, and >65 age groups are against renewables. Meanwhile, in the age groups 18-24, 25-34, it appears that the youngest individuals are in favour of RET. Overall, most people did not have a negative impression of renewable energy, regardless of their age.

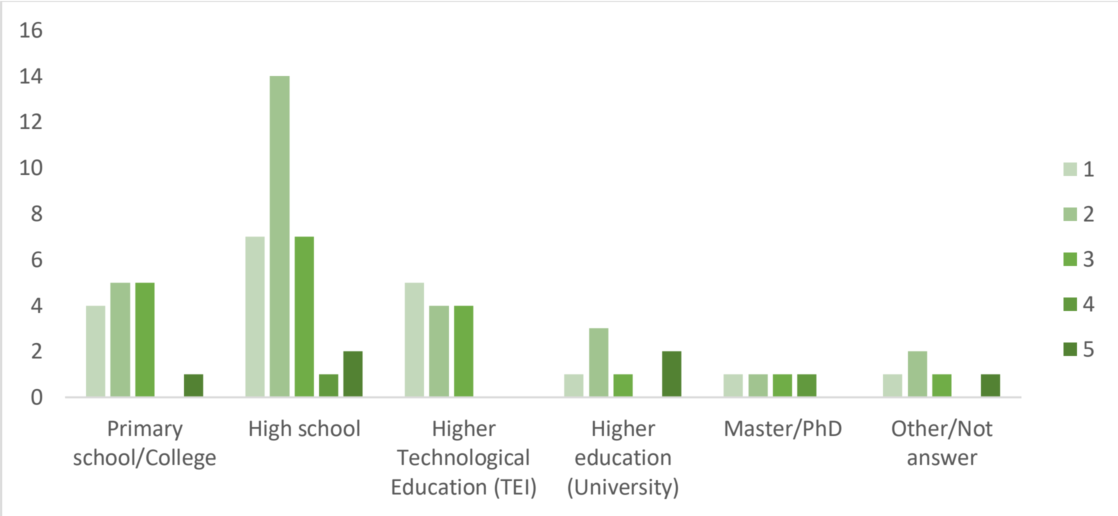


Figure A.15: Diagrams from the locals' questionnaires concerning the answers about their general opinion on renewables, according to their educational level

Results are relevant to all points of observation. There is generally a very good, good, or moderate opinion regarding RET at the educational levels of primary/college, high school, and higher technological education, according to Figure A.15. It was found that most people, regardless of whether or not they had higher or lower levels of education, expressed support for renewable sources of energy.

6. Conclusions

In the conclusion section, the first part of the section is devoted to the conclusion derived from the literature review of the siting process for OWFs. Following that, the conclusions regarding the siting of OWFs, both bottom-fixed and floating, as well as the technoeconomic assessment of WFs are presented. Last but not least, the VI of OWFs is discussed in terms of its conclusions.

This Thesis involves a systematic literature review that critically and comprehensively analyses publications to identify constraints and relevant criteria for determining the optimal location for offshore wind development. The review also offers insights into the methods and criteria employed in the examined articles. The subsequent paragraphs summarize the main findings derived from the obtained results.

The reviewed articles are distributed across 34 different scientific journals, with the majority of articles appearing in the journals Renewable Energy, Renewable and Sustainable Energy Reviews, and Energies. A significant variation in the distribution of different journals indicates that the Offshore Wind market is becoming increasingly challenging, as well as demonstrating that there is a multidisciplinary interest in this emerging technology and that many scientists are concentrating on it.

According to the study area, the studies were conducted in 24 different study areas, with the highest percentage being undertaken in Turkey, China, and Greece. When the conditions are favourable in terms of economic status, studies, legislation, and mature technology, countries with sea areas that have not developed Offshore Wind installations undertake research in order to be prepared for development.

Among the 80 studies, 30 examine the siting of bottom-fixed OWFs, 12 examine the new emerging technology of floating OWFs, and 27 examine both types (bottom-fixed and floating).

It was found that 40 of the 80 papers reviewed (50%) applied MCDM methods in order to assess which sites would be most appropriate for the deployment of OWFs. The global literature confirms that these kinds of methods are particularly suitable for approximating multi-parameter problems, such as the optimal location of OWFs. It is also worth noting that there are 20 out of 80 papers (25%) that use the AHP method as the basis for identifying optimal OWF locations, which means that this is a method that has been thoroughly tested and verified, and it can be applied in this sector widely.

According to the conclusions of the first methodology of the sustainable siting of OWFs the following are emerged. The optimal location for the development of an OWF requires the participation of all stakeholders at all phases of the project development, and particularly during the planning stages. There is no doubt that this is a determining factor that could accelerate the deployment of these large-scale projects and their acceptance by the local community.

Using innovative methodologies concerning the sustainable siting of OWFs, this Thesis contributes to the global literature. As a result of this research, two different methodologies have been proposed about the optimal sites for the development of OWFs, as well as two different techniques for evaluating the VI of an OWF on these sites.

The advantages that arise from our survey are the following, when compared with the project of an onshore WF:

- These emerged marine areas could integrate a large number of WTs and more giant WTs in relation with the onshore sites, so larger quantities of energy could be added to the local electric grid. Thus, they cover the local needs and also be transmitted to the rest of the Greek grid, through the electrical interconnection which is under construction.
- The land unavailability issue, along with a little or no VI from OWFs, could give a good response to the NIMBY phenomenon, which is also quite intense on the insular environments.
- Land heterogeneity makes the siting of solar and wind installations sometimes extremely difficult, so offshore ones avoid this problem.
- Fluctuations of energy needs, especially if they are touristic resorts, during the peak season, could be covered.
- The noise produced and VI due to an OWF could be better eliminated or/and accepted than those of the onshore from the local people, due to the great distances from residential areas.
- This is a valuable yet unexploited asset for regional and national policymakers.

In this study, a hybrid AHP/GIS method was formulated and applied in order to alleviate the complexity of renewables installations siting problems, in terms of islands' energy independence. The advantages of our approach were the relatively high number of EVC used in relation with other similar studies, the relative weights that derived from a satisfying number of locals and experts' personal interviews (questionnaires), and the high resolution of our digital data that used a raster scale 100mx100m. Furthermore, our study ensures a strict environmental framework and it also examines 7 different scenarios, according to the marine areas with high suitability that they emerged. This methodology since it can integrate the experts' opinions, could be an essential decision support system for the stakeholders.

It integrated the opinions of different groups of stakeholders, after conducting analytic discussions with them about the criteria ranking and the suitability of each emerged location. It is believed that in this manner, the crucial realistic problem of social acceptance could be alleviated, or even surpassed. Furthermore, the issue of land-use conflicts that afflicts the local communities, e.g. for the site selection of an onshore WF, could also be avoided with sustainable planning of an OWF.

This work also offers solutions to the dynamic energy autonomy of islands and tries to integrate the critical problem of social acceptance. The final available marine areas for OWF siting are about 205.5 km2, around the island and it is a remarkably adequate area for this purpose. The results showed that from the 18224 km2 of study area, the 1,05%, of the emerged areas were suitable for the sting of OWFs, whereas the 0,65% was characterised as highly suitable. Since the maximum annual energy demand of the island amounted to 676 MW (2019) [242], this demand could actually be overcovered by four main potential OWF around the island (section 4.4). It has also to be noted that the largest (57.47 km^2) emerged area of Agios Nikolaos (a) (Table 9) already has an existing onshore wind park [229], at a very close distance from our emerged polygon. This fact from one point verifies the results of our method, concerning the suitability of the area (distances from NATURA 2000, settlements, wind speed potential etc). On the other side, there could be a potential joint between the existing onshore wind installation and the potential OWF, for example, possibly common installations, substations etc.

According to the results of the second methodology, the majority of the eligible locations are located in the Lassithi RU, while Chania RU does not present any eligible areas. This is mainly a result of the Ex referring to the average wind velocity, which excludes the Chania RU. Also, it removes large parts of the Rethymno and Heraklion RUs, because of the low average wind velocity those areas present (<6 m/s). On the other hand, a small number of locations were excluded in Lassithi due to this criterion. According to relevant research, the lowest chosen value of average wind velocity varies from 4 m/s [215] up to 6 m/s at a 10 m height [121]. In this case, 6 m/s was selected as the lowest value because, given the absence of relative weights, it was necessary to ensure that all the eligible areas would be energy and, as a result, techno-economically efficient. The minimum installation depth was set to the maximum installation depth of BFWTs, which is 50 m because the deployment of floating platforms in shallow waters would be economically inefficient since the bottom-fixed technology is available. Additionally, 1000 m was defined as the maximum depth according to the available technologies (semi-submersible, spar buoy, TLP, Barge).

Eight EVC were implemented in order to express various factors that affect a floating wind project. Subsequently, those criteria were categorised in order to equally express all the project factors due to the absence of relative weights. The introduction of additional criteria would improve the assessment, since the factors of the project would be examined from a broader range of parameters. Furthermore, during the evaluation relating to the distance from a port, all the ports implemented were considered equally suitable to host the basis of a floating wind project. This is not true, as major commercial ports require fewer improvements. As a result, they are much more suitable from a techno-economic standpoint. However, the aim of this Thesis was the definition of the most suitable locations and not a techno-economic analysis of the ports of Crete.

All the "most suitable" locations are located in the Lassithi RU. In similar research where the whole of the Greek EEZ was examined [121], the most suitable location for the deployment of floating hybrid wave and wind energy platforms was on the east coast of Crete, close to the "Zakros" location. To the best of our knowledge, this fact emphasises the verification of the results of our work, but, at the same time, it can also offer a detailed accuracy to the emerged results, concerning our study area. The raster data used were 50m x 50m.

Finally, with the forthcoming interconnection between Crete and Attica, the three thermal power plants will no longer be necessary, because the largest part of the electricity demand will be covered by RES. Suitable siting is a complex problem featuring multiple parameters that many times come in contrast. The current study examines a targeted area to define its suitability relating to the installation of FWFs, increasing the accuracy. The implementation of innovative criteria such as visibility and the proposed methodology that equally expresses all the factors enriches the international literature around suitable sitting. The presentation of all the eligible areas and the rating based on their suitability provides a more detailed result that could be further assessed in the future.

In accordance with the conclusions of the technoeconomic assessment, the following points have been summarized. With exceptional methodical precision and methodical approach, this Thesis examined the extensive techno-economic analysis of an OWF in the Gulf of Heraklion, Crete. The installation and operation of bottom-fixed and FWTs have been analysed using tools such as WAsP, AutoCAD, QGIS, and Google Earth. Choosing the bottom-fixed base models Vestas V164-9.5MW, Vestas V236-15MW, Siemens Gamesa SG167-8MW for areas with a depth of up to 60 m and Siemens Gamesa SG154-6MW for depths greater than 60 m highlights the importance of adaptability in technology selection depending on marine conditions. In order to achieve maximum energy efficiency and sustainability, technological adaptability and accurate equipment selection are critical.

The economic analysis showed the feasibility of the project through the estimation of installation cost (CAPEX), OPEX, DECEX, net NPV, reduced cost of energy (LCOE), PP and IRR, providing a comprehensive view of the economic and time profiles of the selected types of WTs. Particularly, the presentation of costs for floating and BFWTs highlights the potential for this technology to become more competitive as facilities scale up and technology matures.

The methodology employed in this Thesis proved effective in capturing the complexity and holistic approach required for the development of OWFs. The study also identified areas for future research, such as improving the accuracy of wind potential estimation and ensuring that WT technologies continue to evolve and develop.

A major reason for conducting this Thesis is to ensure the independence of large islands from fossil fuels. Due to limited space and untapped offshore wind potential, the turn to offshore wind represents the optimum solution. Finally, the issue of aesthetics is added to the major problem of siting an OWF. Thus, this study contributes to this scientific topic by testing an existing methodology and testing it from the perspective of the residents. The following are summarized, based on the conclusions of methodologies measuring VI on OWFs.

1. It is now clear that the SPM, in its original form needs to be upgraded to represent the degree of nuisance caused by an offshore wind installation. From the modifications tested, it seems that the change of the coefficient v from the literature can, in some cases, produce good results, closer to reality, but for more specific installation schemes, it can give values that do not correspond to reality.
    - On the other hand, it was found that the new coefficient v that does not use cubes gives results much closer to reality and thus is the one chosen as the most suitable for the method.
    - Regarding coefficient d, it seems that both the proposal of the literature [65] and the new proposal using Table 6 generate good results, with the proposal of the literature generally offering better ones.
    - The addition of a coefficient ψf, which changes the degree of nuisance based on the sample view for RES technologies, proved to be a substantial addition to the method, as the degree of impact felt by an observer from a WF proved to be proportional to the observer's opinion on RES.
2. It is also notable that both scenarios 3 and 4, which fully complied with the Greek Ministry suggestions, turned out to have a serious VI, even though they were

supposed to have Minimum or at least Little impact. This fact shows that the proposed methodology from the Greek Ministry is inefficient and, in some way, problematic.

3. Finally, it is observed that the grade of the VI that a person could feel is highly related to their opinion on the RET.

Finally, based on the results of the second methodology, the following conclusions can be drawn:

- In the case of an OWF, the results showed a small VI according to the special limits (legislation).
- In comparison to younger age groups, those over 35 were less positive about both scenarios.
- People with lower education levels had a more negative opinion of the installation than people with high education levels.
- People generally support RET regardless of their location, gender, age, or education level.
- The study concluded that sparsely located WTs will result in a more pleasant landscape (minimal VI) than those located densely. This fact is inversely related to their size.

There is, therefore, a reasonable chance that the communities will accept these large projects more smoothly if a sustainable siting is undertaken, with specific criteria and a preliminary study is conducted about possible VI.

6.1 Limitations and Future research

Firstly, based on the literature review, the following limitations and topics were identified for further investigation. Among the criteria, some have been less investigated and could be studied further, such as VI, extreme environmental conditions, noise level, and heritage sites (including coastal antiquities). Moreover, it is important to encourage the participation of experts in these studies so as to incorporate a more objective assessment of the data.

The reviewed studies inadequately address or overlook certain critical issues, such as the marine ecosystem. These aspects are pivotal for determining the location, installation, and operation of facilities like OWFs. A comprehensive risk analysis, tailored to the specific characteristics of each region, is essential, encompassing uncertainties at technical, economic, social, and environmental levels. While these studies serve as an initial step in identifying suitable sites for OWF deployment, achieving a more thorough and accurate approach necessitates on-site studies, wind measurements, environmental assessments, and VI evaluations for each local site.

The following limitations of the methodologies of sustainable siting of OWFs have been identified. For future research, it is recommended that the aesthetic part of the potential sites of OWFs installations be evaluated distinctively and with scrutiny. How an OWF would look from the nearest shore is a crucial issue, and it concerns large majorities of local people and organisations.

The everlasting changes and the new studies on the available digital data for GIS software could create uncertainty about our final results. However, this uncertainty could easily be surpassed by controlling new emerging data and their incorporation into the already existing maps. After all, a satisfying digital bank of data was created, which is dynamic and could be enriched for each new addition.

Furthermore, more criteria and number of experts involved in the research could also be investigated for further research and more accurate results. Additionally, the combination of other MCDM methods and fuzziness could surely be tested in order to check and compare the relevant results.

Additionally, maintenance criteria are strongly related with the distance from ports criterion. The authors consider this as a complicated and critical criterion to be examined separately, as another supplementary study. Especially in our case study, which involves an insular environment, it has numerous ports around it, so the distances are not too inhabiting from any candidate place for installation. This parameter also needs to be investigated combined with other techno-economic assessments for the viability of the whole project.

Notably, the criterion of distance from shore was evaluated in relation with the potential optical disturbance from an observer on the shore. As the distance from shore increases, the VI is minimized, but the investment and maintenance costs increase.

A further on-site assessment per candidate location is necessary, in order to acquire a better, more detailed, and more comprehensive perception. This assessment is recommended in order to examine the specific biological characteristics, the distance from the nearest port installations, as well as the relation between wind potential and the local geomorphology.

It is concluded that the second methodology of siting FWFs has the following limitations. The introduction of relative weights could be examined through the AHP methodology with the participation of stakeholders, which would result in a more detailed analysis, as the relative weight of every criterion would be expressed. The determination of the suitability for every examined port would be also important for the better implementation of the techno-economic criteria. Relating to the energy assessment, the study of the most efficient layout and installed capacity would better estimate the AEP. Finally, an additional number of locations that would include areas rated as less suitable could be assessed.

The proposed method combines multiple criteria corresponding to different aspects, but it has also some limitations. First of all, the implementation of those criteria in the analysis does not include relevant weights, which would make the method more accurate. This means that local stakeholders did not participate in the evaluation, and therefore, their opinion can change the suitability results, depending on the location. This method includes all the project parameters and can be used in other sites as well using the same exclusion and EVC without the need of participation from local stakeholders.

An energy assessment took place in the “most suitable” areas. During this assessment, a typical 6X9 RD layout was chosen according to the literature. However, this layout is not optimum. In addition, the two examined WTs are not sufficient to draw a safe conclusion, as to what is the optimal WT rated power from a techno-economic viewpoint of view. Another assumption that was made during the energy assessment of the most suitable sites was the insertion of the same weather file for sites located in the same area and rated similarly according to the energy criteria. This assumption was made based on the flat sea terrain because the purpose of this assessment was only to define the most energy-efficient area. According to all the aforementioned, the results of this Thesis should not be considered as absolute numbers of energy production, but as estimations and means to assess the energy efficiency of the most suitable locations.

In light of the limitations of technoeconomic assessment and the need for further research, the following conclusions may be drawn. Further research is required to improve the sustainability and economic efficiency of OWFs. Research could focus on Life Cycle Costing (LCC) analysis of materials and the social challenges and impacts associated with their development.

Additionally, wind data have to be cross-checked with other reliable databases, or wind measurements can be conducted on site in order to obtain a more accurate portrayal of the site. Furthermore, further scenarios have to be evaluated, concerned the WT models, as well as the micro-siting of WTs. Depending on the case scenario, the costs related to the design of the electrical arrays as well as the electrical infrastructures may vary significantly.

In addition, the possibility of all WTs being bottom-fixed or floating might be examined, but this is heavily influenced by the depth of the sea. It is therefore necessary to determine the percentage of floating and bottom-fixed in each site separately. There will be a great deal of variation in the costs in each scenario. Further, since the costs of floating wind industry are expected to be reduced significantly in the coming decades, this factor needs to be considered as well.

Finally, a successful OWF requires the acceptance and screening of local communities. The focus of future research should be on understanding and managing the challenges associated with social acceptance.

According to the 1st methodology about the VI assessment, it is concluded that even with the new changes, the SPM remains incomplete, as it was found that changes to the n factor need to be made in some way. Thus, material for future study could be the correction of this coefficient or other coefficients of the method, if deemed necessary by the researcher. The addition of new additional factors to the SPM could also be considered, which could improve the method.

Finally, according to the 2nd methodology about the VI assessment could be refined in the future with the introduction of new 3D tools so that it can also be tested in this way. It is also possible, with the aid of this method, to provide experience to the relevant policymakers and authorities to give viable and close-to-reality solutions so as to improve the assessment of the potential VI of an OWF.

It should also be noted that, although the number of questionnaires collected is rather small, it is considered as satisfactory, due to the small population of the villages in the area, as well as the fact that the real population is supposed to be significantly smaller Table A.8 due to urbanisation. The personal interviews took place in August in order to meet as many people as possible since these villages are primarily touristic (summer season). The sample size should be much larger, however, so that statistical correlations can be made, and more accurate conclusions can be drawn. Further interviews should be conducted maybe through online questionnaires so that a much larger number of respondents can be reached.

In order to achieve rapid development, OWFs require a high level of social acceptance. Therefore, it is imperative that we address this issue first in order to avoid further conflict between the communities. Finally, further research is needed on the critical topic of the VI of OWFs. In order to obtain a more holistic approach and knowledge, the methodology adopted in this Thesis needs to be compared with other methods (for assessing the VI of OWFs).

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B. Annex A

Table A.1: Number of experts involved in the multicriteria process of the 80 papers

Number of experts	Number of papers
3	1
4	4
5	4
7	3
8	1
9	2
10	1
13	1
15	1
21	1
25	1
26	1
33	1
34	1
n/d	9
no	39
yes, n/d	9
Sum	**80**

Table A.2: Allocation of papers per study area and type of structure, journal, expert Involvement, and GIS Integration

A/A	Study Area/Country	Type of structure (fixed/floating)	Journal name	Year of publication	Number of experts	Use of GIS	Source
1	UK	bottom-fixed	Energies	2018	13	✓	[243]
2	Aegean Sea/Greece	Floating	International Journal of Energy	2019	no	✓	[123]
3	Cyclades (Greece) & İzmir (Turkey)	bottom-fixed	Environmental Monitoring and Assessment	2020	26	✓	[125]
4	Canary Islands (Spain)	Floating	Energies	2021	5	✓	[244]
5	Lake Erie, northern Ohio, USA	bottom-fixed	Renewable and Sustainable Energy Reviews	2015	21	✓	[245]
6	China	Both	Ocean & Coastal Management	2020	n/d	no	[38]
7	Eastern China Sea, China	bottom-fixed	Ocean Engineering	2018	5	no	[35]

8	Crete, Greece	bottom-fixed	Energy	2022	33	✓	[6]
9	local (Basque Country) and regional (Northeast Atlantic and Western Mediterranean)	Both	Science of the Total Environment	2019	n/d	✓	[246]
10	UK	n/d	Annals of Operations Research	2016	no	no	[247]
11	China	n/d	Engineering Optimization	2017	8	✓	[248]
12	UK	Both	Renewable Energy	2016	yes, n/d	✓	[46]
13	Egypt	n/d	Journal of Cleaner Production	2021	n/d	no	[249]
14	Atlantic continental European coastline Portugal, Spain and France	Floating	Renewable and Sustainable Energy Reviews	2020	no	✓	[215]

15	Eastern China Sea, China	n/d	Renewable Energy	2021	4	no	[42]
16	Persian Gulf, Iran.	Both	Ocean & Coastal Management	2015	5	no	[250]
17	Atlantic coastal areas of Portugal, Spain, and France	Floating	Renewable Energy	2022	5	✓	[251]
18	Samothraki island, Greece	Both	Renewable Energy	2021	no	✓	[252]
19	China	Both	Remote Sensing	2019	no	no	[253]
20	n/d	bottom-fixed	Journal of Environmental Management	2020	34	no	[39]
21	Brazil	Both	Renewable and Sustainable Energy Reviews	2021	n/d	✓	[254]
22	Taiwan	Both	Sustainable Energy Technologies and Assessments	2021	7	no	[113]

23	n/d	Both	Energy Policy	2018	25	no	[27]
24	UK	floating	Sustainable Energy Technologies and Assessments	2021	9	no	[117]
25	Brazilian coast, Brazil	bottom-fixed	Sustainable Energy Technologies and Assessments	2021	no	✓	[131]
26	Turkey	bottom-fixed	Energy Strategy Reviews	2019	no	no	[119]
27	Bozcaada, Turkey Aegean Sea, Greece	bottom-fixed	Renewable and Sustainable Energy Reviews	2018	no	no	[132]
28	Gulf of Maine. USA	Floating	Renewable Energy	2022	3	✓	[43]
29	Hong Kong bay	bottom-fixed	Annals of GIS	2019	no	✓	[109]
30	Bozcada, Aegean Sea, Turkey	bottom-fixed	International Journal of Exergy	2021	no	✓	[255]

31	Morocco, North Africa	Both	Energy Conversion and Management	2021	n/d	✓	[256]
32	Greece	Both	Renewable and Sustainable Energy Reviews	2017	no	✓	[121]
33	n/d	Both	European Water	2017	no	✓	[127]
34	Irish Sea	Both	Quarterly Journal of Engineering Geology and Hydrogeology	2020	no	✓	[257]
35	Ireland	bottom-fixed	Energy	2020	n/d	✓	[44]
36	Canary Islands	Both	Renewable and Sustainable Energy Reviews	2021	n/d	✓	[258]
37	Shandong Province, China	n/d	Journal of Cleaner Production	2018	15	no	[45]
38	Galician area (North-West of Spain)	floating	Marine Policy	2020	no	✓	[129]

39	Egypt	bottom-fixed	Renewable Energy	2018	no	✓	[259]
40	Shandong Province, China	n/d	Energy	2020	yes, n/d	no	[260]
41	Esthonia, Latvia, Lithuania, Baltic States	bottom-fixed	Energy Policy	2017	n/d	✓	[261]
42	Atlantic-facing coasts of Europe	floating	Renewable Energy	2016	no	✓	[116]
43	Mediterranean Basin	floating	Energy Conversion and Management	2021	no	no	[138]
44	South Africa	Both	Journal of Energy in Southern Africa	2020	no	✓	[262]
45	Taiwan	bottom-fixed	Ocean & Coastal Management	2017	n/d	no	[263]
46	Jeju Island, South Korea	bottom-fixed	Renewable Energy	2016	no	✓	[111]

47	Turkey’s coastal area	n/d	Applied Soft Computing	2021	4	no	[264]
48	Gulf of Thailand	bottom-fixed	Renewable Energy	2015	no	no	[265]
49	China	bottom-fixed	Ocean & Coastal Management	2018	no	✓	[266]
50	China	bottom-fixed	Energy Conversion and Management	2019	7	no	[267]
51	Atlantic Ocean	floating	Energy Conversion and Management	2022	no	no	[268]
52	Portuguese coast	Both	Renewable Energy	2019	no	✓	[114]
53	southeast coast of Brazil	bottom-fixed	Energy	2019	no	no	[269]
54	United Kingdom	n/d	Annals of Operations Research	2018	no	no	[270]
55	Caspian Sea, Iran and Turkey The Caspian Sea is the largest lake in the	bottom-fixed	Wind Engineering	2019	no	no	[271]

	world. This sea is surrounded by five countries, such as Iran, Russia, Azerbaijan, Turkmenistan, and Kazakhstan.						
56	Greece	Both	Energies	2018	yes, n/d	✓	[272]
57	southwest coast of South Korea	bottom-fixed	Renewable Energy	2018	no	✓	[110]
58	Canary Islands	Both	Energy	2018	no	✓	[112]
59	Greece	Both	Sustainability	2020	7	✓	[126]
60	China	n/d	Energy Conversion and Management	2016	yes, n/d	no	[40]
61	coastal part of Turkey, Turkey's seas	bottom-fixed	Earth Science Informatics	2021	no	✓	[273]

62	Greece	bottom-fixed	Sustainability	2018	no	✓	[124]
63	Chania, Crete, Greece	bottom-fixed	Renewable Energy	2017	no	✓	[274]
64	Turkey	bottom-fixed	Energy Strategy Reviews	2018	no	no	[134]
65	Irish Waters, Ireland	Both	Energies	2019	no	no	[275]
66	Turkey	bottom-fixed	Sustainable Energy Technologies and Assessments	2019	yes, n/d	no	[120]
67	Bass Strait, Australia	Both	Journal of Cleaner Production	2021	no	✓	[276]
68	off the coast of New Jersey, USA	Both	Engineering Applications of Artificial Intelligence	2021	yes, n/d	no	[277]
69	Poland	bottom-fixed	Applied Energy	2021	yes, n/d	no	[278]

70	Poland	bottom-fixed	Energies	2017	no	no	[118]
71	Mediterranean Basin	Floating	Renewable Energy	2024	no	no	[139]
72	Turkey, Iskenderun Bay	Both	Energy for Sustainable Development	2023	4	✓	[41]
73	Turkey	n/d	Journal of Cleaner Production	2024	4	✓	[279]
74	Spain	Both	Science of The Total Environment	2024	no	no	[280]
75	Australia	Both	Ocean & Coastal Management	2022	9	✓	[281]
76	South Korea	Bottom-fixed	Energy Reports	2023	no	no	[135]
77	Norway	Both	Wind Energy	2023	no	no	[282]
78	Colombian Caribbean Coast	Both	Journal of Energy Economics and Polic	2023	10	no	[283]

79	located in French waters of the Bay of Biscay (northeastern Atlantic)	n/d	Journal of Environmental Management	2023	yes, n/d	no	[284]
80	Greece, central Aegean Sea	Floating	Energies	2023	yes, n/d	✓	[285]

Table A.3: Allocation per paper according to the used methodology. *In column "paper ref", numbers indicate the "A/A" of each paper, as it is assigned in Table A.2

Methodology	Reference of paper	Number of papers used the methodology
Marine Spatial Planning	[45], [49], [52], [79]	4
Feasibility analysis	[25], [27], [43], [57], [58], [59], [64], [71], [74], [76]	10
Probabilistic methods	[9]	1
Meteorological data	[18], [19], [26], [34], [42], [51], [53], [55], [65]	9
MCDM	[1], [2], [3], [6], [7], [8], [10], [13], [16], [17], [20], [21], [22], [23], [24], [28], [29], [30], [31], [32], [33], [35], [36], [37], [39], [40], [41], [44], [47], [54], [56], [60], [61], [62], [67], [68], [72], [73], [75], [77], [78]	41
Other methods-Combination of methods	[4] , [12], [15]	15

Table A.4: Allocation per MCDM method. *In column "paper ref", numbers indicate the "A/A" of each paper, as it is assigned in Table A.2

Methodology	Reference of paper	Number of papers used the methodology
AHP	[3], [4], [8],]13], [17], [21], [28], [30], [31], [32], [33], [36], [39], [41], [56], [62], [66], [72], [77], [78]	20
ANP	[6], [16], [40]	3
BWM	[47], [75]	2
DEMATEL	[16], [22]	2
DEPHLI	[20], [23]	2
ELECTRE	[4], [16], [60]	3
Goal programming	[10], [54]	2
GREY	[22]	1
MARCOS	[47]	1
PROMETHEE	[6], [4], [13], [69]	4
TOPSIS	[1], [4], [28], [62]	4
WSA	[77]	1

Table A.5: Criteria chosen and analysed in 80 papers and the reference and number of papers that investigates them. *In column "paper ref", numbers indicate the "A/A" of each paper, as it is assigned in Table A.2

Criterion	paper ref.	Number of papers used the criterion
Wind characteristics (wind potential, wind velocity, wind directions, wind power density, effective wind hours, wind shear, turbulance)	[2], [3], [4], [6], [7], [8], [9], [11], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [35], [37], [39], [40], [42], [46], [47], [48], [49], [50], [51], [52], [53], [55], [56], [57], [59], [60], [61], [62], [65], [66], [68], [69], [71], [72], [73], [74], [75], [76], [77], [80]	61
Water depth (bathymetry)	[2], [3], [4], [7], [8], [9], [11], [13], [14], [16], [17], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [35], [36], [38], [39], [40], [41], [42], [43], [44], [46], [47], [48], [52], [56], [57], [58], [59], [60], [61], [62], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [80]	58
NAVIGATION (shipping routes, impacts on navigation, naitical coordination, IMO traffic schemes, shipping density)	[2], [3], [4], [5], [6], [7], [8], [9], [12], [13], [14], [15], [16], [17], [20], [23], [26], [28], [29], [30], [31], [32], [33], [35], [36], [38], [39], [42], [45], [46], [47], [49], [50], [52], [56], [58], [59], [62], [63], [64], [66], [67], [68], [69], [70], [71], [72], [75], [77], [78], [79], [80]	52
ENERGY RELATED CRITERIA/ FACILITIES (energy generation and distribution, distance from grid, demand, Distance to existing substations, FACILITIES/ UTILITIES/ Road network, Shore support condition,Traffic on the shore)	[1], [2], [4], [5], [6], [8], [10], [11], [13], [14], [16], [17], [20], [22], [23], [24], [25], [27], [29], [30], [31], [32], [33], [35], [36], [37], [39], [40], [42], [43], [44], [45], [46], [47], [49], [50], [54], [55], [56], [57], [59], [60], [61], [63], [68], [70], [73], [74], [75], [76], [77], [78], [80]	52

Distance from shorelines (Accessibility)	[1], [2], [3], [4], [5], [7], [8], [14], [16], [17], [20], [21], [22], [24], [26], [27], [28], [29], [30], [31], [32], [33], [36], [39], [42], [43], [47], [48], [49], [53], [56], [58], [61], [63], [66], [68], [69], [70], [71], [72], [73], [77], [80]	43
ENVIRONMENTAL IMPACT (operational env. Conditions, NATURA 2000, Environmental protected areas)	[2], [3], [4], [8], [10], [14], [16], [17], [20], [21], [22], [24], [26], [28], [29], [31], [33], [35], [36], [37], [38], [39], [40], [41], [42], [45], [46], [47], [50], [52], [54], [56], [57], [58], [60], [62], [63], [67], [70], [71], [75], [78]	43
SOCIAL IMPACT (population served, acceptance, Leisure/ fishing community impacts, employment, mitigation of local impacts, tourism, Distance to marine recreational activities, Multiple resource use conflict, Collaborative process/sitting)	[4], [5], [6], [8], [9], [13], [14], [16], [17], [20], [23], [26], [28], [29], [31], [32], [33], [35], [37], [40], [47], [49], [50], [54], [56], [57], [60], [61], [62], [63], [69], [70], [71], [72], [75]	35
Distance from ports (Distance from anchorage)	[2], [3], [7], [9], [12], [20], [21], [24], [28], [29], [30], [31], [32], [33], [37], [38], [44], [45], [46], [49], [52], [56], [57], [58], [59], [60], [68], [72], [73], [74], [75], [77], [78], [80]	34
Submarine topography (Geotechnical conditions, Soil conditions - Sand and Gravel, flat surface (mountains/hills/rocky/buildings)	[4], [5], [6], [8], [9], [13], [14], [16], [17], [20], [23], [31], [33], [35], [36], [38], [39], [40], [41], [47], [52], [58], [60], [61], [64], [66], [67], [68], [69], [70], [75]	31
Underwater cables (gas pipelines)	[2], [3], [4], [8], [9], [12], [14], [17], [21], [23], [24], [26], [27], [28], [29], [30], [31], [33], [35], [36], [39], [45], [52], [59], [61], [64], [66], [67], [68], [72], [78]	31

Distance from military forbidden zones	[3], [4], [8], [14], [20], [22], [23], [24], [26], [28], [32], [33], [36], [37], [39], [46], [47], [49], [57], [58], [59], [60], [61], [64], [66], [68], [71], [77], [78]	29
ECONOMIC FACTORS (economic exclusion, investment cost, construction cost, PP, O&M, profit, NPV, LCOE, Economic externalities, Local economic benefits, Ratio of local benefits to impacts, Market share, cost-benefit analysis, wake effect loss, Loan period, Investment incentives (price subsidy, tax concessions, production incectives, Sales amount)	[1], [6], [10], [11], [13], [15], [16], [20], [22], [23], [28], [29], [31], [33], [35], [37], [40], [41], [47], [50], [54], [59], [60], [68], [69], [70], [75], [76]	28
Impact on marine life (Posidonia, coral reef, MPAs, migratory marine life paths, narine mammals, Seabed migration and flushing)	[4], [8], [9], [11], [14], [16], [17], [20], [22], [23], [24], [29], [32], [35], [36], [40], [45], [46], [47], [49], [58], [59], [60], [63], [67], [75], [77]	27
Fishing areas	[3], [4], [5], [6], [7], [8], [9], [14], [21], [23], [24], [28], [29], [33], [36], [38], [39], [45], [46], [57], [58], [61], [63], [76], [77], [78]	26
Impacts on avifauna (sea birds, migratory birds' paths, SPAs, IBA)	[4], [5], [6], [8], [9], [13], [14], [16], [17], [20], [23], [31], [36], [40], [45], [46], [57], [58], [59], [60], [61], [63], [66], [72], [77], [78]	26
Wave characteristics (wave potential, mean wave power density, Ocean	[2], [4], [5], [7], [9], [11], [14], [15], [16], [17], [18], [20], [23], [24], [32], [35], [42], [47], [49], [51], [56], [57], [74], [75], [77], [78]	26

waves challenging OWF, Wave height and peiod, Marine currents)		
Airports (Impact of aviation - civil aviation)	[3], [4], [8], [14], [16], [17], [20], [26], [31], [33], [58], [61], [64], [72], [77], [78]	16
Meteorological conditions (Temperature, Met ocean, Extreme weather, Sea ice)	[4], [6], [11], [13], [14], [17], [20], [23], [40], [45], [47], [50], [60], [67], [68], [77]	16
Technical feasibility (viability, logistics, technoeconomic, operation lifetime, operating revenue, construction/maintenance, technological risk)	[4], [14], [16], [17], [20], [23], [24], [25], [27], [35], [37], [40], [42], [57], [77]	15
Hydrocarbons and minerals (and Oil & Gas safety zones and infrastructure)	[4], [8], [12], [14], [20], [23], [32], [33], [35], [39], [47], [67], [69], [75], [77]	15
VI (landscape protection)	[2], [8], [9], [16], [21], [23], [35], [57], [59], [67], [72], [75], [77], [78]	14
WF technical characteristics (WF size, Number of turbines, turbine height, Impeller diameter, WT size, turbine spacing, Nameplate capacity)	[7], [15], [20], [23], [25], [27], [44], [76], [77], [78]	10

Extreme environmental conditions (Seismic risk, Geological disasters)	[1], [11], [33], [47], [50], [52], [59], [61], [67], [75]	10
Distance from residential areas	[4], [8], [14], [17], [30], [41], [59], [62], [63], [73]	10
Physical feasibility (Area of the territory, Alternative sites review)	[4], [14], [16], [17], [24], [50], [66], [69], [72], [80]	10
Policy planning (policy risk, federal, state, local agencies and public, Regulating ecosystem services)	[6], [13], [16], [20], [22], [23], [40], [50], [61], [79]	9
Heritage areas; protected wrecks	[4], [8], [12], [14], [24], [41], [52], [63]	8
Noise level/Acoustic disturbance	[8], [16], [23], [35], [36], [47], [59], [63]	8
water quality (alkalinity degree)	[11], [28], [31], [35], [46], [57], [63]	7
RES existence (WFs, Marine renewable energies pilot zones, MRED, Federal and/or state offshore development regulatory program)	[4], [12], [14], [16], [22], [32], [79]	7
Marine conditions	[14], [23], [37], [61], [69], [76]	6
Multiple resources	[4], [14], [17], [40], [50]	5

Sufficient study times	[4], [14], [16], [17], [55]	5
Pollutant emission reduction benefits	[6], [40], [50], [69], [70]	5
Feed-in-tariff for offshore wind energy	[20], [23], [47], [61]	4
Biological groups	[21], [77], [79]	3
Distance from mining areas and activities	[8], [63]	2
Altitude	[42], [53]	2
Safety level	[15]	1
Ratio of power generation to impacts	[16]	1
Proximity to contaminated/obstructed area	[20]	1

C. Annex B

Questionnaire

Table B.1: Pairwise comparisons for EVC, concerning a sustainable siting of OWFs

		Distance from:											Wind resources	Water depth	Seabed substrate	Noise level/ Acoustic disturbance	Optical disturbance
		Submerged cables	Areas of environmental interest	Shipping / Air routes	Electrical grid	Military areas	Shore	Fishing areas	Road network	Heritage sites	Residential activities	Mining areas and activities					
Distance from:	Submerged cables	1															
	Areas of environmental interest		1														
	Shipping / Air routes			1													
	Electrical grid				1												

	Military areas					1										
	Shore						1									
	Fishing areas							1								
	Road network								1							
	Heritage sites									1						
	Residenti al activities										1					
	Mining areas and activities											1				

Wind resources												**1**				
Water depth													**1**			
Seabed substrate														**1**		
Noise level/ Acoustic disturban ce															**1**	
Optical disturban ce																**1**

Exclusion maps

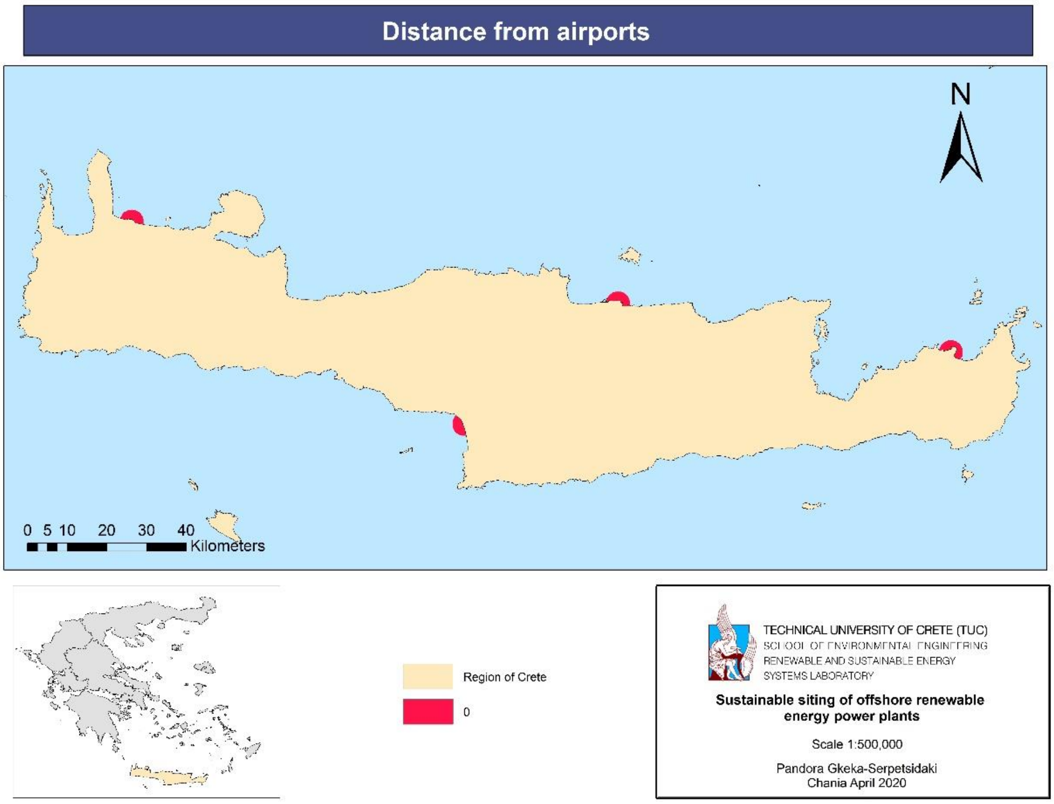


Figure B.1: Exclusion map: Distance from airports

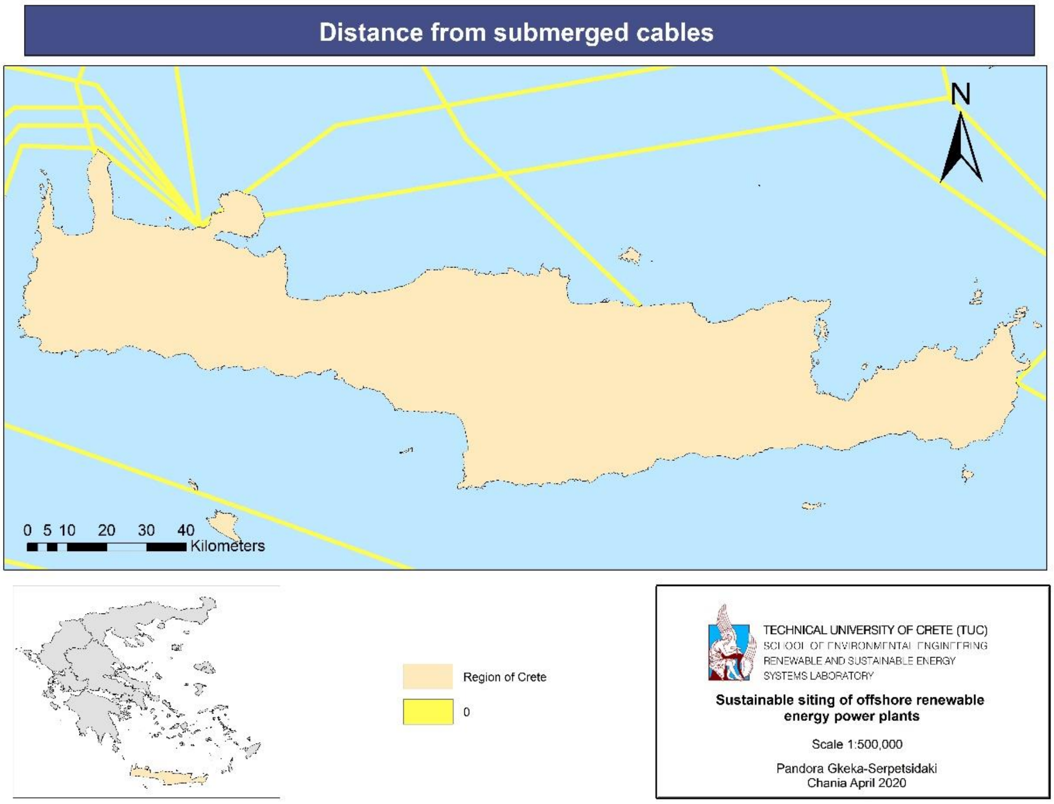


Figure B.2: Exclusion map: Distance from submerged cables

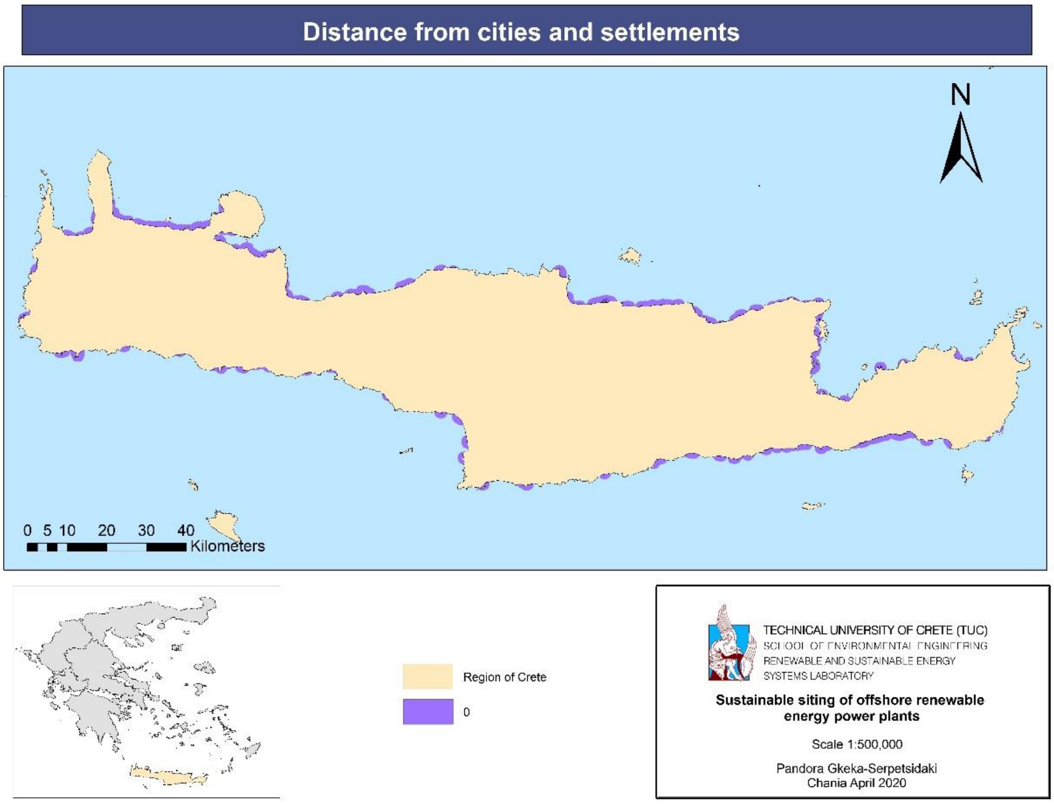


Figure B.3: Exclusion map: Distance from cities and settlements

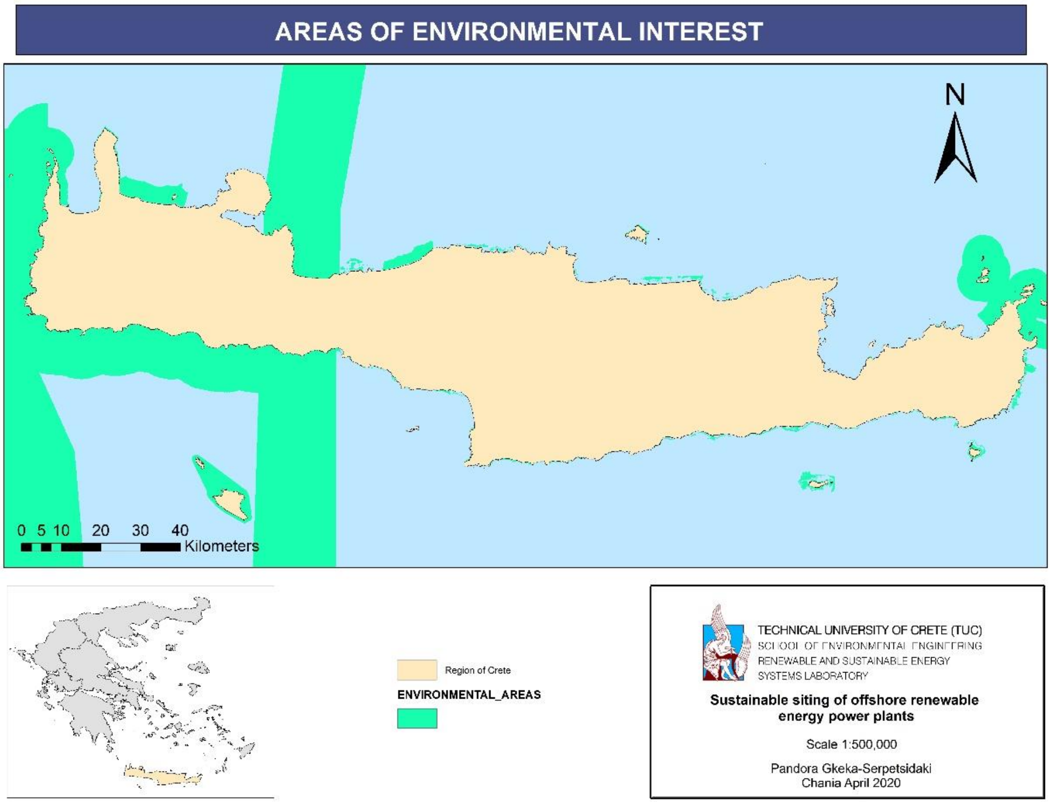


Figure B.4: Exclusion map: Distance from areas of environmental interest

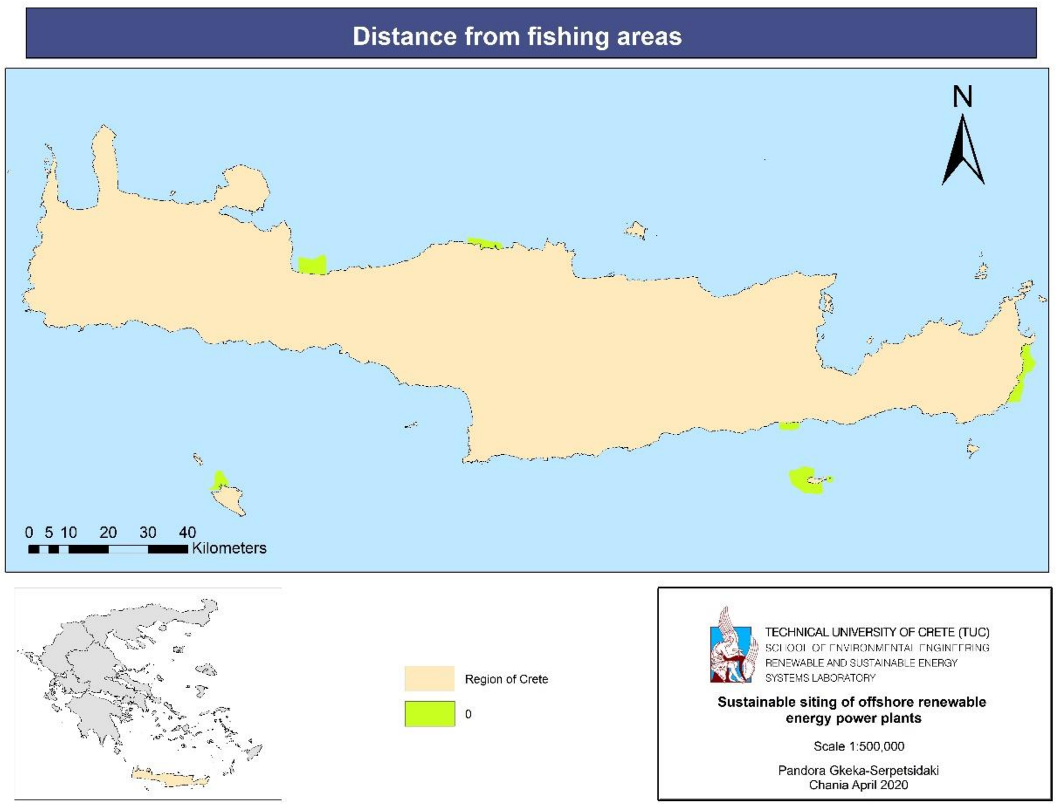


Figure B.5: Exclusion map: Distance from fishing areas

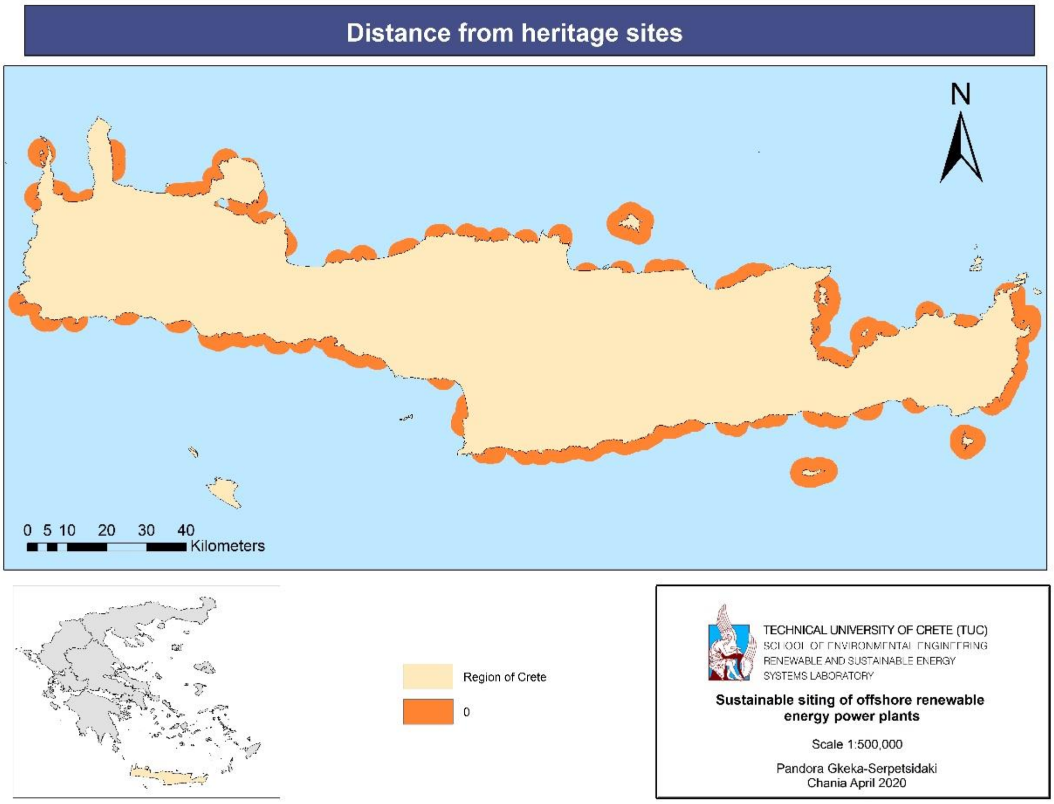


Figure B.6: Exclusion map: Distance from heritage sites

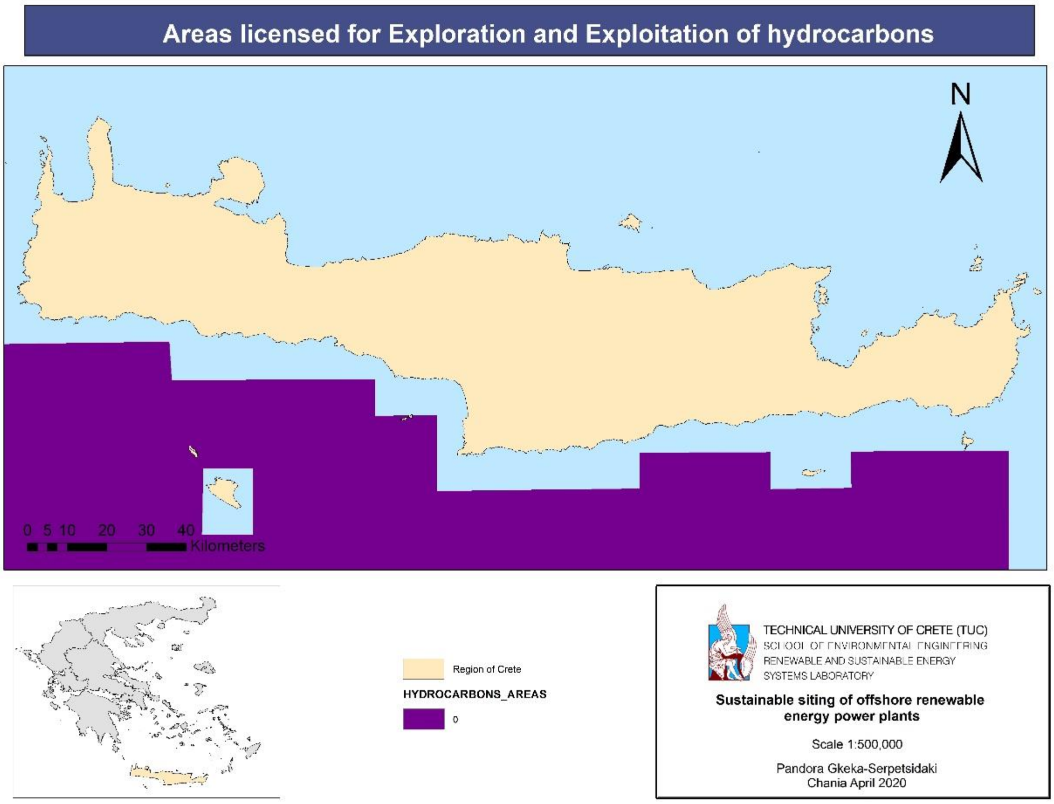


Figure B.7: Exclusion map: Areas licensed for exploration and exploitation of hydrocarbons

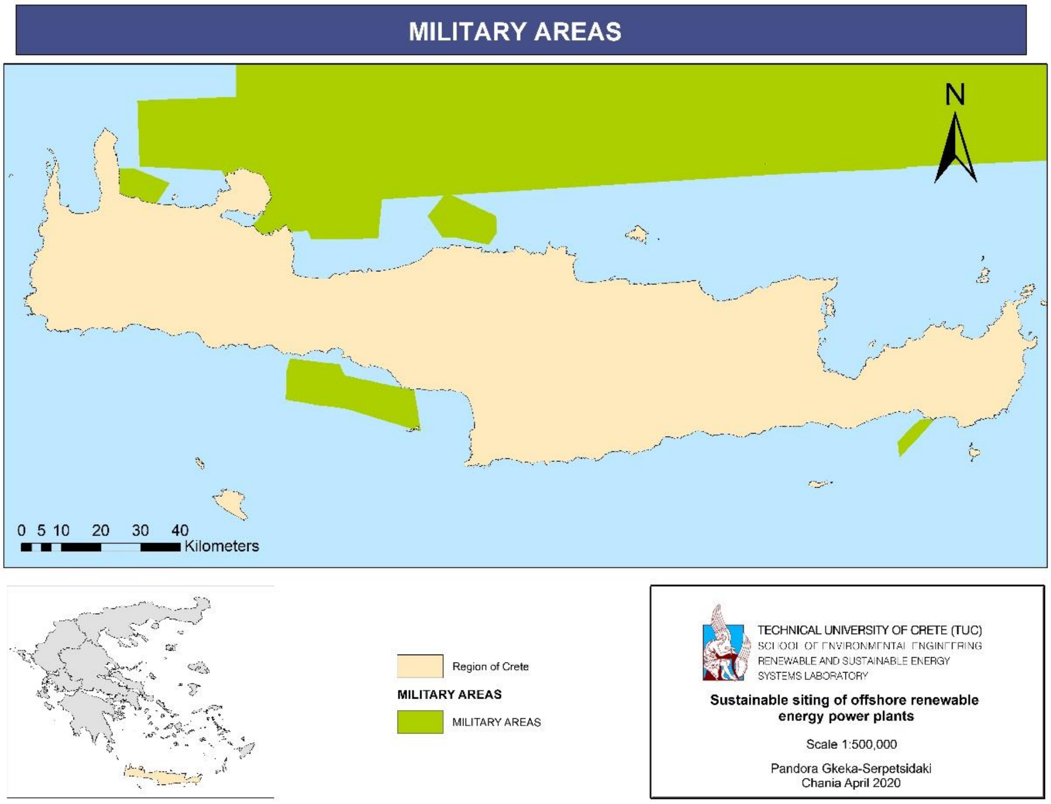


Figure B.8: Exclusion map: Military areas

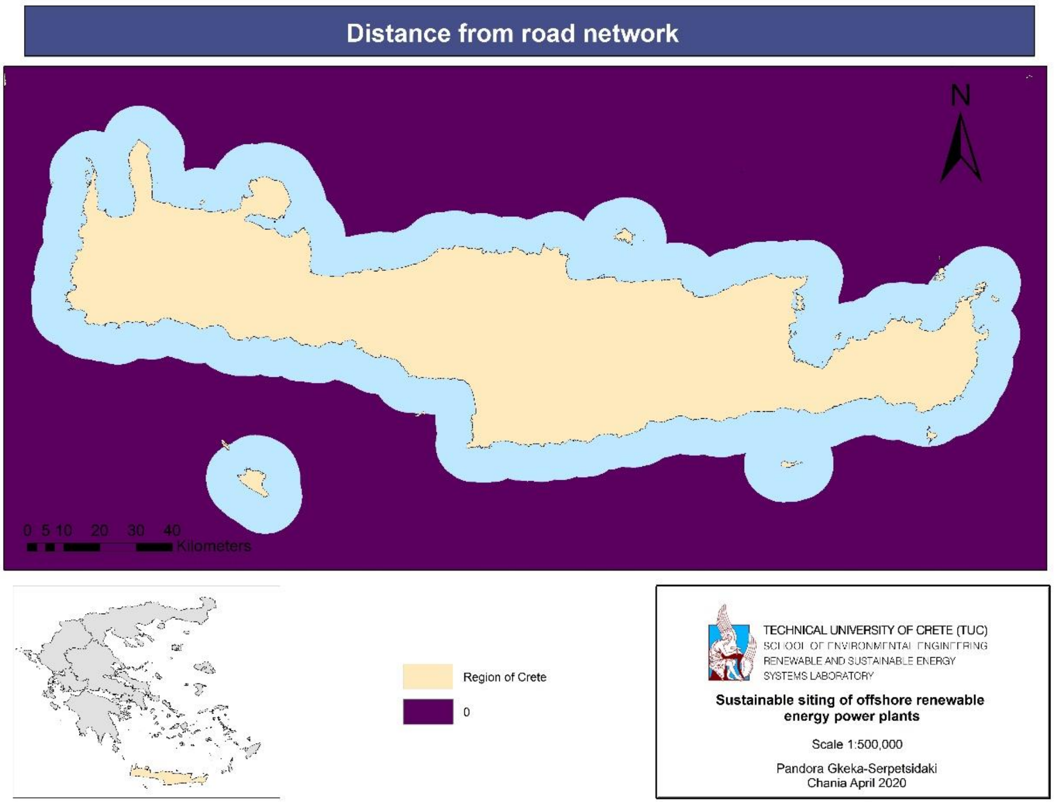


Figure B.9: Exclusion map: Distance from road network

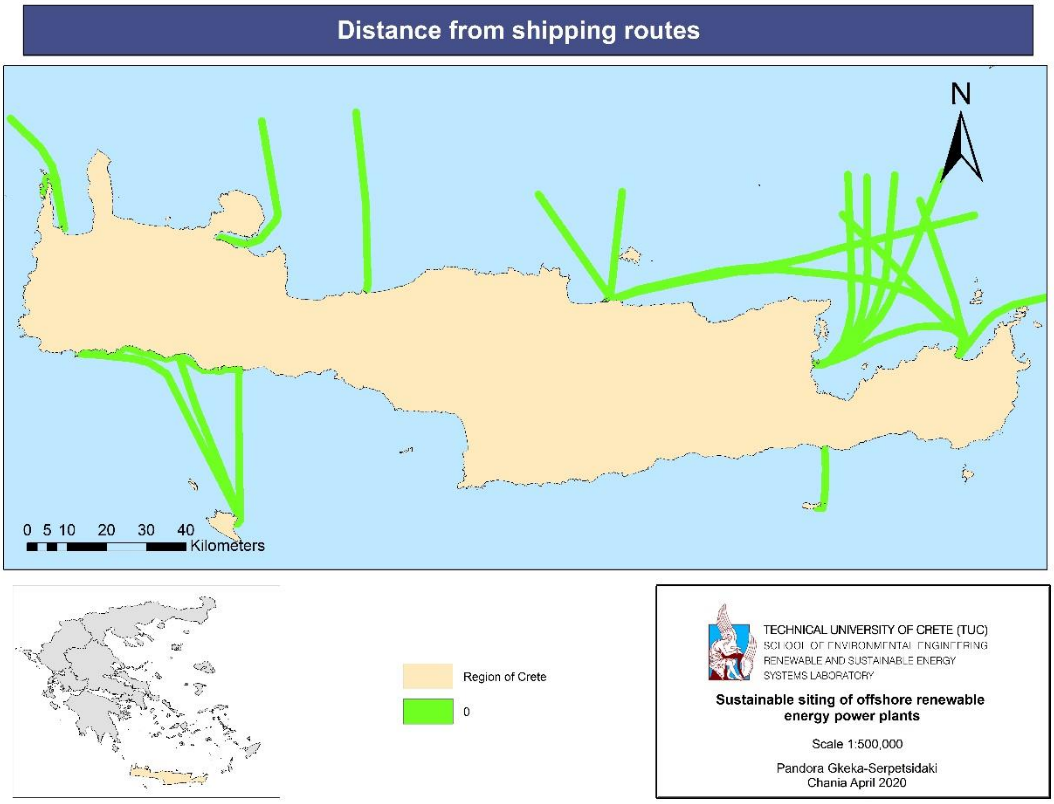


Figure B.10: Exclusion map: Distance from shipping routes

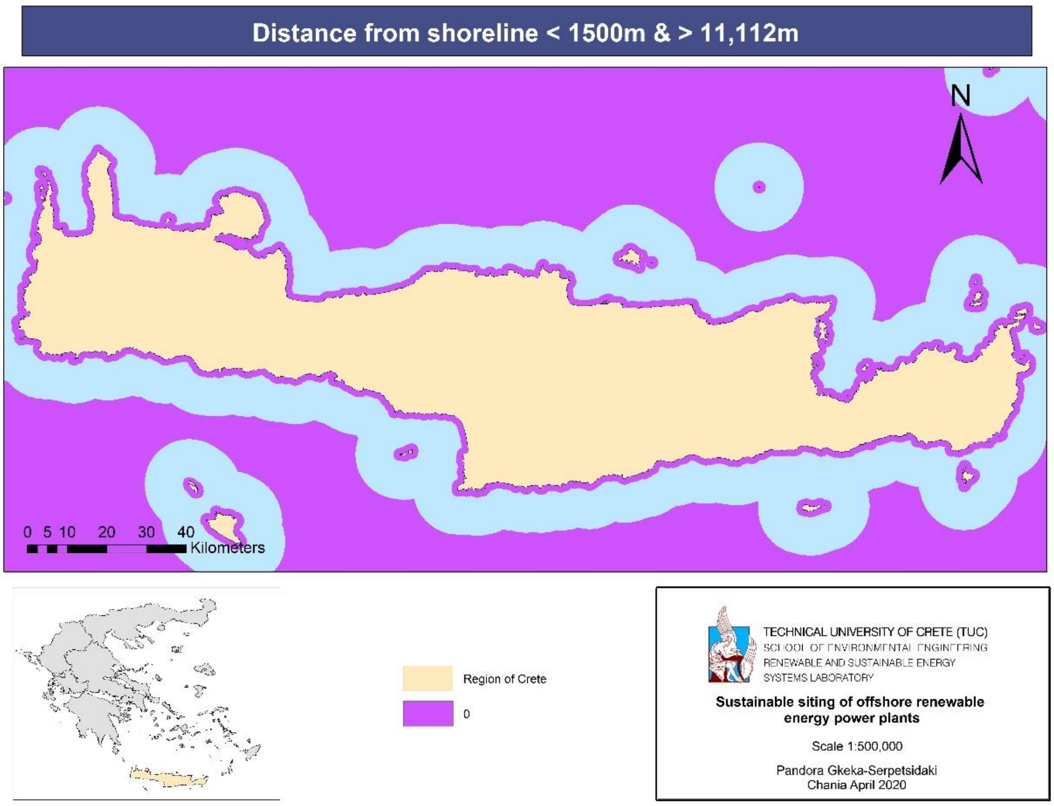


Figure B.11: Exclusion map: Distance from shoreline

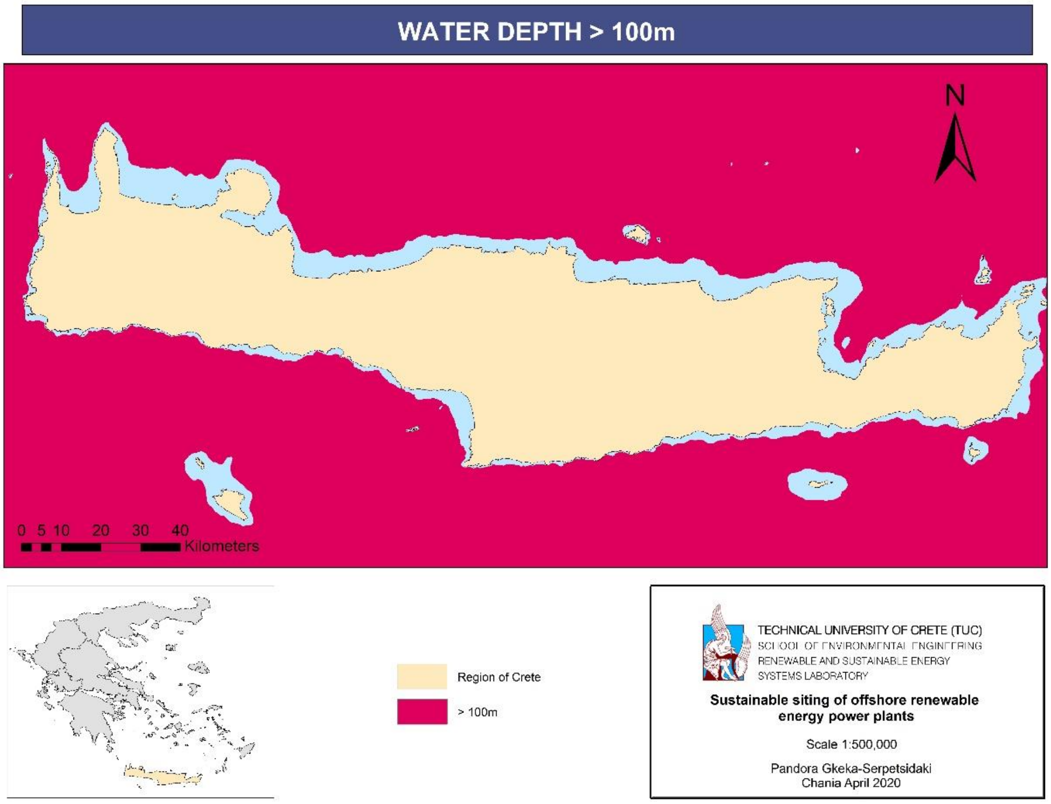


Figure B.12 : Exclusion map: Water depth

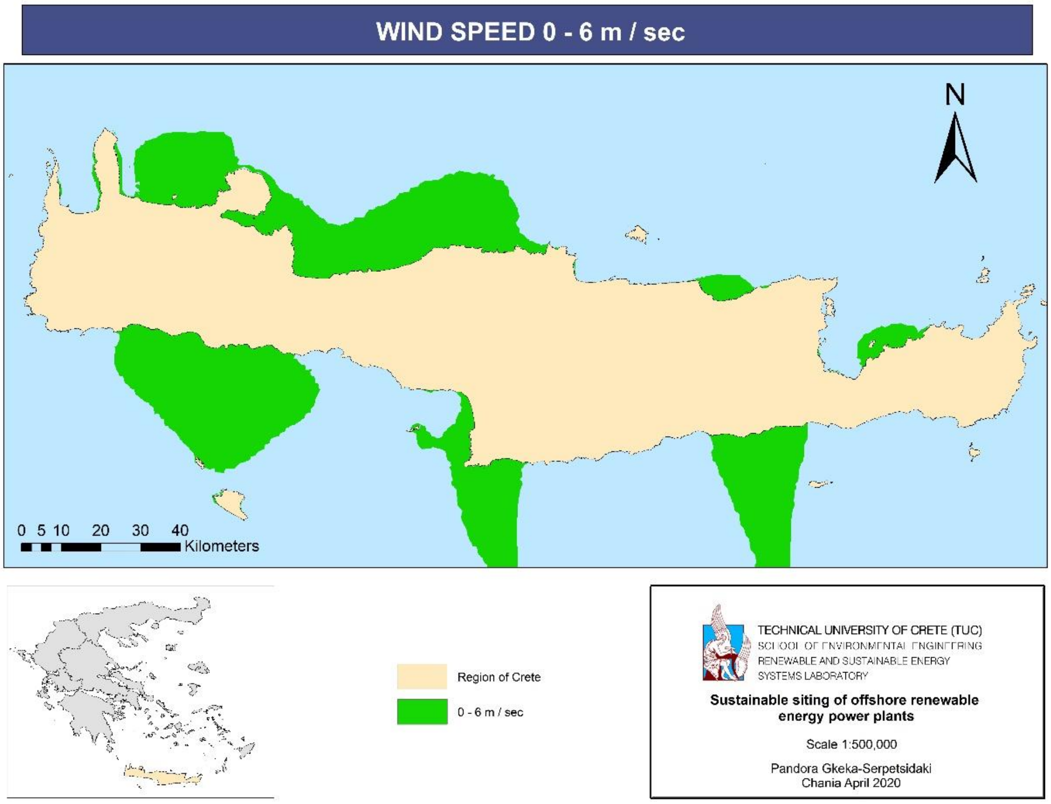


Figure B.13: Exclusion map: Wind speed

Evaluation maps

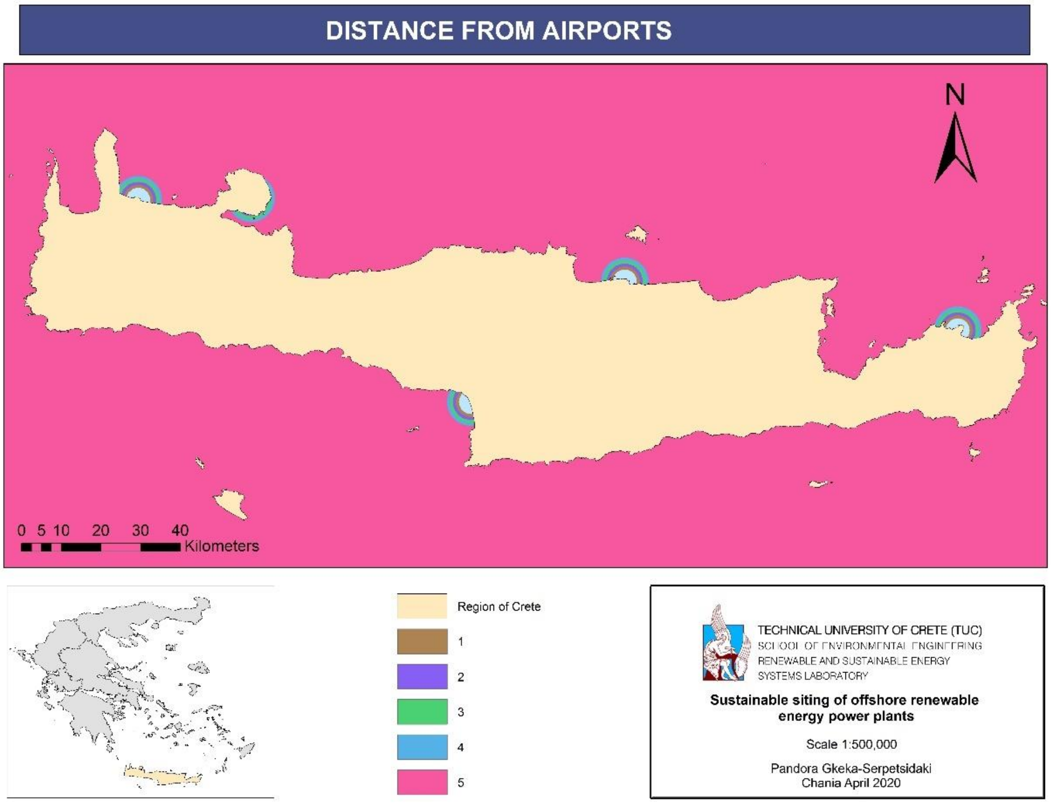


Figure B.14: Evaluation map: Distance from airports

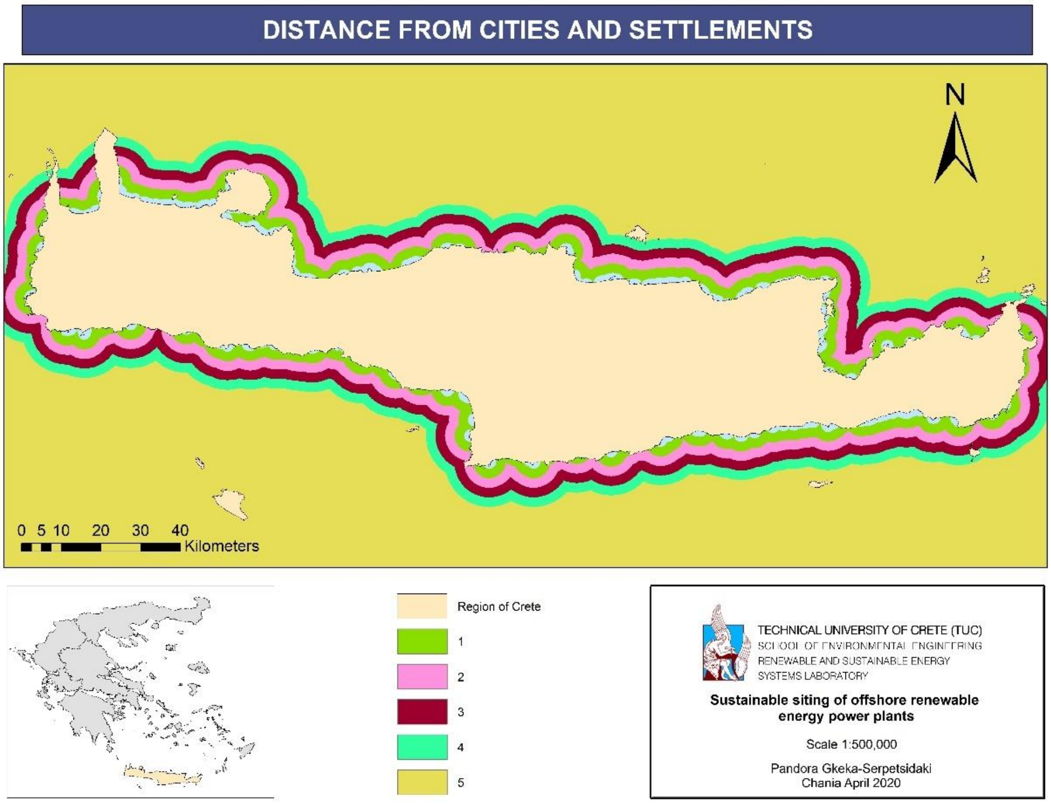


Figure B.15: Evaluation map: Distance from cities and settlements

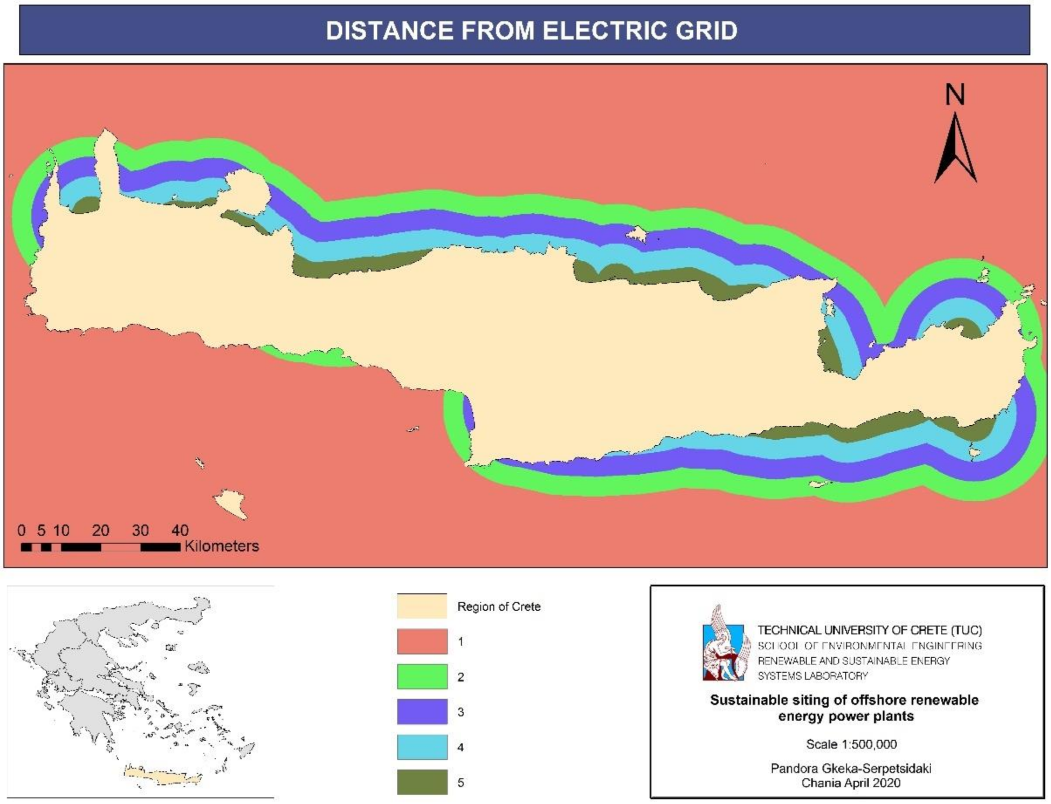


Figure B.16: Evaluation map: Distance from electric grid

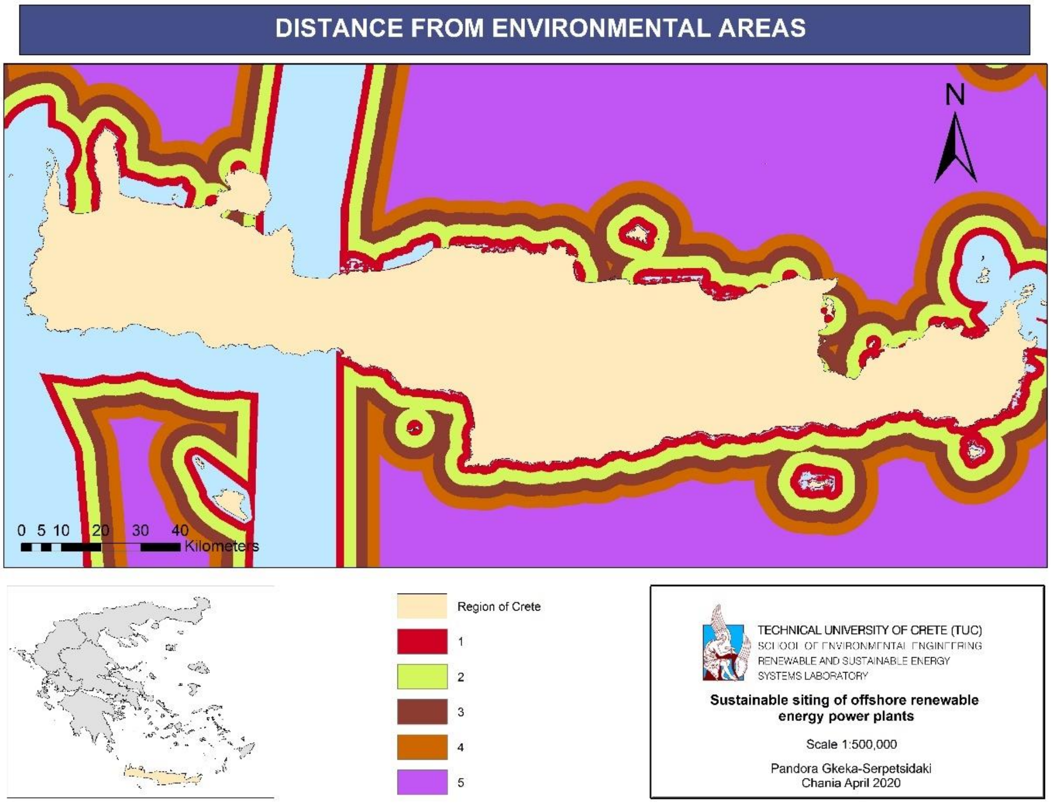


Figure B.17: Evaluation map: Distance from environmental areas

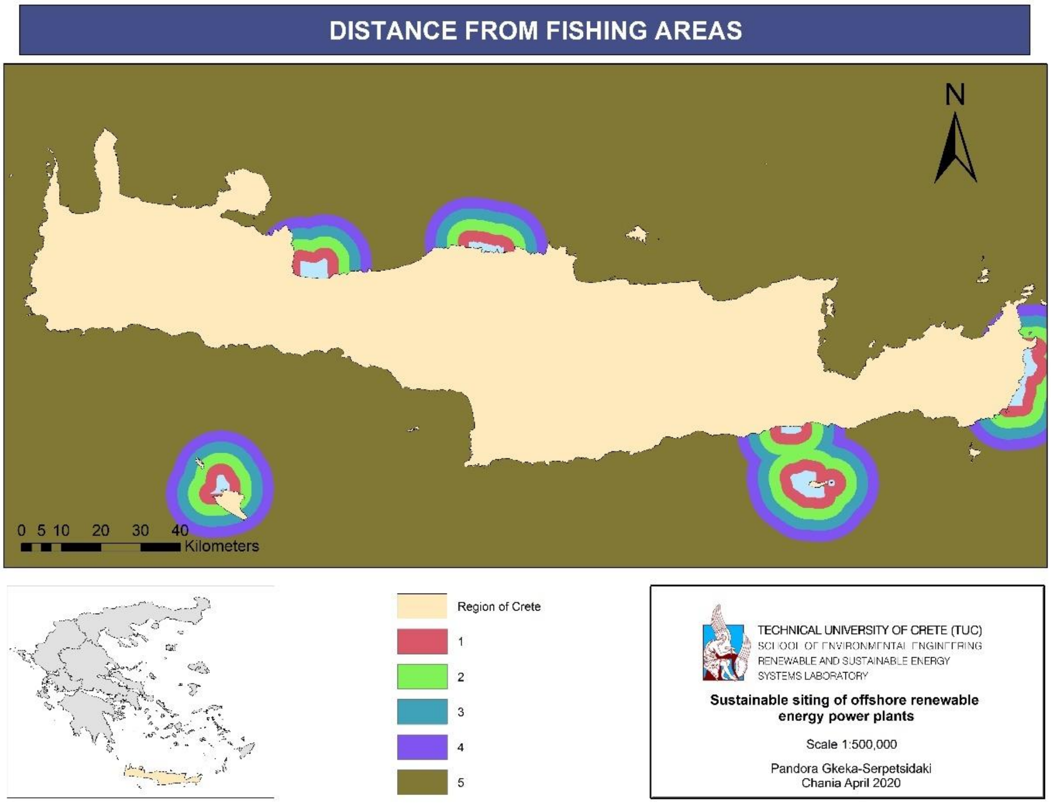


Figure B.18: Evaluation map: Distance from fishing areas

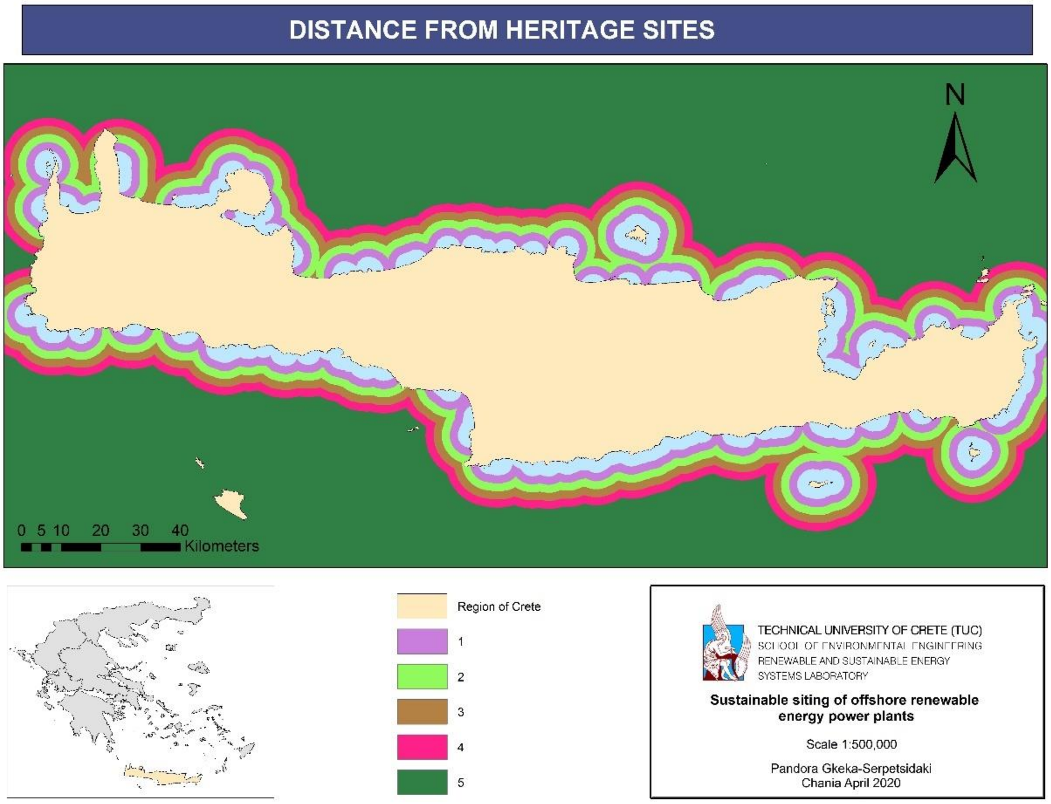


Figure B.19: Evaluation map: Distance from heritage sites

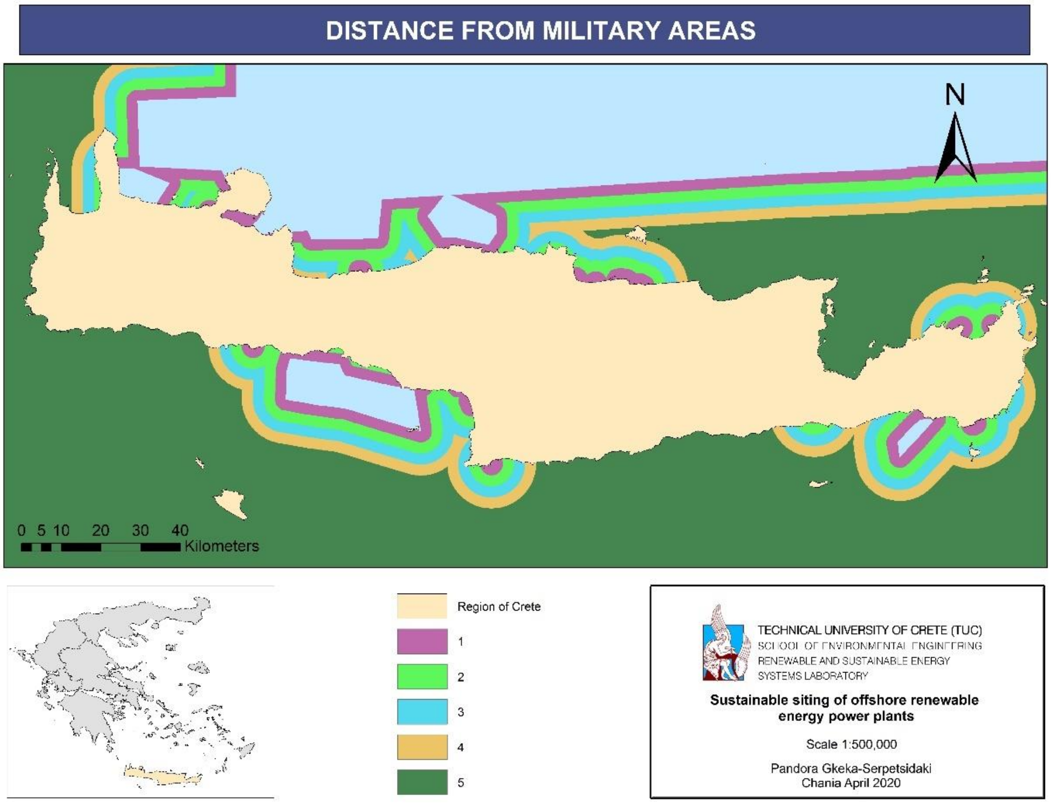


Figure B.20: Evaluation map: Distance from military areas

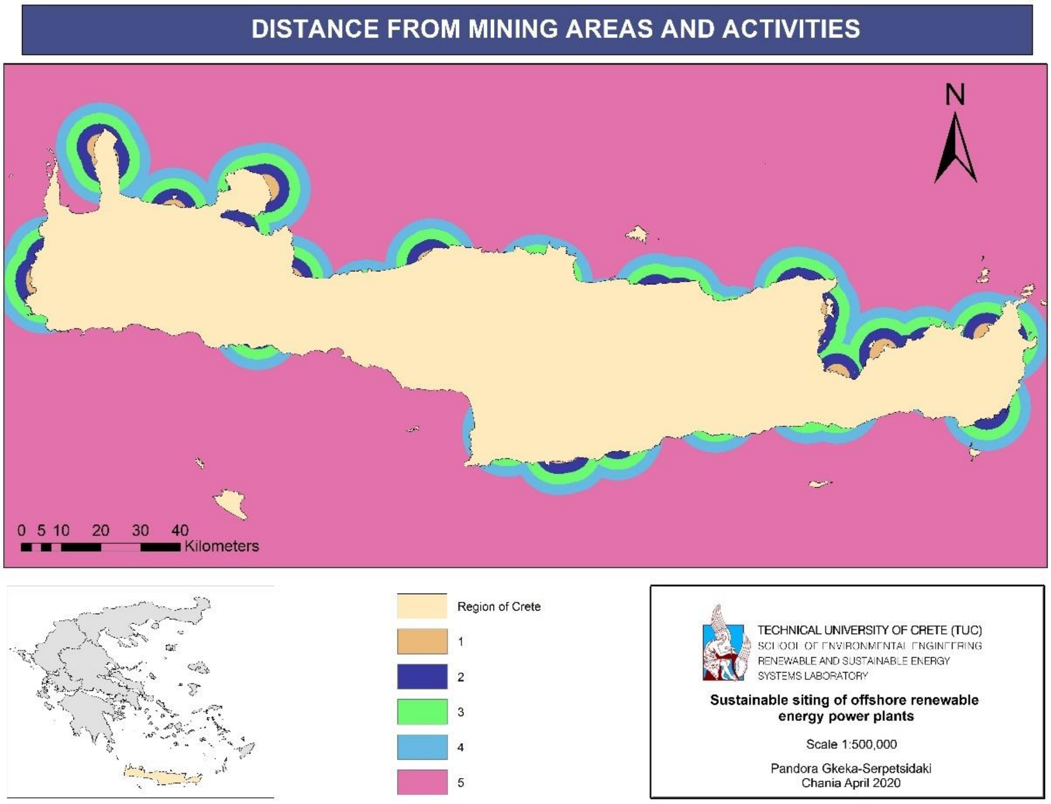


Figure B.21: Evaluation map: Distance from mining areas and activities

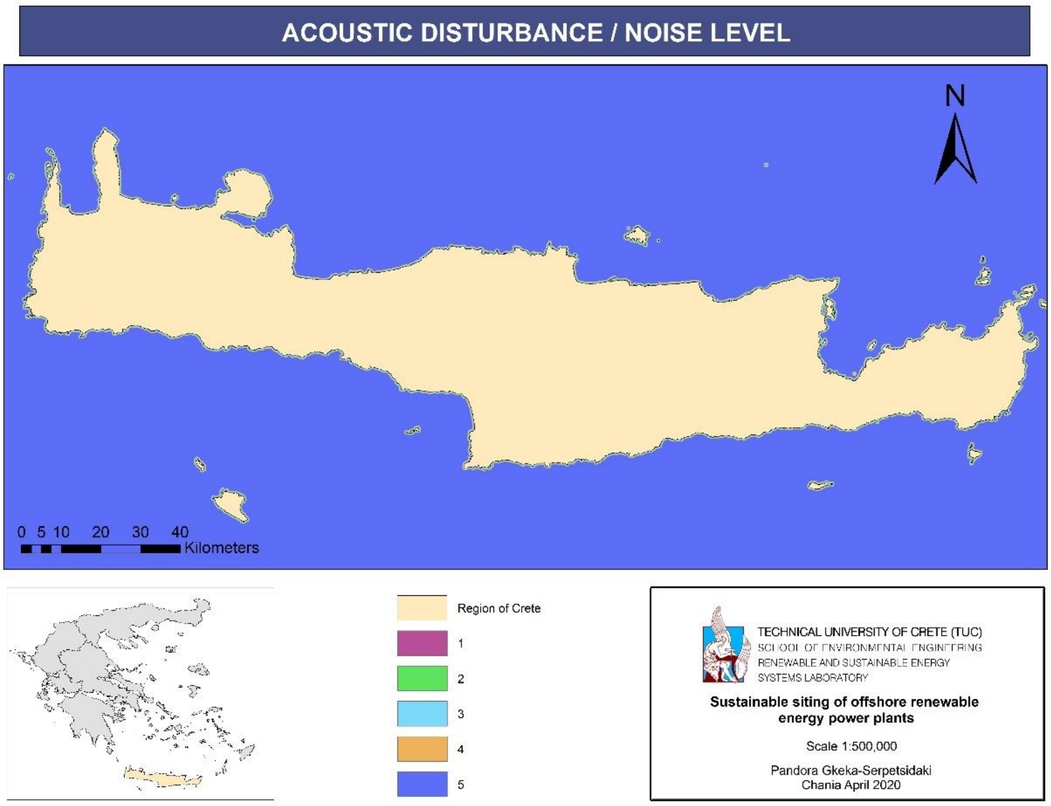


Figure B.22: Evaluation map: Acoustic disturbance/Noise level

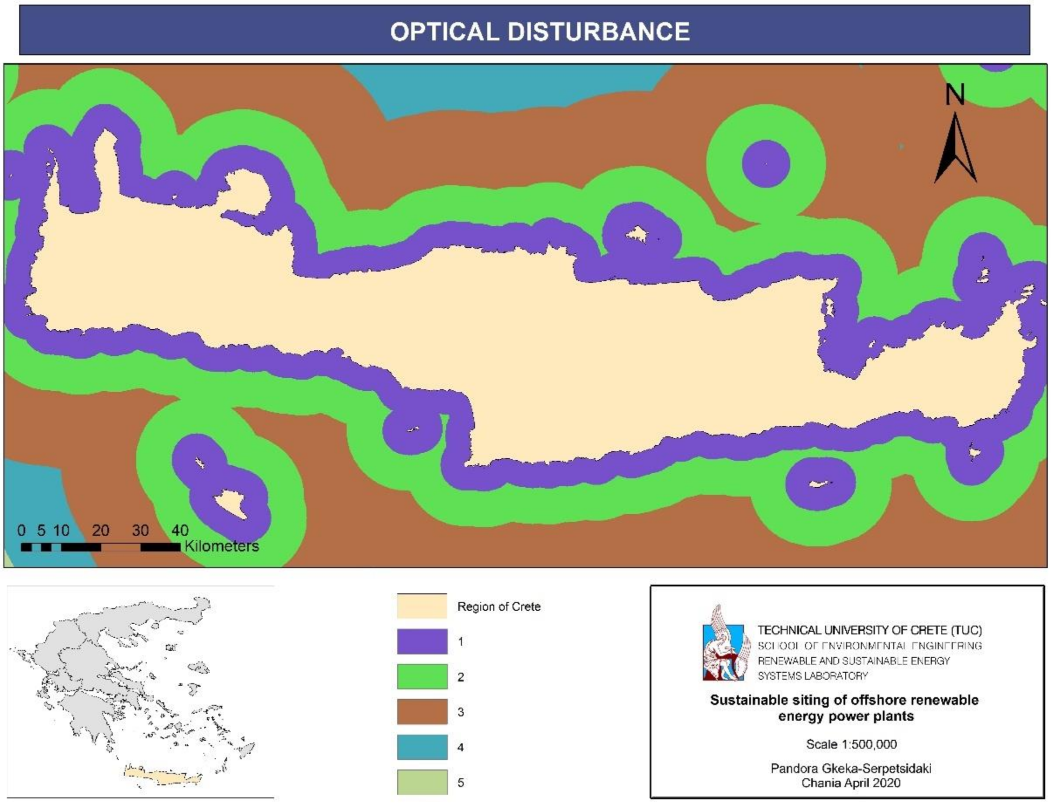


Figure B.23: Evaluation map: Optical disturbance

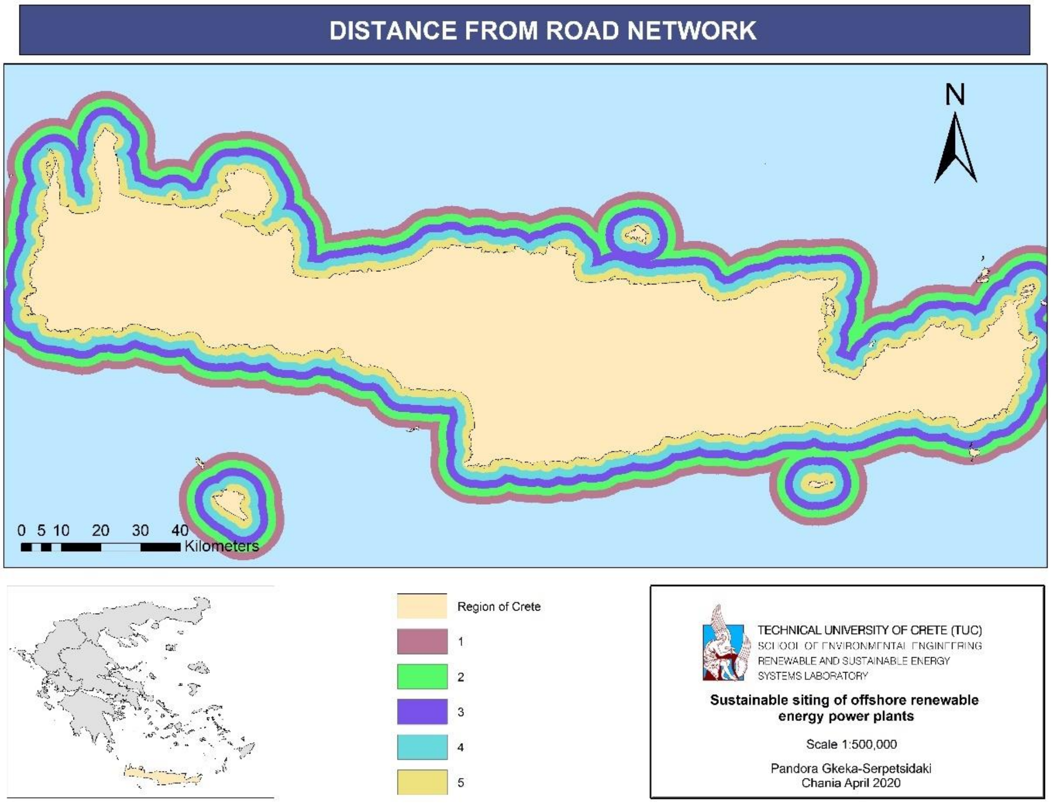


Figure B.24: Evaluation map: Distance from road network

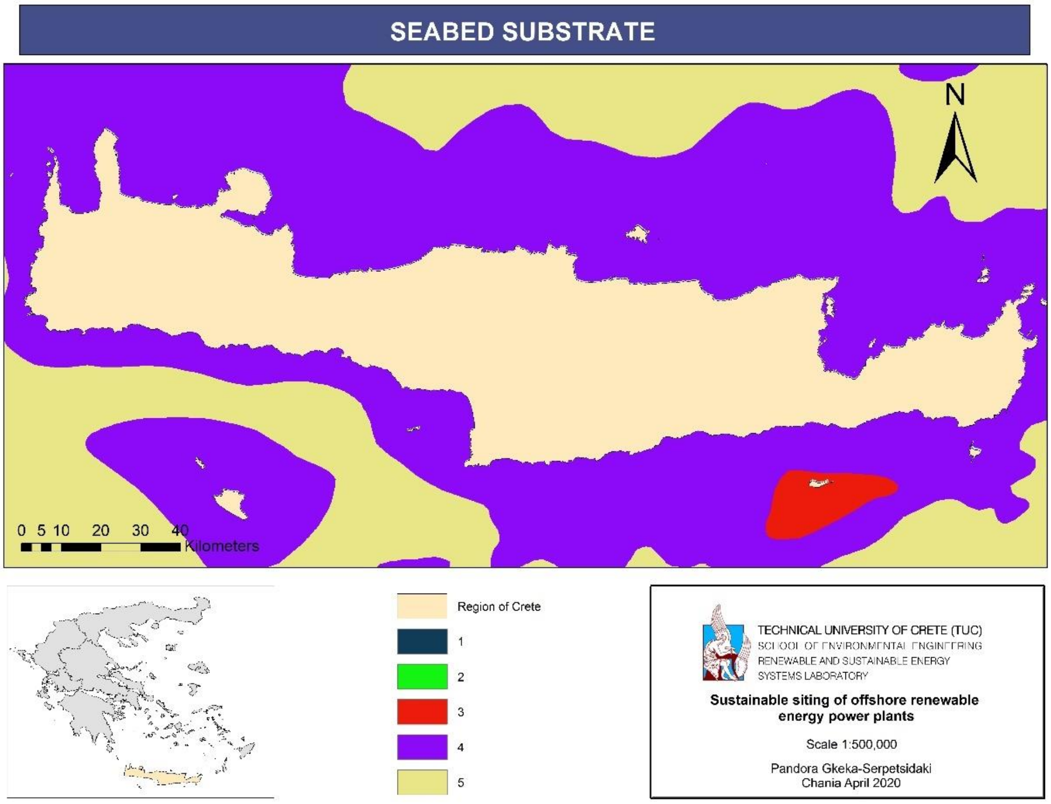


Figure B.25: Evaluation map: Seabed substrate

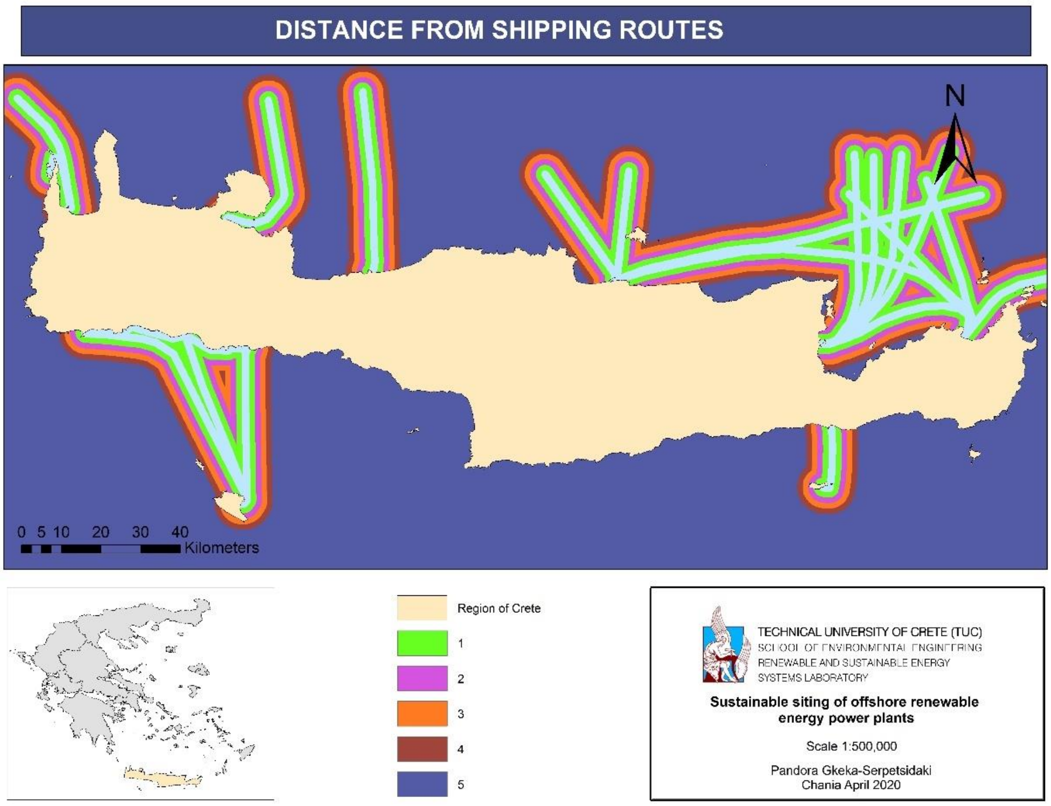


Figure B.26: Evaluation map: Distance from shipping routes

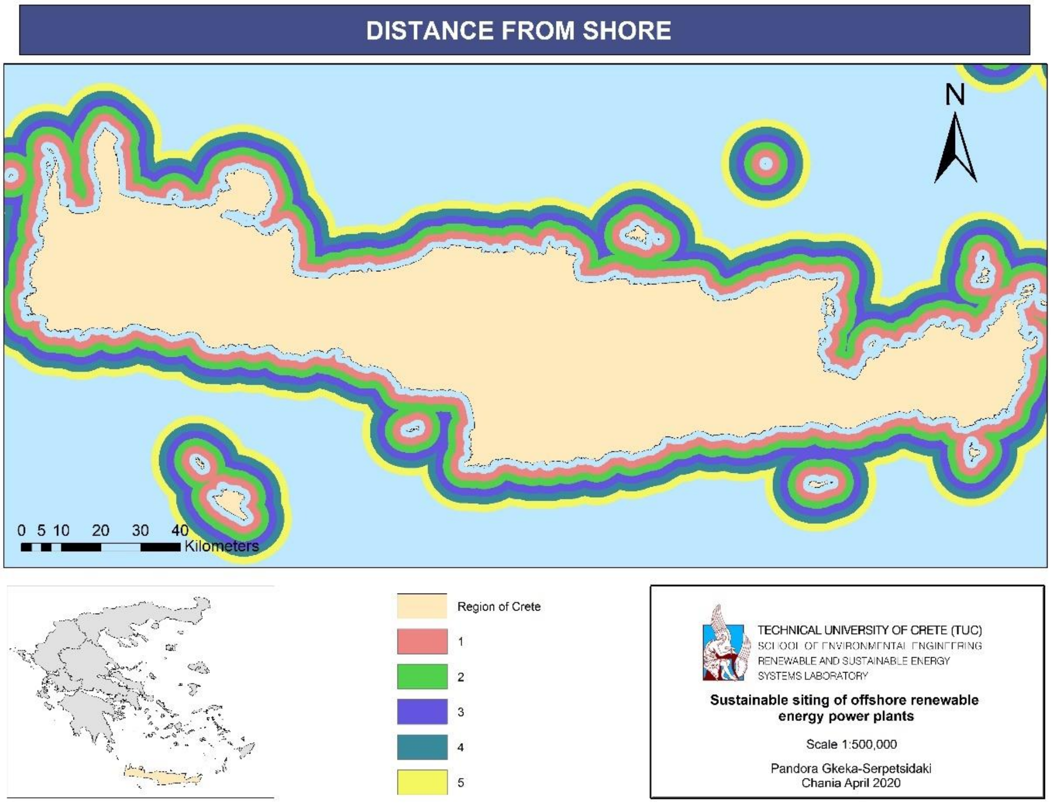


Figure B.27: Evaluation map: Distance from shore

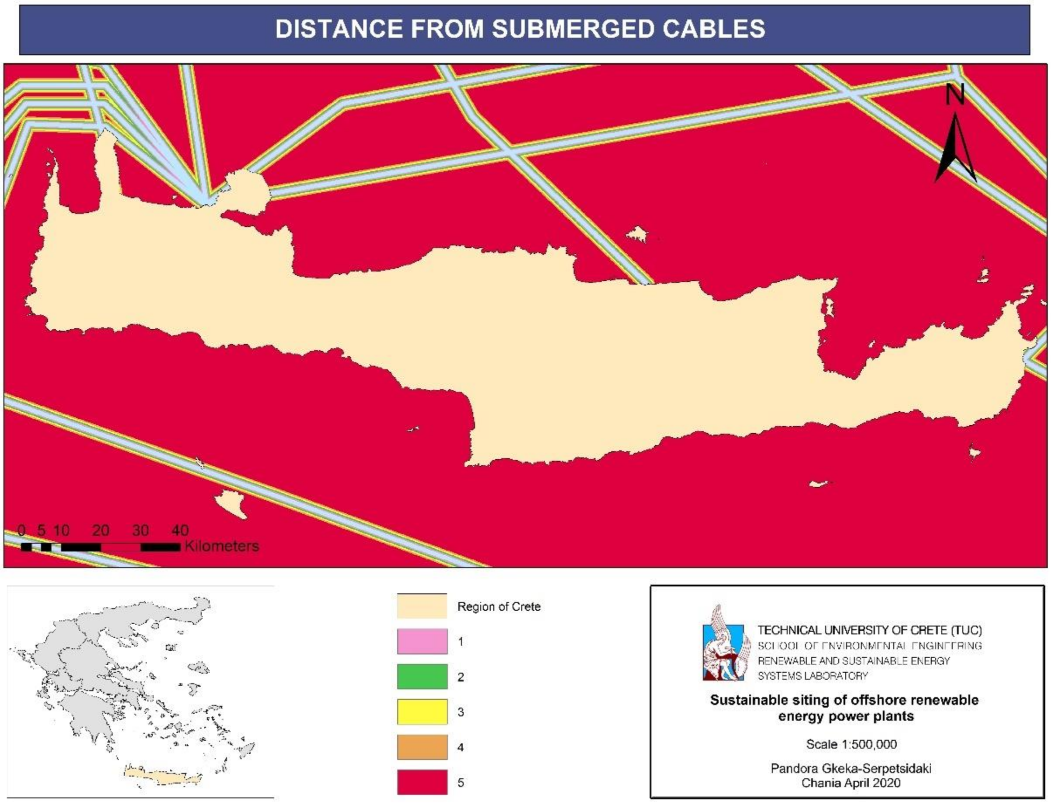


Figure B.28: Evaluation map: Distance from submerged cables

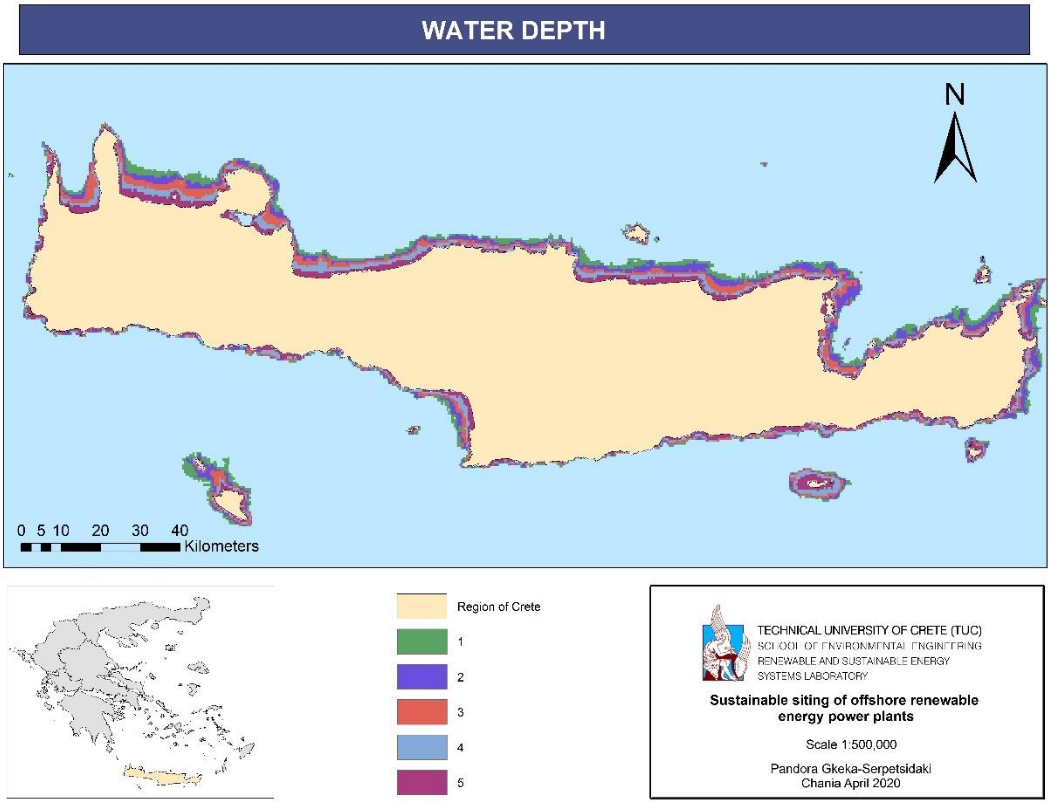


Figure B.29: Evaluation map: Water depth

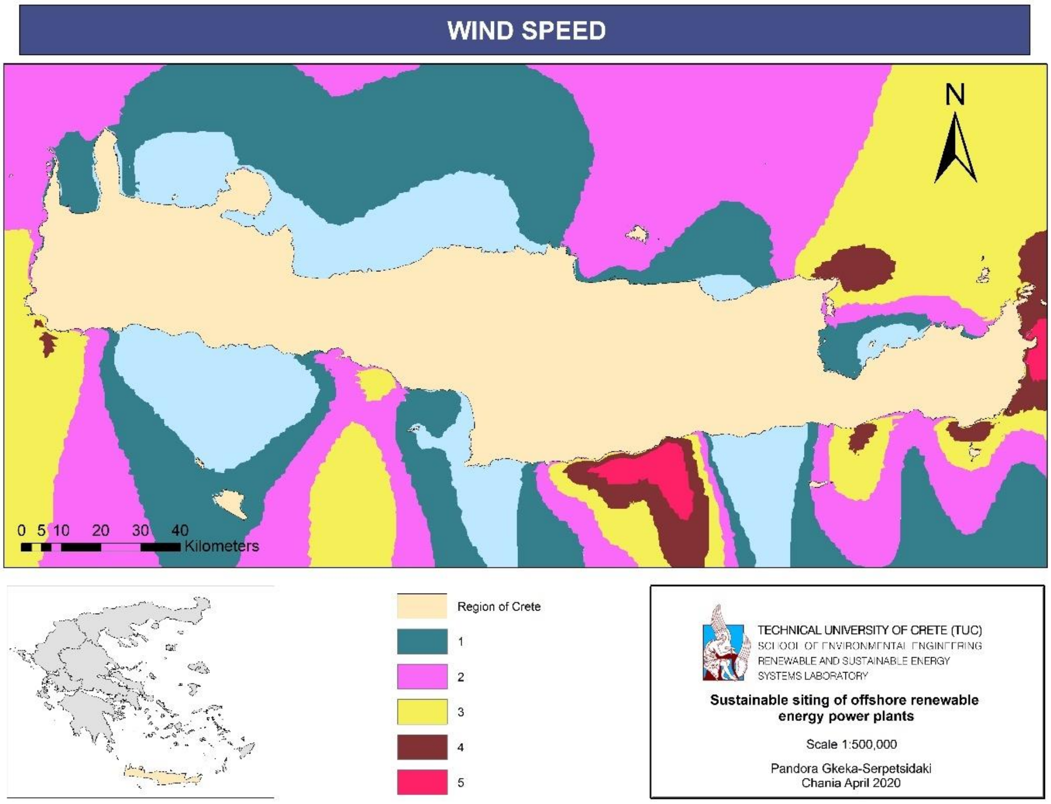


Figure B.30: Evaluation map: Wind speed

D. Annex C

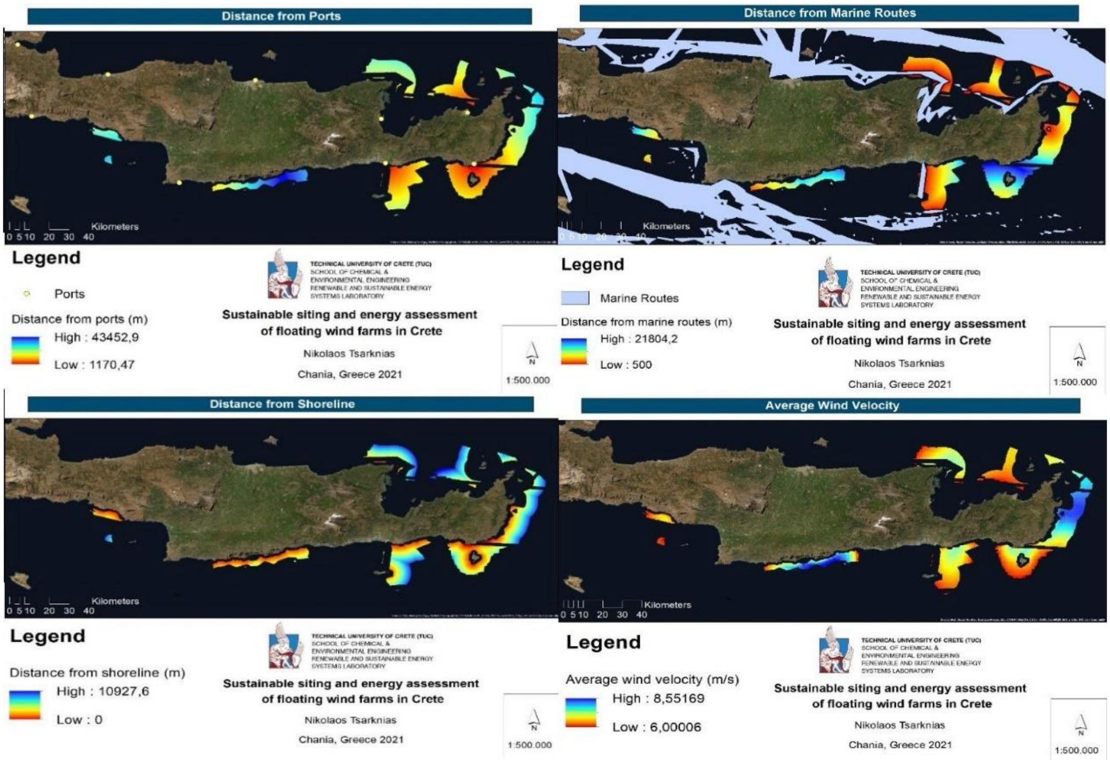


Figure C.1: EVC (1/2)

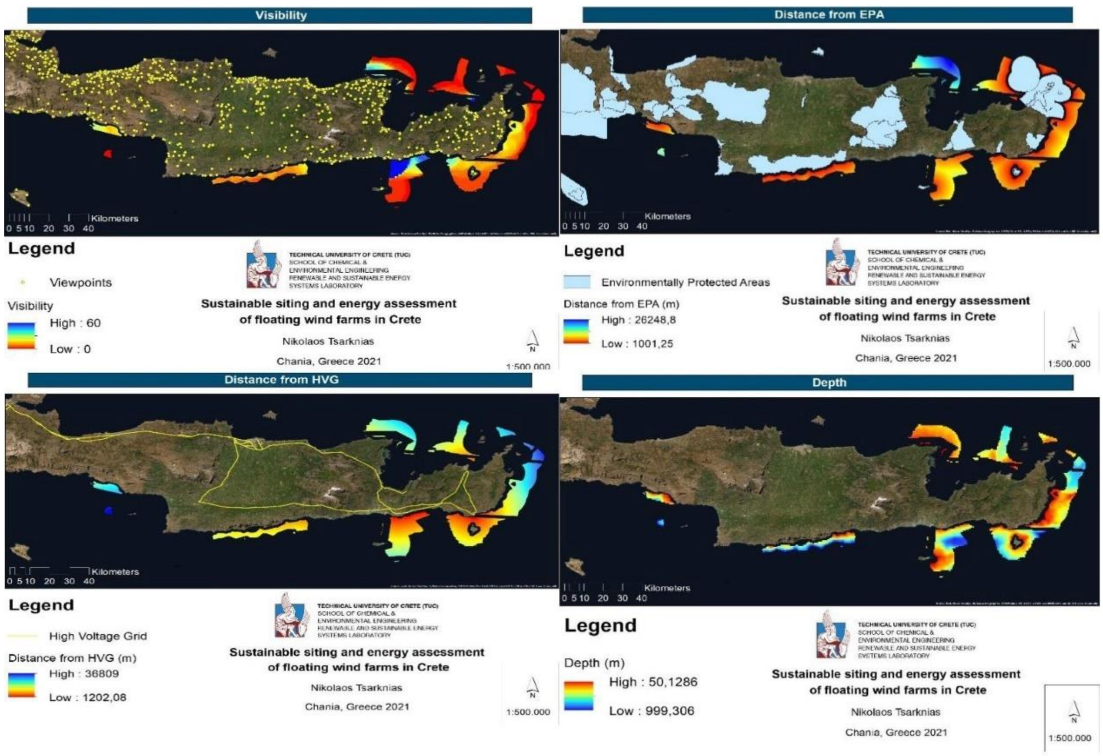


Figure A2:Evaluation Criteria (2/2) (ArcMap 10.7)

Figure C.2: EVC (2/2)

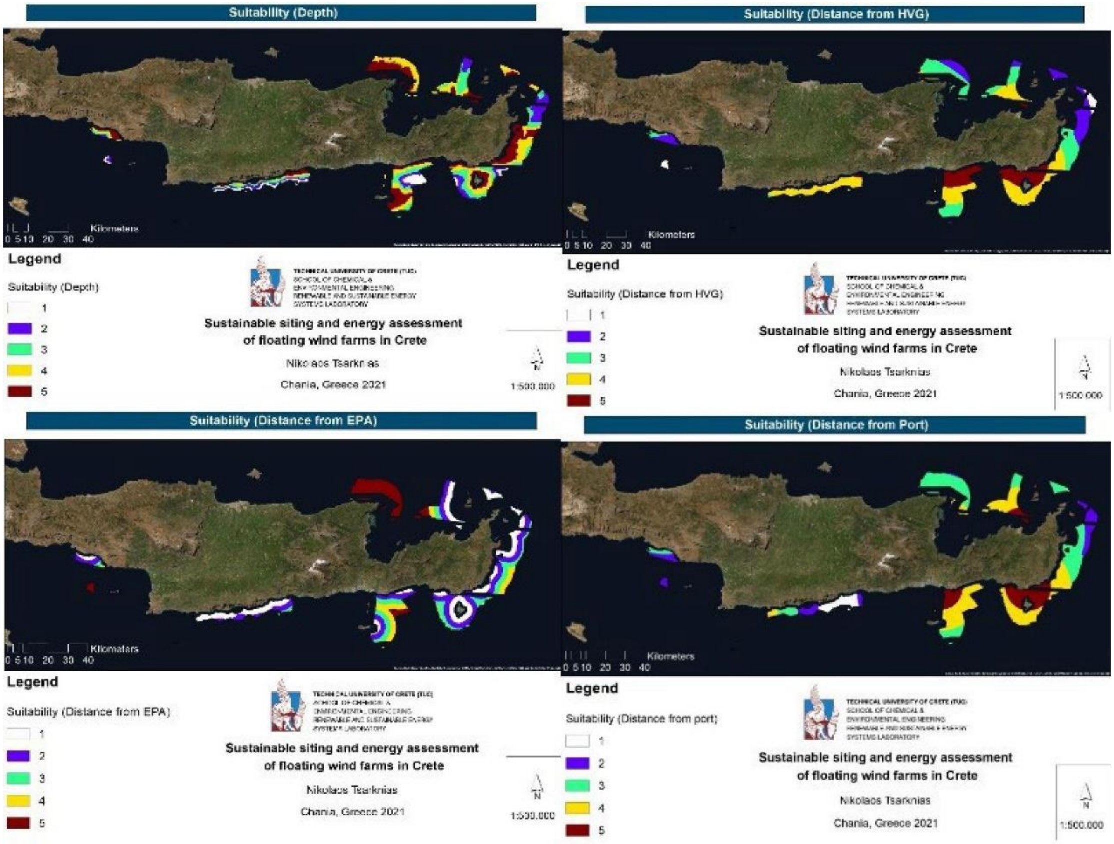


Figure C.3: Suitability of EVC (1/2)

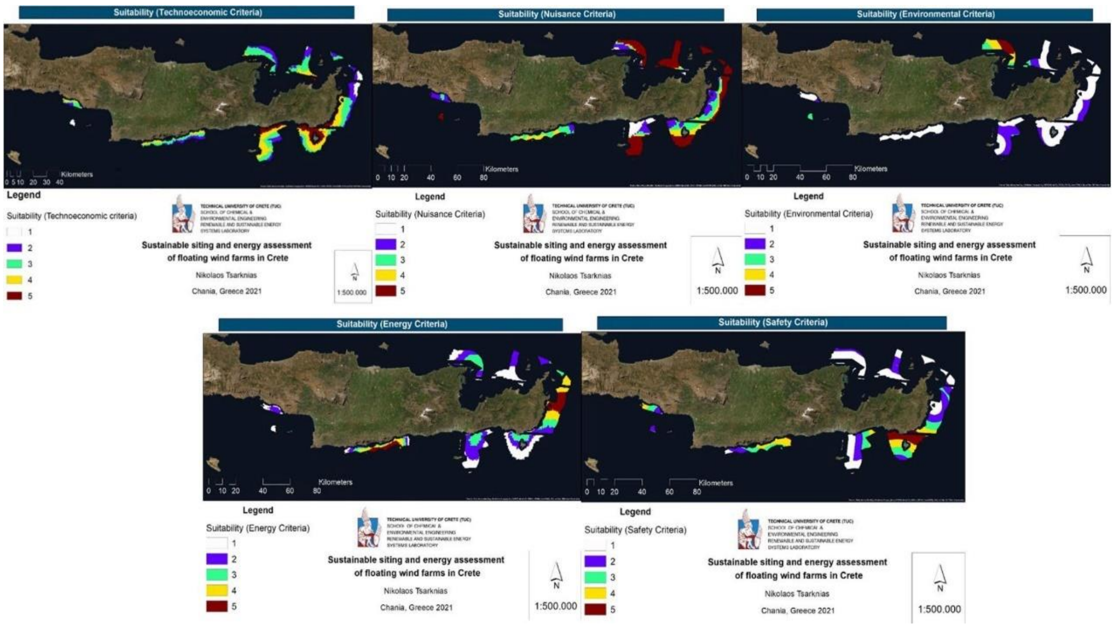


Figure C.4: Suitability of EVC (2/2)

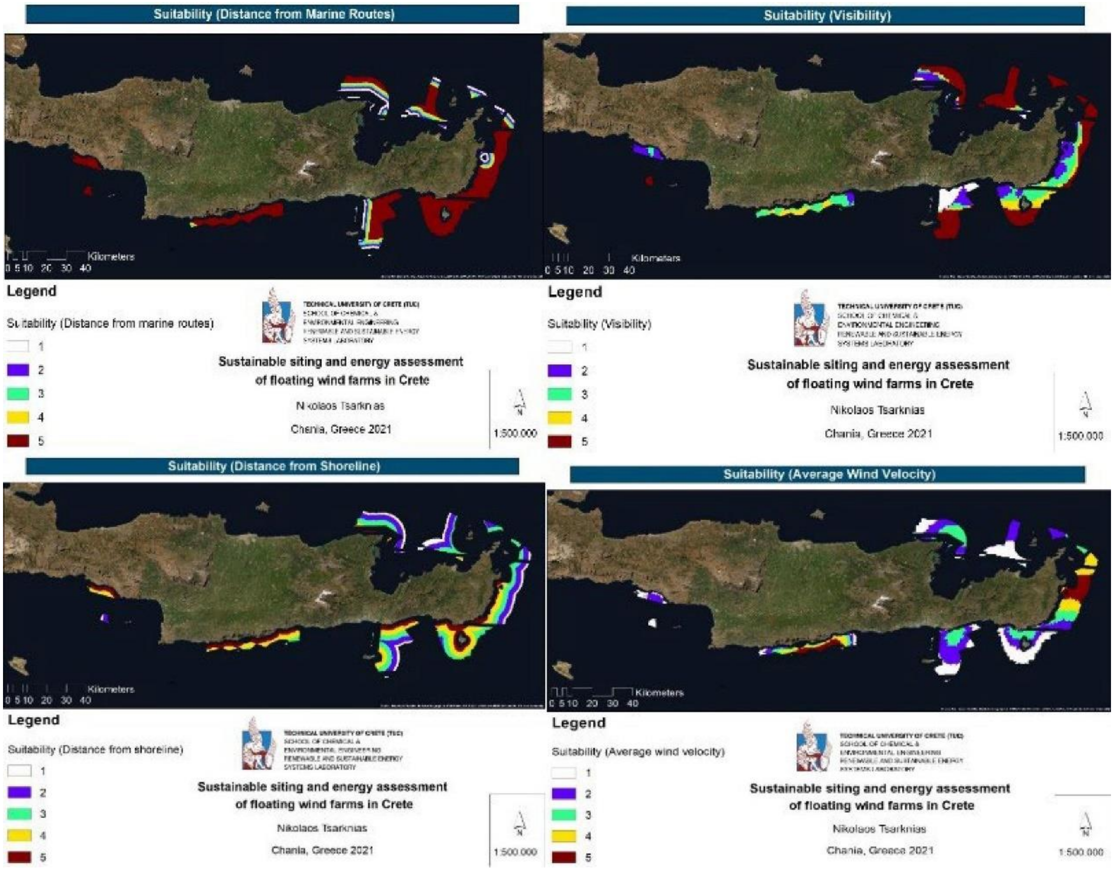


Figure C.5: Suitability of categorized criteria

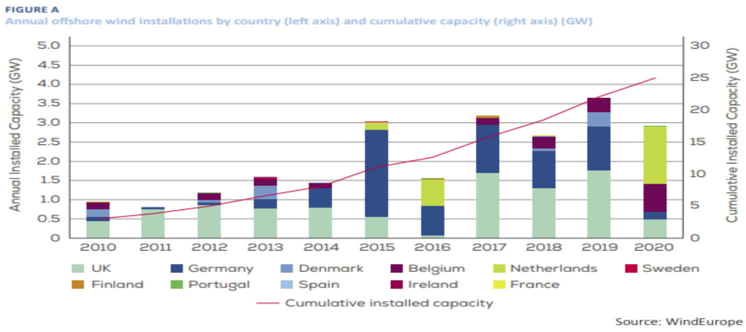


Figure D.6: Installed capacity of OWFs in Europe [104]

Table D.1: Floating Offshore wind potential [286]

Country/Region	Share Of Offshore Wind Resource (60 m Depth)	Potential (GW)
Europe	**80%**	**4000**
USA	**60%**	**2450**
Japan	**80%**	**500**
Taiwan	**-**	**90**

Figure D.7: Summary of floating wind platform technologies [286]

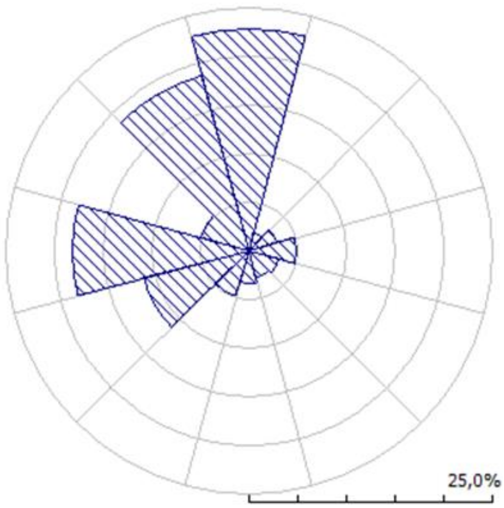


Figure D.8: Windrose diagram "Chrisi"

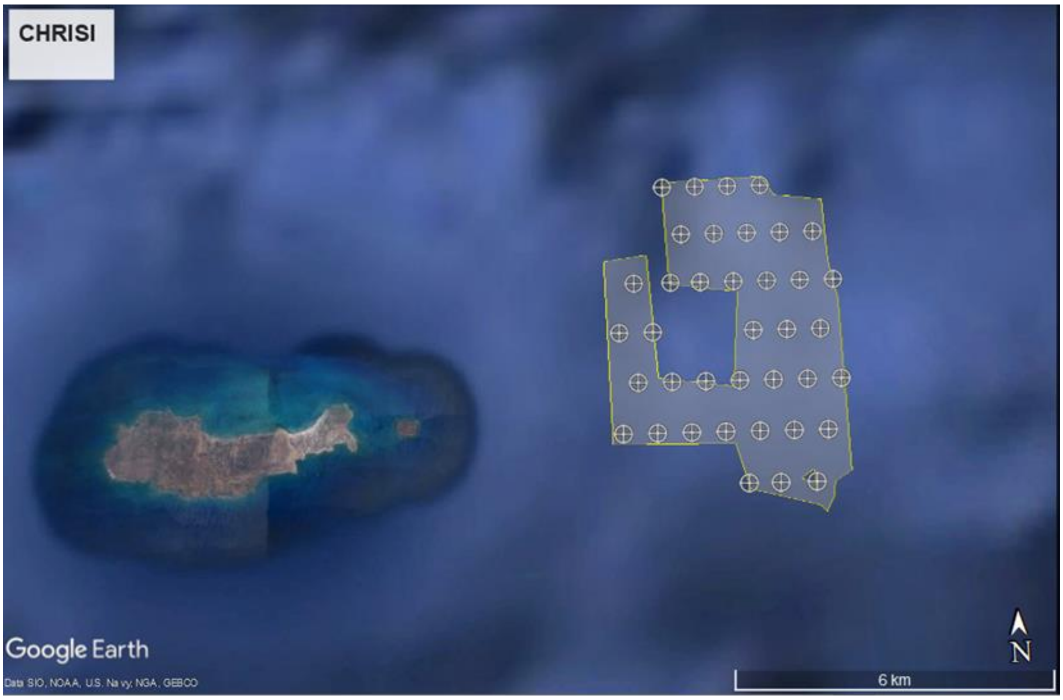


Figure D.9: Vestas V112 – 3 MW, 6X9 RD layout (38x3) 114 MW

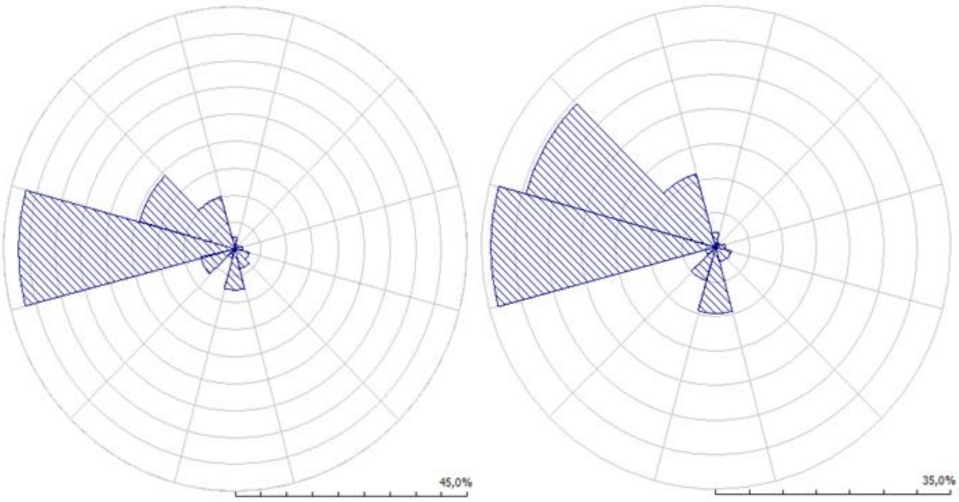


Figure D.10: Windrose diagrams “Elounta”

Figure D.11: Vestas V164 – 8 MW, 6X9 RD layout (16x8) 128 MW

E. Annex D

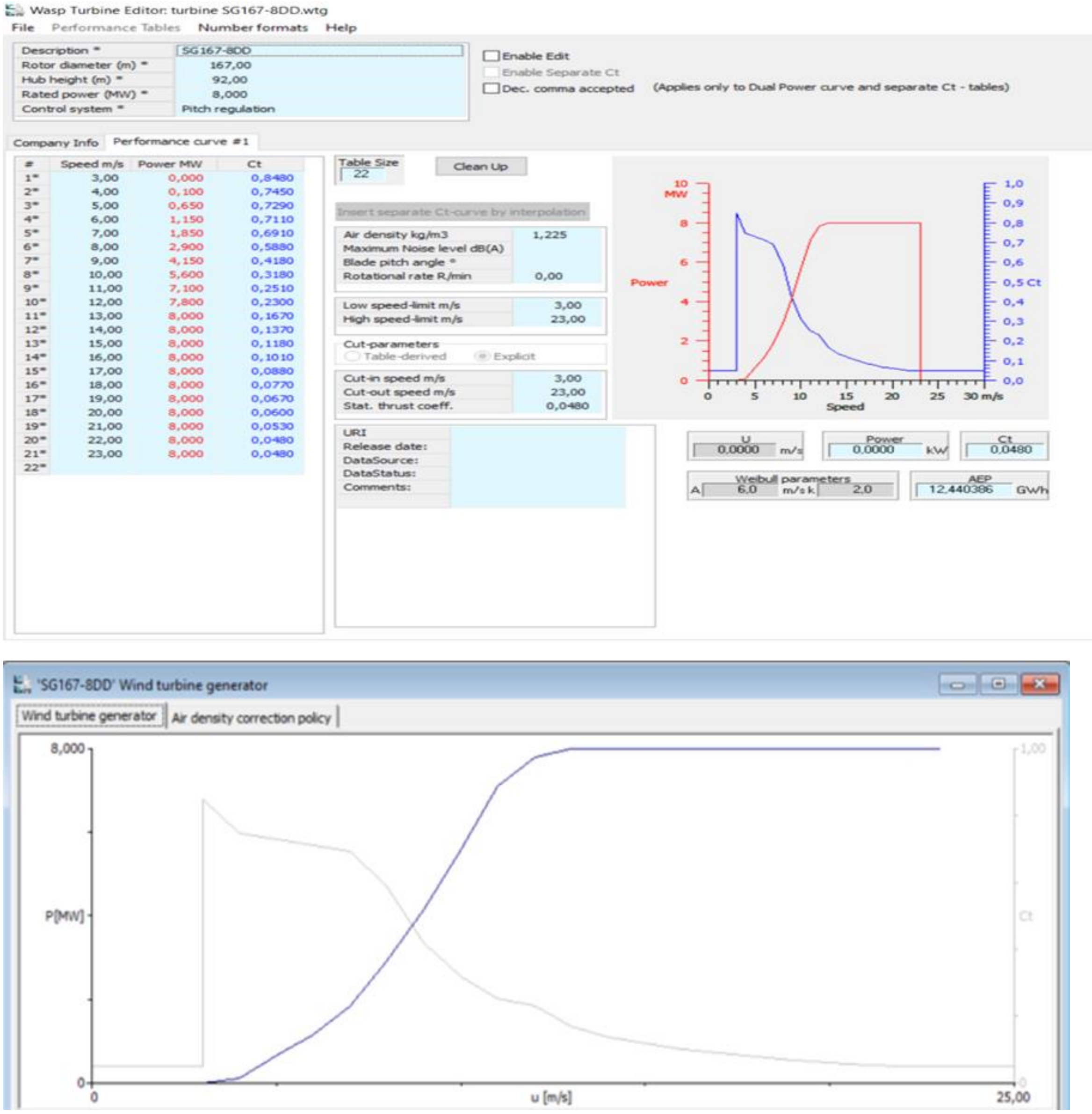


Figure D.1: Creation of Siemens GamesaSG167 - 8 MW profile in the WT Editor and power curve

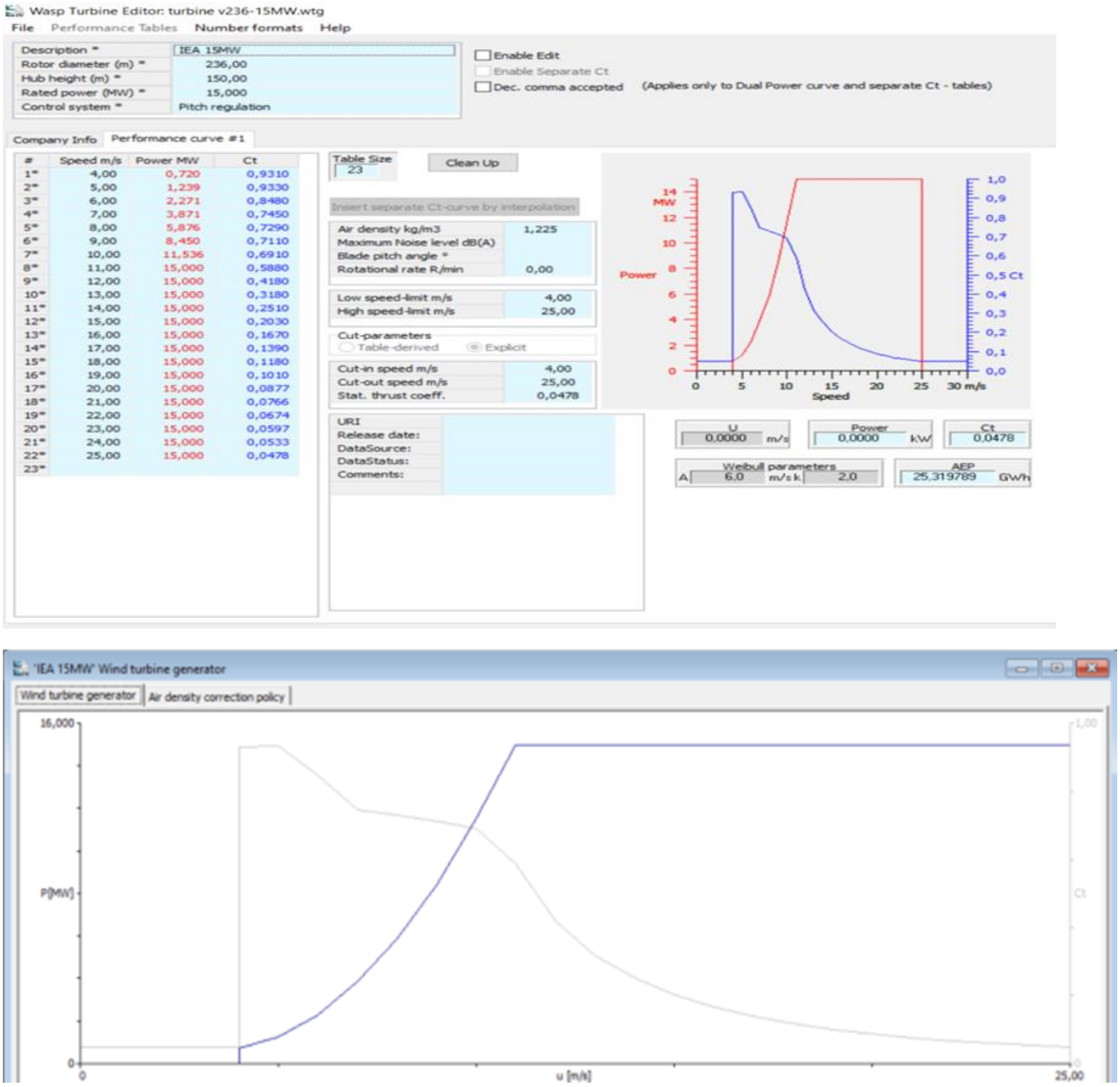


Figure D.2: Creation of Vestas V236 – 15 MW profile in the WT Editor and power curve

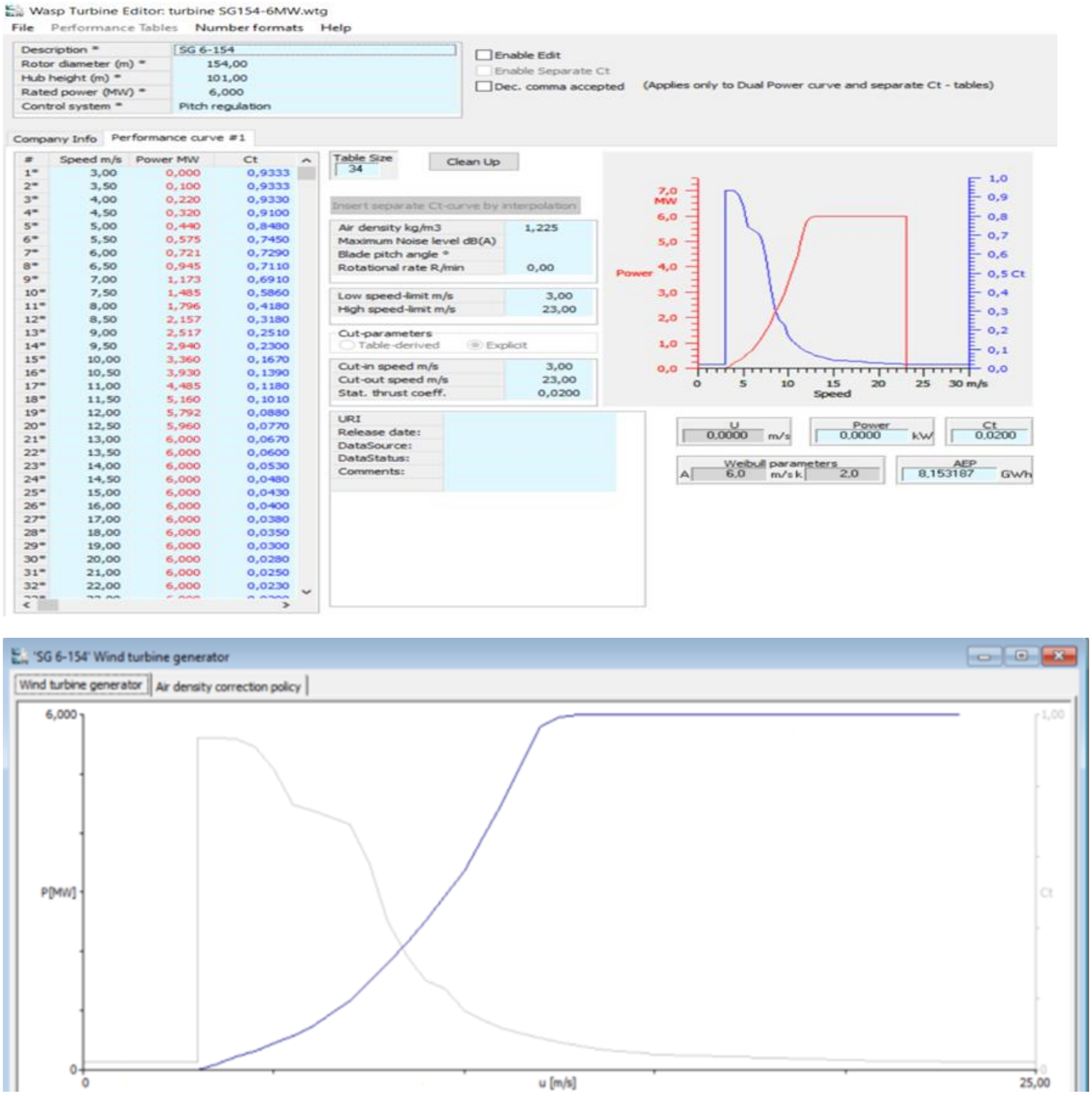


Figure D.3: Creation of Siemens Gamesa SG154-6MW Floating profile in the WT Editor and power curve

Table D.1: Wind data of scenario 2 (V236-15MW & SG154-6MW)

Angle [°]	Frequency [%]	Weibull-A [m/s]	Weibull-k	Average wind speed [m/s]
0	2.7	4.5	1.46	4.05
30	1.4	2.8	1.29	2.59
60	1.2	3	1.39	2.7
90	1.1	4	1.49	3.6
120	1.5	3.3	1.61	2.96

150	3.3	4.6	1	4.56
180	13.4	11.1	1.73	9.93
210	3.6	3.8	0.93	3.98
240	2	3.2	0.94	3.25
270	**21.9**	10.5	**3.13**	9.39
300	**38.7**	8.9	**3.03**	7.99
330	9.2	7	1.92	6.23
Sum	-	-	-	7.68

Table D.2: Results from the energy production analysis of Scenario 2

FWTs	**SG154-6MW**	**8**		
BFWTs	V236-15MW	11		
Sum of WTs		19		
Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	708.64	37.30	15.3	54.94
Total net AEP [GWh]	676.31	35.60	13.98	54.47
Proportional wake loss [%]	4.56	-	0.37	8.65
CF [%]	36.2	-	26.6	41.4
Mean speed [m/s]	-	7.33	7	7.68
Mean speed (wake-reduced) [m/s]	-	7.16	6.71	7.64
Air density [kg/m³]	-	1.19	1.18	1.19
Power density [W/m²]	-	484	429	540
RIX [%]	-	-	0	5.4

Table D.3: Wind data of scenario 3 (SG167-8MW & SG 154-6MW)

Angle [°]	Frequency [%]	Weibull-A [m/s]	Weibull-k	Average wind speed [m/s]
0	2.8	3.9	1.32	3.62
30	1.4	2.4	1.15	2.27
60	1.2	2.7	1.21	2.56
90	1	3.4	1.31	3.09
120	1.4	2.6	1.27	2.4
150	2.9	3.2	0.88	3.44
180	13.9	9.6	1.52	8.68
210	3.7	3.6	0.93	3.72
240	1.9	3	1.01	3.02
270	**21.7**	9.1	**3.1**	8.14
300	**37.3**	8	**2.88**	7.1
330	10.6	6.7	1.89	5.94
Sum				6.78

Table D.4: Results from the energy production analysis of Scenario 3

FWTs	SG154-6MW	11		
BFWTs	SG167-8MW	18		
Sum of WTs		29		
Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	562.47	19.40	15.22	22.80
Total net AEP [GWh]	537.30	18.53	14.43	22.65
Proportional wake loss [%]	4.47	-	0.25	8.08
CF [%]	29.20	-	27.4	32.3

Mean speed [m/s]	-	6.88	6.64	7.05
Mean speed (wake-reduced) [m/s]	-	6.73	6.57	6.95
Air density [kg/m³]	-	1.19	1.19	1.19
Power density [W/m²]	-	414	381	437
RIX [%]	-	-	0	5.2

Table D.5: Complete data per WT Scenario 2

	Site description	X-location [m]	Y-location [m]	RIX [%]	Height. [m]	Gross [GWh]	Net AEP [GWh]	Wake Loss [%]	CF [%]
Bottom-Fixed	**WT 001**	323684	3920593	0.6	150	54.941	54.473	0.85	41.4
	WT 005	329999	3916028	0	150	54.241	50.722	6.49	38.6
	WT 006	329965	3914399	0	150	53.817	49.673	7.7	37.8
	WT 007	328316	3913998	0	150	53.424	49.125	8.05	37.4
	WT 008	326682	3914407	0	150	53.279	49.986	6.18	38
	WT 009	325079	3913983	0.4	150	52.443	49.772	5.09	37.9
	WT 010	323554	3914667	4.3	150	51.084	50.896	0.37	38.7
	WT 011	323319	3916297	5.4	150	51.208	50.672	1.05	38.5
	WT 012	324182	3917725	2.2	150	53.197	52.763	0.82	40.1
	WT 013	325307	3915757	0	150	53.323	51.114	4.14	38.9
	WT 014	327762	3915961	0	150	53.964	50.539	6.35	38.4
Floating	**WT 1F**	324294	3919371	0.8	101	15.529	15.106	2.73	28.7
	WT 2F	325955	3917991	0	101	15.459	14.533	5.99	27.6
	WT 3F	325192	3918728	0.4	101	15.484	14.908	3.71	28.3
	WT 4F	325393	3917094	0.2	101	15.3	13.977	8.65	26.6

	WT 6F	326423	3916543	0	101	15.351	14.283	6.95	27.2
	WT 7F	326979	3917522	0	101	15.496	14.533	6.22	27.6
	WT 8F	328063	3917333	0	101	15.548	14.563	6.34	27.7
	WT 9F	329088	3917014	0	101	15.556	14.677	5.65	27.9

Table D.6: Complete data per WT Scenario 3

	Site description	**X-location [m]**	**Y-location [m]**	**RIX [%]**	**Height. [m]**	**Gross [GWh]**	**Net AEP [GWh]**	**Wake Loss [%]**	**CF [%]**
Bottom-Fixed	**WT 001**	324485	3916137	1.9	92	21.651	20.83	3.79	29.7
	WT 002	323679	3920602	0.6	92	22.804	22.651	0.67	32.3
	WT 004	324254	3918668	1.3	92	22.185	21.846	1.53	31.2
	WT 005	324120	3917503	2.5	92	21.714	21.512	0.93	30.7
	WT 006	323386	3916580	5.2	92	20.82	20.599	1.06	29.4
	WT 007	323538	3915425	4.3	92	20.819	20.61	1	29.4
	WT 008	323661	3914261	3.9	92	20.605	20.553	0.25	29.3
	WT 009	324772	3913899	0.9	92	21.265	20.525	3.48	29.3
	WT 010	325883	3914268	0	92	21.745	20.551	5.49	29.3
	WT 011	327057	3914342	0	92	21.946	20.48	6.68	29.2
	WT 012	328191	3914041	0	92	21.982	20.334	7.5	29
	WT 013	329369	3914106	0	92	22.133	20.345	8.08	29
	WT 014	330412	3914640	0	92	22.293	20.617	7.52	29.4
	WT 015	330159	3915784	0	92	22.428	21.125	5.81	30.1
	WT 021	329037	3915210	0	92	22.275	20.588	7.57	29.4
	WT 022	327861	3915177	0	92	22.156	20.678	6.67	29.5
	WT 024	326678	3915452	0	92	22.08	20.665	6.41	29.5

	WT 026	325011	3915053	0.2	92	21.661	20.811	3.93	29.7
Floating	**WT 11F**	324485	3919789	0.6	101	15.625	15.159	2.99	28.8
	WT 1F	325379	3918752	0.3	101	15.507	14.895	3.95	28.3
	WT 2F	325955	3917846	0	101	15.443	14.895	3.55	28.3
	WT 3F	327038	3917630	0	101	15.508	14.719	5.08	28
	WT 4F	328113	3917640	0	101	15.569	14.912	4.22	28.4
	WT 5F	329432	3916661	0	101	15.541	14.797	4.79	28.1
	WT 6F	328433	3916153	0	101	15.457	14.523	6.05	27.6
	WT 7F	327377	3916375	0	101	15.395	14.433	6.25	27.4
	WT 8F	326353	3916791	0	101	15.371	14.589	5.09	27.7
	WT 9F	325200	3917075	0.5	101	15.268	14.567	4.59	27.7
	WT 10F	325625	3915985	0	101	15.221	14.492	4.79	27.6

Table D.7: CAPEX Calculation Data Scenario 2 [193][237]

Project development and management	**120,000**	**£/MW**	**£25,560,000**
Development and licensing services	50,000	£/MW	£10,650,000
(i) Environmental studies (=4000£) (ii) Assessment of resources (=4000£) (iii) Geological and hydrological studies (=4000£) (iv) Engineering and consultancy (=4000£)	16,000	£/MW	£3,408,000
Other (includes developer staff hours and other subcontracted work)	42,000	£/MW	£8,946,000
OWTs (Nacelle, rotor, tower, etc)			
10 BFWTs	1,000,000	£/MW	£165,000,000
19 FWTs	1,300,000	£/MW	£62,400,000

Offshore substation (electrical system, facilities, structure)	120,000	£/MW	£25,560,000
Onshore substation (Buildings, access and security, other)	30,000	£/MW	£6,390,000
Cables (Extract & Type & Anchor & Protect)	170,000	£/MW	£36,210,000
Installation and commissioning	650,000	£/MW	£107,250,000
Foundation installation	100,000	£/MW	£16,500,000
Offshore substation installation	35,000	£/MW	£5,775,000
Construction of onshore substation	25,000	£/MW	£4,125,000
Onshore installation of export cables	5,000	£/MW	£825,000
Offshore cable installation	220,000	£/MW	£36,300,000
WT installation	50,000	£/MW	£8,250,000
Offshore logistics	3,000	£/MW	£495,000
Other	212,000	£/MW	£34,980,000
Installation Floating type TLP (steel)	108,663	£/MW	£5,215,814
Anchorages			£481,395
Synthetic rope	1860	M£	£334,884
Chain	698	M£	£125,581
Wire rope	116	M£	£20,930
Anchor	132,558	M£	£265,116
TOTAL CAPEX	3,390,000	£/MW	£434,332,326
	3,941,860	**€/MW**	**505,037,588 €**

Table D.8: Results of Economic Analysis of Scenario 2

Index	Years	Cost (€)

CAPEX	8	505,037,588
OPEX	25	485,295,159
DECEX	3	19,806,655
Sum (CAPEX+OPEX+DECEX)	36	1,010,139,402
Average Energy Price Net Cash Flows	36	713,615,905
Maximum Energy Price Net Cash Flows	36	1,168,944,306
AEP (MWh)	33	16,907,850
NPV Average Energy Price	25	12,298,372
NPV Maximum Energy Price	25	167,140,297 €

Table D.9: CAPEX Calculation Data Scenario 3 [193][237]

Project development and management	**120,000**	**£/MW**	**£25,200,000**
Development and licensing services	50,000	£/MW	£10,500,000
(i) Environmental studies (=4000£) (ii) Assessment of resources (=4000£) (iii) Geological and hydrological studies (=4000£) (iv) Engineering and consultancy (=4000£)	16,000	£/MW	£3,360,000
Other (includes developer staff hours and other subcontracted work)	42,000	£/MW	£8,820,000
OWTs (Nacelle, rotor, tower, etc)			
10 BFWTs	860,000	£/MW	£144,000,000
19 FWTs	1,300,000	£/MW	£85,800,000

Offshore substation (electrical system, facilities, structure)	120,000	£/MW	£25,200,000
Onshore substation (Buildings, access and security, other)	30,000	£/MW	£6,300,000
Cables (Extract & Type & Anchor & Protect)	170,000	£/MW	£35,700,000
Installation and commissioning	650,000	£/MW	£93,600,000
Foundation installation	100,000	£/MW	£14,400,000
Offshore substation installation	35,000	£/MW	£5,040,000
Construction of onshore substation	25,000	£/MW	£3,600,000
Onshore installation of export cables	5,000	£/MW	£720,000
Offshore cable installation	22,0000	£/MW	£31,680,000
WT installation	50,000	£/MW	£7,200,000
Offshore logistics	3,000	£/MW	£432,000
Other	212,000	£/MW	£30,528,000
Installation Floating type TLP (steel)	108,663	£/MW	£7,171,744
Anchorages			£481,395
Synthetic rope	1860	M£	£334,884
Chain	698	M£	£125,581
Wire rope	116	M£	£20,930
Anchor	132,558	M£	£265,116
TOTAL CAPEX	3,390,000	£/MW	£423,718,256
	3,941,860	**€/MW**	492,695,646 €

Table D.10: Results of Economic Analysis of Scenario 3

Index	Years	Cost (€)

CAPEX	8	492,695,646
OPEX	25	473,435,677
DECEX	3	19,322,626
Sum (CAPEX+OPEX+DECEX)	36	985,453,949
Average Energy Price Net Cash Flows	36	383,989,426
Maximum Energy Price Net Cash Flows	36	745,726,651
AEP (MWh)	25	13,432,500
NPV Average Energy Price	36	-94,166,631
NPV Maximum Energy Price	36	28,848,073

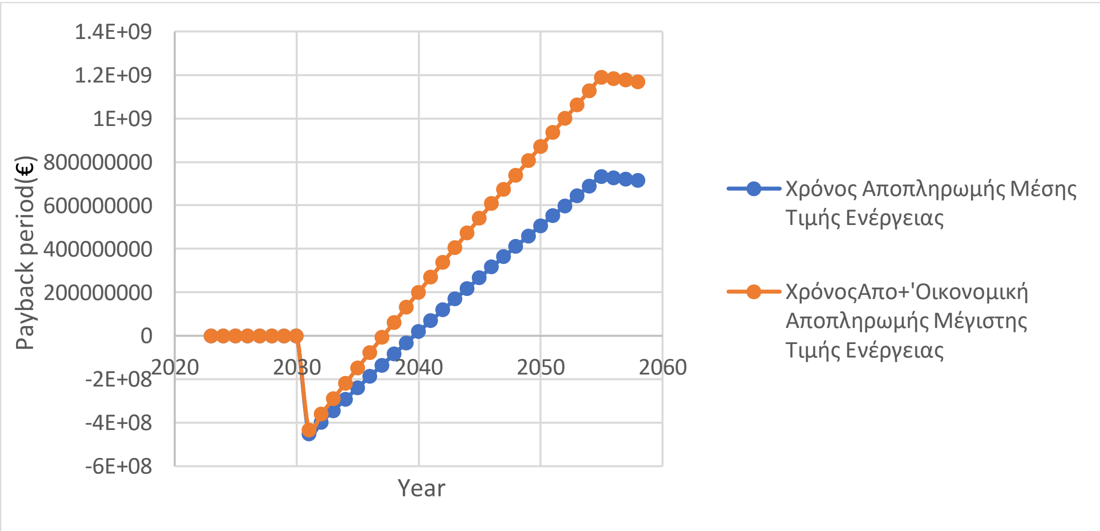


Figure E.4: Average and Maximum Energy Price PP vs Investment Time Scenario 2

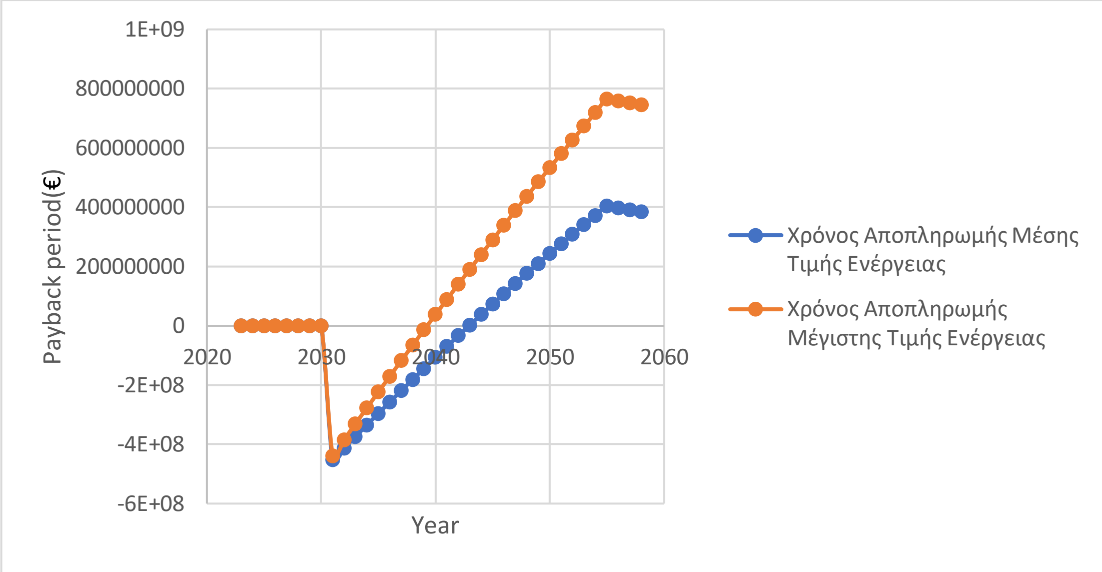


Figure E.5: Average and Maximum Energy Price PP vs Investment Time Scenario 3

F. Annex E

Table F.1: Results from SPM for Scenario 1

V.C	a	b	n	v	c	x	d	e	pa1	Visual impact	pa2	Visual impact
1	1.0	1.0	1.1	0.5	0.55	5000	0.100	0.9	0.055	Minimum	0.050	Minimum
2	1.0	1.0	1.1	0.2	0.22	3103	0.429	1.0	0.094	Minimum	0.094	Minimum
3	1.0	1.0	1.1	0.2	0.22	2991	0.452	1.0	0.099	Minimum	0.099	Minimum
4	1.0	1.0	1.1	0.2	0.22	2893	0.471	1.0	0.104	Light	0.104	Light
5	1.0	1.0	1.1	0.5	0.55	2984	0.453	0.6	0.249	Light	0.150	Light
6	1.0	1.0	1.1	1.0	1.10	2692	0.453	0.9	0.563	Serious	0.506	Serious

Table F.2: Results from SPM for Scenario 2

V.C	a	b	n	v	c	x	d	e	pa1	Visual impact	pa2	Visual impact
1	1.0	1.0	1.05	0.5	0.530	5138	0.100	0.9	0.053	Minimum	0.047	Minimum
2	1.0	1.0	1.05	0.2	0.21	3545	0.341	1.0	0.072	Minimum	0.072	Minimum
3	1.0	1.0	1.05	0.2	0.21	3458	0.358	1.0	0.075	Minimum	0.075	Minimum
4	1.0	1.0	1.05	0.2	0.21	3329	0.384	1.0	0.081	Minimum	0.081	Minimum
5	1.0	1.0	1.05	0.5	0.53	2840	0.482	0.6	0.253	Light	0.152	Light
6	1.0	1.0	1.05	1.0	1.05	2388	0.572	0.9	0.601	Serious	0.541	Serious

Table F.3: Results from SPM for Scenario 3

V.C	a	b	n	v	c	x	d	e	pa1	Visual impact	pa2	Visual impact
1	1.0	1.0	1.0	0.5	0.5	5000	0.100	0.9	0.050	Minimum	0.045	Minimum
2	1.0	1.0	1.0	0.2	0.2	3937	0.263	1.0	0.053	Minimum	0.053	Minimum
3	1.0	1.0	1.0	0.2	0.2	3871	0.276	1.0	0.055	Minimum	0.055	Minimum

4	1.0	1.0	1.0	0.5	0.5	4074	0.235	1.0	0.118	Light	0.118	Light
5	1.0	1.0	1.0	1.0	1.0	5559	0.100	0.6	0.100	Light	0.060	Minimum
6	1.0	1.0	1.0	1.0	1.0	4260	0.198	0.9	0.198	Light	0.178	Light

Table F.4: Results from SPM for Scenario 4

V.C	**a**	**b**	**n**	**v**	**c**	**x**	**d**	**e**	**pa1**	**Visual impact**	**pa2**	**Visual Impact**
1	1.0	1.0	0.9	0.2	0.18	5138	0.100	0.9	0.018	Minimum	0.016	Minimum
2	1.0	1.0	0.9	0.2	0.18	4654	0.119	1.0	0.021	Minimum	0.021	Minimum
3	1.0	1.0	0.9	0.5	0.45	4601	0.130	1.0	0.058	Minimum	0.058	Minimum
4	1.0	1.0	0.9	0.5	0.45	4742	0.102	1.0	0.046	Minimum	0.046	Minimum
5	1.0	1.0	0.9	1.0	0.90	5748	0.100	0.6	0.090	Minimum	0.054	Minimum
6	1.0	1.0	0.9	1.0	0.90	4438	0.162	0.9	0.146	Light	0.132	Light

Table F.5: Results from sequence of calculations 1 for Scenario 1 and Scenario 2

	Scenario 1						**Scenario 2**					
V.C	v	c	PA1	Visual Impact	PA2	Visual Impact	v	c	PA1	Visual Impact	PA2	Visual Impact
1	1.000	1.100	0.110	Light	0.099	Min	1.000	1.050	0.105	Light	0.095	Min
2	0.556	0.611	0.262	Light	0.262	Light	0.601	0.631	0.215	Light	0.215	Light
3	0.556	0.611	0.276	Light	0.276	Light	0.601	0.631	0.226	Light	0.226	Light
4	0.556	0.611	0.288	Light	0.288	Light	0.601	0.631	0.242	Light	0.242	Light
5	1.000	1.100	0.499	Medium	0.299	Light	1.000	1.050	0.506	Serious	0.304	Medium

2	0.831	0.915	0.468	Medium	0.421	Medium		0.800	0.840	0.481	Medium	0.433	Medium

Table F.6: Results from sequence of calculations 1 for Scenario 3 and Scenario 4

	Scenario 3						**Scenario 4**					
V.C	v	c	PA1	Visual Impact	PA2	Visual Impact	v	c	PA1	Visual Impact	PA2	Visual Impact
1	1.000	1.000	0.100	Min	0.090	Min	0.336	0.302	0.030	Min	0.027	Min
2	0.192	0.192	0.050	Min	0.050	Min	0.336	0.302	0.036	Min	0.036	Min
3	0.192	0.192	0.053	Min	0.053	Min	1.000	0.900	0.117	Light	0.117	Light
4	1.000	1.000	0.235	Light	0.235	Light	1.000	0.900	0.091	Min	0.091	Min
5	0.984	0.984	0.098	Min	0.059	Min	0.974	0.876	0.088	Min	0.053	Min
6	0.984	0.984	0.195	Light	0.175	Light	0.974	0.876	0.142	Light	0.128	Light

Table F.7: Results from sequence of calculations 2 for Scenario 1 and Scenario 2

	Scenario 1						**Scenario 2**					
V.C	v	c	PA1	Visual Impact	PA2	Visual Impact	v	c	PA1	Visual Impact	PA2	Visual Impact
1	0.752	0.828	0.083	Min	0.074	Min	0.803	0.843	0.084	Min	0.076	Min
2	0.627	0.690	0.296	Light	0.296	Light	0.669	0.702	0.239	Light	0.239	Light

3	0.653	0.718	0.325	Medium	0.325	Medium	0.695	0.729	0.261	Light	0.261	Light
4	0.671	0.738	0.348	Medium	0.348	Medium	0.737	0.774	0.297	Light	0.297	Light
5	0.827	0.910	0.412	Medium	0.247	Light	0.818	0.858	0.414	Medium	0.248	Light
6	1.000	1.100	0.563	Serious	0.506	Serious	0.993	1.042	0.597	Serious	0.537	Serious

Table F.8: Results from sequence of calculations 2 for Scenario 3 and Scenario 4

	Scenario 3						**Scenario 4**					
V.C	v	c	PA1	Visual Impact	PA2	Visual Impact	v	c	PA1	Visual Impact	PA2	Visual Impact
1	0.394	0.394	0.039	Min	0.035	Min	0.374	0.336	0.034	Min	0.030	Min
2	0.255	0.255	0.067	Min	0.067	Min	0.478	0.430	0.051	Min	0.051	Min
3	0.336	0.336	0.093	Min	0.093	Min	0.531	0.478	0.062	Min	0.062	Min
4	0.432	0.432	0.102	Light	0.102	Light	0.602	0.542	0.055	Min	0.055	Min
5	0.881	0.881	0.088	Min	0.053	Min	0.950	0.855	0.086	Min	0.051	Min
6	0.979	0.979	0.194	Light	0.174	Light	0.946	0.852	0.138	Light	0.124	Light

Table F.9: Results from sequence of calculations 3 for Scenario 1 and Scenario 2

	Scenario 1	**Scenario 2**

V.C	d	PA1	Visual Impact	PA2	Visual Impact	d	PA1	Visual Impact	PA2	Visual Impact
1	1.0	0.550	Serious	0.495	Medium	1.0	0.525	Serious	0.473	Medium
2	1.0	0.220	Light	0.220	Light	1.0	0.210	Light	0.210	Light
3	1.0	0.220	Light	0.220	Light	1.0	0.210	Light	0.210	Light
4	1.0	0.220	Light	0.220	Light	1.0	0.210	Light	0.210	Light
5	1.0	0.550	Serious	0.330	Medium	1.0	0.525	Serious	0.315	Medium
6	1.0	1.100	Deep	0.990	Deep	1.0	1.050	Deep	0.945	Very Serious

Table F.10: Results from sequence of calculations 3 for Scenario 3 and Scenario 4

	Scenario 3					**Scenario 4**				
V.C	d	PA1	Visual Impact	PA2	Visual Impact	d	PA1	Visual Impact	PA2	Visual Impact
1	1.0	0.500	Medium	0.450	Medium	1.0	0.180	Light	0.162	Light
2	1.0	0.200	Light	0.200	Light	1.0	0.180	Light	0.180	Light
3	1.0	0.200	Light	0.200	Light	1.0	0.450	Medium	0.450	Medium
4	1.0	0.500	Medium	0.500	Medium	1.0	0.450	Medium	0.450	Medium
5	1.0	1.000	Deep	0.600	Serious	1.0	0.900	Very Serious	0.540	Serious
6	1.0	1.000	Deep	0.900	Very Serious	1.0	0.900	Very Serious	0.810	Very Serious

Table F.11: Results from sequence of calculations 4 for Scenario 1 and Scenario 2

	Scenario 1				**Scenario 2**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	1.100	Deep	0.990	Deep	1.050	Deep	0.945	Deep
2	0.611	Serious	0.611	Serious	0.631	Serious	0.631	Serious

3	0.611	Serious	0.611	Serious	0.631	Serious	0.631	Serious
4	0.611	Serious	0.611	Serious	0.631	Serious	0.631	Serious
5	1.100	Deep	0.660	Serious	1.050	Deep	0.630	Serious
6	0.915	Deep	0.823	Very Serious	0.840	Very Serious	0.756	Very Serious

Table F.12: Results from sequence of calculations 4 for Scenario 3 and Scenario 4

	Scenario 3				**Scenario 4**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	1.000	Deep	0.900	Very Serious	0.302	Medium	0.272	Light
2	0.192	Light	0.192	Light	0.302	Medium	0.302	Medium
3	0.192	Light	0.192	Light	0.900	Very Serious	0.900	Very Serious
4	1.000	Deep	1.000	Deep	0.900	Very Serious	0.900	Very Serious
5	0.984	Deep	0.590	Serious	0.876	Very Serious	0.526	Serious
6	0.984	Deep	0.885	Very Serious	0.876	Very Serious	0.789	Very Serious

Table F.13: Results from sequence of calculations 5 for Scenario 1 and Scenario 2

	Scenario 1				**Scenario 2**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.828	Very Serious	0.745	Very Serious	0.843	Very Serious	0.759	Very Serious
2	0.690	Serious	0.690	Serious	0.702	Very Serious	0.702	Very Serious

3	0.718	Very Serious	0.718	Very Serious	0.730	Very Serious	0.730	Very Serious
4	0.738	Very Serious	0.738	Very Serious	0.774	Very Serious	0.774	Very Serious
5	0.910	Deep	0.546	Serious	0.859	Very Serious	0.515	Serious
6	1.100	Deep	0.990	Deep	1.043	Deep	0.938	Deep

Table F.14: Results from sequence of calculations 5 for Scenario 3 and Scenario 4

	Scenario 3				**Scenario 4**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.394	Medium	0.355	Medium	0.336	Medium	0.303	Medium
2	0.255	Light	0.255	Light	0.430	Medium	0.430	Medium
3	0.336	Medium	0.336	Medium	0.478	Medium	0.478	Medium
4	0.432	Medium	0.432	Medium	0.542	Serious	0.542	Serious
5	0.881	Very Serious	0.529	Serious	0.855	Very Serious	0.513	Serious
6	0.979	Deep	0.881	Very Serious	0.852	Very Serious	0.767	Very Serious

Table F.15: Results from sequence of calculations 6 for Scenario 1 and Scenario 2

	Scenario 1					**Scenario 2**				
V.C	d	PA1	Visual Impact	PA2	Visual Impact	d	PA1	Visual Impact	PA2	Visual Impact
1	0.593	0.326	Medium	0.294	Light	0.770	0.404	Medium	0.364	Medium
2	0.779	0.171	Light	0.171	Light	0.866	0.182	Light	0.182	Light
3	0.789	0.174	Light	0.174	Light	0.872	0.183	Light	0.183	Light
4	0.799	0.176	Light	0.176	Light	0.880	0.185	Light	0.185	Light

5	0.790	0.435	Medium	0.261	Light	0.909	0.477	Medium	0.286	Light
6	0.819	0.901	Deep	0.811	Very Serious	0.937	0.984	Deep	0.885	Very Serious

Table F.16: Results from sequence of calculations 6 for Scenario 3 and Scenario 3

	Scenario 3					**Scenario 4**				
V. C	d	PA1	Visual Impact	PA2	Visual Impact	d	PA1	Visual Impact	PA2	Visual Impact
1	0.593	0.297	Light	0.267	Light	0.770	0.139	Light	0.125	Light
2	0.697	0.139	Light	0.139	Light	0.799	0.144	Light	0.144	Light
3	0.703	0.141	Light	0.141	Light	0.802	0.361	Medium	0.361	Medium
4	0.684	0.342	Medium	0.342	Medium	0.794	0.357	Medium	0.357	Medium
5	0.538	0.538	Serious	0.323	Medium	0.733	0.659	Serious	0.396	Medium
6	0.665	0.665	Serious	0.599	Serious	0.812	0.731	Very Serious	0.658	Serious

Table F.17: Results from sequence of calculations 7 for Scenario 1 and Scenario 2

	Scenario 1				**Scenario 2**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.652	Serious	0.587	Serious	0.808	Very Serious	0.727	Very Serious
2	0.476	Medium	0.476	Medium	0.546	Serious	0.546	Serious
3	0.482	Medium	0.482	Medium	0.550	Serious	0.550	Serious

4	0.488	Medium	0.488	Medium	0.555	Serious	0.555	Serious
5	0.869	Very Serious	0.522	Serious	0.955	Deep	0.573	Serious
6	0.749	Very Serious	0.674	Serious	0.787	Very Serious	0.708	Very Serious

Table F.18: Results from sequence of calculations 7 for Scenario 3 and Scenario 4

	Scenario 3				**Scenario 4**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.593	Serious	0.534	Serious	0.233	Light	0.209	Light
2	0.134	Light	0.134	Light	0.242	Light	0.242	Light
3	0.135	Light	0.135	Light	0.722	Very Serious	0.722	Very Serious
4	0.684	Serious	0.684	Serious	0.714	Very Serious	0.714	Very Serious
5	0.530	Serious	0.318	Medium	0.642	Serious	0.385	Medium
6	0.655	Serious	0.589	Serious	0.712	Serious	0.641	Serious

Table F.19: Results from sequence of calculations 8 for Scenario 1 and Scenario 2

	Scenario 1				**Scenario 2**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.491	Medium	0.442	Medium	0.649	Serious	0.584	Serious
2	0.537	Serious	0.537	Serious	0.609	Serious	0.609	Serious
3	0.567	Serious	0.567	Serious	0.636	Serious	0.636	Serious
4	0.589	Serious	0.589	Serious	0.681	Serious	0.681	Serious

5	0.719	Very Serious	0.432	Medium	0.781	Very Serious	0.469	Medium
6	0.901	Deep	0.811	Very Serious	0.977	Deep	0.879	Very Serious

Table F.20: Results from sequence of calculations 8 for Scenario 3 and Scenario 4

	Scenario 3				**Scenario 4**			
V.C	PA1	Visual Impact	PA2	Visual Impact	PA1	Visual Impact	PA2	Visual Impact
1	0.234	Light	0.210	Light	0.259	Light	0.233	Light
2	0.178	Light	0.178	Light	0.344	Medium	0.344	Medium
3	0.236	Light	0.236	Light	0.383	Medium	0.383	Medium
4	0.295	Light	0.295	Light	0.430	Medium	0.430	Medium
5	0.474	Medium	0.285	Light	0.626	Serious	0.376	Medium
6	0.651	Serious	0.586	Serious	0.692	Serious	0.623	Serious

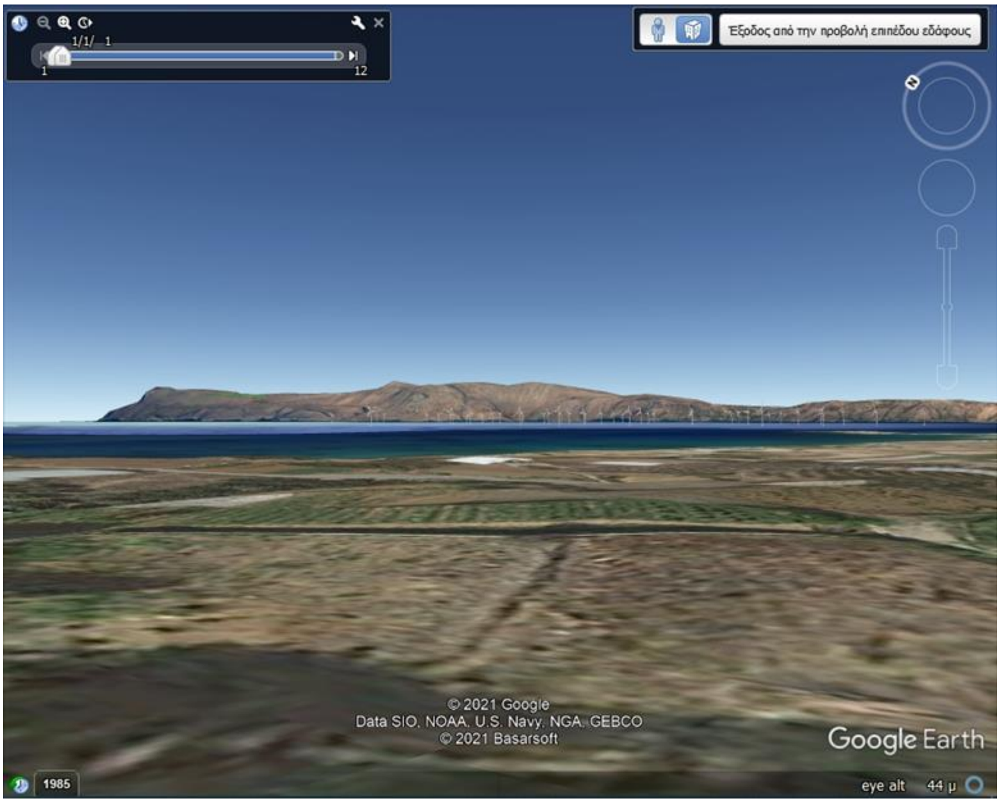


Figure F.1: Kaliviani, Scenario 1

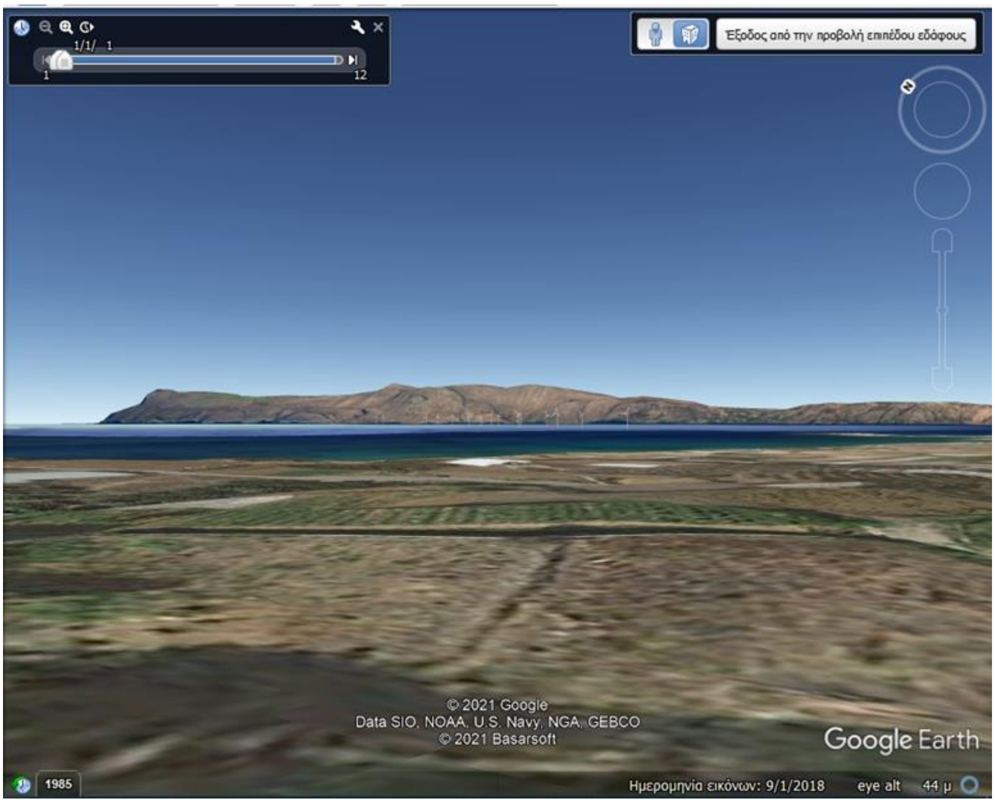


Figure F.2: Kaliviani, Scenario 2

Figure F.3: Kaliviani, Scenario 3

Figure F.4: Kaliviani, Scenario 4

Figure F.5: Kissamos 1, Scenario 1

Figure F.6: Kissamos 1, Scenario 2

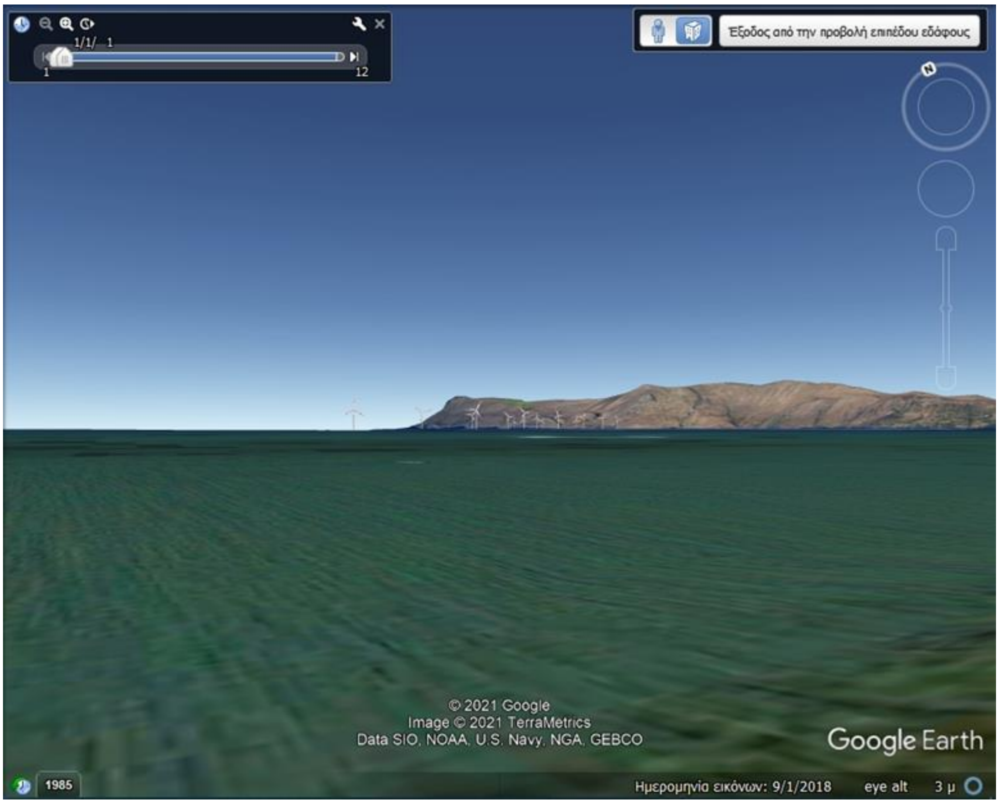


Figure F.7: Kissamos 1, Scenario 3

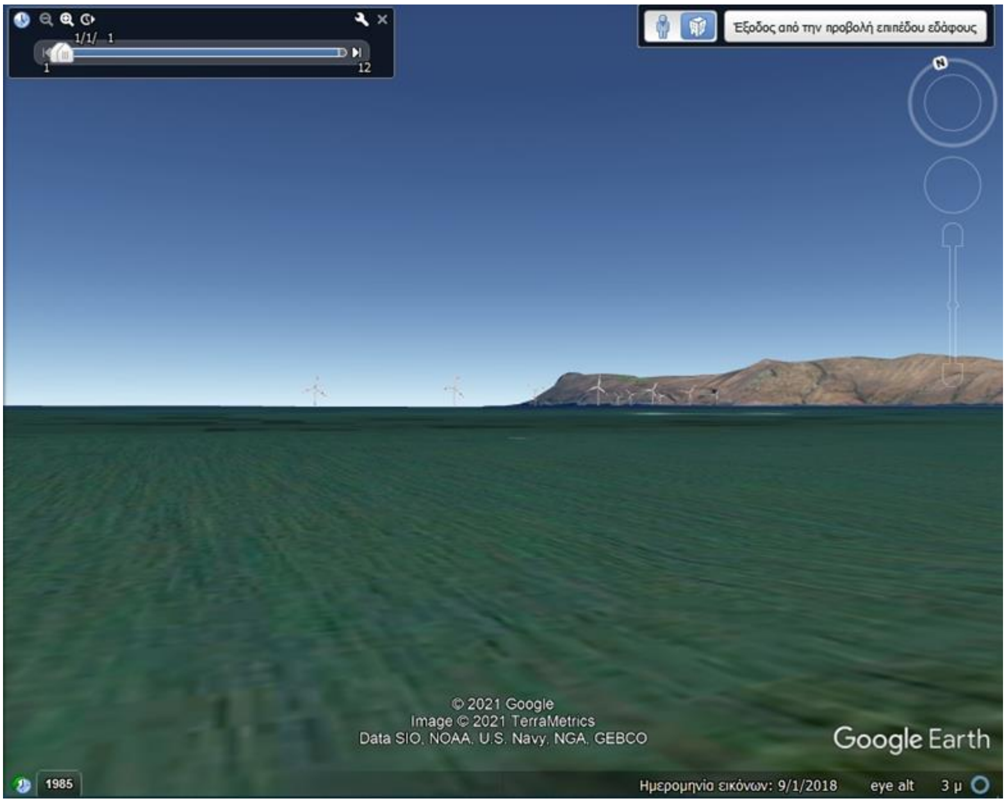


Figure F.8: Kissamos 1, Scenario 4

Figure F.9: Kissamos 2, Scenario 1

Figure F.10: Kissamos 2, Scenario 2

Figure F.11: Kissamos 2, Scenario 3

Figure F.12: Kissamos 2, Scenario 4

Figure F.13: Kissamos 3, Scenario 1

Figure F.14: Kissamos 3, Scenario 2

Figure F.15: Kissamos 3, Scenario 3

Figure F.16: Kissamos 3, Scenario 4

Figure F.17: Nopigeia, Scenario 1

Figure F.18: Nopigeia, Scenario 2

Figure F.19: Nopigeia, Scenario 3

Figure F.20: Nopigeia, Scenario 4

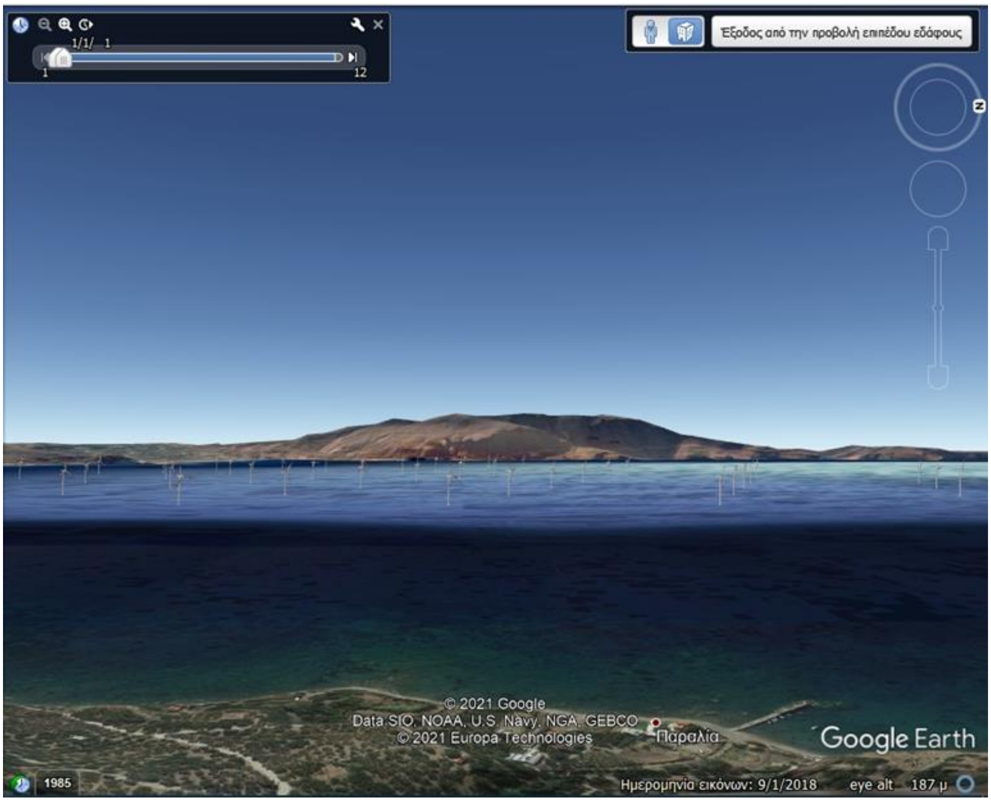


Figure F.21: Ravdouxa, Scenario 1

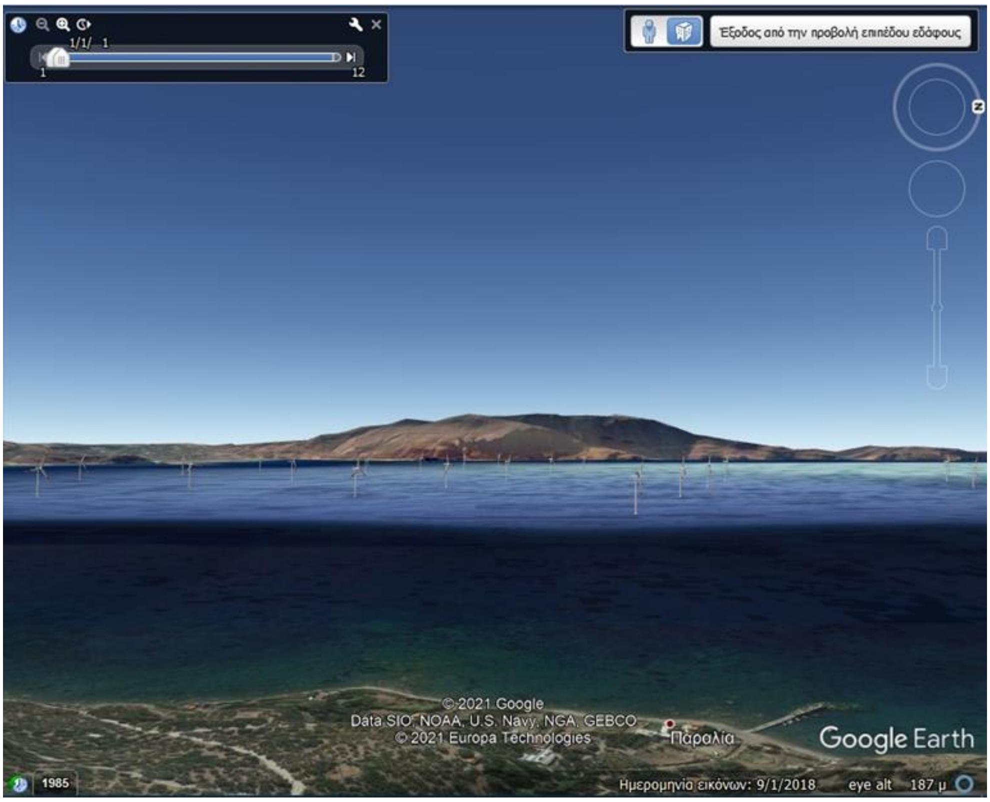


Figure F.22: Ravdouxa, Scenario 2

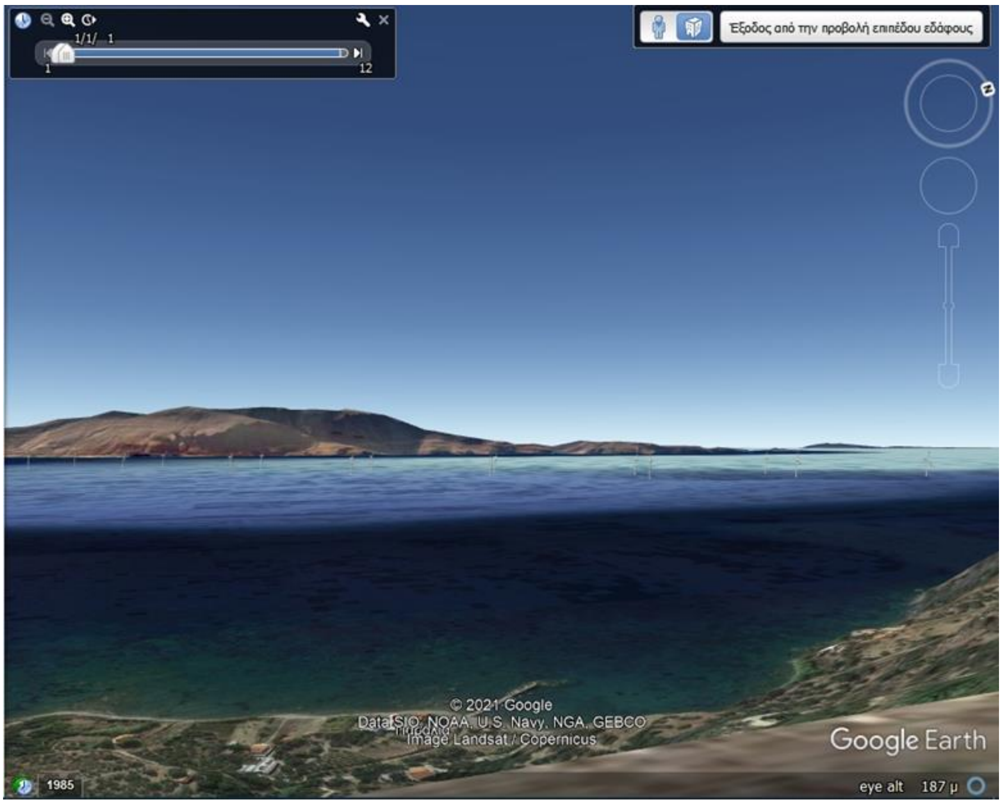


Figure F.23: Ravdouxa, Scenario 3

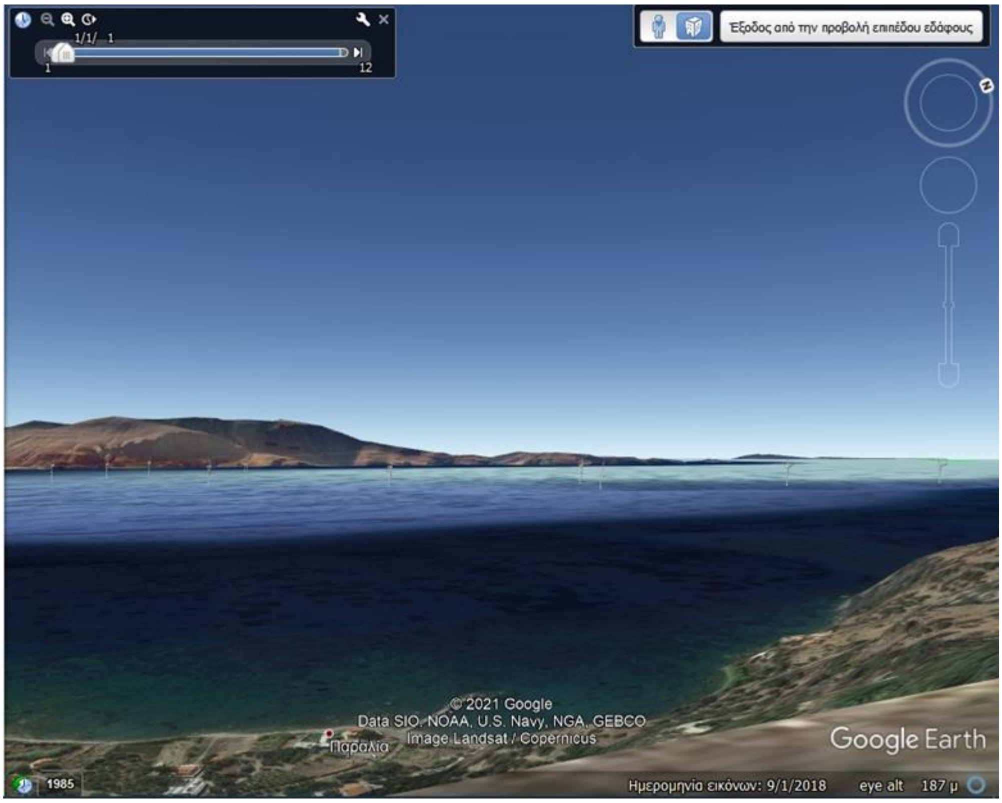


Figure F.24: Ravdouxa, Scenario 4

G. Annex F

Questionnaires

To what extent are you visually affected by the OWFs below?

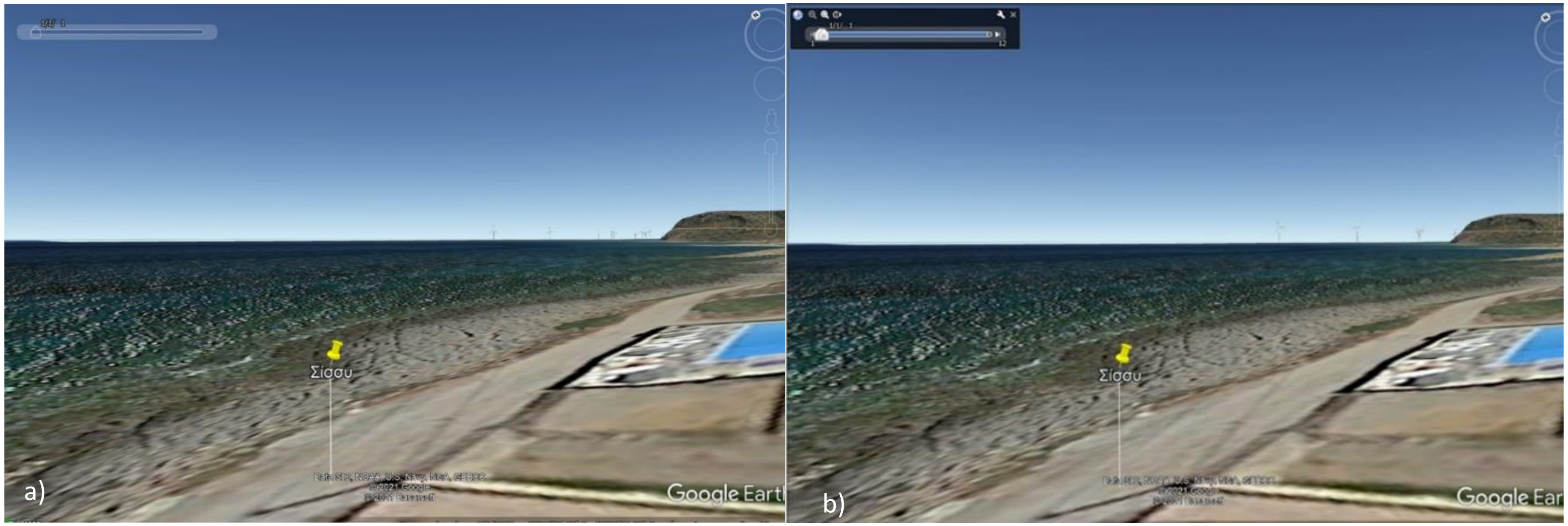


Figure G.1: Observer point: Sissi a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

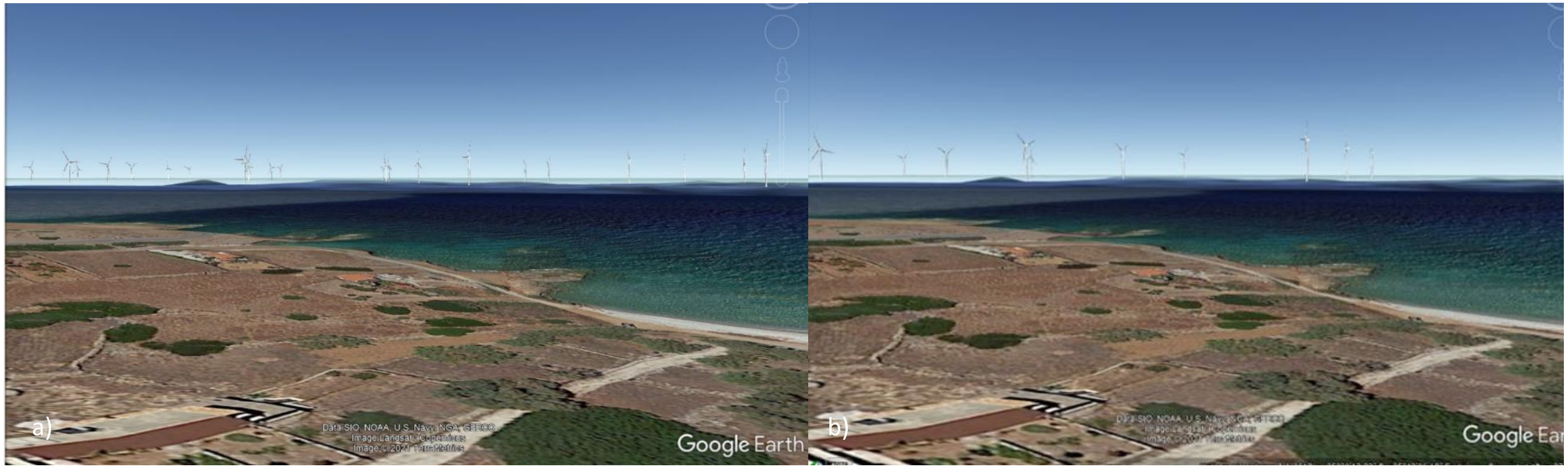


Figure G.2: Observer point: Kato Selles a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

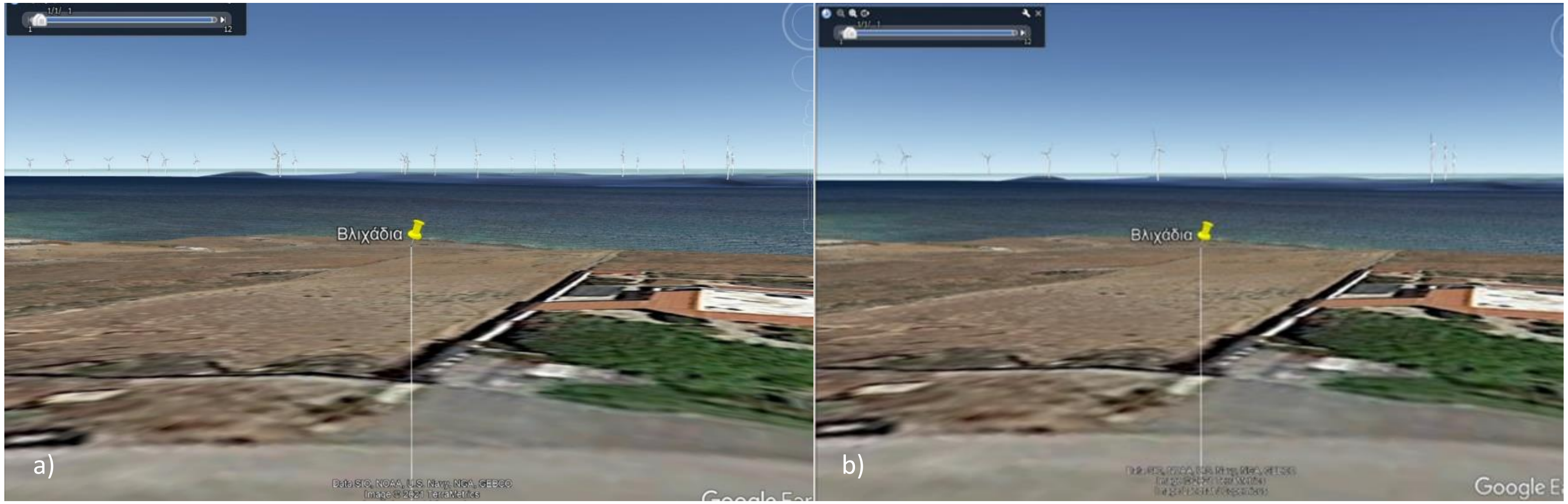


Figure G.3: Observer point: Vlichadia a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

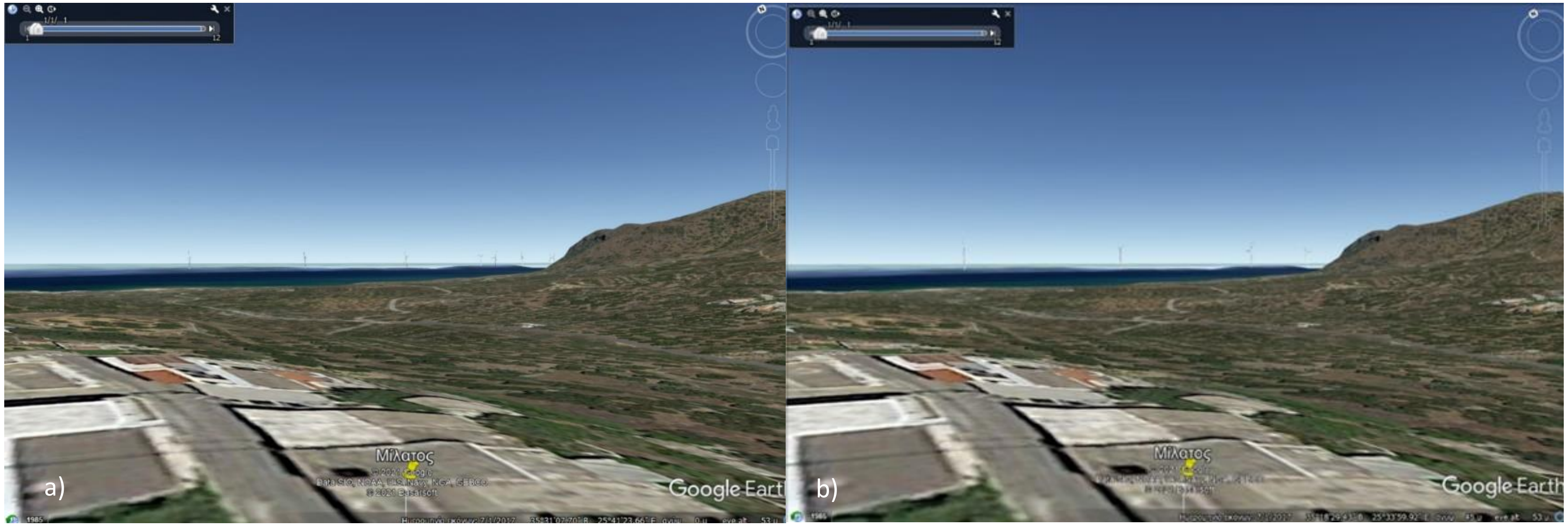


Figure G.4: Observer point: Milatos a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

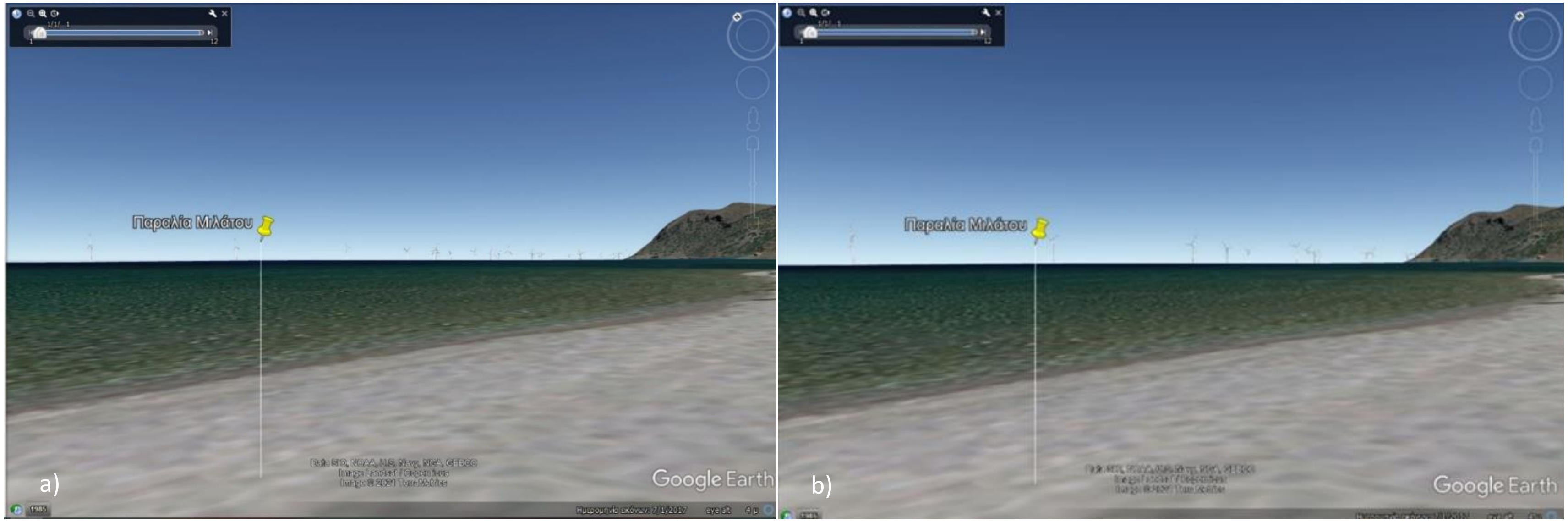


Figure G.5: Observer point: Milatos Beach a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

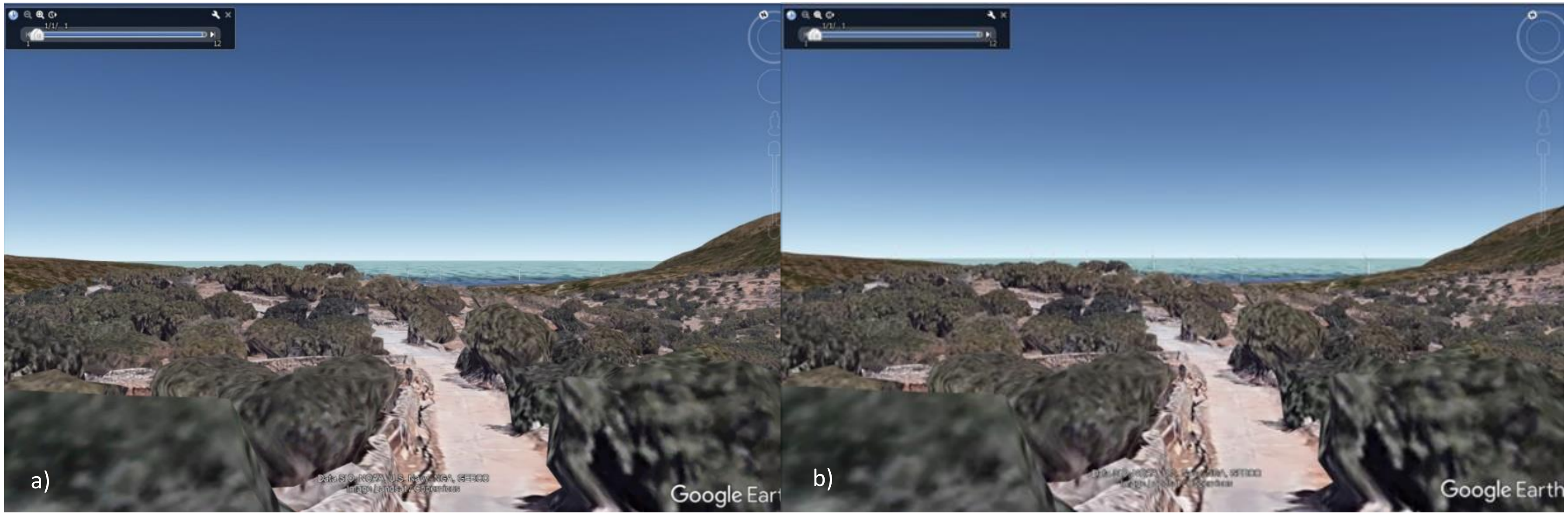


Figure G.6: Observer point: Vrouchas a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

To what extent are you visually affected by the OWFs below?

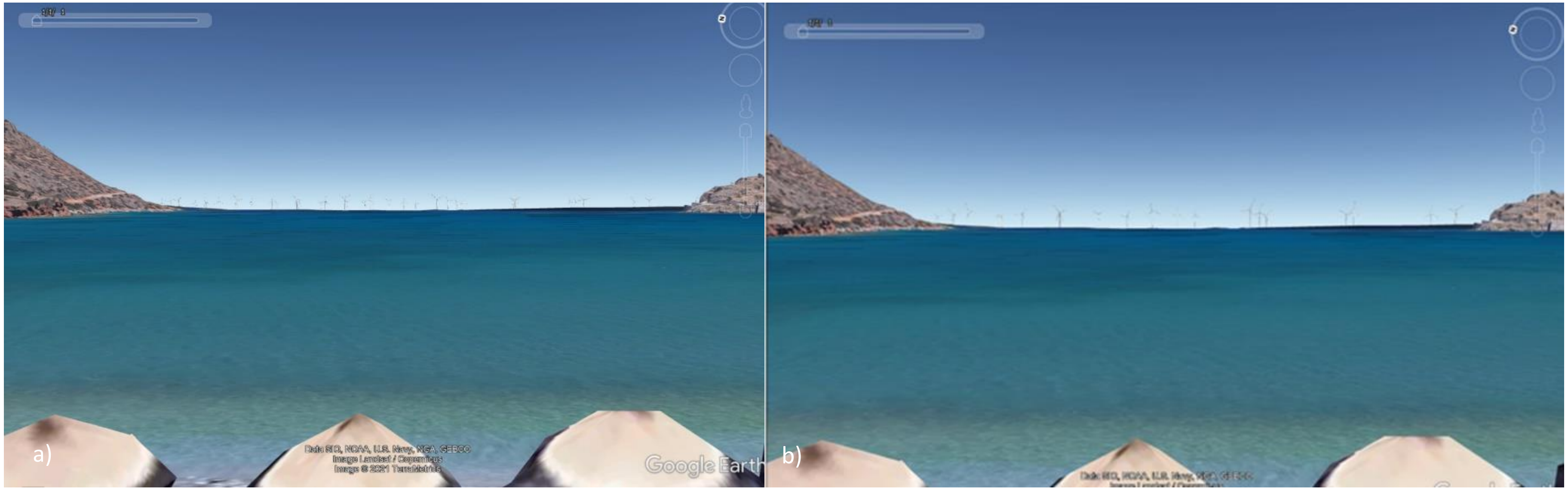


Figure G.7: Observer point: Plaka a) Scenario a, b) Scenario b

Little/Not at all ☐

Little ☐

Moderate ☐

Very ☐

Very much ☐

Demographics

2.1. Gender

Male ☐

Female ☐

Άλλο/Δεν απαντώ

2.2. Age group

<18 ☐

18-24 ☐

25-34 ☐

35-44 ☐

45-54 ☐

55-64 ☐

>65 ☐

2.3. Education level

Primary school/College ☐

High school ☐

Higher Technological Education (TEI) ☐

Higher education (University) ☐

Master/PhD ☐

Other/Not answer ☐

3. Opinion on RES, Comments/Suggestions

3.1. What is your opinion on RET (RES: photovoltaic panels, WTs)?

Very bad ☐

Bad ☐

Moderate ☐

Good ☐

Very good ☐

Other/Not answer ☐

3.2. Comments / Suggestions (optional)

…………………………………………………………………

Wind data from Global Wind Atlas

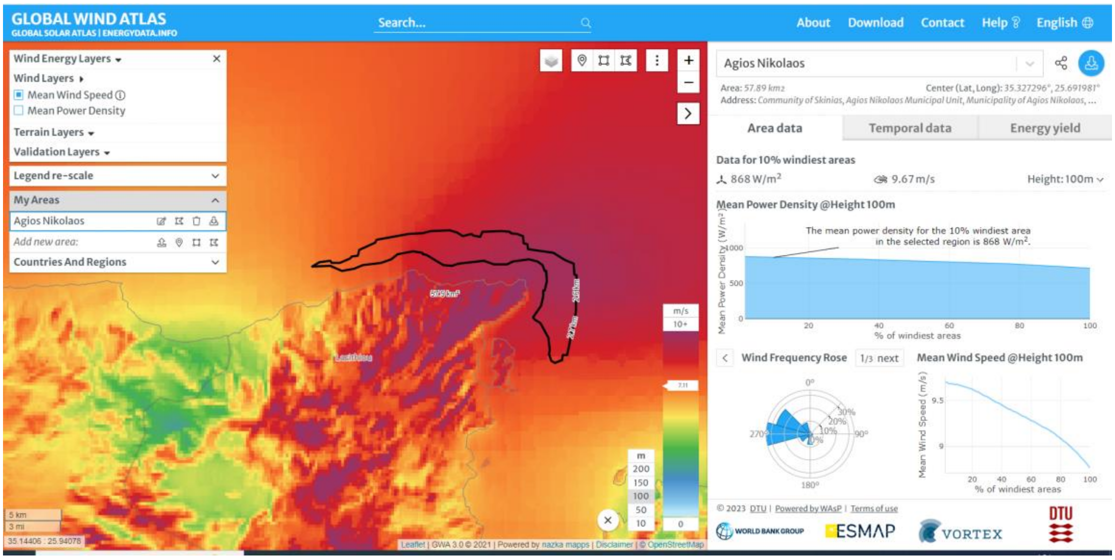


Figure G.8: Data from Global wind Atlas

Area data

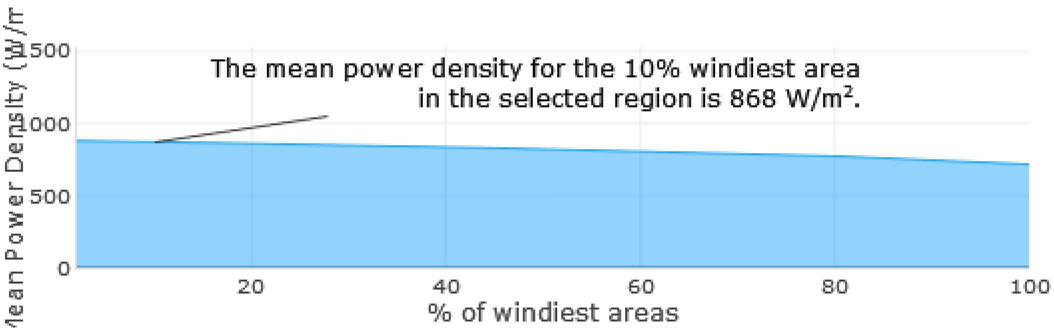


Figure G.9: Mean Power Density @Height 100m

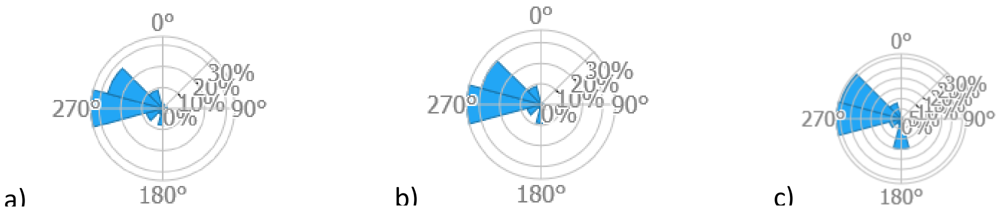


Figure G.10: a) Wind Frequency Rose b) Wind Speed Rose c) Wind Power Rose

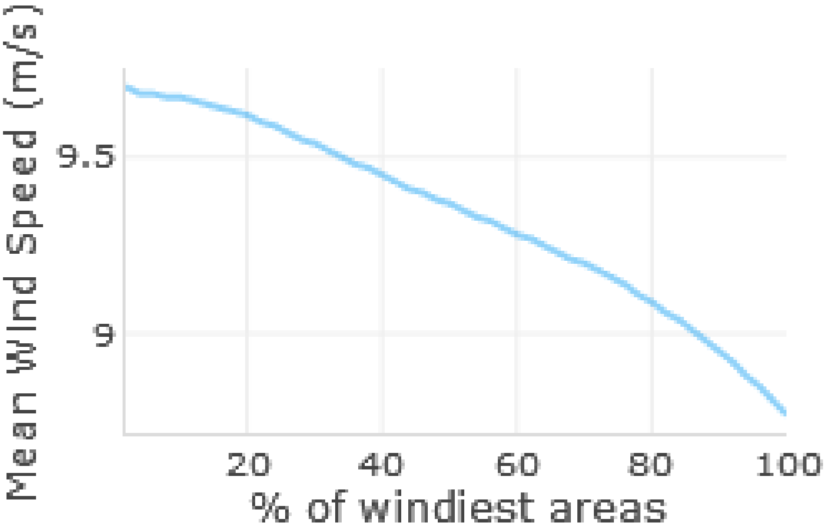


Figure G.11: Mean Wind Speed @Height 100m

Temporal data

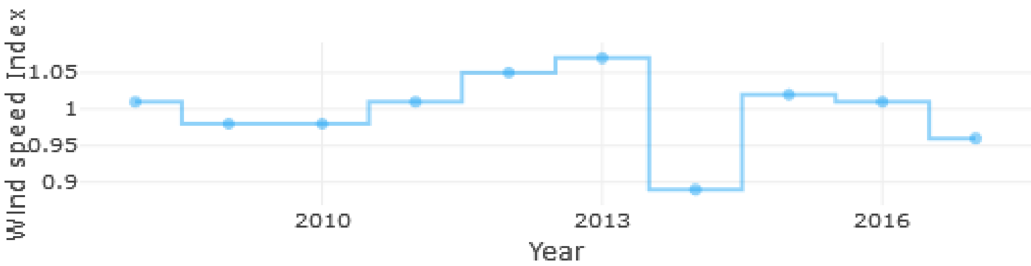


Figure G.12: Wind Speed Variability (Annual)

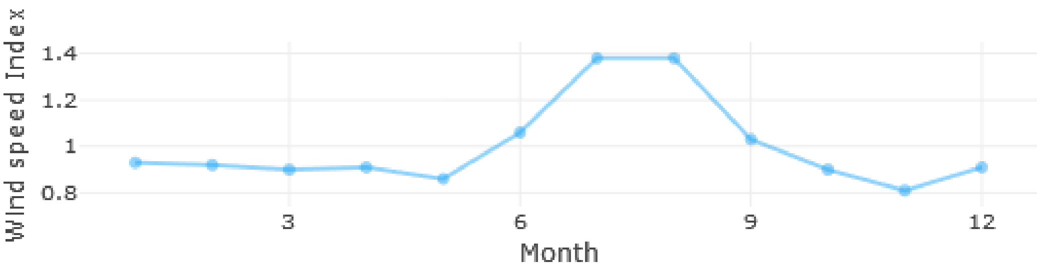


Figure G.13: Wind Speed Variability (Monthly)

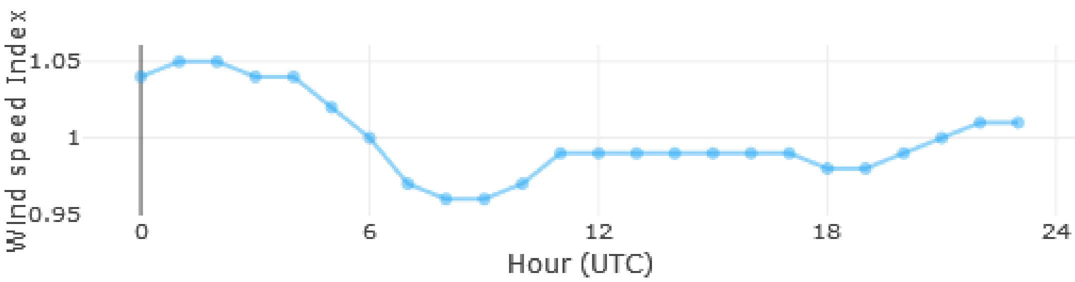


Figure G.14: Wind Speed Variability (Hourly)

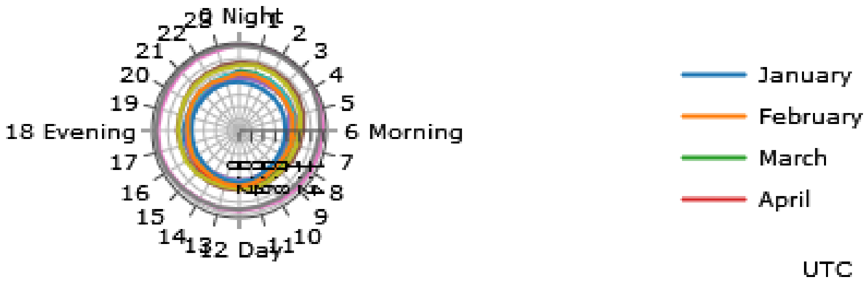


Figure G.15: Hourly vs. monthly (radar plot)

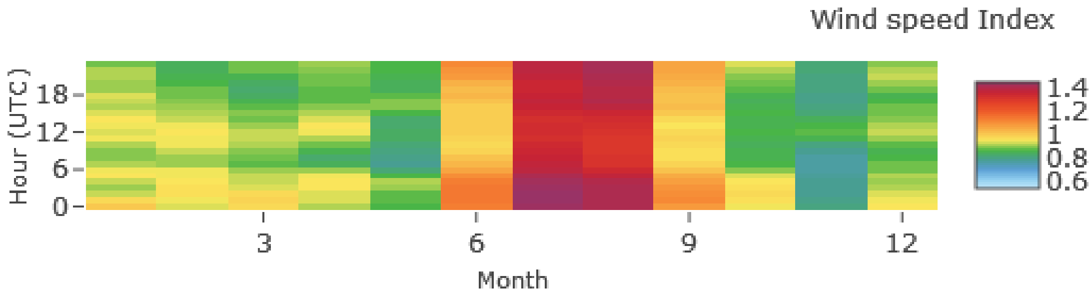


Figure G.16: Hourly vs. monthly (cross table)

Results of questionnaires

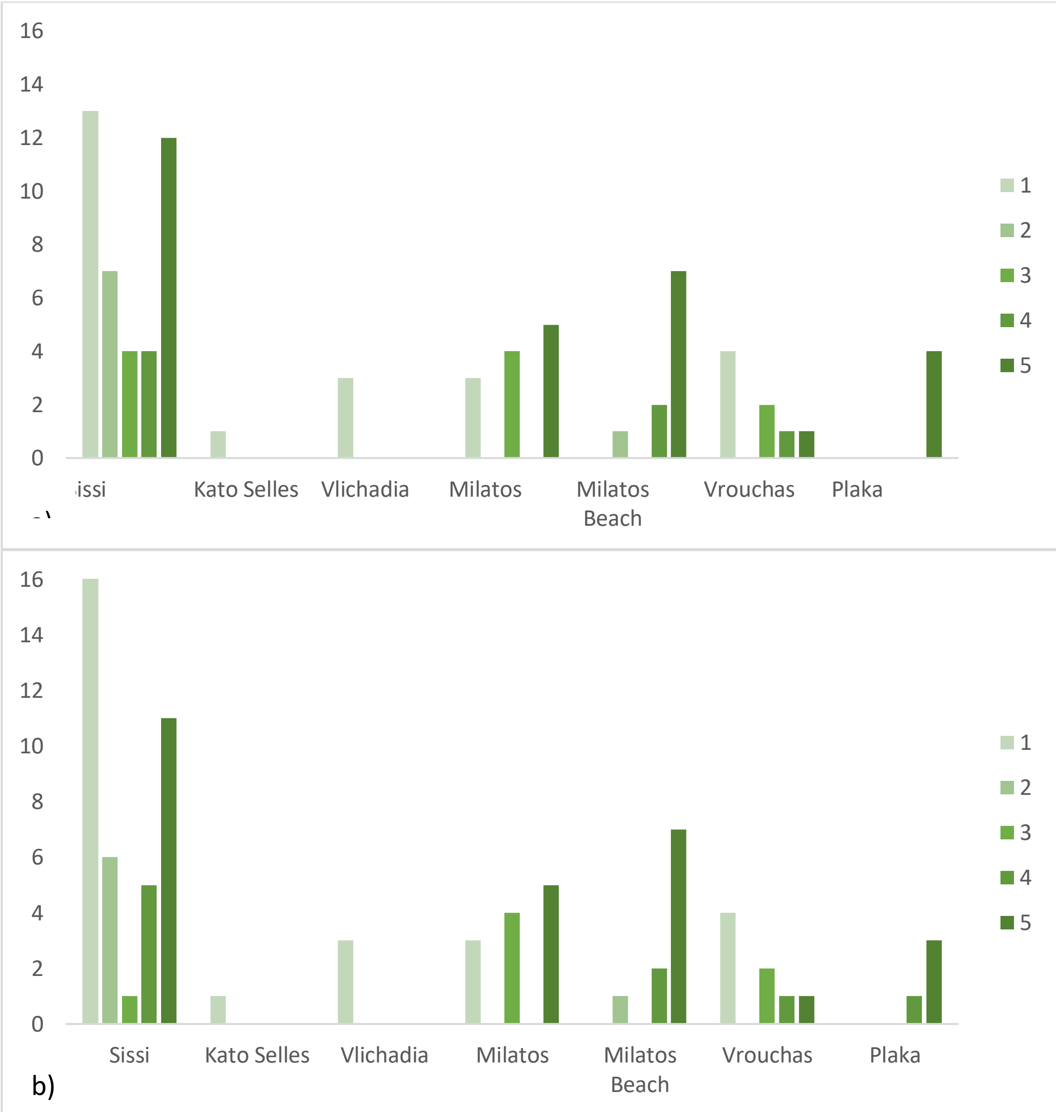


Figure G.17: Diagrams from the locals' questionnaires concerning their answers about the two pictures, a) 1st and b) 2nd scenario, respectively, according to their village (point of interest)

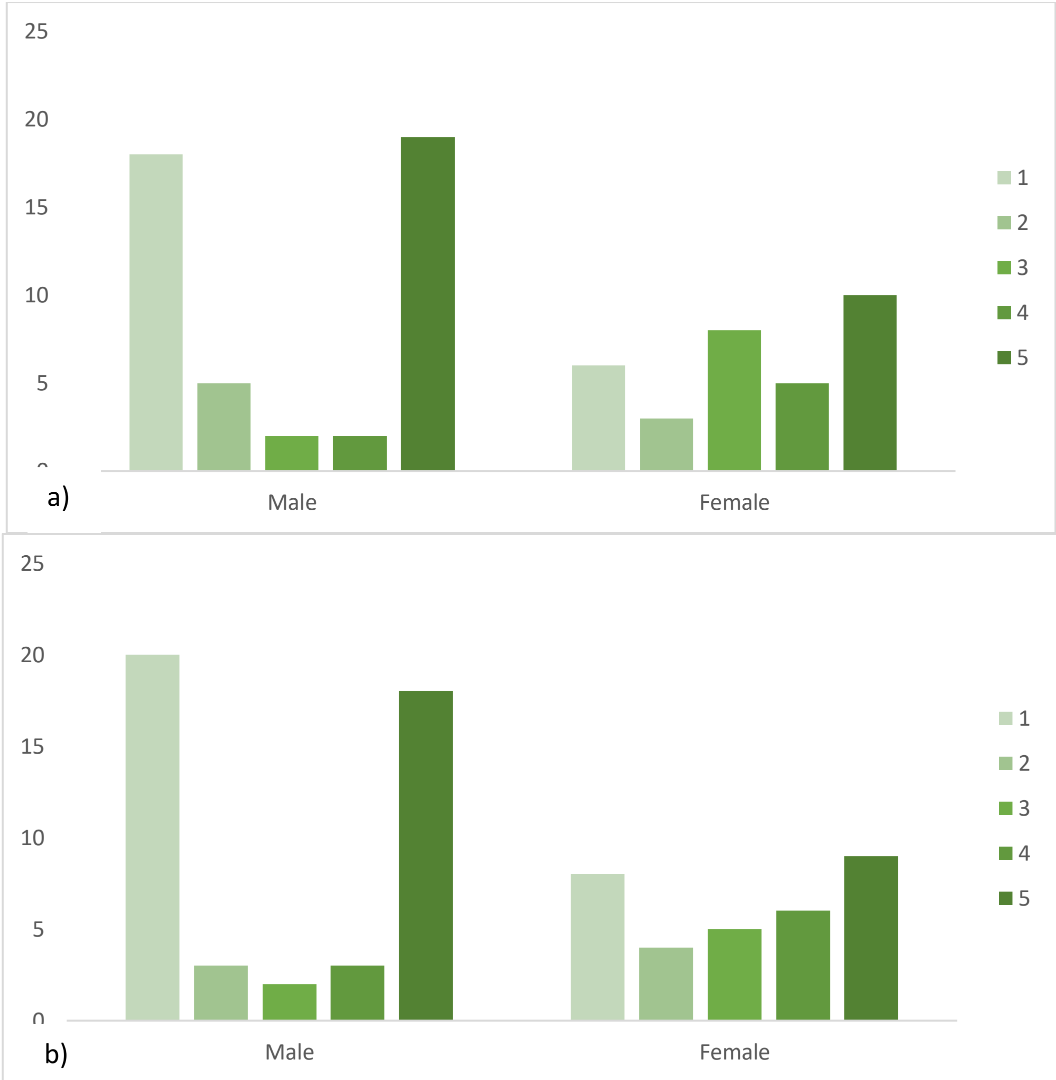
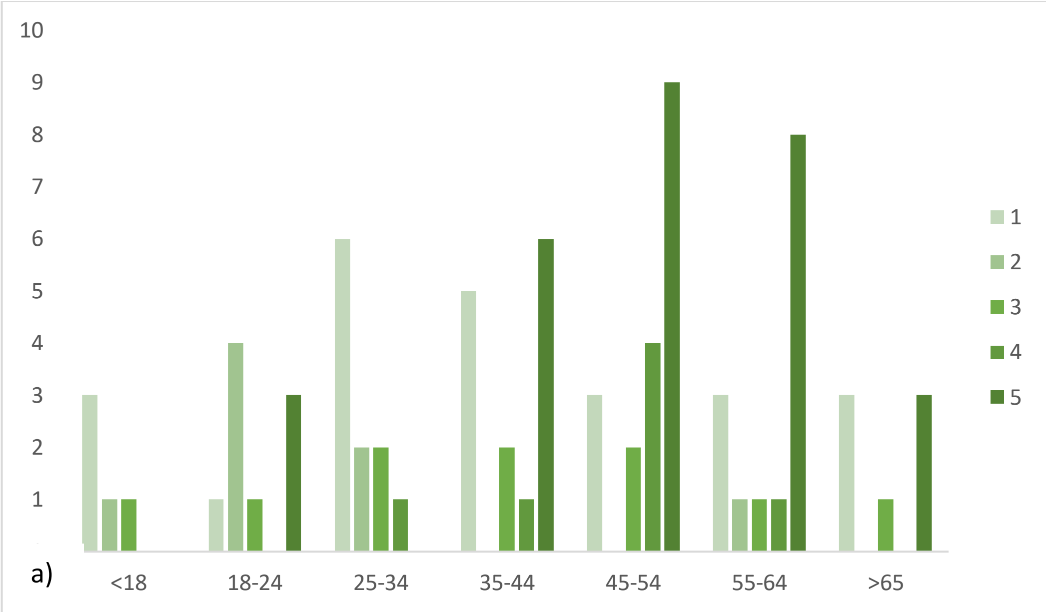


Figure G.18: Diagrams from the locals' questionnaires concerning their answers about the two pictures, a) 1st and b) 2nd scenario, respectively, according to their gender



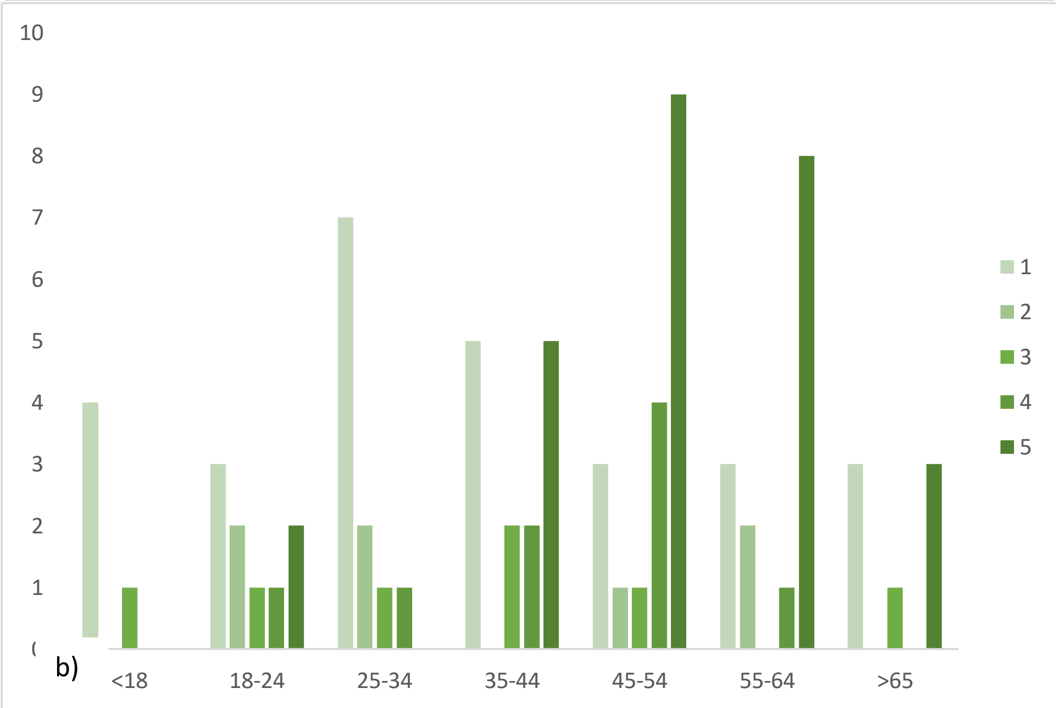


Figure G.19: Diagrams from the locals' questionnaires concerning their answers about the two pictures, a) 1st and b) 2nd scenario, respectively, according to their age group

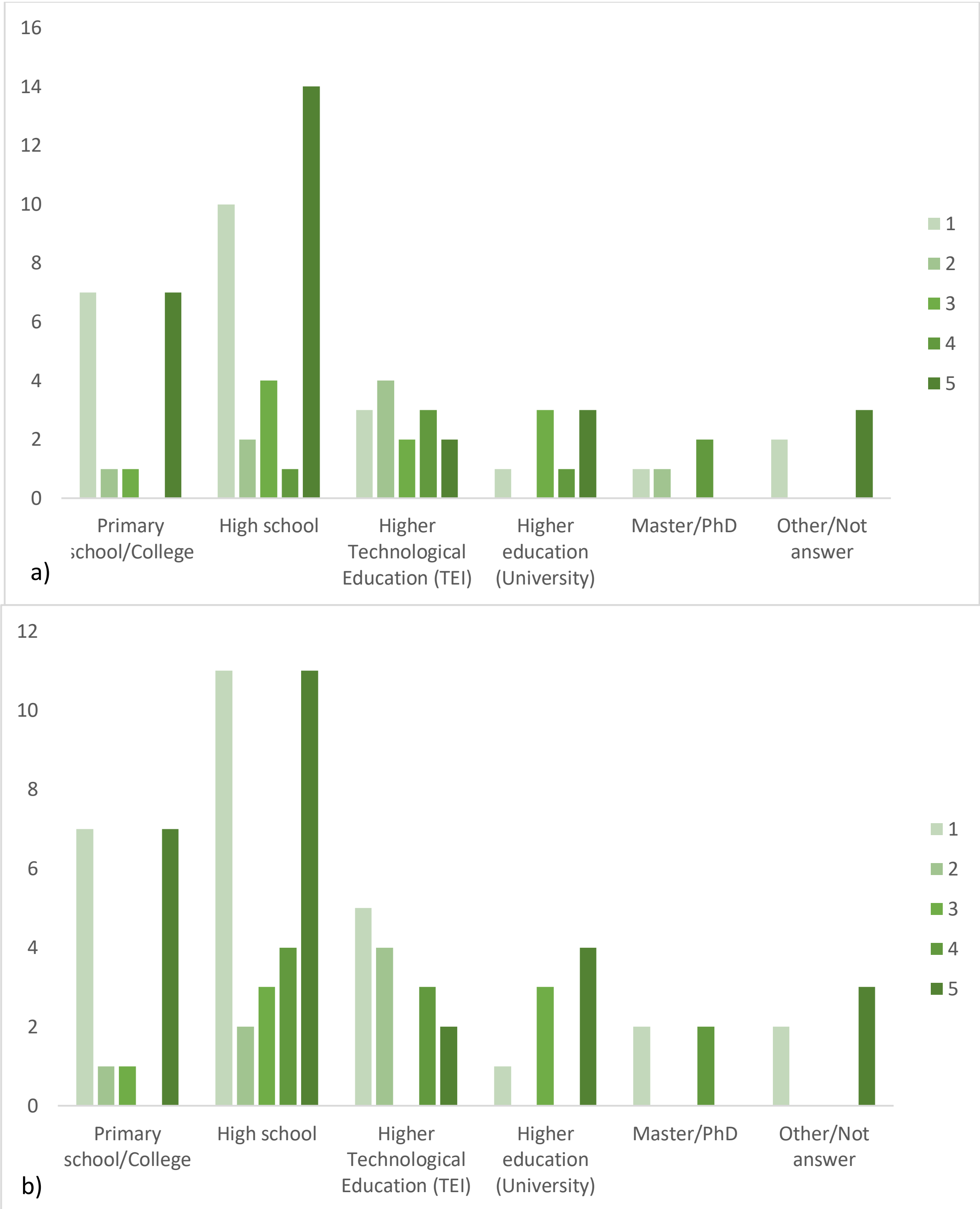


Figure G.20: Diagrams from the locals' questionnaires concerning their answers about the two pictures, a) 1st and b) 2nd scenario, respectively, according to their education level