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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

Εγκατάσταση υπεράκτιων αιολικών πάρκων στην Ελλάδα: Μια Πολυκριτηριακη & GIS Προσέγγιση

Installation of Offshore Windfarms in Greece: An MCDM & GIS Approach

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Abstract

The growing global demand for renewable energy due to climate change has brought Offshore Wind Farms (OWFs) into focus as a promising solution for increase the penetration of renewables to the energy mix. This paper presents an innovative approach to tackle the challenges of OWF placement, introducing a Multi-Criteria Decision-Making (MCDM) methodology integrated with Geographic Information Systems (GIS) for optimal OWF siting. The methodology presented in this project, accommodates incomplete criteria weights and uses the Analytic Hierarchy Process (AHP) to identify and rank available OWF areas. Diverse data were gathered from official sources, unify it into a flexible format, and validate it through AHP, providing criteria values and ranking orders. These insights inform the VIKOR method, enhancing the methodology's robustness. The proposed methodology was experimentally applied in the Greek region, yielding 35 distinct areas for potential OWF development. Experts from the wind power industry rated evaluation criteria through a pairwise comparison questionnaire, producing a preference order expressed as weak inequalities. The ranking process presented valuable insights, implementing various decision-maker profiles and identifying the most preferable OWF areas. The flexibility of this method makes it applicable for different OWF spatial planning and proves to be a useful tool for decision-makers.

Περίληψη

Η αυξανόμενη παγκόσμια ζήτηση για ανανεώσιμες πηγές ενέργειας λόγω της κλιματικής αλλαγής έχει φέρει στο προσκήνιο τα υπεράκτια αιολικά πάρκα (ΥΑΠ) ως μια πολλά υποσχόμενη λύση για την αύξηση της διείσδυσης των ανανεώσιμων πηγών ενέργειας στο ενεργειακό μείγμα. Το παρόν έγγραφο παρουσιάζει μια καινοτόμο προσέγγιση για την αντιμετώπιση των προκλήσεων της τοποθέτησης των ΥΑΠ, εισάγοντας μια μεθοδολογία λήψης αποφάσεων με πολλαπλά κριτήρια (MCDM), ενσωματωμένη με γεωγραφικά συστήματα πληροφοριών (GIS) για τη βέλτιστη τοποθέτηση ΥΑΠ. Η μεθοδολογία που παρουσιάζεται σε αυτό το έργο, δέχεται ελλιπή πληροφορία κριτηρίων και χρησιμοποιεί τη διαδικασία αναλυτικής ιεράρχησης (AHP) για τον εντοπισμό και την κατάταξη των διαθέσιμων περιοχών ΥΑΠ. Συγκεντρώθηκαν ποικίλα δεδομένα από επίσημες πηγές, ενοποιήθηκαν σε μια ευέλικτη μορφή και επικυρώθηκαν μέσω της AHP, παρέχοντας τιμές κριτηρίων και σειρά κατάταξης. Τα αποτελέσματα της χωρικής ανάλυσης και της AHP, ενημερώνουν τη μέθοδο VIKOR, ενισχύοντας την ευρωστία της μεθοδολογίας. Η προτεινόμενη μεθοδολογία εφαρμόστηκε πειραματικά στον ελληνικό χώρο, αποδίδοντας 35 διακριτές περιοχές για πιθανή ανάπτυξη ΥΑΠ. Εμπειρογνώμονες από τον κλάδο της αιολικής ενέργειας βαθμολόγησαν τα κριτήρια αξιολόγησης μέσω ενός ερωτηματολογίου σύγκρισης ανά ζεύγη, παράγοντας μια σειρά προτίμησης που εκφράζεται ως αδύναμες ανισότητες. Η διαδικασία κατάταξης παρουσίασε πολύτιμα αποτελέσματα, εφαρμόζοντας διάφορα προφίλ φορέων λήψης αποφάσεων και προσδιορίζοντας τις πλέον προτιμώμενες περιοχές ΥΑΠ. Η ευελιξία αυτής της μεθόδου την καθιστά εφαρμόσιμη για διαφορετικό χωροταξικό σχεδιασμό ΥΑΠ και αποδεικνύεται χρήσιμο εργαλείο για τους υπεύθυνους λήψης αποφάσεων.

Εισαγωγή

Η αυξανόμενη παγκόσμια ζήτηση για ανανεώσιμες πηγές ενέργειας (ΑΠΕ) για την καταπολέμηση της κλιματικής αλλαγής έχει δώσει ώθηση στην ανάπτυξη των υπεράκτιων αιολικών πάρκων (ΥΑΠ) ως μια πολλά υποσχόμενη λύση [1].Καθώς οι χώρες προσπαθούν να επιτύχουν τους στόχους τους για τις ανανεώσιμες πηγές ενέργειας, η Ελλάδα, με τους άφθονους αιολικούς πόρους και την εκτεταμένη ακτογραμμή της, παρουσιάζει μια σημαντική ευκαιρία για την ανάπτυξη υπεράκτιων έργων αιολικής ενέργειας. Η Ελλάδα, ως κράτος μέλος της Ευρωπαϊκής Ένωσης (ΕΕ), έχει δεσμευτεί για φιλόδοξους στόχους στον τομέα των ανανεώσιμων πηγών ενέργειας, σε ευθυγράμμιση με τους στρατηγικούς στόχους της ΕΕ. Οι στόχοι αυτοί περιλαμβάνουν σημαντική αύξηση του μεριδίου των ανανεώσιμων πηγών ενέργειας στο ενεργειακό μείγμα της χώρας έως το 2030 [2], [3]. Η ανάπτυξη υπεράκτιων αιολικών πάρκων στην Ελλάδα μπορεί να διαδραματίσει καθοριστικό ρόλο στην επίτευξη αυτών των στόχων, καθώς και να συμβάλει στις παγκόσμιες προσπάθειες για τον μετριασμό της κλιματικής αλλαγής.

Η Ελλάδα είναι ευλογημένη με ένα τεράστιο δυναμικό αιολικής ενέργειας, ιδίως στις παράκτιες περιοχές της. Η γεωγραφική θέση της χώρας την εκθέτει στους ισχυρούς και σταθερούς ανέμους που επικρατούν στο Αιγαίο και το Ιόνιο Πέλαγος. Η αξιοποίηση αυτού του υπεράκτιου αιολικού δυναμικού μπορεί να προσφέρει μια βιώσιμη και καθαρή πηγή ηλεκτρικής ενέργειας, μειώνοντας την εξάρτηση της Ελλάδας από τα ορυκτά καύσιμα και προωθώντας την ενεργειακή ασφάλεια.

Ενώ τα οφέλη της υπεράκτιας αιολικής ενέργειας είναι σημαντικά, υπάρχουν διάφορες προκλήσεις που πρέπει να αντιμετωπιστούν για να εξασφαλιστεί η επιτυχής εφαρμογή της στην Ελλάδα.

- Ο σχεδιασμός και η κατασκευή υπεράκτιων αιολικών πάρκων απαιτούν εξειδικευμένη τεχνική εμπειρογνωμοσύνη λόγω του ιδιαίτερα δύσκολου θαλάσσιου περιβάλλοντος και των πολύπλοκων διαδικασιών εγκατάστασης. Παράγοντες όπως τα φορτία κύματος και ανέμου, οι συνθήκες του βυθού και η πρόληψη της διάβρωσης δημιουργούν μοναδικές προκλήσεις που πρέπει να ξεπεραστούν για να διασφαλιστεί η μακροπρόθεσμη αξιοπιστία και αποδοτικότητα των υπεράκτιων ανεμογεννητριών.
- Η ανάπτυξη υπεράκτιων αιολικών πάρκων συνεπάγεται την πλοήγηση σε ένα πολύπλοκο ρυθμιστικό και αδειοδοτικό πλαίσιο. Η απόκτηση των απαραίτητων περιβαλλοντικών αδειών, η διενέργεια εκτιμήσεων επιπτώσεων και η εξασφάλιση συνδέσεων δικτύου απαιτούν στενή συνεργασία μεταξύ των προγραμματιστών, των φορέων χάραξης πολιτικής και των αρμόδιων αρχών. Ο εξορθολογισμός αυτών των διαδικασιών και η διασφάλιση του αποτελεσματικού συντονισμού μεταξύ των ενδιαφερομένων μερών είναι ζωτικής σημασίας για την έγκαιρη υλοποίηση των υπεράκτιων αιολικών έργων.

- Η εμπλοκή των τοπικών κοινοτήτων, των ενδιαφερομένων και των σχετικών ομάδων συμφερόντων είναι απαραίτητη για την εξασφάλιση της κοινωνικής αποδοχής και υποστήριξης της ανάπτυξης υπεράκτιων αιολικών πάρκων. Η αντιμετώπιση των ανησυχιών σχετικά με τις οπτικές επιπτώσεις, τον θόρυβο και τις πιθανές περιβαλλοντικές επιπτώσεις είναι ζωτικής σημασίας για την οικοδόμηση εμπιστοσύνης και τη διασφάλιση της επιτυχούς ένταξης της υπεράκτιας αιολικής ενέργειας στο ελληνικό ενεργειακό τοπίο.

Η αυξανόμενη ανάγκη για πράσινες ΑΠΕ και το ανεκμετάλλευτο δυναμικό υπεράκτιων αιολικών σταθμών, εντείνουν την ανάγκη για την ανάπτυξη σταθμών υπεράκτιων αιολικών σταθμών, ιδίως σε νησιωτικά περιβάλλοντα. Επιπλέον, υπάρχει ένα αυξανόμενο κενό, όσον αφορά την κοινωνική αποδοχή, το οποίο έχει διερευνηθεί εν μέρει. Μελέτες έχουν δείξει ότι το κοινό συχνά διαμαρτύρεται για τα νέα υπεράκτια αιολικά έργα, γεγονός που προκλήθηκε από το γεγονός ότι οι υπεύθυνοι λήψης αποφάσεων και οι τοπικοί ενδιαφερόμενοι αγνοήθηκαν κατά τα πρώτα στάδια ανάπτυξης του έργου. Δεδομένου ότι το κυρίαρχο συναίσθημα είναι ότι δεν τους ακούνε πλέον, αισθάνονται αδύναμοι να παρέμβουν και παραμένουν επιφυλακτικοί για τις πιθανές αρνητικές περιβαλλοντικές επιπτώσεις. Επομένως, είναι ζωτικής σημασίας να προλάβουμε τη μονόπλευρη άποψη, που εκφράζεται από τους επενδυτές και τους παραγωγούς. Με αυτόν τον τρόπο, οι προηγούμενες δυσκολίες σχετικά με τα χερσαία αιολικά έργα και τις κοινωνικές διαμαρτυρίες θα μπορούσαν να ελαχιστοποιηθούν δραματικά ή να αποφευχθούν. Από την άποψη αυτή, είναι αξιοσημείωτο ότι οι αρμόδιοι φορείς και οι υπεύθυνοι χάραξης πολιτικής ανησυχούν για την ανάπτυξη πάρκων ΑΠΕ. Υπάρχουν πολλά αντικρουόμενα κριτήρια σχετικά με διάφορες πτυχές, όπως οι προστατευόμενες φυσικές περιοχές, η οικονομική σκοπιμότητα, οι τεχνικοί περιορισμοί και μάλιστα η κοινωνική αποδοχή του έργου. Αυτά τα κριτήρια πρέπει να ληφθούν υπόψη για τον προσδιορισμό της βιώσιμης χωροθέτησης

Απαιτείται μια διαφανής και αξιόπιστη μέθοδος για την ενσωμάτωση των αντικρουόμενων περιβαλλοντικών, κοινωνικών και τεχνικοοικονομικών κριτηρίων με βιώσιμο τρόπο. Από την άποψη αυτή, είναι ζωτικής σημασίας να επισημανθούν οι ανησυχίες των σχετικών φορέων και των φορέων χάραξης πολιτικής σχετικά με την ανάπτυξη πάρκων ανανεώσιμων πηγών ενέργειας στην Ελλάδα. Με διάφορους παράγοντες να παίζουν ρόλο, όπως η ανάγκη διατήρησης των φυσικών περιοχών, η διασφάλιση της οικονομικής σκοπιμότητας, η αντιμετώπιση των τεχνικών περιορισμών και η κοινωνική αποδοχή, υπάρχει ένα πλήθος αντικρουόμενων κριτηρίων που πρέπει να λαμβάνονται προσεκτικά υπόψη κατά τη διαδικασία εντοπισμού βιώσιμων περιοχών. Είναι σημαντικό να αναπτυχθεί μια μεθοδολογία η οποία θα υλοποιεί τους διάφορους αντικρουόμενους παράγοντες της διαδικασίας λήψης αποφάσεων, με διαφανή τρόπο, έτσι ώστε οι υπεύθυνοι λήψης αποφάσεων να είναι σε θέση να τη χρησιμοποιήσουν ως εργαλείο λήψης αποφάσεων. Η μέθοδος θα πρέπει επίσης να είναι εφαρμόσιμη σε διάφορες περιπτώσεις.

Με την επινόηση μιας καινοτόμου προσέγγισης, είναι δυνατή η αποτελεσματική αντιμετώπιση του πιεστικού ζητήματος που τίθεται, το οποίο αφορά τους περιορισμένους εδαφικούς πόρους και τη συνεχώς αυξανόμενη ζήτηση ενέργειας, ιδιαίτερα στα νησιά της χώρας. Επομένως, είναι επιτακτική ανάγκη να δρομολογηθεί άμεσα η εφαρμογή ενός συστηματικού σχεδίου που θα διασφαλίζει τη βιώσιμη τοποθέτηση υπεράκτιων αιολικών πάρκων .Αυτό όχι μόνο μετριάζει το κεντρικό πρόβλημα εντός του νησιού, αλλά και ικανοποιεί την κρίσιμη απαίτηση για άφθονη παροχή ενέργειας.

Αυτή η ολοκληρωμένη προσέγγιση λαμβάνει υπόψη τις διαφορετικές προοπτικές και τα συμφέροντα που εμπλέκονται, διασφαλίζοντας ότι η ανάπτυξη των ΥΑΠ ευθυγραμμίζεται με τους ευρύτερους στόχους της προστασίας του περιβάλλοντος, της οικονομικής βιωσιμότητας και της κοινωνικής αποδοχής. Με την υιοθέτηση της διαφάνειας και της συνεργασίας, η Ελλάδα μπορεί να πλοηγηθεί αποτελεσματικά στις πολυπλοκότητες της ανάπτυξης υπεράκτιων αιολικών πάρκων και να ξεκλειδώσει το πλήρες δυναμικό αυτής της καθαρής και ανανεώσιμης πηγής ενέργειας.

Οι μέθοδοι λήψης αποφάσεων με πολλαπλά κριτήρια (MCDM) έχουν αναδειχθεί ως ισχυρή λύση για την αντιμετώπιση της πολυπλοκότητας των προκλήσεων που συνδέονται με τη βιώσιμη χωροθέτηση, συμπεριλαμβανομένης της ανάπτυξης υπεράκτιων αιολικών πάρκων [4]-[8]. Οι μέθοδοι αυτές παρέχουν μια δομημένη προσέγγιση για την αντιμετώπιση προβλημάτων πολλαπλών κριτηρίων με την ταυτόχρονη εξέταση πολλαπλών παραγόντων. Στο πλαίσιο της βιώσιμης χωροθέτησης, μπορούν να εφαρμοστούν διάφορες μέθοδοι MCDM, όπως η Διαδικασία Αναλυτικής Ιεράρχησης (AHP), η Διαδικασία Αναλυτικού Δικτύου (ANP), η Elimination et Choix Traduisant la Réalité (ELECTRE), η Μέθοδος Σταθμισμένου Μέσου Όρου (OWA), η Μέθοδος Οργάνωσης Κατάταξης Προτίμησης για Αξιολογήσεις Εμπλουτισμού (PROMETHEE) και η Τεχνική για την Προτεραιότητα Τάξης με Ομοιότητα με την Ιδανική Λύση (TOPSIS).

Η ενσωμάτωση των μεθόδων λήψης αποφάσεων με πολλαπλά κριτήρια έχει αναδειχθεί ως μια ισχυρή λύση για την αντιμετώπιση των περίπλοκων προκλήσεων που συνδέονται με τη βιώσιμη χωροθέτηση των ΥΑΠ Αυτές οι δομημένες μεθοδολογίες δίνουν τη δυνατότητα στους υπεύθυνους λήψης αποφάσεων να αξιολογούν συστηματικά και αντικειμενικά διάφορα κριτήρια, διευκολύνοντας τον προσδιορισμό των βέλτιστων θέσεων ΥΑΠ. Οι μέθοδοι MCDM λαμβάνουν υπόψη παράγοντες όπως το περιβαλλοντικό αντίκτυπο, η οικονομική σκοπιμότητα, η κοινωνική αποδοχή και οι τεχνικοί περιορισμοί, παρέχοντας ένα ολοκληρωμένο πλαίσιο για τη λήψη αποφάσεων κατά τη διαδικασία χωροθέτησης.

Για την ενίσχυση της διαδικασίας χωροθέτησης των ΥΑΠ, η συγχώνευση των μεθόδων MCDM με τα γεωγραφικά συστήματα πληροφοριών (GIS) έχει αποδειχθεί ανεκτίμητη. Τα GIS συγχωνεύουν τις χωρικές πληροφορίες για τη δημιουργία κρίσιμων χαρτών και ενσωματώνουν προσαρμοσμένη αξιολόγηση και περιορισμούς αποκλεισμού. Η ακρίβεια και η αξιοπιστία της ανάλυσης των GIS εξαρτώνται από τη χωρική κλίμακα, την ανάλυση των γεωαναφερμένων δεδομένων και την ακεραιότητα των διαθέσιμων πηγών, εξασφαλίζοντας την αποτελεσματική απεικόνιση των αποτελεσμάτων σε χάρτες. Μαζί, οι μέθοδοι MCDM και GIS αποτελούν ένα δυναμικό δίδυμο, παρέχοντας κρίσιμη υποστήριξη στη διαδικασία χωροθέτησης και βοηθώντας στη λήψη τεκμηριωμένων αποφάσεων.

Συνολικά, αυτές οι στρατηγικές, που περιλαμβάνουν μεθόδους MCDM και τη χρήση GIS, έχουν υιοθετηθεί ευρέως για τη βέλτιστη χωροθέτηση υποδομών ανανεώσιμων πηγών ενέργειας [7], [9]-[13]. Χρησιμοποιώντας αυτές τις προσεγγίσεις, οι ενδιαφερόμενοι φορείς και οι υπεύθυνοι χάραξης πολιτικής μπορούν να περιηγηθούν στο πολύπλοκο τοπίο της ανάπτυξης υπεράκτιων αιολικών πάρκων, λαμβάνοντας υπόψη πολλαπλά κριτήρια και λαμβάνοντας τεκμηριωμένες αποφάσεις που προωθούν τη βιωσιμότητα, την περιβαλλοντική διαχείριση και τα κοινωνικοοικονομικά οφέλη

Introduction

The increasing global demand for renewable energy sources (RES) to combat climate change has spurred the development of offshore wind farms (OWFs) as a promising solution [1]. As countries strive to achieve their renewable energy targets, Greece, with its abundant wind resources and extensive coastline, presents a significant opportunity for the deployment of offshore wind energy projects. Greece, as a member state of the European Union (EU), has committed to ambitious renewable energy targets, in alignment with the EU's strategic goals. These targets include a significant increase in the share of renewable energy in the country's energy mix by 2030 [2], [3]. The development of offshore wind parks in Greece can play a crucial role in achieving these targets, as well as contributing to global efforts in mitigating climate change.

Greece is blessed with a vast wind energy potential, especially in its coastal regions. The country's geographical location exposes it to the strong and consistent winds that prevail in the Aegean and Ionian Seas. Harnessing this offshore wind potential can provide a sustainable and clean source of electricity, reducing Greece's dependence on fossil fuels and promoting energy security.

The current energy landscape in Greece heavily relies on conventional energy sources, including fossil fuels. The development of offshore wind parks offers an opportunity to diversify the energy mix, enhancing the resilience and sustainability of the country's energy sector. It also provides a chance to reduce greenhouse gas emissions, leading to a cleaner and more environmentally friendly energy system.

While the benefits of offshore wind energy are significant, there are various challenges that need to be addressed to ensure successful implementation in Greece.

- Designing and constructing offshore wind parks require specialized technical expertise due to the harsh marine environment and complex installation procedures. Factors such as wave and wind loads, seabed conditions, and corrosion prevention pose unique challenges that must be overcome to ensure the long-term reliability and efficiency of offshore wind turbines.
- The development of offshore wind parks entails navigating through a complex regulatory and permitting framework. Obtaining the necessary environmental permits, conducting impact assessments, and securing grid connections require close collaboration between developers, policymakers, and relevant authorities. Streamlining these processes and ensuring efficient coordination among stakeholders are critical for the timely realization of offshore wind projects.
- Engaging local communities, stakeholders, and relevant interest groups is essential for securing social acceptance and support for offshore wind park development. Addressing concerns related to visual impact, noise, and potential environmental effects is crucial to build trust and ensure the successful integration of offshore wind energy into the Greek energy landscape.

From this perspective, it is crucial to highlight the concerns of relevant stakeholders and policymakers regarding the development of renewable energy (RE) parks in Greece. With various factors at play, such as the need to preserve natural areas, ensure economic feasibility, address technical constraints, and gain social acceptance, there exists a multitude of conflicting criteria that must be carefully considered in the process of identifying sustainable sites. It is important to develop a methodology which will implement the various conflicting factors of the decision process, in a transparent way, so that the decision makers will be able to use it as a decision-making tool. The method should also be applicable in various cases.

By devising a novel approach, it is possible to effectively tackle the pressing issue at hand, which involves the limited land resources and the ever-increasing demand for energy. It is imperative, therefore, to promptly initiate the implementation of a systematic blueprint that ensures the sustainable placement of offshore wind farms (OWFs). This not only mitigates the central problem within island, but also fulfills the crucial requirement for ample energy supply.

This comprehensive approach takes into account the diverse perspectives and interests involved, ensuring that the development of OWFs aligns with the broader goals of environmental protection, economic viability, and social acceptance. By embracing transparency, inclusivity, and collaboration, Greece can effectively navigate the complexities of offshore wind park development and unlock the full potential of this clean and renewable energy source.

The Multi-Criteria Decision-Making (MCDM) methods have emerged as robust solution for addressing the complexity of the challenges involved in the energy sector [4]–[7], including the development of offshore wind parks [8]–[12]. These methods provide a structured approach to tackle multi-criteria problems by considering multiple factors simultaneously. In the context of sustainable siting, various MCDM methods can be applied, such as the Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Elimination et Choix Traduisant la Réalité (ELECTRE), Ordered Weighted Averaging (OWA), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

The integration of Multi-Criteria Decision-Making (MCDM) methods has emerged as a robust solution to confront the intricate challenges involved in sustainable OWF siting These structured methodologies empower decision-makers to systematically and objectively assess various criteria, facilitating the identification of optimal OWF sites. MCDM methods take into account factors such as environmental impact, economic feasibility, social acceptance, and technical constraints, providing a comprehensive framework for decision-making in the siting process

To augment the OWFs siting process, the fusion of MCDM methods with Geographic Information Systems (GIS) has proven invaluable. GIS amalgamates spatial information to generate crucial maps and integrates customized evaluation and exclusion constraints.

The precision and dependability of GIS analysis hinge on the spatial scale, the resolution of geo-referenced data, and the integrity of available sources, ensuring the effective visualization of outcomes on maps.The accuracy and reliability of the results obtained through GIS analysis heavily rely on the spatial scale and resolution of the digital data utilized, ensuring that the outcomes can be effectively visualized on maps. Together, MCDM methods and GIS form a dynamic duo, providing crucial support in the siting process and aiding in informed decision-making.

Overall, these strategies, encompassing MCDM methods and the utilization of GIS, have been widely adopted for the optimal siting of renewable energy infrastructures[11], [13]–[17]. By employing these approaches, stakeholders and policymakers can navigate the complex landscape of offshore wind park development, considering multiple criteria and making informed decisions that promote sustainability, environmental stewardship, and socio-economic benefits.

Chapter 1: OFFSHORE WIND PARKS

1.1 Greek Legislation

Greece has demonstrated its commitment to renewable energy by establishing a robust regulatory framework that encompasses offshore wind parks. The Greek regulatory system for offshore wind energy is characterized by a complex network of legislation, policies, and procedures.

Law 3851/2010 serves as the cornerstone of the legal framework for renewable energy sources in Greece, including offshore wind parks. This law establishes the conditions and procedures for granting licenses for the construction and operation of renewable energy facilities, specifically addressing offshore wind parks. It outlines the requirements for conducting environmental and social impact assessments and provides guidelines for connecting renewable energy facilities to the national electricity grid [18].

To further facilitate the licensing process for offshore wind parks, Presidential Decree 4546/2018 was enacted. This decree specifically establishes the regulatory framework governing the licensing of offshore wind parks in Greece. It sets out the criteria against which applications for offshore wind park licenses are evaluated and approved. These criteria encompass technical and environmental considerations, ensuring that the development of offshore wind parks adheres to established requirements[19].

In addition to licensing, Joint Ministerial Decision 4447/2016 plays a crucial role in defining the technical specifications and requirements for the construction and operation of offshore wind parks in Greece. This decision outlines the necessary parameters for designing, installing, and maintaining offshore wind turbines, as well as associated infrastructure such as foundations, towers, and cables[20].

Recognizing the need for continuous improvement and adaptation, Law 4608/2019 introduced updates to the legal framework for renewable energy sources in Greece, including offshore wind parks. This law emphasizes the importance of a detailed spatial planning process to identify suitable locations for offshore wind park development.

By integrating spatial planning considerations, Greece aims to optimize the allocation of resources and minimize potential conflicts with other marine activities[21].

Guided by its energy and climate objectives, Greece has formulated the National Energy and Climate Plan (NECP), which outlines its strategic plan for the period 2021-2030. Within this plan, Greece sets ambitious targets for offshore wind park development, aiming to install 7.5 GW of offshore wind capacity by 2030. This commitment reflects Greece's recognition of the significant potential offered by offshore wind energy in meeting its renewable energy goals[22].

Facilitating collaboration and advocacy within the industry, the Hellenic Wind Energy Association (HWEA) serves as a vital stakeholder. As a non-profit organization, the HWEA represents the Greek wind energy sector, including offshore wind parks. It actively supports the development of policies that promote offshore wind energy and provides crucial information and assistance to industry stakeholders [23].

Through this legislation, with the latest being Law 4964/2022 [24], Greece has established a comprehensive regulatory framework that supports the development of offshore wind parks. The legislation, regulations, and policies governing licensing, design, construction, and operation contribute to creating an enabling environment for the growth of offshore wind energy. With a target of 7.5 GW of offshore wind capacity by 2030, Greece affirms its commitment to renewable energy and emphasizes the significance of offshore wind in its energy transition. The active involvement of the Hellenic Wind Energy Association further strengthens the advancement of offshore wind energy in Greece.

1.2 Pros & Cons

Offshore wind parks are a type of renewable energy source that is generated by wind turbines located in bodies of water. These wind turbines are designed to harness the power of wind, which is then converted into electricity that can be used to power homes, businesses, and other facilities. While offshore wind parks offer a number of benefits, there are also several disadvantages to consider. In this response, we will explore the pros and cons of offshore wind parks in great detail.

Pros of Offshore Wind Parks:

- *Renewable & Clean Energy*: One of the most significant benefits of offshore wind parks is that they provide renewable energy. Unlike fossil fuels, which are a finite resource that will eventually run out, wind is an infinite resource that can be harnessed for electricity generation indefinitely.
- *Lower Carbon Footprint*: The use of offshore wind parks is an effective way to reduce carbon footprint, making it a vital tool in the fight against climate change. By using wind power to generate electricity, we can significantly reduce our reliance on fossil fuels and their associated emissions.
- *Economic Benefits*: Offshore wind parks can provide significant economic benefits, both to the surrounding area and the nation as a whole. These benefits include job creation, increased tax revenue, and local investment opportunities.
- *Energy Security*: Offshore wind parks can also provide energy security by reducing our dependence on foreign oil and other non-renewable energy sources. By generating electricity from wind, we can ensure a more stable and secure energy supply.

Cons of Offshore Wind Parks:

- *High Capital Costs*: One of the most significant disadvantages of offshore wind parks is their high capital costs. Building and installing wind turbines offshore is a complex and expensive process, which can make it difficult to justify the initial investment.
- *Visual Impact*: Offshore wind turbines can have a significant visual impact on the surrounding area. Some people find the sight of large turbines on the horizon to be unattractive or even intrusive.
- *Environmental Impact*: While offshore wind parks are a clean source of energy, they can still have environmental impacts. For example, the construction and maintenance of offshore wind turbines can disrupt marine habitats and impact local wildlife.
- *Distance from Shore*: Offshore wind turbines are located far from shore, which can make them difficult and expensive to maintain. The harsh marine environment can also make it challenging to access the turbines for maintenance and repairs.
- *Energy Transmission*: Offshore wind parks are typically located far from the point of consumption, which means that energy transmission can be a significant challenge. The cost and complexity of building and maintaining transmission infrastructure can add to the overall cost of offshore wind power.

Offshore wind parks offer a range of benefits, including clean, renewable energy, economic benefits, and enhanced energy security. However, there are also several disadvantages to consider, including high capital costs, visual and environmental impacts, and challenges associated with maintenance and energy transmission. Ultimately, the decision to invest in offshore wind power will depend on a range of factors, including local energy demand, available resources, and environmental considerations.[25]

1.3 Offshore and Onshore Wind Parks

Offshore wind parks and onshore wind parks are two types of renewable energy sources that generate electricity using wind turbines. While both types of wind parks offer renewable, low-carbon energy, there are several advantages to offshore wind parks compared to onshore wind parks:

- *Stronger Wind Speeds*: Wind speeds tend to be higher and more consistent offshore than onshore, resulting in more energy being generated by offshore wind turbines. This is because there are fewer obstructions, such as buildings and trees, to disrupt the wind flow offshore. As a result, offshore wind turbines can generate more electricity with fewer turbines compared to onshore wind parks.
- *Less Visual Impact*: One of the main criticisms of onshore wind turbines is their visual impact on the landscape. Offshore wind turbines are less visible to the public, and while they can still impact the views from the shore, they can be located further offshore to mitigate visual impacts.
- *Lower Noise Levels*: Offshore wind turbines generate less noise than onshore turbines, which can be beneficial for the local communities. This is because the wind turbines are located further away from residential areas, and the noise is dispersed by the ocean.
- *Higher Capacity Factors*: Capacity factor is the ratio of actual energy generated by a wind turbine to its theoretical maximum output. Offshore wind turbines typically have higher capacity factors compared to onshore turbines, due to the higher and more consistent wind speeds offshore.
- *Less Land Use*: Onshore wind parks require significant amounts of land to install wind turbines, access roads, and other infrastructure. In contrast, offshore wind parks require little to no land use, making them a good option in densely populated areas or where land is scarce.
- *Fewer Permitting Challenges*: Onshore wind parks may face challenges in obtaining permits due to environmental and local opposition concerns. Offshore wind parks generally face fewer permitting challenges, as they are less visible and less disruptive to local land use.

Offshore wind parks offer stronger and more consistent wind speeds, less visual and noise impact, higher capacity factors, less land use and fewer permitting challenges than onshore wind parks. However, offshore wind parks also come with higher capital costs and logistical challenges due to their location offshore. The choice of wind park type will depend on a variety of factors, including location, energy demand, available resources, and economic considerations.[25], [26]

1.4 Requirements

The ideal location for offshore wind park installation depends on several technical factors, including wind speed, water depth, distance from shore, and other environmental and social considerations:

Wind Speed: Offshore wind turbines require consistent and strong winds to generate electricity. Two prominent types of wind turbines that have been widely used are fixed-speed wind turbines and variable-speed wind turbines. In the early 1990s, fixed-speed wind turbines were the most common installation due to their simplicity, robustness, reliability, and lower cost of electrical parts. These turbines were equipped with a squirrel cage induction generator (SCIG) directly connected to the grid, a soft starter, and a capacitor bank to reduce reactive power consumption. However, their rotor speed remained almost fixed and tied to the grid frequency, limiting their efficiency and controllability. The fixed-speed design aimed for maximum efficiency at a specific wind speed, typically the most prevalent in the region where the turbine was installed. Despite their advantages, fixed-speed wind turbines faced challenges such as high mechanical stress, uncontrollable reactive power consumption, and limited power quality control.

In contrast, variable-speed wind turbines emerged as the dominant technology in the past decade, offering significant improvements over fixed-speed turbines. The key characteristic of variable-speed turbines is their ability to decouple the electrical grid frequency and mechanical rotor frequency through a power electronic interface. This enables the turbine to continuously adapt its rotational speed to match varying wind speeds, allowing it to operate at its highest level of aerodynamic efficiency across a wide range of wind speeds. Variable-speed wind turbines have several advantages, including increased annual energy capture (about 5% more compared to fixed-speed technology) and the ability to easily control active and reactive power. They also experience less mechanical stress, offer improved power quality, and are more grid-friendly, making them suitable for large wind farm integration.

While variable-speed wind turbines offer numerous benefits, they do come with certain drawbacks. The introduction of power electronics for variable-speed operation increases losses, component count, and overall complexity, resulting in approximately 7% higher costs compared to fixed-speed turbines. Despite this, their advantages outweigh the drawbacks, making them a preferred choice for modern wind energy projects. variable-speed wind turbines have emerged as the dominant technology in recent years, offering improved efficiency, controllability, and grid integration capabilities. Fixed-speed wind turbines, though simpler and more cost-effective, suffer from limitations in efficiency and power quality control. As the renewable energy landscape continues to evolve, further advancements in wind turbine technology are expected to enhance efficiency and reduce costs, contributing to a sustainable and cleaner future.

The ideal wind speed for offshore wind park installation is between 6 and 10 meters per second (m/s) or higher. In general, areas with average wind speeds above 6.5 m/s are considered suitable for offshore wind park installation [25]–[29].

Water Depth and Seabed Conditions: Offshore wind turbines are typically installed in water depths of up to 50 meters. Shallow water depths are ideal for offshore wind park installation because they reduce the cost and complexity of foundation design and installation. Areas with water depths between 20 and 30 meters are considered ideal for offshore wind park installation [30]. The seabed conditions are an important consideration in offshore wind park installation. Areas with a stable seabed and low levels of sediment are preferable, as they reduce the risk of foundation instability or damage. In general, areas with hard, rocky seabeds or sand and gravel sediments are considered suitable for offshore wind park installation [17], [31].

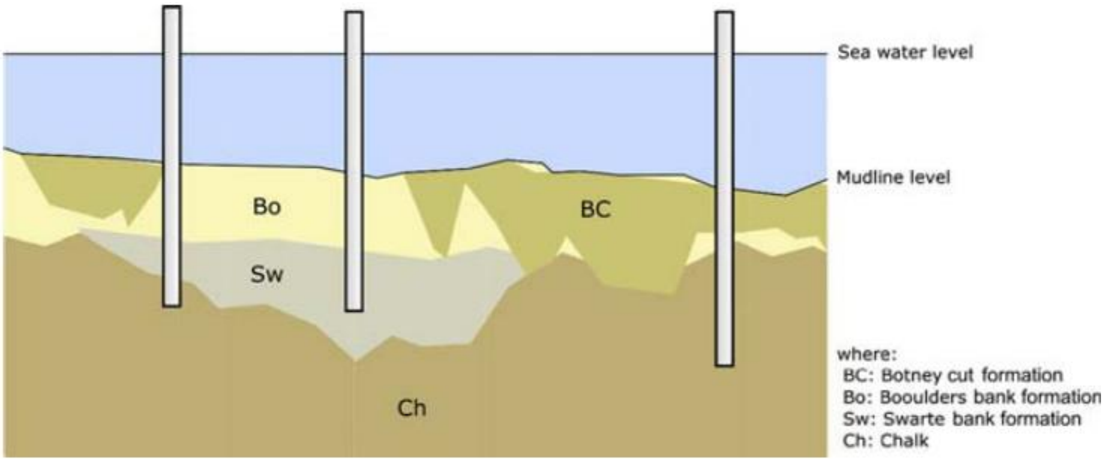

Figure 1 Monopile foundation in Westermost Rough.][25], [32]

Foundations play a crucial role in the design and financial viability of a project, typically accounting for 25%-34% of the total project cost. Therefore, efforts are made to reduce foundation costs without compromising on safety and efficiency. Several factors must be considered when choosing and designing the foundation for a specific site. These factors include the ease of installation under various weather conditions, seabed conditions, requirements for specialized vessels and equipment during installation, and compliance with local environmental regulations, especially concerning noise. Figure 2 illustrates different types of foundations commonly used for offshore wind farms based on water depths.

For water depths of about 30 meters, the most commonly used or considered foundation types are monopiles (Figure 2 C), gravity-based foundations (Figure 2 B), and suction caissons (Figure 2 A). In the range of 30 to 60 meters water depth, jackets or seabed frame structures supported on piles or caissons are either utilized or planned. For even deeper waters, typically exceeding 60 meters, floating systems are being considered. It is important to note that the choice of foundation depends not only on water depth but also on other factors such as seabed conditions, site-specific characteristics, turbine and loading requirements, and economic considerations.

The substructure of offshore wind turbines can be classified into two main types:

1. **Grounded system or fixed structure**: In this type, the structure is firmly anchored to the seabed. Grounded systems can be further categorized into shallow foundations (e.g., gravity-based solutions and suction caissons) and deep foundations.
2. **Floating system**: In this type, the system is allowed to float and is anchored to the seabed using a mooring system. Floating systems offer certain ecological advantages as they leave a minimal seabed footprint and are relatively easy to decommission and maintain. The system can be de-anchored and floated out to a harbor for maintenance or decommissioning purposes.

The selection of the appropriate foundation for offshore wind turbines is a critical decision, impacting both the project's financial viability and its long-term performance. Factors such as water depth, seabed conditions, site-specific characteristics, loading requirements, and economic considerations influence the choice between grounded and floating systems. While each type of foundation has its advantages and challenges, ongoing research and advancements in foundation technologies are likely to improve the efficiency and cost-effectiveness of offshore wind energy projects [25].

The size and scale of a wind farm can lead to significant variations in seabed conditions, including varying water depths and distances from the shore. Consequently, the loads on the foundations supporting the wind turbines will differ based on their specific locations. Ideally, the most effective approach would be to design each foundation individually, taking into account the unique conditions of each turbine location. This customized foundation design would optimize performance and ensure safety.

However, from an economic standpoint, it is more desirable to minimize costs and achieve overall efficiency in the wind farm's construction and operation. One way to achieve this is by using a limited number of foundation types, allowing for streamlined fabrication and installation processes using the same installation vessel. This approach is particularly relevant for large-scale projects. Many North European developers choose to standardize on a single type of foundation, such as monopiles or jackets, for the entire wind farm site. This decision often influences the layout of the farm, with developers avoiding areas of deeper water or soft locally available mud to maintain consistency in foundation design.

In the interest of cost optimization and project efficiency, developers may conduct case studies to evaluate different foundation options and their impact on the overall economy of the wind farm. These case studies can provide valuable insights into the performance and cost-effectiveness of various foundation types in specific seabed conditions and water depths. The findings from these studies inform the decision-making process and help developers select the most suitable foundation type for the entire wind farm or specific regions within it.

By striking a balance between customized design for optimal performance and standardization for cost efficiency, wind farm developers can achieve a successful and economically viable project.

This approach ensures that the unique challenges posed by varying seabed conditions are effectively addressed while keeping the overall construction and operational costs within reasonable bounds.[26]

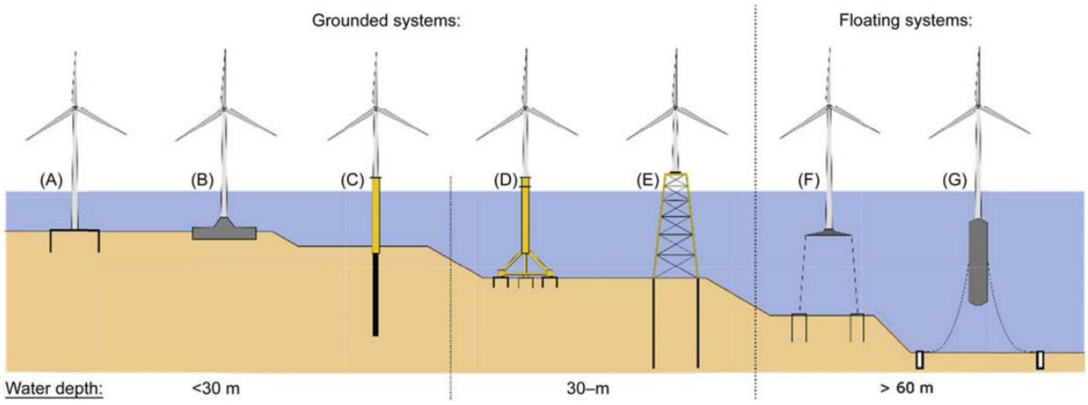

Figure 2 :(A) Bucket/suction caisson; (B) gravity based; (C) monopile; (D) tripod on bucket/suction caisson; (E) jacket/lattice structure; (F) tension leg platform; (G) Floating spar buyo system [25]

Distance from Shore: Offshore wind parks are typically located between 10 and 50 kilometers from shore. The distance from shore is an important factor in determining the cost of the project, as it affects the length of the undersea cables required to transmit electricity to the grid. The ideal distance from shore depends on several factors, including the cost of the undersea cables, the availability of land-based electrical infrastructure, and the impact on marine life and coastal communities[27], [33].

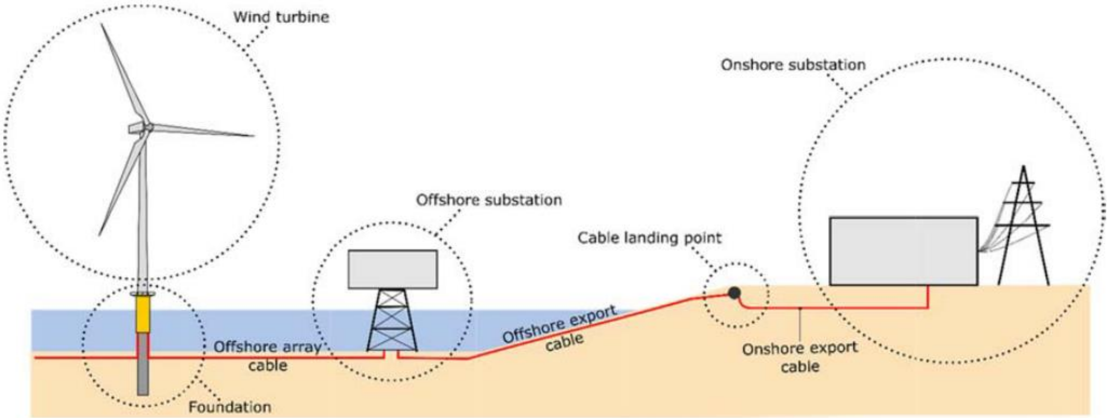

Figure 3: Wind park overview[25]

Environmental and Social Considerations: Offshore wind park installation must also consider environmental and social factors, including the impact on marine life and coastal communities. The ideal location for offshore wind park installation is one that minimizes the impact on sensitive habitats and species and has good community support. Environmental impact assessments and stakeholder engagement processes are typically used to evaluate the environmental and social suitability of offshore wind park locations.

Spacing: Wind farm developers strategically space wind turbines in order to maximize energy generation while minimizing upfront costs, known as CAPEX (Capital expenditure).

The spacing of turbines is a crucial optimization challenge, striking a balance between the wind farm's compactness to reduce CAPEX associated with subsea cables and the need for adequate separation to minimize energy loss caused by wind shadowing from turbines upstream. An aerial photo, depicted in **Error! Reference source not found.**, showcases the wake turbulence created by individual wind turbines enveloped in the foggy expanse of the Horns Rev wind farm off Denmark's Western coast. The geometric layout of a wind farm can take various forms, such as a single line, square, or rectangular configuration. With the advent of advanced optimization techniques and differing constraints and site conditions, alternative layout patterns are increasingly employed [26].

Figure 4: Wake turbulence Vattenfall Wind Power, Denmark [25]

Typically, the spacing between turbines is approximately three times the rotor diameter multiplied by ten, depending on the dominant wind direction. Additionally, the spacing perpendicular to the prevailing wind direction should exceed three times the rotor diameter multiplied by four, while a spacing of eight times the rotor diameter multiplied by ten is recommended for directions parallel to the wind. For instance, Figure 5 illustrates a potential site layout for a wind farm in Northern Ireland, where the prevailing wind direction is from the southwest. In this scenario, the spacing along the wind direction is maintained at six times the rotor diameter (6D), while the spacing across the wind can be slightly reduced to four times the rotor diameter (4D). The substantial spacing between turbines, typically ranging from 800 to 1200 meters, necessitates a significant land area for small to medium-sized wind farms. For reference, modern wind farms can extend over an area of approximately 20 km by 36.5 km, as exemplified by the Sandbank wind farm in the German North Sea [25].

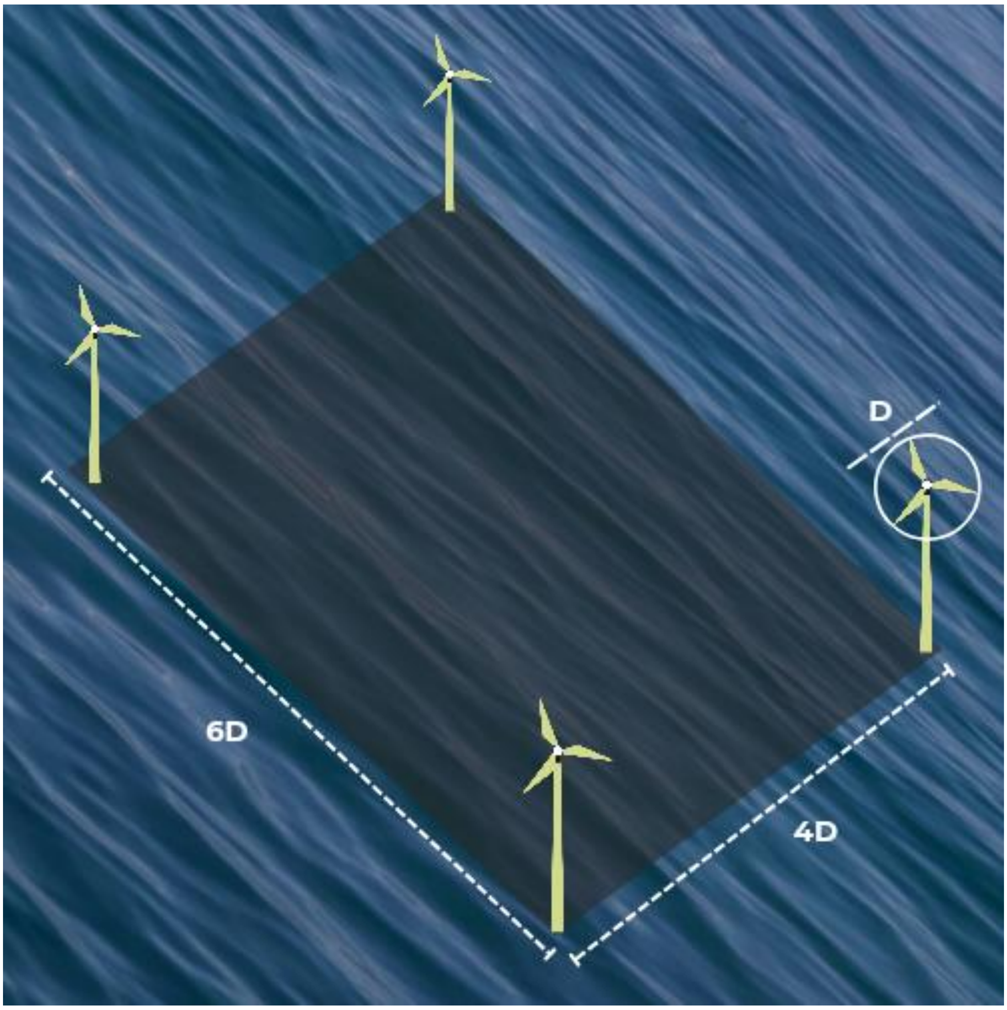

Figure 5: Spacing of turbines [25]

Given the extensive coverage of a wind farm, geological and subsurface conditions, as well as practical considerations, may exhibit considerable variation. Factors such as sudden changes in water depth due to a drop in the sea floor, paleochannels, alterations in ground stratification, submarine slopes, presence of obstacles like shipwrecks, and the location of important utility lines (e.g., gas pipelines, fiber optic cables) pose challenges. Consequently, a comprehensive site investigation program involving geotechnical and geophysical tests is conducted to establish a detailed 3D geological model, which often dictates the final layout of the wind farm.

Chapter 2: GIS & MCDM

2.1 Literature review

In the field of offshore wind energy development, several studies have explored methodologies for identifying suitable sites and evaluating their potential. This literature review highlights key studies that have applied Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) approaches to assess the suitability of areas for wind energy development.

In the field of power generation site evaluation, several studies have utilized Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) techniques to identify suitable locations for various technologies.

In the United States, [34] embarked on a GIS-based MCDM endeavor to evaluate new power generation sites with the aim to unearth parcels of land with the potential to accommodate diverse power generation technologies. Moreover, on the shores of Egypt, [11] introduced an innovative methodology to pinpoint potential offshore wind energy sites with precision. Their approach artfully wove together AHP, GIS, and pairwise comparison methods. The outcome was impressive—Egypt's capacity to generate a whopping 33 GW of offshore wind power. This not only underscores the country's vast renewable energy resources but also aligns with its ambitious energy targets. Meanwhile, on the global stage, other GIS-centric studies focused their lenses on the ideal locations for biogas plants. [15] explored the landscapes of southern Finland, while [35] ventured into Alberta, Canada, and [36] navigated Denmark. Armed with MCDM tools like AHP and GIS, they sought out prime spots, optimal sizes, and the magic numbers of biogas facilities.

Entering a comparable domain, the work of [27]. in 2018 embarked upon a mission that closely paralleled these endeavors, yet with a distinctive twist - focusing on hybrid OWFs and wave energy systems, underpinned by a comprehensive environmental assessment. Wind velocity, wave energy potential, and environmental impact surfaced as pivotal considerations within their site selection process. Their findings accentuated the imperative nature of holistic environmental assessments, aiming to ensure a congruence between energy production and ecological preservation. Transitioning our focus to Europe, [37] undertook the intricate task of delineating areas suitable for offshore combined platforms within expansive marine environments. Their investigation revealed Northern and Western Europe as prime candidates, distinguished by abundant wind potential and favorable water depths. Nonetheless, they conscientiously acknowledged the multifaceted challenges inherent to these marine settings, ranging from accessibility issues to intricate construction logistics, as well as unpredictable meteorological conditions. The corollary of their research was the generation of comprehensive insights into the factors guiding site selection and a heightened comprehension of the attendant challenges, thereby facilitating more judicious decision-making within the realm of offshore renewable energy development.

As we traverse to Greece, the focal point of attention alights upon the captivating island of Crete, serving as a prominent backdrop for myriad studies infused with MCDM and GIS. [38] adeptly charted a course for the siting of offshore wind farms (OWFs) in Chania, Crete, adroitly maneuvering through an intricate landscape of environmental restrictions, wind power potential, and electricity demand. This methodological approach not only serves to stimulate sustainable development within the Mediterranean Sea region but also furnishes Greek decision-makers with a robust toolkit for fostering the growth of OWFs. In parallel, [33] meticulously navigated the pathway to the deployment of hybrid OWFs, synergistically harnessed with wave kinetic energy. The bedrock of their methodology rested upon GIS-based AHP.

The strategy comprised a dual-pronged approach: firstly, the exclusion of unsuitable marine areas through the application of Exclusion criteria, followed by an evaluation of the remaining options using the AHP method. The discernment derived from this endeavor led to the identification of propitious marine areas, with particular emphasis on the regions encompassing Crete and the north-central to central Aegean Sea.

Delving deeper into the exclusive economic zone of Greece, particularly the environs surrounding Crete, [17] embarked on a quest to orchestrate sustainable progress. At the epicenter of their endeavor stood the Analytic Hierarchy Process (AHP) alongside GIS, as they meticulously united Exclusion and Evaluation criteria within an elaborate methodological framework. The culmination of this rigorous approach bore fruit in the form of a precise ranking of suitability areas for offshore wind park installation. Building upon this foundation, in a subsequent study, [39] delved even further into the intricacies, probing the visual impact of potential offshore wind parks

Similar Tsoutso et.all [40] implemented an onshore analysis of the available wind farm development areas on the island of Crete, with particular emphasis to grid infostructure and capacity. They used the GIS tool to determine available areas, while Latinopoulos and Kechagia [41] developed a land suitability assessment tool for wind farm siting using GIS, spatial analysis, and MCDM techniques. The aim of their decision tool was to identify the most suitable areas for wind farm projects and provide support to potential project planners.

However, even as these studies have substantially enriched our comprehension of wind farm site selection, an evident gap persists in the current body of research. This gap is particularly pronounced when considering the alignment of MCDM methods with the intricacies of wind energy planning. This shortage of investigations that seamlessly unite MCDM methodologies with the complexities of wind energy planning underscores the need for a standardized approach within this domain. Although extant studies have made strides in elucidating various facets of the site selection process, methodological disparities between these studies further accentuate the necessity for a harmonized framework. Thus, in this study, we glean valuable insights from the knowledge presented in Table 1, from which exclusion constraints and evaluation criteria are derived.

Table 1: GIS and MCDM literature review

Study	Methodical framework	Case study
Leda-Ioanna Tegou [42]	AHP & GIS Evaluation Score	Lesvos island. Greece
Tim Höfer[14]	AHP & AIP, GIS Evaluation Score	Aachen, Germany
Abdullah Almasad.et.al.[43]	Fuzzy AHP & PROMETHEE II, GIS	Saudi Arabia
Pandora Gkeka [17], [39]	AHP & GIS Suitability	Crete, Greece
S.K. Saraswat.et.al. [44]	Fuzzy AHP &GIS Suitability	India
Mary Christoforaki [38]	AHP & GIS Suitability	Chania, Crete Greece
Juan M. Sánchez-Lozano.et.al [45]	AHP & TOPSIS, GIS	Cartagena, Spain
T. Tsoutsos [40]	SFSPSD-RES & GIS with Evaluation Score	Crete, Greece
Isabel C. Gil-García [10]	AHP-TOPSIS and fuzzy-GIS	The Gulf of Maine,USA
Georgiou et al.[46]	AHP & GIS with SAW weighting method	Larnaca District, Cyprus
Garlapati Nagababu et al [47]	Fuzzy AHP-TOPSIS & GIS	India
Ioannou Konstantinos [48]	AHP & TOPSIS, GIS	Macedonia and Thrace region, Greece
Dimitra G. Vagiona [49]	AHP & TOPSIS, GIS	South Aegean, Greece
Harish Puppala et. al. [50]	TOPSIS & GIS	India
Joss J.W. Watson [8]	AHP & GIS Suitability	UK
Ramirez-Rosado et al. [13]	AHP & GIS with Evaluation Score	La Rioja, Spain
Nazli Yonca Aydin [51]	GIS & Fuzzy MCDM	Western Turkey
Margarita Vasileiou [16]	AHP &GIS Suitability	Greece
Jason R. Janke [52]	GIS	Colorado, USA
Jianwei Gao.et.al [53]	GIS & Unique MCDM method	China
D. Latinopoulos [41]	AHP & GIS Suitability	Kozani, Greece
Geovanna Villacreses.et.al. [54]	GIS with AHP & OWA, OCRA, VIKOR,TOPSIS Comparison	Ecuador
Sassi Rekik [55]	AHP & GIS Suitability	Tunisia
George Xydis [56]	GIS & Techno-economic analysis	Kythira island, Greece
Xiaoxun Huang et. al.[57]	GIS & RTF	China
Tyagaraja S.M. Cunden.et.al [58]	AHP with WLS & GIS	Mauritius, Africa

According to the literature review, several criteria were used to produce available areas and suitability score. The criteria were categorized into two main groups: exclusion constraints and evaluation criteria. The exclusion constraints aimed to identify prohibited areas based on legal or other unviolated factors. The evaluation criteria were used to assess the remaining suitable areas based on a range of values.

Vasileiou et al. [33] applied exclusion constraints such as military areas, licensed hydrocarbon areas, areas of environmental interest, and various techno-economic criteria such as wind speed, water depth, wave potential, and distance from the shore. They also used as evaluation criteria several techno-economic factors such as: connectivity to the electric grid, population served, shipping density, and distance from ports. After careful evaluation, the criteria which were most impactful for this study were found to be Wind velocity, wave energy potential, and water depth.

Similarly, Wu et al. [59] considered exclusion constraints such as military areas, shipping routes, existing engineering infrastructures, and environmentally protected areas. They evaluated 22 criteria grouped into categories related to the economy, wind resources, technical constraints, environment, society, and construction/maintenance. To handle imprecise decision information and eliminate likelihood-based comparisons, they employed fuzzy ELECTRE-III method. The researchers also took into account exclusion constraints such as military, protected, and operational marine areas, while evaluating 18 factors related to the economy, environment, society, wind potential, potential risks, and construction constraints. Additionally, they utilized the PROMETHEE method in a fuzzy environment to mitigate the loss of decision information. Their comprehensive approach aimed to identify suitable development locations while considering various societal, environmental, and technical aspects.

Vagiona et al. [49] employed exclusion constraints such as water depth, wind velocity, distance from protected environmental areas, and a safe distance from cities and settlements. They assessed various factors including wind velocity, population served, shipping density, and proximity to protected environmental areas as part of their criteria. As a result of their study, they identified two marine areas that were in close proximity to either existing onshore wind farms or those being currently considered for development.

Loukogeorgaki et al. [27] utilized exclusion constraints that focused on the co-existence of marine activities, techno-economic constraints, and social considerations. They meticulously assessed multiple criteria, including wind and wave energy potential, water depth, distance from shore, shipping density, proximity to ports, grid connection feasibility, population served, and potential environmental impacts. Among these criteria, wind velocity, wave energy potential, and environmental performance emerged as the most crucial factors in their analysis. By considering these various aspects, the researchers aimed to make informed decisions regarding the optimal utilization of resources while addressing societal, economic, and environmental concerns.

Stefanakou et al. [60] excluded four specific criteria outlined by the Ministry of the Environment and Energy in Greece. Additionally, they evaluated nine criteria that encompassed spatial, social, techno-economic, and environmental considerations. The objective of their research was to develop a decision-making tool that could effectively identify suitable areas, with a particular focus on floating wind turbines and other marine renewable energy systems in Greece. Through their study, they aimed to provide valuable insights and guidance for the sustainable development of such technologies in the country.

Sourianos et al. [61] categorized the various criteria, used for exclusion and evaluation into three groups: exclusionary, mitigable, and constraints. Exclusionary criteria acted as strict limits, while mitigable criteria allowed for varying values. They aimed to develop a software tool which could be used for decision support process, for both stakeholders and decision-makers involved in offshore wind farm development.

Kim et al. [62] evaluated marine areas surrounding Jeju Island for offshore wind farm development using different combinations of siting criteria. Their criteria were grouped into categories which mirrored social and environmental interests as well as techno-economic factors such as wind energy, water depth, and connectivity to the electric grid. The number of potential areas for wind farms was significantly reduced when considering criteria beyond energy resources and economics. This approach aimed to reduce conflicts among stakeholders and minimize environmental impacts.

Fetanat et.al [63] took into consideration several criteria which were later divided into six main categories: wave characteristics, environmental constraints, proximity to other important facilities, economic indicators, technical factors and resources and cultural aspects related to social acceptance. The study showcased the resilience of the methodology when experts' opinions were exposed to alterations in criteria. This robustness underscored the suitability of their approach, which could be effectively applied to diverse coastal areas.

The literature review highlighted various siting criteria used in different studies. These criteria encompassed a wide range of factors, including environmental, technical, social, and economic aspects, which contribute to effective decision-making in offshore wind farm planning and implementation.

Chapter 3: METHODOLOGY

3.1 Exclusion Constraints

In order to define the available areas for evaluation, a series of Exclusion constraintswere used, in combination with the latest Greek legislation for Offshore Wind parks installation, Law 4964/2022, Law 4893/2019 and Incorporation into Greek legislation of Directive 2014/89/EU "establishing a framework for marine spatial planning" and other provisions. [19], [24].

The criteria were divided in four main categories: Technical, Environmental, Legislative and Safety. In addition, a stricter approach was implemented regarding the exclusion of zones with important environmental interest.

3.1.1 Technical Constraints:

When identifying suitable marine areas for offshore wind farms (OWFs), certain technical constraints must be considered.

One critical constraint is the water depth, specifically areas with depths exceeding -100 meters. Constructing the foundations of an OWF in deeper waters requires advanced technology and entails significant economic constraints. Fixed foundations are typically employed in depths no greater than 50 meters, while below 50 meters, the available options for offshore wind turbines foundation are floating.[17], [63], [64]

Additionally, marine areas with wind velocities below 6.5 m/s at an elevation of 100 meters above sea level were excluded from consideration, according to [17] and [14] . These areas lack the necessary investment opportunities and commercial availability of offshore wind turbine designs. Based on the opinions of experienced wind farm planners, wind speeds above 6.5 m/s are commonly regarded as favourable for wind farm siting. This threshold serves as a general benchmark for assessing the wind energy potential of a specific location. Higher wind speeds facilitate more efficient and productive energy generation.

3.1.2 Environmental Constraints:

When evaluating potential sites for OWFs, certain environmental constraints need to be considered.

According to national legislation, Areas of environmental interest were not entirely prohibited, which allows the development of OWFs if specific conditions were met to protect critical habitats. However, certain protected areas, such as NATURA 2000 sites and Important Bird Areas (IBAs), were strictly excluded from consideration, in the spirit of a strict environmental approach.

By excluding the aforementioned areas, this study aims to safeguard the habitat of endangered, endemic, or endangered bird species as well as areas of unique environmental impact. Greece has identified 208 areas meeting scientific criteria for this purpose. Additionally, the presence of Posidonia oceanica meadows, which form extensive seagrass beds along the coastal zone, influences site selection. Furthermore, migratory bird corridors were excluded from the survey to protect the habitat of these birds[17], [27], [65].

3.1.3 Legislative Constraints:

Various legislative constraints impact the selection of OWF sites. Distances from the shore are strictly regulated, with areas outside the exclusive economic zone of Greece (12 Nautic miles) being excluded. Additionally, areas closed to the coast of neighbour country, such as Turkey, were kept within the 6 Nautic miles zone, in accordance with the United Nations Law [66]

Furthermore, areas close to the shore, up to 1.5 kilometres, were excluded according to legislation which is governing the monitoring program of bathing waters and preliminary procedures for installation of OWFs.

Areas with the title of Posidonia oceanica meadows as well as Prohibited fishing areas, specifically regions around islands where fishing is banned, were also excluded. A minimum distance of 3,000 meters from sites of historical landmarks such as world heritage monuments and archaeological sites is required by law. Moreover, a buffer zone of 1,500 meters from cities and settlements with populations exceeding 2,000 residents, 1,000 meters from smaller traditional settlements, and 500 meters from monasteries is mandated. To implement a stricter approach, this study used a universal 2 kilometres buffer as safe distance from shore and a 3 kilometres buffer around areas of historical landmarks.

Military exercise areas pose safety concerns, such as potential collisions or unconventional activities, and are therefore excluded. Finally, a buffer zone of 1 kilometre from passenger and commercial shipping routes was used as a safety constraint. Additionally, a buffer of 3 kilometres from all civil and military airports and ports was excluded. This measure was used to ensure the safety of aircraft and radar systems and minimize potential interference with turbines as well as the avoidance of congestion near civil and commercial ports[17], [27], [33].

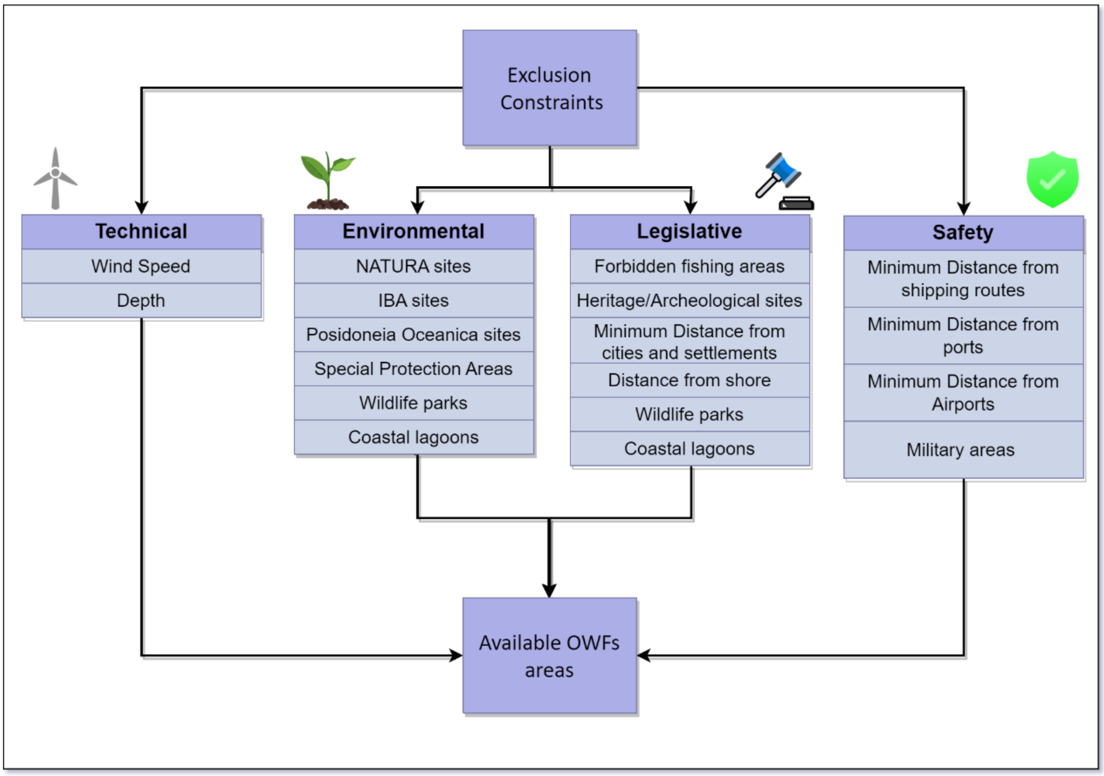

Figure 6: Exclusion Constraints

3.2 Evaluation Criteria for Offshore Wind Farm

The evaluation criteria for selecting suitable sites for offshore wind farms were chosen with consideration for various environmental, techno-economic, and socio-political factors specific to the region. The criteria were designed to assess the suitability of different areas based on a range of values for each criterion. The overall structure of the evaluation criteria, divided into five key categories, is illustrated in **Error! Reference source not found.**. A total of nine evaluation criteria were chosen as outlined below:

3.2.1 Environmental Criteria:

Distance from areas of Environmental Interest: Areas farther away from environmentally sensitive locations received higher suitability scores compared to those near such areas.

3.2.2 Technical/Economic Criteria:

Wind resources: The wind speeds at a height of 100 m were considered, and areas with wind speeds below 6.5 m/s were deemed inefficient and excluded from further evaluation. The remaining areas produced polygons which were deemed suitable for further evaluation. For this project, we decided to implement the wind resource as wind power. We used the Global Wind Atlas to produce wind power values for its polygon. The produced wind power is calculated in w/m^2 for 10% of the windiest areas of every polygon. In Figure 7, Figure 8, Figure 9, 3 out of 35 available areas are presented, produced by above mentioned procedure.

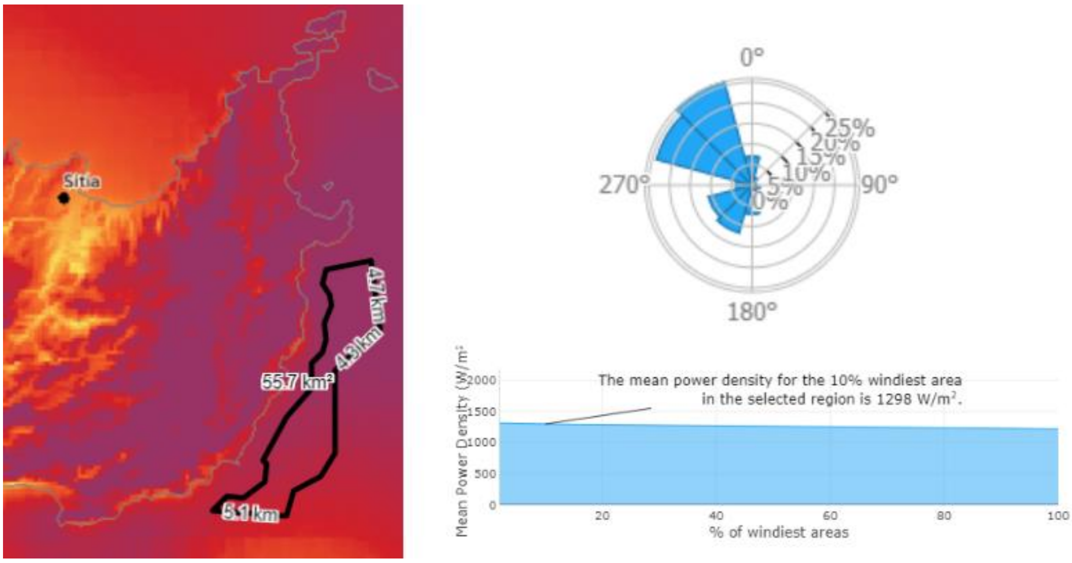

Figure 7: Xerokampos,Lasithi Regional Unit, Region of Crete, 55.71 km²

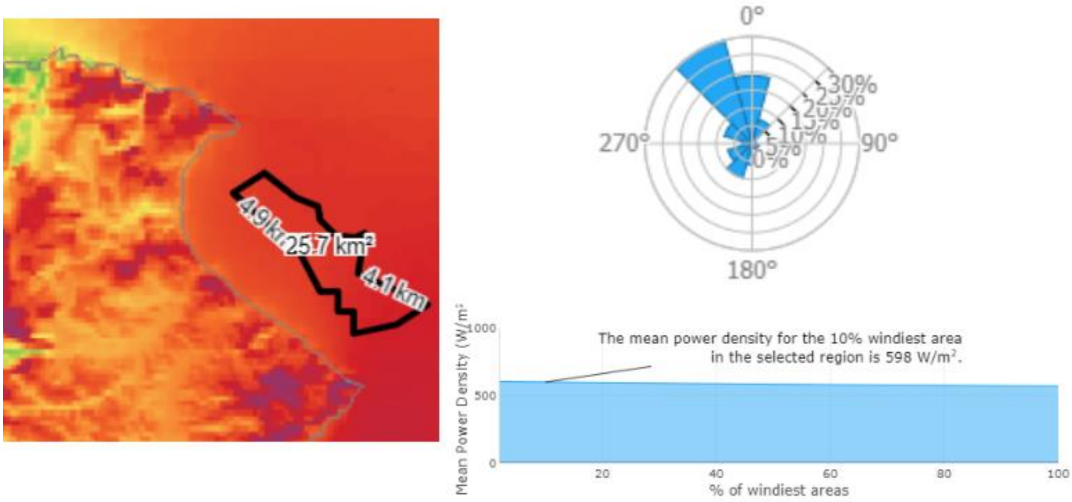

Figure 8: Euboea Regional Unit, Central Greece, Thessaly and Central Greece, 25.67 km²

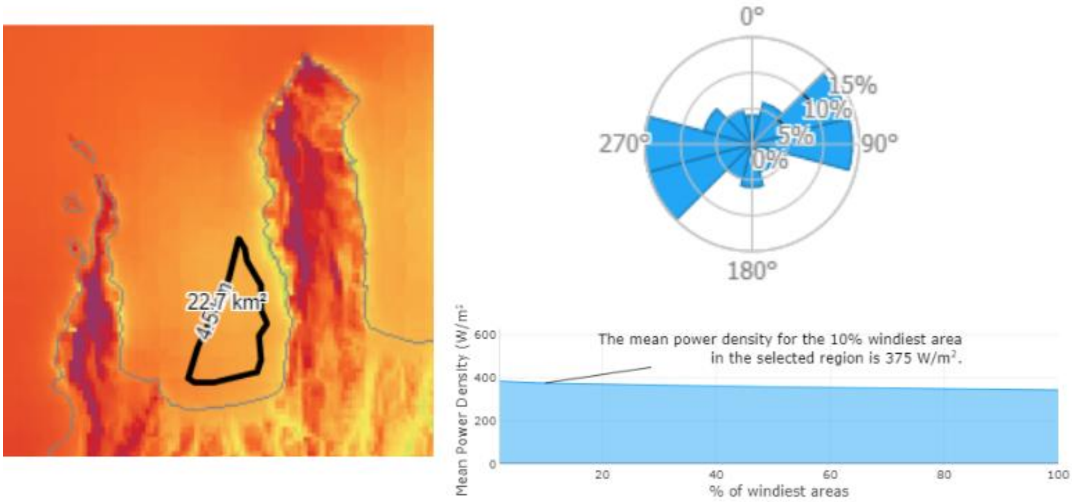

Figure 9: Kissamos, Municipality of Kissamos, Chania Regional Unit, Region of Crete, 22.68 km²

Water Depth: Areas with shallower waters were preferred due to cost benefits and convenience for installing wind farm structures. These areas were considered more suitable.

Seabed Substrate: Sandy seabed substrates were preferred over rocky ones for the installation of offshore wind farms. The Seabed Substrate is defined in five categories: Coarse & mixed sediment, Mixed Seabed, Sand, Maddy Sand, Fine Mud which are graded 1 to 5 respectively, similar to the study of Pandora Gkeka-Serpetsidaki and Tsoutsos [17]. Since some available areas have a combination of Seabed Substrate, the suitability score was calculated according to the percentage of the Seabed category.

3.2.3 Safety Criteria

Distance from Shipping Ports/Airports: The placement of offshore wind farms should not disrupt existing marine activities, such as vessel routes. Consideration of appropriate distances from airports was also important to mitigate the risk of potential collisions during aircraft take-off and landing.

Distance from Military Areas: Marine exercise areas were excluded from consideration due to safety reasons.

3.2.4 Social & Disturbance Criteria

Distance from Heritage Sites: In accordance with legislation [21] a minimum buffer of 3 kilometres from heritage sites (UNESCO), archaeological sites, and historical sites was defined.

Noise Level/Acoustic Disturbance: Greek legislation [21] stipulated that noise levels around residential areas (cities, settlements, traditional villages, and monasteries) should not exceed 45 dB.

Optical Disturbance: Optical disturbance caused by offshore wind farms was evaluated by the distance from shore. Polygons which were further from shore, were deemed more suitable since they would have a lower potential of having an optical disturbing impact.

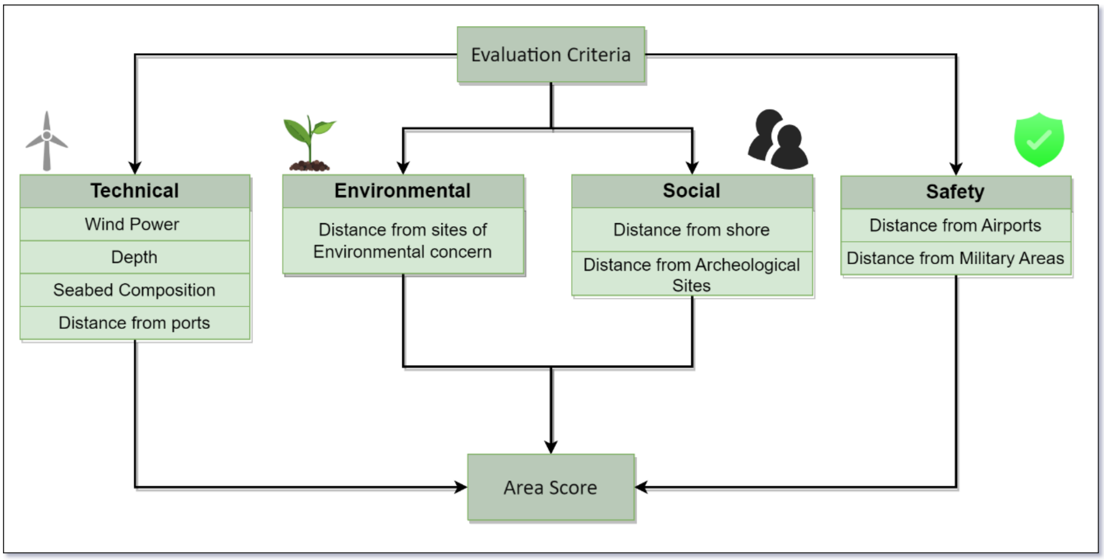

Figure 10: Evaluation Criteria

3.3 Workflow

In order to implement the exclusion constraints effectively, as constraints, the ArcGIS Pro 3.0 was used, which was the latest version of GIS tool of the ArcGIS series, at that time. The GIS tool allowed us to create exclusion layers as feature layers which, when combined, produced the available areas for offshore wind park development. The available data, as presented in Table 2, where gathered from different sources and were of various formats.

First, technical constraints, in form of raster files, were used like mean wind speed at 100 m above sea level (Figure 11) and water depth (Figure 12).

Combining the technical parameters as a GIS feature layer and implementing technical constraints (wind speed >6.5 m/s and water depth >-100m), the first polygons of available areas were created (Figure 13). While the polygons need further reduction due to environmental and social constraints, they contribute into realising the potential of OWF development in Greece.

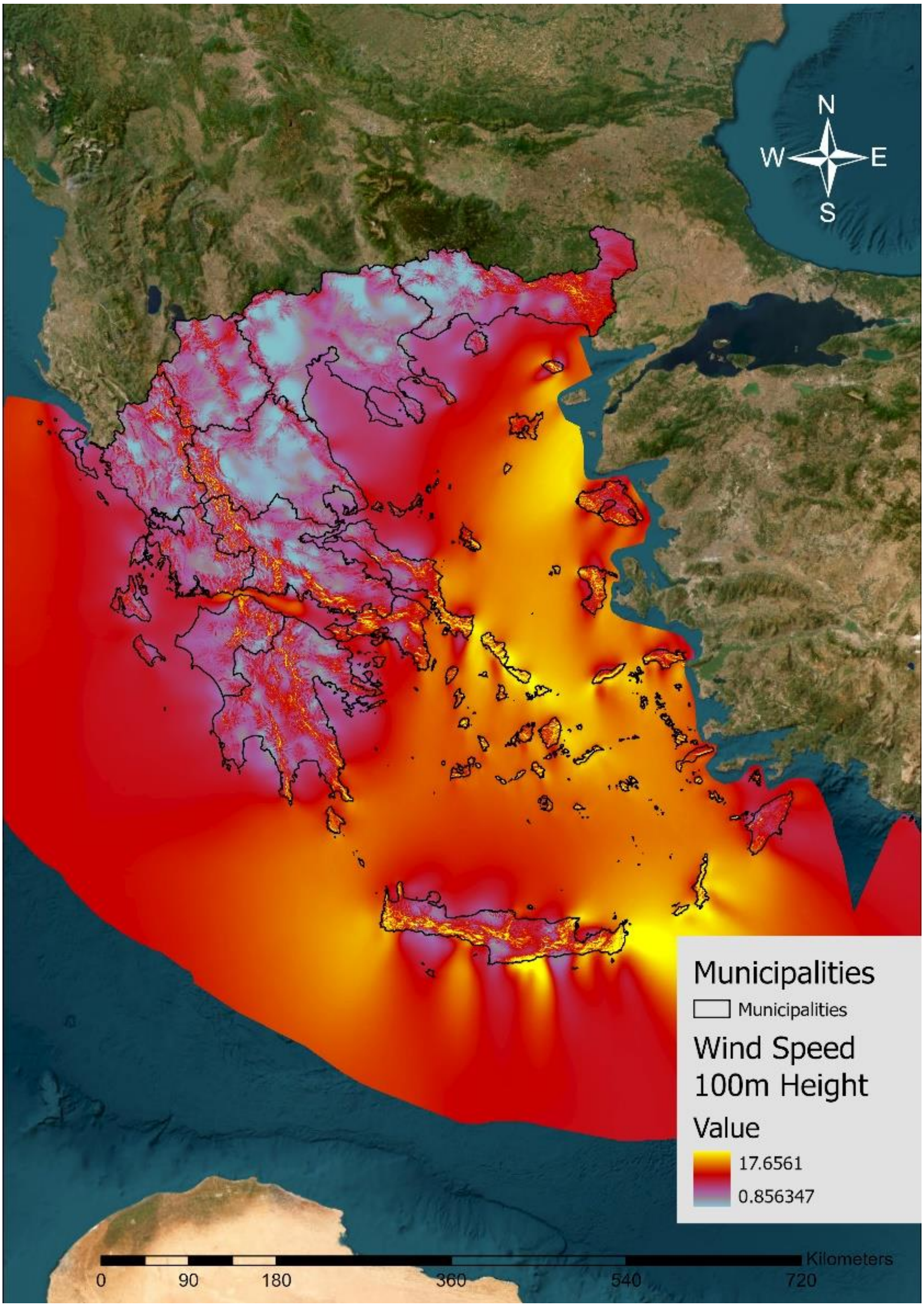

Figure 11: Mean Wind speed map at 100m Height above sea level

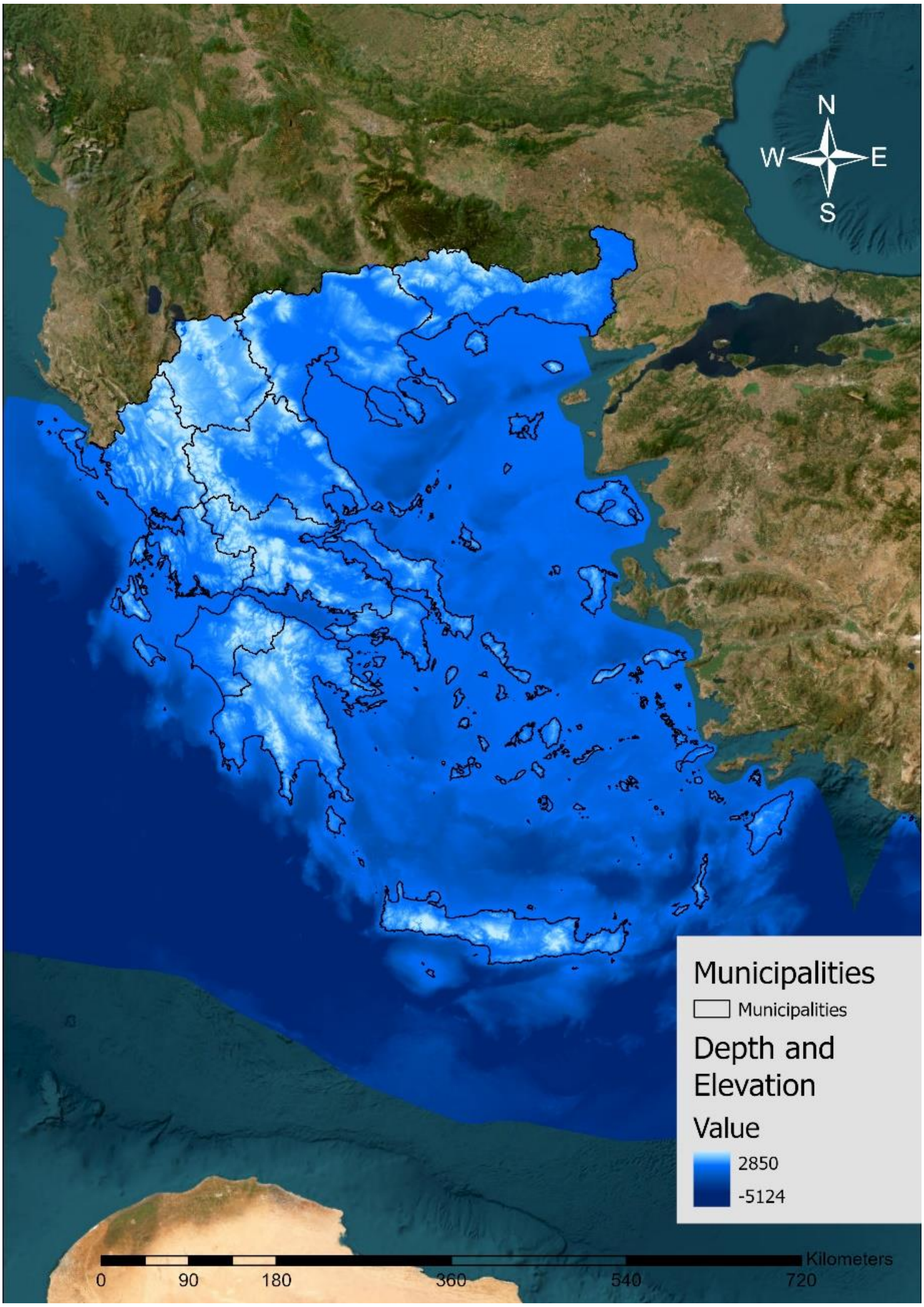

Figure 12: Depth and Elevation map

Figure 13: Polygons of available areas produced by technical constraints

Next, environmental constraints were introduced. Areas of NATURA, Special areas of conservation, National Parks etc. were used as feature layers of areas captioned as areas of environmental interest, which were excluded from potential OWF development (Figure 14). A minimum distance buffer was also implemented, as described in the section of 3.2.4 Social & Disturbance Criteria

The buffer, showcased in Figure 15, creates a social feature layer, imitating the available areas for development of OWF further. Finally, the available areas for OWF development were produced, as shown in Figure 16. These areas were, on a later stage, furnished with information of the seabed composition to be evaluated accordingly.

Figure 14 : Areas of Environmental Interest

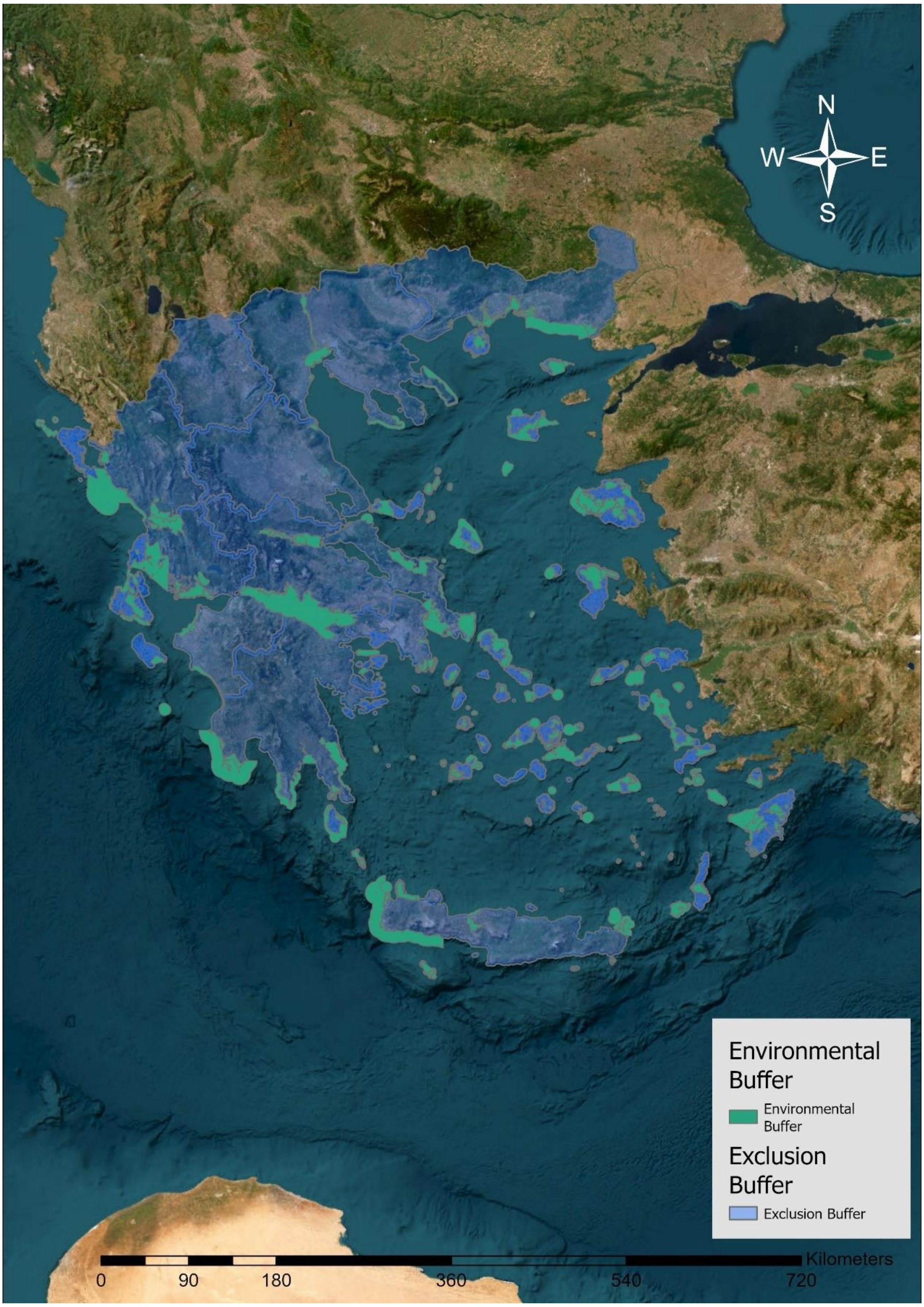

Figure 15: Exclusion Areas

Figure 16: Final Areas of development

While other GIS based suitability studies, such as [17], used the GIS suitability modeler in combination with AHP, in order to evaluate the decision criteria and produce a suitability score for every available area, we had a different approach.

After determining the available areas for OWF development, the available areas were populated with a network of offshore wind turbines, as shown in Figure 18. For the sake of this paper, two types of offshore wind turbines where used: the SG 8.0-167 DD of Siemens Gamesa and the V164-9.5 MW of MHI Vestas. Both models having similar rotor diameter, 167m and 164m respectively, and similar hub height at 105m, which were optimal for the needs of this project. In addition they have been used extensively in offshore wind parks of Netherlands and the United Kingdom [25]. Due to the available data, the fishnet of the wind turbines was created with a spacing of 6Dx6D, as illustrated on Figure 5, which was deemed a safe approach. The fishnet produced technical data such as mean wind speed and depth, as well as social-environmental data such as the distance from areas of NATURA and the distance from shore, for every wind turbine.

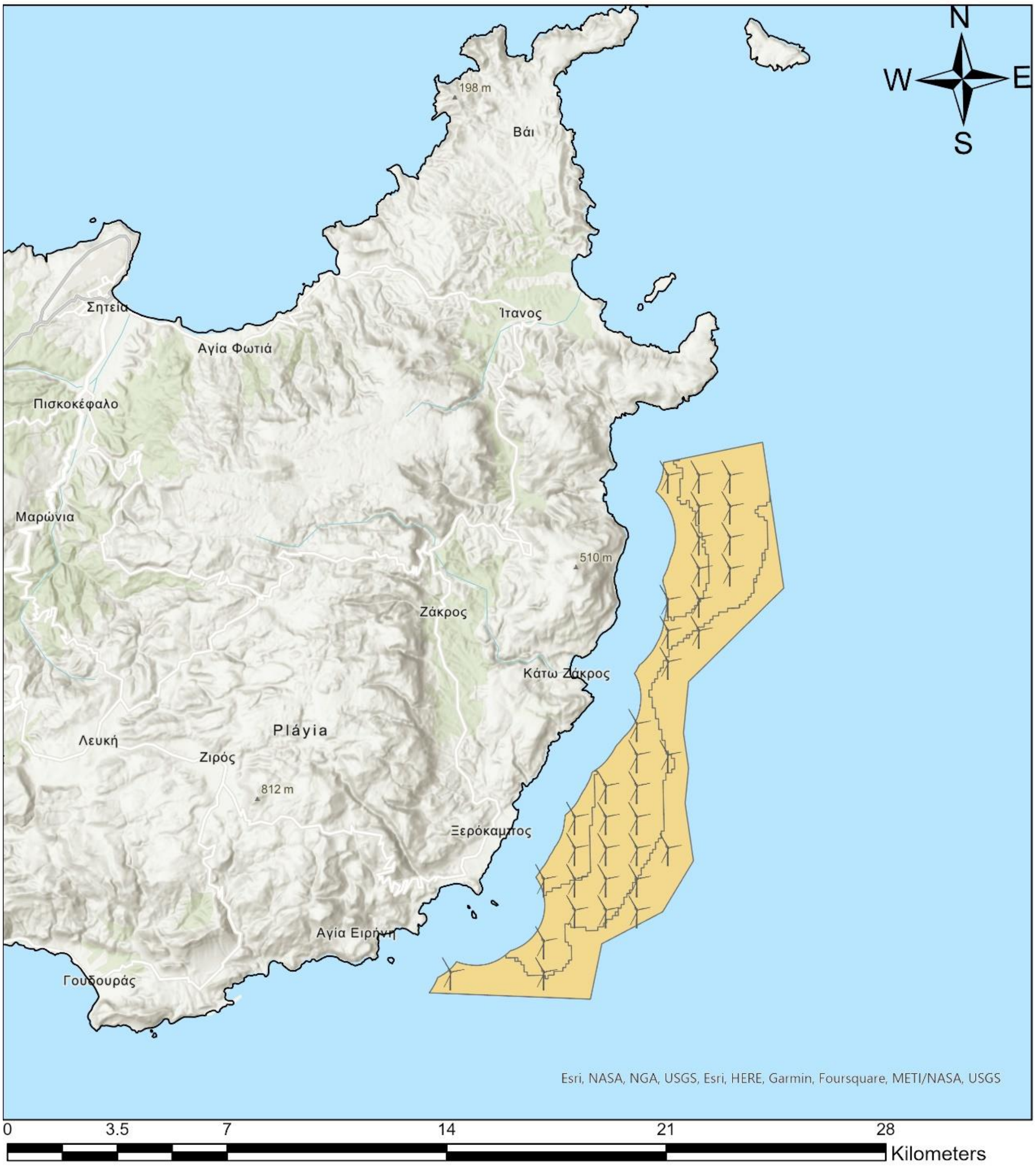

Figure 17: Xerokampos, East Crete

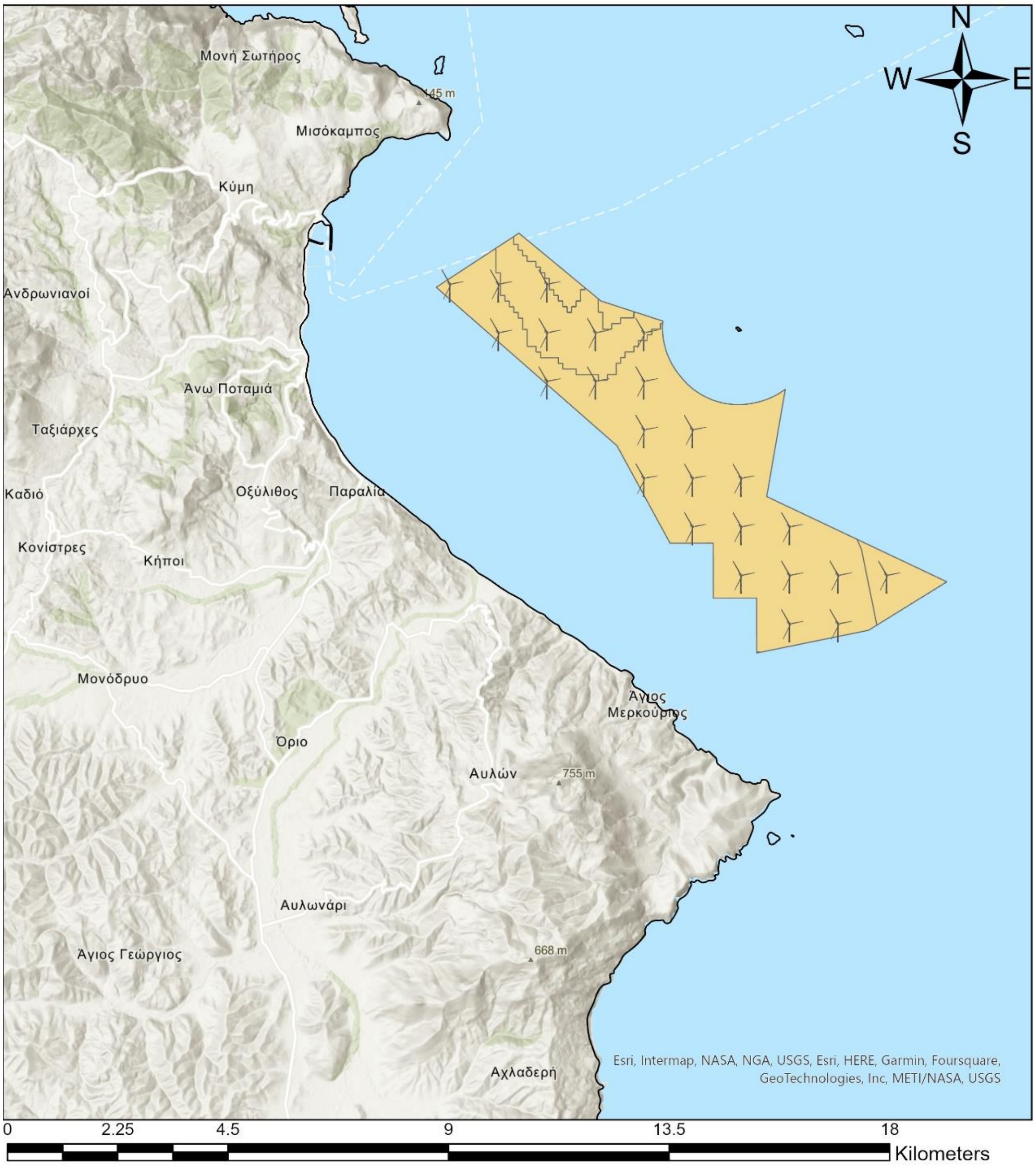

Figure 18: Center-East Euoia

The data were collected and organised in accordance to the available polygons in order to be implemented in the MCDM process. The complete process of the workflow is presented in Figure 19.

Table 2: GIS data source

Sources of digital data used in GIS for export of maps.	
Data	**Source**
Wind Velocity (100 m)	[67]
Water Depth	[68]
NATURA 2000 areas	[69]
Posidonia oceanica meadows	[69]
IBA	[70]
Birds' migratory corridors	[70]
Shipping routes	[71]
Sea geology and substrates	[71]
Municipalities and shore	[72]

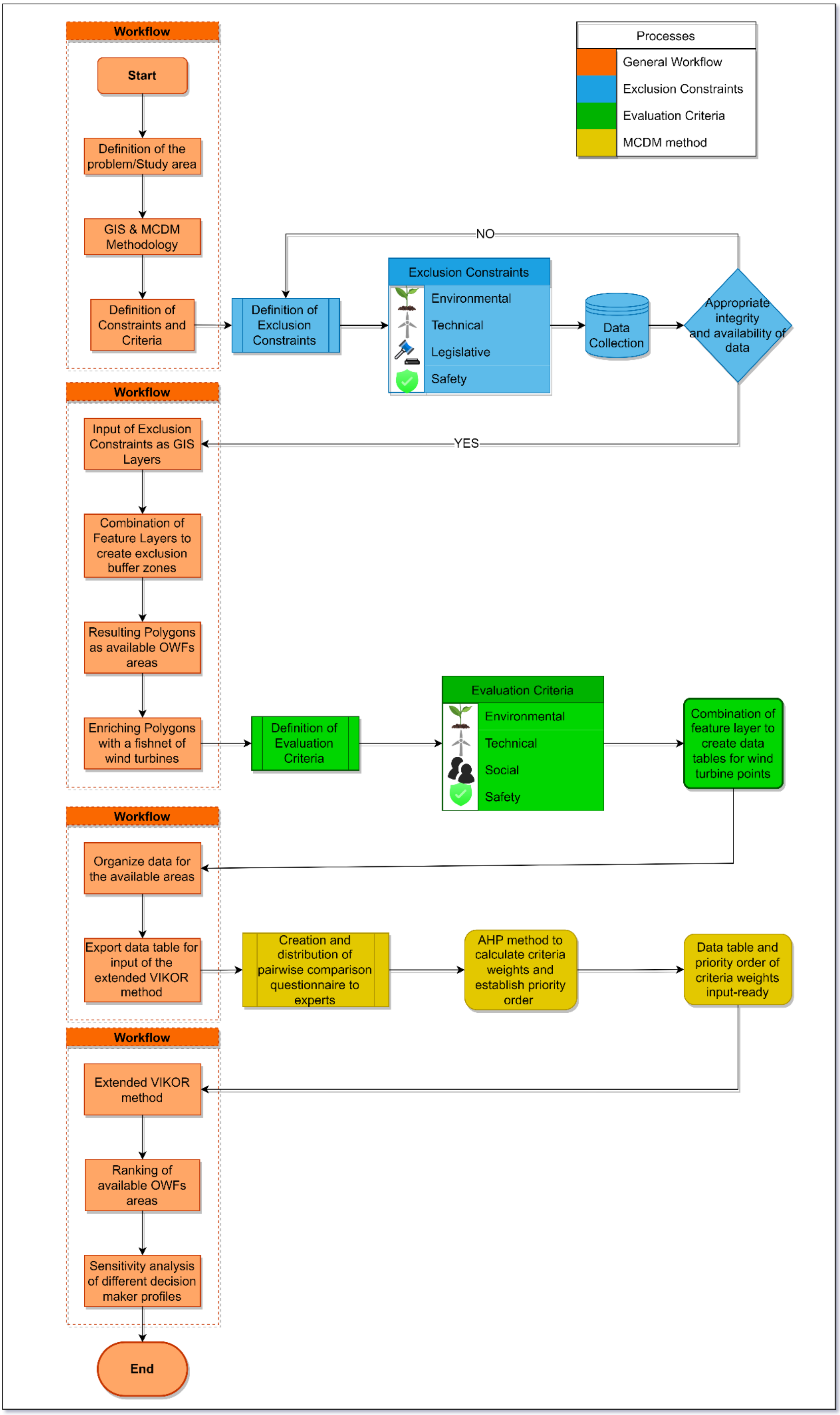

Figure 19: Essential Workflow

On a later stage, the data table of the available wind turbines, was exported and organised accordingly, so the MCDM process can be applied. For the purpose of this project, the data collected was organised in 35 available OWF areas, with their individual wind turbines. The data of the available areas were used in order to produce min and max values for every evaluation criterion. Wind power and Seabed Substrate were unique for every polygon. The data tables are showcased in Table 3, Table 4, Table 5 and Table 6.

For the MCDM method itself, an integrated AHP-VIKOR method was implemented. While the combination of both methods, has been used as a decision making tool in several renewable energy studies [9], [73], in this study an incomplete criteria weight VIKOR method was implemented, proposed by Kim et.al [74]. The main aspect of the proposed method is to approach in a more realistic way the ranking of the various evaluation criteria as relationships of weak inequalities. For the purpose of completion, it was deemed necessary to use the AHP method in combination with a pairwise comparison of the evaluation criteria in order to produce the basic weak inequality order.

Table 3: Data input of final polygons produced by GIS

OID_	Region	Id	Mean Power Density (W/m^2)
1	Alexandroupoli/Samothraki.1	8.00	614.33
2	Alexandroupoli/Samothraki.2	10.00	970.00
3	Limnos.1	43.00	742.00
4	Othonoi/Erikousa	54.00	649.00
5	Mathraki Kerkyra	67.00	447.00
6	Limnos.2	68.00	688.67
7	Kerkyra	78.00	564.67
8	Agios Eustratios.1	87.00	766.00
9	Agios Eustratios.2	93.00	495.00
10	Mytiline.1	167.00	497.00
11	Mytiline.2	182.00	493.50
12	Mytiline.3	198.00	437.00
13	Euoia.1	255.00	597.00
14	Euoia.2	260.00	480.00
15	Rio	311.00	922.00
16	Messologi	321.00	763.00
17	Andros	420.00	628.00
18	Attica	422.00	626.00
19	Samos	492.00	631.50
20	Mykonos	586.00	918.00
21	Psathonysi	604.00	565.00
22	Leipsh	627.00	626.00
23	Farmakonisi.1	656.00	376.00
24	Leros	672.00	434.50
25	Farmakonisi.2	678.00	874.00
26	Naxos	712.00	628.00
27	Kos	843.00	724.00
28	Elaffonisos	931.00	691.00
29	Anafi	980.00	964.00
30	Kythira	1006.00	688.00
31	Rhodes	1024.00	611.00
32	Chania	1065.00	376.00
33	Iraklio	1085.00	832.00
34	South Iraklio	1119.00	886.00
35	Xerokampos Crete	1121.00	1298.00

Table 4: Data input of final polygons produced by GIS (continued pt.1)

Depth (-m)		Distance from the shore (Km)		Distance from arceological sites (Km)	
Min_Bathimetry	Max_Bathimetry	Min_Shore Distance	Max_Shore_Distance	Min_Archeological_Distance	Max_Archeological_Distance
34	99	0.492	28.655	4.829	45.994
0	99	0.342	26.265	3.316	33.757
0	85	14.135	26.819	16.320	29.517
38	99	0.425	4.887	11.877	26.778
38	99	0.201	3.821	8.886	21.537
10	99	0.042	25.559	3.072	29.217
28	89	0.018	2.154	4.100	12.077
76	99	5.446	16.660	24.225	36.205
31	99	0.396	5.634	27.984	46.553
39	62	0.013	2.176	3.303	8.900
0	44	0.827	7.537	3.183	9.574
45	52	1.442	5.523	4.186	9.776
78	99	0.303	3.845	53.493	58.611
21	99	0.404	3.339	45.773	48.374
36	71	0.075	3.005	68.194	76.185
7	69	0.069	2.967	35.845	61.206
47	86	2.260	3.235	4.451	6.115
38	99	0.011	3.875	26.351	41.687
55	99	0.048	6.185	7.117	16.259
74	94	1.614	3.662	4.097	9.029
67	97	0.024	9.626	3.089	15.356
81	86	1.904	3.973	8.647	10.280
0	93	0.029	11.064	7.763	28.596
83	99	0.056	9.888	11.173	16.307
0	96	0.431	9.407	12.314	21.408
62	96	0.048	3.916	3.499	11.868
17	49	0.048	2.338	3.461	7.973
41	99	0.018	1.863	3.266	13.196
49	97	0.029	2.982	3.767	9.492
58	94	1.227	4.236	6.216	9.570
22	97	0.016	2.624	3.150	15.928
36	82	0.442	2.682	51.036	54.569
40	95	0.103	2.460	94.970	99.887
18	96	0.108	3.259	51.829	59.398
18	96	0.003	3.203	81.570	97.434

Table 5: Data input of final polygons produced by GIS (continued pt.2)

Distance from Airports (Km)		Distance from ports (Km)		Distance from militarry base (Km)	
Min_Airport_Distance	Max_Airport_Distance	Min_Port_Distance	Max_Port_Distance	Min_Distance_from_militarry	Max_Distance_from_Military
55.737	101.509	1.290	43.608	0.005	36.401
67.590	103.430	9.086	46.113	0.148	30.901
32.285	42.343	15.737	29.283	45.948	63.883
35.547	49.708	1.501	7.682	59.549	71.755
31.382	40.769	1.032	6.623	52.133	60.327
5.788	38.000	1.870	31.296	38.992	77.323
20.441	29.333	3.524	8.876	40.768	52.501
28.467	40.663	11.979	23.562	55.843	68.358
34.521	54.005	4.119	12.147	48.504	60.499
14.942	23.791	2.391	5.262	35.484	37.100
1.484	11.363	1.529	8.834	38.799	45.639
1.259	6.098	4.063	10.483	42.458	47.202
55.623	61.384	55.617	61.500	67.648	74.158
43.969	47.770	38.080	40.520	2.034	12.628
83.342	93.478	64.842	73.774	0.118	6.804
56.112	75.723	33.905	56.902	4.310	31.950
55.467	57.546	11.137	13.329	0.181	1.847
84.903	98.242	25.619	41.422	40.149	49.675
6.811	22.191	0.829	12.765	72.320	92.505
5.676	11.618	9.904	15.775	18.603	21.501
6.840	31.652	3.531	12.162	102.993	124.489
5.831	8.797	7.016	9.781	105.632	108.403
19.151	30.352	1.983	15.925	105.952	123.204
14.726	25.906	9.255	16.445	97.531	109.512
16.404	30.324	5.716	18.388	97.321	115.061
18.026	21.910	4.088	14.648	55.943	68.972
3.457	13.546	2.569	7.609	61.657	85.078
20.025	34.876	2.380	12.483	41.959	50.325
23.935	29.477	1.393	5.802	0.418	4.414
14.216	17.521	6.755	9.895	70.258	72.462
38.774	65.309	2.499	18.431	92.006	117.777
97.312	100.879	50.022	53.548	6.283	9.257
113.920	118.640	102.042	107.567	12.095	17.178
159.631	162.745	51.327	58.772	0.418	9.325
58.297	74.576	61.270	77.450	19.634	32.269

Table 6: Data input of final polygons produced by GIS (continued pt.3)

NATURA Distance (Km)		Seabed composition						
Min_Distance_from_NATURA	Max_Distance_from_NATURA	Coarse & mixed sediment	Fine mud	Muddy sand	Sand	Mixed Seabed	Score	
0.104	22.920	0.004	0.033	0.450	0.450	0.064	3.384	1: Mixed Seabed
0.026	16.172	0.007	0.108	0.441	0.441	0.002	3.645	2: Coarse & mixed sediment
4.444	11.737	0.000	0.000	0.500	0.500	0.000	3.500	3: Sand
0.039	4.271	0.000	1.000	0.000	0.000	0.000	5.000	4: Muddy sand
0.015	3.450	0.000	1.000	0.000	0.000	0.000	5.000	5: Fine mud
0.003	17.465	0.000	0.002	0.484	0.484	0.029	3.432	
0.058	8.026	0.000	1.000	0.000	0.000	0.000	5.000	
5.093	16.307	0.000	0.036	0.482	0.482	0.000	3.553	
0.042	5.280	0.000	0.014	0.486	0.486	0.014	3.486	
0.176	2.243	0.000	0.000	0.500	0.500	0.000	3.500	
5.673	13.205	0.352	0.000	0.324	0.324	0.000	2.972	
7.552	12.100	0.207	0.000	0.397	0.397	0.000	3.190	
17.051	23.994	0.000	1.000	0.000	0.000	0.000	5.000	
3.161	7.254	0.000	1.000	0.000	0.000	0.000	5.000	
3.924	13.212	0.000	1.000	0.000	0.000	0.000	5.000	
0.583	3.454	0.000	0.385	0.308	0.308	0.000	4.077	
0.070	1.041	0.250	0.000	0.375	0.375	0.000	3.125	
1.247	7.287	0.000	0.000	0.468	0.468	0.065	3.338	
1.882	13.357	0.006	0.000	0.497	0.497	0.000	3.491	
0.085	5.850	0.000	0.619	0.190	0.190	0.000	4.429	
0.433	11.677	0.003	0.178	0.409	0.409	0.000	3.762	
0.047	1.896	0.000	1.000	0.000	0.000	0.000	5.000	
1.138	12.502	0.000	1.000	0.000	0.000	0.000	5.000	
2.592	11.629	0.000	0.849	0.075	0.075	0.000	4.774	
1.418	11.403	0.000	0.788	0.106	0.106	0.000	4.683	
0.520	4.100	0.000	0.219	0.391	0.391	0.000	3.828	
0.867	10.872	0.056	0.944	0.000	0.000	0.000	4.833	
1.474	6.941	0.000	0.000	0.214	0.214	0.571	2.071	
0.991	4.247	0.214	0.786	0.000	0.000	0.000	4.357	
0.075	3.620	0.000	0.000	0.000	0.000	1.000	1.000	
0.091	11.221	0.214	0.786	0.000	0.000	0.000	4.357	
2.493	4.404	0.000	0.000	0.294	0.294	0.412	2.471	
35.734	41.740	0.000	1.000	0.000	0.000	0.000	5.000	
16.411	23.152	0.000	0.000	1.000	0.000	0.000	4.000	
1.671	7.868	0.000	1.000	0.000	0.000	0.000	5.000	

3.4 AHP

The Analytic Hierarchy Process (AHP) is a structured decision-making technique that provides a rigorous and systematic approach for evaluating and prioritizing alternatives in complex decision problems. Developed by Thomas Saaty [75], the AHP method combines elements of mathematics, psychology, and operations research to handle multi-criteria decision analysis problems.

At its core, AHP is based on the principle that decision-making involves comparing and assessing the relative importance of various criteria and alternatives. It aims to decompose a complex decision problem into a hierarchical structure, consisting of a goal, criteria, sub-criteria, and alternatives. By breaking down the decision problem into smaller, more manageable components, the AHP method facilitates a systematic evaluation process. The method employs pairwise comparisons of the evaluation criteria to quantify the relative importance or preference between criteria and alternatives. Decision makers are asked to make judgments about the importance of each criterion or alternative relative to another, using a scale as the one developed by Saaty [76], known as the AHP scale (Table 7). These pairwise comparisons generate numerical values, which are used to derive priority weights for each element in the decision hierarchy. To sum up, the AHP method follows the following distinct steps:

- Define the Decision Problem and the alternatives.
- Define the evaluation criteria.
- Pairwise comparison of all criteria to establish hierarchy with weights. The comparisons are made based on the judgment of the decision-makers using a pairwise questionnaire.
- Use the Aggregation of Experts' Judgments (AIJ) or the Aggregating individual priority weights (AIP) method to create a single comparison matrix, produced by the multiple comparison matrixes of the decision makers.
- Compute the priority vector and establish that consistency of the pairwise comparison is present through the eigenvector calculation.

Table 7 : AHP Comparison Scale [76]

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2. 4. 6. 8	Intermediate values between the two adjacent judgments	When compromise is needed

Due to the adopted multi-criteria methodology (VIKOR with incomplete information weights), it was deemed unnecessary to implement the whole comparison scale since the aim of the comparison matrix was to produce only an order of importance for the various criteria and at the same time, facilitate the various experts to scale the evaluation criteria. Therefore, a simpler pairwise comparison scale with only three options was used, as presented in Table 8. The comparison scale was later implemented in a questionnaire which included 8 pairwise questions and was completed by 21 experts.

Table 8 : AHP pairwise comparison scale

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another

To ensure consistency and minimize biases, the AHP method employs a mathematical framework to analyse the pairwise comparison data. The technique uses eigenvector calculations and the eigenvalue principle to compute the priority weights and assess the consistency of the judgments.

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

It is important to note that the matrix eigenvector for pairwise comparisons is calculated through the following equations:

1. $A(w) = \lambda_{max}(A) * w(A),$ where A represents the consistent matrix, w is the eigenvector, λmax is the maximum eigenvalue, and I is a unit quadratic matrix with a diagonal equal to 1.
2. $(A - \lambda_{max}\, I) * w = 0,$ which ensures that the matrix subtraction and multiplication yield a zero matrix.

When decision makers lack expertise in the decision-making process, a consistency check becomes necessary. Several conditions must be satisfied, including the reciprocity condition ($a_{ij} = 1/a_{ji}$) and the transitive condition$a_{ij} = a_{ik} * a_{kj}\ \forall\, i, j, k \in \{1, \dots, n\}$, where aij represents the value in row i and column j in the matrix A, and n denotes the number of criteria [77].

The consistency ratio is calculated to determine the reliability of the decision maker's judgments, ensuring that the decision process remains robust and logical. Once the priority weights are derived, the AHP method synthesizes the judgments to obtain a global priority ranking of the alternatives. This ranking reflects the relative importance of the alternatives in achieving the overall goal.

The consistency ratio is computed to validate the consistency of the matrix values using Saaty's eigenvector method [75]. The Consistency Index (CI) is calculated using the formula:

- $CI = \frac{\lambda_{max} - n}{n-1}$, where λmax is the maximum eigenvalue and n is the number of rows in a quadratic pairwise comparison matrix.

The Random Index (RI) is a predefined value based on the size of the matrix, as provided by Saaty, where n is the number of criteria and RI the random index respectively. The Consistency Ratio (CR) should be less than 0.1 (CR < 0.1) and is calculated as follows:

η	3	4	5	6	7	8	9
RI	0.5245	0.8815	1.1086	1.2479	1.3417	1.4056	1.4499

- $CR = \frac{CI}{RI}$.

Regarding the hierarchical structure for sub-criteria, the final weights are computed as follows:

- $w_{Ai} = \frac{w_j}{\sum_{ja=1}^{m} w_j} * \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}}$, where wj is the weight of the upper level, wij is the eigenvector of the current level, and $\sum_{k=1}^{n} w_{ik}$ represents the sum of weights in the current level.

Since there are multiple answers to the pairwise comparison, there is a need to aggregate the values of the comparison matrixes into a single comparison matrix. In this study, the geometric mean is utilized to avoid rank reversal. This approach is applied to both the aggregation of individual judgments and individual priorities.

Since we are dealing with a group of experts as decision makers, the process of aggregating individual-level data becomes crucial in order to establish overall priority weights. Two distinct approaches can be employed to achieve this goal. The first approach involves aggregating individual priority (AIP) weights, which are derived from individual judgment matrices. This approach proves valuable when the objective is to acknowledge or explore individual valuations or variations among individuals. Additionally, it can be useful for identifying disparities that necessitate discussion, clarification, or resolution. However, a potential limitation arises as individuals may not provide honest responses or engage fully if they are wary of having their valuations scrutinized. An alternative approach is the aggregation of individual judgment (AIJ) matrices. In this method, the individual judgment matrices are consolidated into a single matrix, from which the overall priority weights are derived. It is essential to note that due to the ratio nature of the comparison matrices, the geometric mean is employed rather than the arithmetic mean [77], [78].

$$J = \sqrt[n]{\prod_{i=1}^{n} J_i}$$

Where J states the aggregated comparison matrix of the geometric means, produced by the individual answers.

The AIJ method is preferred over the AIP method when the aim is to obtain a consolidated comparison matrix that reflects the collective judgment of the group of decision makers. In such cases, evaluating individual priority weights is not of interest. Since the experts have similar backgrounds, the AIJ method would be more appropriate for our approach.

Finally, the relative weights of the AHP method are derived based on the final matrix produced the AIJ method with the geometric mean of 21 individual answers. As showed in Table 9, the relative weights are summing to 1, while the CR = 0.023865836 < 10%, meaning that the relative weights of the evaluation criteria produced by the comparison matrix are consistent.

Table 9 : AHP relative criteria weights

Criteria	AVG (Criteria Weights)
Wind Speed	0.212
Depth	0.156
Seabed composition	0.138
Distance from areas of Environmental Interest	0.117
Distance from shore	0.099
Distance from Archaeological Sites	0.082
Distance from Airports	0.074
Distance from Ports	0.068
Distance from Military areas	0.053
Sum	1

3.5 VIKOR with incomplete criteria weights

In this section, for the sake of completeness, we describe the main steps of the adopted multi-criteria decision-making method to cope with the emerged decision analysis problem. In particular, we apply a recent extension of the VIKOR methodology [79] developed in [74] which allows both interval uncertainty in the payoff table and incomplete information for the criteria weights.

Consider a set of alternatives $A = \{A_1, \ldots, A_m\}$ which are evaluated across a set of criteria $C = \{C_1, \ldots, C_n\}$ with consequences $f_{ij} = [f_{ij}^L, \ldots, f_{ij}^U], i = 1, \ldots, m, j = 1, \ldots, n.$

We denote by

$$W = \left\{ \boldsymbol{w} \in \mathbb{R}^n : \sum_{j=1}^{n} w_j = 1, w_j \geq 0, j = 1, \ldots, n \right\}$$

the set of criteria weights $\boldsymbol{w} = (w_1, \ldots, w_n)$, which in our case are of weak inequalities incomplete form, thus, they additionally satisfy a relation of the form.

$$w_1 \geq w_2 \geq \cdots \geq w_n \geq 0$$

Let I and J denote the set of indices associated with the benefit and cost criteria, respectively. Then,

Step 1. Determine the positive and the negative ideal solution as follows:

$$\boldsymbol{f}^* = (f_1^*, \ldots, f_n^*) = \left\{ \left(\max_i f_{ij}^U : j \in I \right) \text{or} \left(\min_i f_{ij}^L : j \in J \right) \right\}$$

$$\boldsymbol{f}^- = (f_1^-, \ldots f_n^-) = \left\{ \left(\min_i f_{ij}^L : j \in I \right) \text{or} \left(\max_i f_{ij}^U : j \in J \right) \right\}$$

Step 2. For each alternative, calculate the measures $S_i = [S_i^L, S_i^U]$ and $R_i = [R_i^L, R_i^U]$ as follows:

$$S_i^L = \min\{\boldsymbol{d}_i^L \boldsymbol{E}\}, i = 1, \ldots, m$$

$$S_i^U = \max\{\boldsymbol{d}_i^U \boldsymbol{E}\}, i = 1, \ldots, m$$

$$R_i^L = \min_k \left\{ \max_j \{ d_{ij}^L \lambda_{kj} \} \right\}, i = 1, \ldots, m$$

$$R_i^U = \max_k \left\{ \max_j \{ d_{ij}^U \lambda_{kj} \} \right\}, i = 1, \ldots, m$$

where

$$\boldsymbol{d}_i^L = \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-} | j \in I, \quad \frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*} | j \in J \right), i = 1, \ldots, m$$

$$\boldsymbol{d}_i^U = \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-} | j \in I, \quad \frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*} | j \in J \right), i = 1, \ldots, m$$

$$\boldsymbol{E} = (\boldsymbol{\lambda_1}, \dots, \boldsymbol{\lambda_n}) = \begin{pmatrix} 1 & 1/2 & \cdots & 1/(n-1) & 1/n \\ 0 & 1/2 & \cdots & 1/(n-1) & 1/n \\ 0 & 0 & \cdots & 1/(n-1) & 1/n \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 1/(n-1) & 1/n \\ 0 & 0 & \cdots & 0 & 1/n \end{pmatrix}$$

and λ_{kj} is the jth element of $\boldsymbol{\lambda_k}$.

Step 3. For each alternative, calculate the measure values $Q_i = [Q_i^L, Q_i^U]$ as follows:

$$Q_i^L = \nu \frac{S_i^L - S^*}{S^- - S^*} + (1-\nu)\frac{R_i^L - R^*}{R^- - R^*}, i = 1, \dots, m$$

$$Q_i^L = \nu \frac{S_i^U - S^*}{S^- - S^*} + (1-\nu)\frac{R_i^U - R^*}{ - R^*}, i = 1, \dots, m$$

where

$$S^+ = \min_i S_i^L, \qquad S^- = \max_i S_i^U$$

$$R^+ = \min_i R_i^L, \qquad S^- = \max_i R_i^U$$

and $\nu \in [0, 1]$ stands for the strategy coefficient of the VIKOR family methods.

Step 4. Rank values $Q_i, i = 1, \dots, m$. To cope with their interval nature, in the present study, we adopt the degree of possibility based method [80]. In particular, consider two interval numbers $Q_i = [Q_i^L, Q_i^U], Q_j = \left[Q_j^L, Q_j^U\right]$ and let $l_i = Q_i^U - Q_i^L$ and $l_j = Q_j^U - Q_j^L$ for all $i, j = 1, \dots, m$. Then, the degree of possibility of Q_i over Q_j is defined as

$$p_{ij} = p\left(Q_i \geq Q_j\right) = \max\left\{1 - \max\left\{\frac{Q_j^U - Q_i^L}{l_i + l_j}, 0\right\}, 0\right\}.$$

Similarly, the degree of possibility of Q_j over Q_i is defined as

$$p_{ji} = p\left(Q_j \geq Q_i\right) = \max\left\{1 - \max\left\{\frac{Q_i^U - Q_j^L}{l_i + l_j}, 0\right\}, 0\right\}.$$

The degree of possibility of all intervals is expressed through a complementary matrix defined as follows:

$$\boldsymbol{P} = \begin{pmatrix} p_{11} & \cdots & p_{1m} \\ \vdots & \ddots & \vdots \\ p_{m1} & \cdots & p_{mm} \end{pmatrix}, p_{ij} \geq 0, p_{ij} + p_{ji} = 1, p_{ii} = \frac{1}{2}$$

Then, to rank the intervals, the aggregated degree of possibility is used, which is calculated as follows:

$$p_i = \sum_{j=1}^{m} p_{ij}, i = 1, \dots, m.$$

3.6 Results and Discussion

Following the proposed extended VIKOR method, in combination with the AHP and AIJ methods to establish the weak inequality criteria order, resulted to the final ranking of the 35 alternatives.

Metric Q of the VIKOR methodology depends on coefficient ν which is used to weigh two different perspectives, as reflected by metrices S and R and express the ”majority of criteria” (or group utility) and the ”individual regret” decision maker’s point of view, respectively [76].By varying the values of ν from 0 to 1, allows decision maker to assess the effects of his/her level of conservativeness, as expressed by the abovementioned perspectives, on the alternatives’ outperformance.

As shown in Table 10, the alternatives are categorized according to QM (intermediate value) or Pi (aggregated degree of possibility) values. While some areas are close to each other, each area is distinct through a single ID number. Different values of ν were implemented in order to illustrate the effect of strategy coefficient to the priority order of the alternatives. In this study the different alternatives were ranked according to 11 different values of ν, from 0 to 1. Interestingly, the QM creates a slightly different priority order than Pi, due to the different approach of the two methods.

Table 10: Ranking of Alternatives with v= 0.5

ID	Area	SiL	SiU	RiL	RiU	v	QiL	QiU	QM	Pi
8.00	Alexandroupoli/Samothraki.1	0.360	0.715	0.082	0.742	0.5	0.2212	0.7283	0.4748	16.5322
10.00	Alexandroupoli/Samothraki.2	0.178	0.356	0.084	0.500	0.5	0.1307	0.4279	0.2793	7.6855
43.00	Limnos.1	0.302	0.731	0.083	0.603	0.5	0.1922	0.6669	0.4296	14.8755
54.00	Othonoi/Erikousa	0.363	0.852	0.100	0.704	0.5	0.2312	0.7779	0.5045	17.5615
67.00	Mathraki	0.436	0.961	0.103	0.923	0.5	0.2691	0.9422	0.6057	20.5605
68.00	Limnos.2	0.369	0.860	0.086	0.661	0.5	0.2273	0.7607	0.4940	17.2056
78.00	Kerkyra (Corfu)	0.359	0.847	0.103	0.795	0.5	0.2311	0.8213	0.5262	18.2482
87.00	Agios Efstratios.1	0.532	0.789	0.085	0.577	0.5	0.3084	0.6828	0.4956	17.2647
93.00	Agios Efstratios.2	0.521	0.935	0.097	0.871	0.5	0.3090	0.9032	0.6061	20.8106
167.00	Lesvos.1	0.546	0.869	0.105	0.869	0.5	0.3255	0.8688	0.5971	20.6833
182.00	Lesvos.2	0.436	0.873	0.104	0.873	0.5	0.2702	0.8726	0.5714	19.6786
198.00	Lesvos.3	0.614	0.934	0.108	0.934	0.5	0.3607	0.9338	0.6473	22.2297
255.00	Euboea.1	0.493	0.880	0.096	0.760	0.5	0.2948	0.8202	0.5575	19.3836
260.00	Euboea.2	0.366	0.944	0.100	0.887	0.5	0.2331	0.9154	0.5743	19.6032
311.00	Gulf of Patras	0.257	0.606	0.105	0.408	0.5	0.1811	0.5068	0.3439	10.7839
321.00	Missolonghi	0.294	0.698	0.102	0.580	0.5	0.1979	0.6393	0.4186	14.3810
420.00	Andros	0.557	0.828	0.109	0.727	0.5	0.3331	0.7775	0.5553	19.4863
422.00	Attica	0.509	0.864	0.096	0.729	0.5	0.3028	0.7966	0.5497	19.1755
492.00	Samos	0.552	0.861	0.097	0.723	0.5	0.3243	0.7922	0.5582	19.5381
586.00	Mykonos	0.412	0.773	0.104	0.475	0.5	0.2582	0.6237	0.4409	15.0382
604.00	Psathonisi	0.594	0.887	0.097	0.795	0.5	0.3454	0.8412	0.5933	20.7119
627.00	Leipsoi	0.516	0.799	0.106	0.729	0.5	0.3109	0.7638	0.5373	18.8030
656.00	Farmakonisi.1	0.333	1.000	0.111	1.000	0.5	0.2222	1.0000	0.6111	20.4445
672.00	Leros	0.611	0.968	0.104	0.937	0.5	0.3573	0.9524	0.6549	22.3723
678.00	Farmakonisi.2	0.180	0.753	0.091	0.485	0.5	0.1354	0.6189	0.3772	13.0225
712.00	Naxos	0.549	0.848	0.101	0.727	0.5	0.3248	0.7874	0.5561	19.4742
843.00	Kos	0.279	0.731	0.105	0.623	0.5	0.1921	0.6769	0.4345	15.0773
931.00	Elaffonisos	0.536	0.892	0.104	0.658	0.5	0.3201	0.7752	0.5477	19.1794
980.00	Anafi	0.339	0.762	0.107	0.490	0.5	0.2232	0.6257	0.4245	14.4849
1006.00	Kythira	0.624	0.922	0.111	0.662	0.5	0.3674	0.7920	0.5797	20.4661
1024.00	Rhodes	0.376	0.862	0.101	0.745	0.5	0.2385	0.8038	0.5211	18.1042
1065.00	Chania	0.639	1.000	0.111	1.000	0.5	0.3749	1.0000	0.6874	23.2532
1085.00	Heraklion	0.227	0.733	0.105	0.505	0.5	0.1664	0.6190	0.3927	13.4561
1119.00	South Heraklion	0.293	0.708	0.103	0.485	0.5	0.1978	0.5966	0.3972	13.4039
1121.00	Xerokampos Crete	0.000	0.586	0.000	0.485	0.5	0.0000	0.5354	0.2677	9.5208

Table 10 and Table 11 showcase the impact of different ν values on ranking of the different alternatives. In Table 11 and Table 12 we observe that, independently of ν, three locations outperform in terms of metric Q, that is Gulf of Patras, Xerokampos, and Alexandroupoli/Samothraki.2. Focusing on these solutions, there are two critical values of ν that change the final ranking. More precisely, Xerokampos is the best alternative for $\nu < 0.2$, while Gulf of Patras outperforms only for $\nu = 0.2$. On the other hand, Alexandroupoli/Samothraki.2 is the best alternative for all $\nu > 0.3$. The above results indicate that by adopting an aggregating viewpoint across criteria, location Xerokampos not only outperforms for all values of ν that are close to 1, but also presents a rather stable behavior for this type of decision maker's profile. This is not the case when adopting an almost" individual regret" strategy, where best location alternates between Xerokampos and Gulf of Patras. Additionally, Farmakonisi.2 keeps the fourth place, regardless of v values, making it the most stable decision regardless of the profile of the decision maker.

Table 11: Ranking of all alternatives for ν values 0 to 0.4

	v				
Rank	0	0.1	0.2	0.3	0.4
1	Gulf of Patras	Gulf of Patras	Xerokampos Crete	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2
2	Xerokampos Crete	Xerokampos Crete	Gulf of Patras	Xerokampos Crete	Xerokampos Crete
3	Mykonos	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2	Gulf of Patras	Gulf of Patras
4	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2
5	South Heraklion	South Heraklion	South Heraklion	South Heraklion	South Heraklion
6	Alexandroupoli/Samothraki.2	Mykonos	Heraklion	Heraklion	Heraklion
7	Anafi	Anafi	Mykonos	Anafi	Anafi
8	Heraklion	Heraklion	Anafi	Mykonos	Messologi
9	Agios Efstratios.1	Messologi	Messologi	Messologi	Mykonos
10	Messologi	Limnos.1	Limnos.1	Limnos.1	Limnos.1
11	Limnos.1	Agios Efstratios.1	Kos	Kos	Kos
12	Kos	Kos	Agios Efstratios.1	Agios Efstratios.1	Agios Efstratios.1
13	Limnos.2	Limnos.2	Limnos.2	Limnos.2	Alexandroupoli/Samothraki.1
14	Elaffonisos	Elaffonisos	Alexandroupoli/Samothraki.1	Alexandroupoli/Samothraki.1	Limnos.2
15	Kythira	Othonoi/Erikousa	Othonoi/Erikousa	Othonoi/Erikousa	Othonoi/Erikousa
16	Othonoi/Erikousa	Alexandroupoli/Samothraki.1	Elaffonisos	Rhodes	Rhodes
17	Samos	Kythira	Rhodes	Elaffonisos	Kerkyra (Corfu)
18	Alexandroupoli/Samothraki.1	Samos	Leipsh	Leipsh	Leipsh
19	Attica	Attica	Kythira	Kerkyra (Corfu)	Elaffonisos
20	Naxos	Rhodes	Attica	Attica	Attica
21	Leipsh	Leipsh	Samos	Samos	Naxos
22	Andros	Naxos	Naxos	Naxos	Samos
23	Rhodes	Andros	Andros	Andros	Euoia.1
24	Euoia.1	Euoia.1	Kerkyra (Corfu)	Euoia.1	Andros
25	Psathonysi	Kerkyra (Corfu)	Euoia.1	Kythira	Euoia.2
26	Kerkyra (Corfu)	Psathonysi	Psathonysi	Euoia.2	Kythira
27	Agios Efstratios.2	Lesvos.1	Lesvos.1	Lesvos.1	Lesvos.1
28	Lesvos.1	Euoia.2	Euoia.2	Psathonysi	Psathonysi
29	Lesvos.2	Agios Efstratios.2	Agios Efstratios.2	Lesvos.2	Lesvos.2
30	Euoia.2	Lesvos.2	Lesvos.2	Agios Efstratios.2	Mathraki
31	Mathraki	Mathraki	Mathraki	Mathraki	Agios Efstratios.2
32	Leros	Lesvos.3	Farmakonisi.1	Farmakonisi.1	Farmakonisi.1
33	Lesvos.3	Leros	Lesvos.3	Lesvos.3	Lesvos.3
34	Farmakonisi.1	Farmakonisi.1	Leros	Leros	Leros
35	Chania	Chania	Chania	Chania	Chania

Table 12 : Ranking of all alternatives for v values 0.4 to 1

v					
0.5	0.6	0.7	0.8	0.9	1
Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2	Alexandroupoli/Samothraki.2
Xerokampos Crete	Xerokampos Crete	Xerokampos Crete	Xerokampos Crete	Xerokampos Crete	Xerokampos Crete
Gulf of Patras	Gulf of Patras	Gulf of Patras	Gulf of Patras	Gulf of Patras	Gulf of Patras
Farmakonisi.2	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2	Farmakonisi.2
South Heraklion	Heraklion	Heraklion	Heraklion	Heraklion	Heraklion
Heraklion	South Heraklion	South Heraklion	South Heraklion	South Heraklion	Messologi
Messologi	Messologi	Messologi	Messologi	Messologi	South Heraklion
Anafi	Anafi	Kos	Kos	Kos	Kos
Limnos.1	Limnos.1	Limnos.1	Limnos.1	Limnos.1	Limnos.1
Mykonos	Kos	Anafi	Anafi	Alexandroupoli/Samothraki.1	Alexandroupoli/Samothraki.1
Kos	Mykonos	Mykonos	Alexandroupoli/Samothraki.1	Anafi	Anafi
Alexandroupoli/Samothraki.1	Alexandroupoli/Samothraki.1	Alexandroupoli/Samothraki.1	Mykonos	Mykonos	Mykonos
Limnos.2	Limnos.2	Limnos.2	Othonoi/Erikousa	Othonoi/Erikousa	Kerkyra (Corfu)
Agios Efstratios.1	Othonoi/Erikousa	Othonoi/Erikousa	Limnos.2	Kerkyra (Corfu)	Othonoi/Erikousa
Othonoi/Erikousa	Agios Efstratios.1	Kerkyra (Corfu)	Kerkyra (Corfu)	Limnos.2	Limnos.2
Rhodes	Rhodes	Rhodes	Rhodes	Rhodes	Rhodes
Kerkyra (Corfu)	Kerkyra (Corfu)	Agios Efstratios.1	Agios Efstratios.1	Agios Efstratios.1	Euoia.2
Leipsh	Leipsh	Leipsh	Leipsh	Euoia.2	Lesvos.1
Attica	Attica	Euoia.2	Euoia.2	Leipsh	Farmakonisi.1
Elaffonisos	Euoia.1	Lesvos.1	Lesvos.1	Lesvos.1	Leipsh
Euoia.1	Lesvos.1	Attica	Farmakonisi.1	Farmakonisi.1	Agios Efstratios.1
Naxos	Euoia.2	Euoia.1	Attica	Euoia.1	Euoia.1
Andros	Elaffonisos	Farmakonisi.1	Euoia.1	Attica	Attica
Samos	Andros	Andros	Andros	Mathraki	Mathraki
Euoia.2	Naxos	Naxos	Naxos	Andros	Andros
Lesvos.1	Samos	Elaffonisos	Mathraki	Naxos	Naxos
Farmakonisi.1	Farmakonisi.1	Samos	Elaffonisos	Samos	Lesvos.2
Kythira	Mathraki	Mathraki	Samos	Elaffonisos	Samos
Mathraki	Lesvos.2	Lesvos.2	Lesvos.2	Lesvos.2	Elaffonisos
Lesvos.2	Agios Efstratios.2	Agios Efstratios.2	Agios Efstratios.2	Agios Efstratios.2	Agios Efstratios.2
Psathonysi	Psathonysi	Psathonysi	Psathonysi	Psathonysi	Psathonysi
Agios Efstratios.2	Kythira	Kythira	Kythira	Kythira	Lesvos.3
Lesvos.3	Lesvos.3	Lesvos.3	Lesvos.3	Lesvos.3	Kythira
Leros	Leros	Leros	Leros	Leros	Leros
Chania	Chania	Chania	Chania	Chania	Chania

While the different v values, seem to have an important impact on the rank of available areas between 30th and 5th place, the best and worst options showcase only small changes. This leads us to the conclusion that the top 5 areas have high scores in the most important evaluation criteria, as they were ranked by the 21 decision makers. In addition, the founding of this research seems to agree with the recent developments on the subject of potential OWF installation in Greece, according to [81]–[84].

Chapter 4: CONCLUSION

The research highlights several advantages of offshore wind farms compared to onshore projects, in the context of energy independence for islands and as important contributing factors towards a cleaner future of energy production in Greece. Higher Energy Generation Potential: Offshore wind farms can integrate a larger number of wind turbines, including wind turbines with nominal power from 8 to 15 MW, in comparison to onshore sites. Wind turbines based on floating bases will also allow the development of OWF in greater depths, where potential stronger winds are applied. This results in the addition of larger quantities of energy to the local electric grid, covering local energy needs and potentially exporting excess power to the national grid through ongoing electrical interconnections.

This study also presents a comprehensive methodology for identifying and prioritizing potential areas for OWF development, with an extended application in the Greek region. The proposed methodology seamlessly combines the geo-spatial capabilities of ArcGIS Pro 3.0 with the extended VIKOR method, accommodating incomplete decision criteria weights. The AHP method plays a pivotal role in defining the weighting factors, incorporating the preferences of 21 experts through a pairwise comparison questionnaire of the alternatives. Additionally, we explore various decision maker profiles through a sensibility analysis, shedding light on distinct decision strategies, including individual regret and group utility.

The adaptability of our methodology renders it suitable for addressing diverse decision-making challenges that require the insights of GIS, which can be highlighted by an extended use case in the Greek region. Throughout this process, we generated and evaluated 35 different areas using the extended VIKOR method. The results pinpoint the most favorable regions in Greece for potential OWF development, notably including areas south of Alexandoupoli, near Xerokampos east of the island of Crete, and in the vicinity of the Gulf of Patras. These outcomes align with recent developments in potential OWF projects in Greece, as mentioned in recent articles such as [81]–[83], [85]–[87].

Regarding prospects, it remains imperative to enhance the availability of spatial and geo-referenced data to yield more precise results for decision makers. While the proposed methodology offers valuable insights into realizing the potential of available OWF areas, further in-depth analyses are essential for the precise implementation of offshore wind farms. This entails utilizing accurate and dynamic wind data, examining seabed composition, conducting techno-economic analyses, among other factors. We also recommend continued exploration of MCDM methods integrated with GIS capabilities, leveraging updated and enriched geo-referenced data while giving due consideration to the input of various experts and policy makers. Moreover, we propose a thorough review of legislation pertaining to potential OWF development either in Greece or in the respective country of interest, tailoring it to the preferences and needs of the local population and emphasizing the preservation and protection of environmentally significant areas. Finally, it is pertinent to explore innovative approaches like Wind to X and integrate them with the findings of this study to showcase the full potential of wind power projects in the Greek region.

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