ΔΙΑΤΜΗΜΑΤΙΚΟ ΠΡΟΓΡΑΜΜΑ
ΜΕΤΑΠΤΥΧΙΑΚΩΝ ΣΠΟΥΔΩΝ
ΕΝΕΡΓΕΙΑΚΑ ΣΥΣΤΗΜΑΤΑ

POST-GRADUATE THESIS:

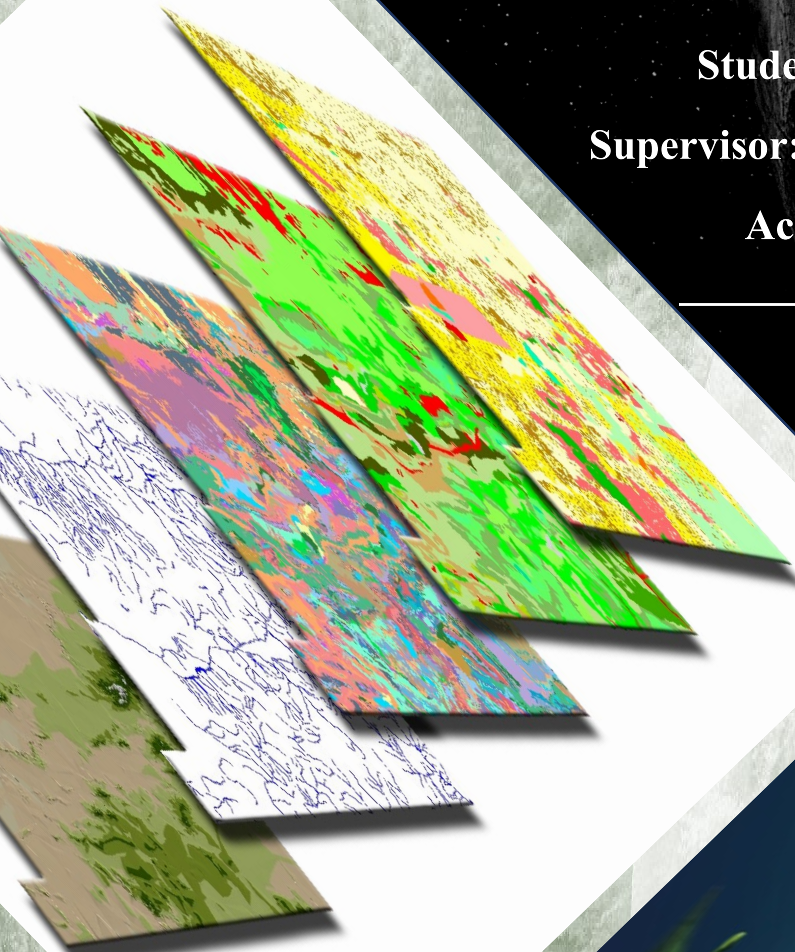
"FEASIBILITY STUDY OF MICROGRID VILLAGE WITH RENEWABLE ENERGY SOURCES"

Student: Loukakis Emmanouil

Supervisor: Prof. Karapidakis Emmanouil

Academic Year: 2017-2018

Heraklion Crete,
May 2018



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ABSTRACT

The exploitation of distributed energy resources and problems associated with islanded-remoted energy grids are important in optimizing sustainability of electricity supply, where microgrids play a major role in the decentralized and dispersed production. As defined, a microgrid is a group of interconnected electrical loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the central grid. Can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode (remoted). The main focus of this study is the evaluation of an interconnected microgrid of Vorias village, located in the inland of Crete island. Considering the household, agricultural and industrial loads of the village, were chosen RESs, such as wind turbines and photovoltaic panels. The co-production of RESs aims the 100% energy independence of the village, considering economic and environmental impact boundaries. To maintain the highest degree of reliability and security of the operating system, the designed potential project is also represented through Geographical Information Systems (GIS) in map forms (wind and solar energy distribution potential maps). The extensive region of Vorias village presents intense relief that justifies the installation of both wind and solar photovoltaic parks, regardless of the possibility of individual RES installation in the settlement of the region.

Index Terms—Microgrid, distributed energy, RES, GIS, sustainability, environment.

ΣΥΝΟΨΗ

Η αξιοποίηση των διεσπαρμένων ενεργειακών πόρων και τα προβλήματα που σχετίζονται με τα απομακρυσμένα-αυτόνομα ενεργειακά δίκτυα είναι σημαντικά για τη βελτιστοποίηση της βιωσιμότητας της παροχής ηλεκτρικής ενέργειας, όπου τα μικροδίκτυα παίζουν σημαντικό ρόλο στην αποκεντρωμένη και διεσπαρμένη παραγωγή. Εξ ορισμού, ένα μικροδίκτυο είναι μία ομάδα διασυνδεδεμένων ηλεκτρικών φορτίων και κατανεμημένων ενεργειακών πόρων εντός σαφώς καθορισμένων ηλεκτρικών ορίων που λειτουργεί ως μία ενιαία ελεγχόμενη οντότητα, συναρτήσει του κεντρικού δικτύου. Μπορεί να συνδεθεί και να αποσυνδεθεί από το κεντρικό δίκτυο για να μπορέσει να λειτουργήσει σε διασύνδεση, αλλά και σε αυτόνομη λειτουργία (απομακρυσμένη πρόσβαση). Η κύρια εστίαση αυτής της μελέτης είναι η αξιολόγηση ενός διασυνδεδεμένου μικροδικτύου εντός του χωριού του Βοριά, που βρίσκεται στην ενδοχώρα της Κρήτης. Λαμβάνοντας υπόψη τα οικιακά, γεωργικά και βιομηχανικά φορτία του χωριού, επιλέχθηκαν ανανεώσιμες πηγές ενέργειας (ΑΠΕ), όπως ανεμογεννήτριες και φωτοβολταϊκά. Η συμπαραγωγή των ΑΠΕ έχει ως στόχο την 100% ενεργειακή αυτονομία, λαμβανομένων υπόψη ορίων των οικονομικών και περιβαλλοντικών επιπτώσεων. Για να διατηρηθεί ο υψηλότερος βαθμός αξιοπιστίας και ασφάλειας του λειτουργικού συστήματος, το σχεδιασμένο δυναμικό του έργου εκπροσωπείται επίσης μέσω των Γεωγραφικών Συστημάτων Πληροφοριών (ΓΣΠ) με μορφές χάρτη κατανομής αιολικού και ηλιακού δυναμικού. Η ευρύτερη περιοχή του χωριού του Βοριά παρουσιάζει έντονο ανάγλυφο που δικαιολογεί την εγκατάσταση αιολικών και φωτοβολταϊκών πάρκων, ανεξάρτητα από τη δυνατότητα-πιθανότητα εγκατάστασης μεμονωμένων ΑΠΕ στους οικισμούς της περιοχής.

Ευρετήριο όρων—Μικροδίκτυο, διεσπαρμένη ενέργεια, ΑΠΕ, ΓΣΠ, περιβάλλον.

SUMMARY

Although microgrid (MG) concept is recently developing in the scientific community, the interest and research first presented by the Consortium for Electric Reliability Technology Solutions (CERTS) [1]. Fast depleting fossil fuels and Greenhouse Gases (GHGs) emissions made awareness for environmental protection a fast-growing research domain. Hence, in recent years, there is an effort to spread the use of Renewable Energy Sources (RESs) as a clean energy project, worldwide [2]. Despite the fact that RESs have minimum environmental impact, they are simultaneously a perfect solution for Distributed Generation (DG) of energy, especially in isolated (islanded) off-grid areas with growing energy demands, such as the island of Crete. A microgrid is a hybrid energy system, where conventional and RESs incorporate. They are often viewed as controllable subsystem, generating power from Distributed Energy Resources (DERs) which are mostly renewable in nature [1]. Amongst renewable energy sources, the vast majority of energy studies have come up with the hybrid use of two energy sources: wind and solar, despite the fact that they are highly variable in time and site specific. It is known that MG designing requires multiple complex model formulation and multi-objective optimization, targeting the ultimate task of optimal functioning of individual elements. Therefore, researchers give the highest importance to the optimum sustainable techno-economical study of hybrid MGs [3]. In addition, due to uncertainty of weather conditions (wind and solar), it is a crucial element to classify the best operational strategy, though the existence of related literature is vast. This irregular nature of RESs is a major drawback, though it can be equalized and even annihilated, particularly in RES rich countries. Moreover, a RES rich region can sustain an autonomous MG with continuous power flow, even without energy storage systems, simply by the optimal design of incorporating RESs [4]. Though the accuracy of this speculation is questionable, at the moment it is plausible and successful only in grid-connected mode [5]. Another problem is to model the requirements of energy storage with RES generation and the simultaneous complex nature of charging/discharging. Therefore, the main tasks are represented by flexible loads derived from consumer's preferences and uncertainties due to RESs, in parallel with the absence of modeling tools/methods, including such parameters in a "smart" grid environment [6]. Considering consumer's load profiles can provide advanced and long-term analysis, enhancing the simulation of a more realistic scenario [7]. At this point, sizing, operation and control challenges or RESs, drawbacks can be addressed by the use of the strengths and disadvantages of one source to counterbalance those of the other [2]. Despite the fact that there is a variety of negative elements, plus the fact that the studies are made on the basis of the Worst-Case Scenario (WCS), there is an abundance of technical, financial and environmental advantages that justify the development of MGs [7]:

- Cost and energy production efficiency
- Environmental friendly option (zero GHGs)
- Suitable for isolated (islanded) regions
- Long-life system expectancy
- Power loss minimization
- Distributed energy resource management
- Frequency, voltage control and stabilization during islanded operation mode
- Reactive power planning
- Self-healing properties
- Increased reliability
- Improved asset and demand side management
- Pervasive use of RESs

- Increased customer participation, along with high rates of investment
- Robustness, simplicity of design and low maintenance requirements of RESs
- Decentralization of power generation
- Low storage capacity, as a result of optimum RESs combination
- High level of autonomy
- Utilization of state of the art computer programs [4], [8], [9], [10], [1], [2], [3], [11], [12].

In accordance with the preceding, wind and solar sites are the fastest growing RES implementations around the world. Therefore, it is extremely important to preference the optimal location for RESs settlement within strict considerations, some of which are electrical and communication infrastructures, environmental and economic feasibility and accessibility of the Area of Interest (AOI), (topographical features) [13], [14], [15]. Classification and understanding of these parameters require Multi-Criteria Decision Analysis (MCDA) mathematical models. Geographical Information Systems (GIS) widely use MCDA models for determining the implementable areas, making it the best tool for this task since 2000 in various countries, although it is used as a tool of research and application since 1970. Among other benefits, GIS are designed to store, retrieve, manipulate, analyze and map geographical data, with the aim of enriching the geographical database of the study [16].

ΠΕΡΙΛΗΨΗ

Αν και το μικροδίκτυο (ΜΔ) είναι μία έννοια που αναπτύχθηκε πρόσφατα στην επιστημονική κοινότητα, το ενδιαφέρον και η έρευνα παρουσιάστηκε για πρώτη φορά από την Κοινοπραξία για την Ηλεκτρική Αξιοπιστία Τεχνολογικών Λύσεων (ΚΗΑΤΛ) [1]. Η γρήγορη εξάντληση των ορυκτών καυσίμων και τα Αέρια του Θερμοκηπίου (ΑΘ) έκανε την ευαισθητοποίηση για την προστασία του περιβάλλοντος έναν ταχέως αναπτυσσόμενο τομέα έρευνας. Ως εκ τούτου, τα τελευταία χρόνια γίνεται μια προσπάθεια να διαδοθεί η χρήση των Ανανεώσιμων Πηγών Ενέργειας (ΑΠΕ) ως ένα καθαρό ενεργειακό έργο, σε όλο τον κόσμο [2]. Παρά το γεγονός ότι οι ΑΠΕ έχουν ελάχιστες περιβαλλοντικές επιπτώσεις, είναι ταυτόχρονα μια τέλεια λύση για την Διεσπαρμένη Παραγωγή (ΔΠ) της ενέργειας, ειδικά σε απομονωμένες, εκτός δικτύου περιοχές, με αυξανόμενες ενεργειακές απαιτήσεις, όπως το νησί της Κρήτης. Ένα μικροδίκτυο, είναι ένα υβριδικό ενεργειακό σύστημα, όπου ενσωματώνονται συμβατικές και ΑΠΕ μονάδες. Θεωρείται συχνά ως ένα ελέγξιμο υποσύστημα παραγωγής ενέργειας από Κατανεμημένους Ενεργειακούς Πόρους (ΚΕΠ), οι οποίοι είναι ως επί το πλείστων ανανεώσιμοι στη φύση τους [1]. Μεταξύ των ανανεώσιμων πηγών ενέργειας, η συντριπτική πλειοψηφία των ενεργειακών μελετών πραγματοποιείται κατά κόρον με την υβριδική χρήση δύο πηγών ενέργειας: την αιολική και την ηλιακή, παρά το γεγονός ότι είναι εξαιρετικά μεταβλητές στο χρόνο και την τοποθεσία. Είναι γνωστό ότι ο σχεδιασμός του μικροδικτύου απαιτεί πολλαπλά σύνθετα μοντέλα διατύπωσης και βελτιστοποίησης, με απόλυτο στόχο τη βέλτιστη λειτουργία των επιμέρους στοιχείων. Ως εκ τούτου, οι ερευνητές αποδίδουν ύψιστη σημασία στη βέλτιστη βιώσιμη τεχνο-οικονομική μελέτη υβριδικών μικροδικτύων [3]. Επιπλέον, η αβεβαιότητα των καιρικών συνθηκών (αιολικών και ηλιακών), είναι ένα κρίσιμο στοιχείο για να χαρακτηριστεί η καλύτερη επιχειρησιακή στρατηγική, παρόλο που η ύπαρξη σχετικής βιβλιογραφίας είναι ογκώδης. Αυτή η απρόβλεπτη φύση των ΑΠΕ είναι ένα σημαντικό μειονέκτημα, αν και μπορεί να ισορροπηθεί, ακόμη και να εκμηδενιστεί, ιδιαίτερα στις πλούσιες από ΑΠΕ χώρες. Επιπροσθέτως, μια πλούσια σε ΑΠΕ περιοχή μπορεί να στηρίξει ένα αυτόνομο μικροδίκτυο με συνεχή ροή ισχύος, ακόμη και χωρίς συστήματα αποθήκευσης ενέργειας, απλά με το βέλτιστο σχεδιασμό ενσωμάτωσης των ΑΠΕ [4]. Αν και η ακρίβεια αυτής της εικασίας είναι αμφισβητήσιμη, αυτή τη στιγμή είναι εύλογο και επιτυχές μόνο σε λειτουργία διασύνδεσης [5]. Ένα άλλο πρόβλημα είναι η μοντελοποίηση των απαιτήσεων της αποθήκευσης ενέργειας με την παραγωγή από ΑΠΕ και την ταυτόχρονη περίπλοκη φύση της φόρτισης/εκφόρτισης. Ως εκ τούτου, οι κύριοι στόχοι εκπροσωπούνται από ευέλικτα φορτία, που προέρχονται από τους καταναλωτές, τις προτιμήσεις και τις αβεβαιότητες των ΑΠΕ, παράλληλα με την απουσία εργαλείων/μεθόδων μοντελοποίησης, συμπεριλαμβανομένων αυτών των παραμέτρων σε ένα περιβάλλον «έξυπνου» δικτύου [6]. Λαμβάνοντας υπόψη το προφίλ φορτίου των καταναλωτών, μπορεί να παρέχει προηγμένη και μακροπρόθεσμη ανάλυση, ενισχύοντας την προσομοίωση, ενός πιο ρεαλιστικού σεναρίου [7]. Σε αυτό το σημείο, για την ταξινόμηση, τη λειτουργία και τον έλεγχο των προκλήσεων των ΑΠΕ, τα μειονεκτήματα μπορούν να αντιμετωπιστούν με τη χρήση των πλεονεκτημάτων και των μειονεκτημάτων της μίας πηγής, για να αντισταθμιστούν αυτά των άλλων [2]. Παρά το γεγονός ότι υπάρχει μια ποικιλία αρνητικών στοιχείων, συν το γεγονός ότι οι μελέτες γίνονται βάσει τα χειρότερα πιθανά σενάρια (ΧΠΣ), υπάρχει μια αφθονία τεχνικών, οικονομικών και περιβαλλοντικών πλεονεκτημάτων που δικαιολογούν των ανάπτυξη των μικροδικτύων:

- Αποδοτικότητα κόστους και ενεργειακής παραγωγής
- Φιλική προς το περιβάλλον επιλογή (μηδενικές εκπομπές αερίων του θερμοκηπίου)
- Κατάλληλο για απομονωμένες (δυσπρόσιτες/νησιωτικές) περιοχές
- Μακράς διαρκείας προσδόκιμου ζωής του συστήματος
- Ελαχιστοποίηση των απωλειών ενέργειας
- Διαχείριση των διεσπαρμένων ενεργειακών πόρων

- Έλεγχος και σταθεροποίηση της συχνότητας και της τάσης σε αυτόνομη λειτουργία
- Διαδραστικός έλεγχος της ενέργειας
- Αυξημένη αξιοπιστία
- Βελτιστοποίηση του κεφαλαίου και της ενεργειακής ζήτησης
- Διάχυτη χρήση των ΑΠΕ
- Αυξημένη πελατειακή συμμετοχή, σε συνδυασμό με υψηλά ποσοστά επενδύσεων
- Αξιοπιστία, απλότητα στο σχεδιασμό και χαμηλές απαιτήσεις συντήρησης των ΑΠΕ
- Αποκεντροποίηση της παραγωγής ενέργειας
- Χαμηλή απαίτηση χωρητικότητας αποθήκευσης, ως αποτέλεσμα του βέλτιστου συνδυασμού των ΑΠΕ
- Υψηλό επίπεδο αυτονομίας
- Αξιοποίηση προγραμμάτων τελευταίας τεχνολογίας των ηλεκτρονικών υπολογιστών [4], [8], [9], [10], [1], [2], [3], [11], [12].

Σύμφωνα με τα προηγούμενα, τα αιολικά και φωτοβολταϊκά πάρκα είναι οι ταχύτερα αναπτυσσόμενες υλοποιήσεις ΑΠΕ σε όλο τον κόσμο. Συνεπώς, είναι εξαιρετικά σημαντικό να επιλεχθεί η βέλτιστη θέση για την εγκατάσταση των ΑΠΕ, εντός αυστηρών εκτιμήσεων, μερικές από τις οποίες είναι οι υποδομές ηλεκτρισμού και επικοινωνιών, η περιβαλλοντική και οικονομική σκοπιμότητα του έργου, καθώς και η προσβασιμότητα της περιοχής ενδιαφέροντος (τοπογραφικά χαρακτηριστικά γνωρίσματα) [13], [14], [15]. Για την ταξινόμηση και την κατανόηση αυτών των παραμέτρων, απαιτούνται σύνθετα μαθηματικά μοντέλα Πολυκριτηριακής Ανάλυσης Αποφάσεων (ΠΑΑ). Τα Γεωγραφικά Συστήματα Πληροφοριών (ΓΣΠ) χρησιμοποιούν ευρέως μοντέλα ΠΑΑ, για τον προσδιορισμό των υλοποιήσιμων περιοχών, καθιστώντας τα το καλύτερο εργαλείο για αυτή την εργασία από το 2000 σε διάφορες χώρες, αν και χρησιμοποιείται ως εργαλείο έρευνας και εφαρμογής από το 1970. Μεταξύ άλλων παροχών, τα ΓΣΠ είναι σχεδιασμένα να αποθηκεύουν, να ανακτούν, να αναλύουν και να διαχειρίζονται χάρτες γεωγραφικών δεδομένων, με στόχο τον εμπλουτισμό της γεωγραφικής βάσης δεδομένων της εκάστοτε μελέτης [16].

2 BIBLIOGRAPHY: LITERATURE OVERVIEW

2.1 The evolution of renewable energy

The fast-growing development of modern industry, fossil fuel facing great crisis of depletion stimulates the expansion of clean and efficient renewable energy for satisfying the power requirement. Although renewable energy connects to the grid via distribution at early days, filling the urgent demand at users in some degree, the instability causes a large amount of troubles considering safe and stable operation of power grid. At present, grid-connected renewable energy is transported to the grid mainly through the way of centralization or distribution. The way of distributed access favors promoting renewable energy local utilization and power supply reliability, which attracts large-scale attention on research and application between scholars across Europe and other developed countries[17].

The analysis of the renewable energy sources with emphasis on technological and economical characteristics of the social and environmental impacts, provide a rather static, narrow framework of analysis. The participation and response of the social partners and other stakeholders is usually defaulted, with consultation documents and public meetings, collection of complaints and project proposals. This often encourages local development. Therefore, it is imperative to establish a new participatory planning platform to incorporate the wider socio-economic aspects of renewable energy systems and to provide an operational analytical decomposition. For the various renewable energy technologies (RETs) projects and programmes in particular, often occurs only a loose connection with the public, through a constricted, limited-scope public participation process. The available social tools, like cost-benefit analysis (CBA), multi-criteria analysis (MCA), express the general content in which they have been developed and applied[18].

The European Union (EU) aims to reduce its dependency on fossil fuels and counterbalance the demand by increasing the level of renewable energy in the EU's overall mix to 20% by 2020. Greece, as a member of the EU, faces respectively the same energy problems as other member states (MS). There are plenty of examples of MS, such as Denmark, that try to apply a renewable energy policy (feed-in-tariff) that encourages investment and reduces energy import dependency. The basic benefit for these countries is that they accomplish a reduction of the environmental impact from conventional and non-renewable fuels, gaining an advantage on both political and economic levels. In contrast, Greece applies a policy that aims in making the country an energy crossroad. Furthermore, the extensive use of conventional fuels that contributes positively to the country's economy, creates a non-environmental friendly energy practice that is extremely difficult to alter without substantial RES investment motives [19].

RETs tend to attract the interest also at a global level. Yet, as these systems attract growing interests, it is crucial to understand how they are planned, for achieving successful energy supply and long-term viability. Res also have a huge potential to meet the energy needs of approximately 1,3 billion people globally, who do not have access to the modern energy supply, especially in areas rich in solar and wind energy [20].

The advantage of using multiple RES together like wind and solar energy, are their seasonal and diurnal balancing properties in relation to each other. According to the EU directive 2009/28/EC on the promotion of the use of energy from renewable sources, all EU countries are obliged to rise the share of renewables in the final energy consumption, compared to the year 2005 [21].

Progress and development of modern civilization has been achieved mainly due to the use of fossil fuels. But at the same time, this use has a serious impact, resulting in heavy pollutants that are contaminating and degrading water systems, climate systems, are, specie’s survival, natural habitats and every aspect of the environment. We conclude that the use of renewable energy, as a clean form of energy, needs to spread more, though already is in a satisfactory point of development and investment across the world [22].

Despite the fact that fossil fuels have a high environmental impact, are also characterized and of high cost. Amongst RESs, more promising and more efficient, seems to be wind energy. Consequently, the installations of wind farms have been developed particularly in the last few years all over the world. For example, in the last 20 years, the global total installed capacity of wind power has reached 369,6 GW in 2014, compared to 1997, which was only 7,6 GW. The European Commission fixed a motivated goal that 20% primary energy should be generated by using renewable energy resources by 2020 and 27% by 2030 and this target needs to be implemented in all member countries [23].

As a result of the EU’s energy objectives, are the energy savings and the reduction of greenhouse gases (GHGs). Therefore, it becomes evident that the correct quantification of dispersed renewable energy sources, requires new methods for the optimization of supply and demand, integrated with spatial planning, despite the fact that it is observed that small scale wind turbines require less space and electrical power systems, hence, less extensive studies. The primary research area on technical and innovative projects on distributed RESs has become imperative in the last few years. Further, the current transition in energy demand and supply also involves many aspects, such as the resource availability evaluation, the compliance with environmental and legal constraints, various technical aspects and the irregular nature of RESs. By combining technical and spatial research, integrating it with regulatory, economic and social constraints, a new interdisciplinary research and innovation area is unfolded with a high exploitation potential for energy investors on a local scale. A reliable approach depends on a number of factors that are context-related: the size of the analyzed area, the required volume of the results, the climatic and topographical characteristics of the analyzed area, the density of the available meteorological measurements, etc. [24].

Currently, most dominant and increasing forms of RESs worldwide, sharing in power supply are grid-connected wind turbines and photovoltaic systems (PV), especially even in high density populated areas. According to the last report from International Energy Agency (IEA-PVPS), the total installed photovoltaic capacity in the EU exceeded 97 GW at the end of the year 2015. But at the same time with the development of RES arise various technical problems, such as limited penetration and the intermittent nature of RESs, alongside the limited capacity of the contractual work for the production of electrical energy to raise or lower the load, quickly and in accordance with the co-production of RES. Thus, arises the need for digitization of the existing electricity network, in order to offset the energy demand, the ability of consumers to regulate their energy need and the development of reliable systems for production, transmission and distribution, such as microgrids (MGs), smart-grids (SGs) and web of cells [25].

2.2 The socio-economic situation of the energy

Worldwide, more than 1,1 billion people do not have access to affordable, reliable and secure provision of electrical services. Combating this problem has set as a goal by 2030, the development and implementation of small scale renewable energy projects, with a total investment ratio of 43% or respectively 244 billion euros [26].

Despite the increasing awareness of the environmental problems, the investments in the field of renewable energy sources is an extremely complex plan that involves many investors with conflicting interests and a variety of scenarios in the design and implementation. In more detail, the scholars of these complex energy plans are invited to cooperate in a framework of understanding and mutual compromise. Despite the opposition of the methods used, the most reliable and widely used method is the multi-criteria analysis, which takes into account each and every time technological, economic, environmental and social parameters. Among these, it is important the rational management of RESs, in order not to endanger future developments [27].

In addition, it is important to consider the economic viability of the investment. Generally, it is a multi-dimensional approach and involves all of the factors associated with the economic evaluation and the performance of the investment. These investments will have to be apart of economically attractive, also accepted by the local communities for employment of the availability of land, among other things, but not to disturb the ecological homeostasis of the flora and fauna of the environment in parallel [28].

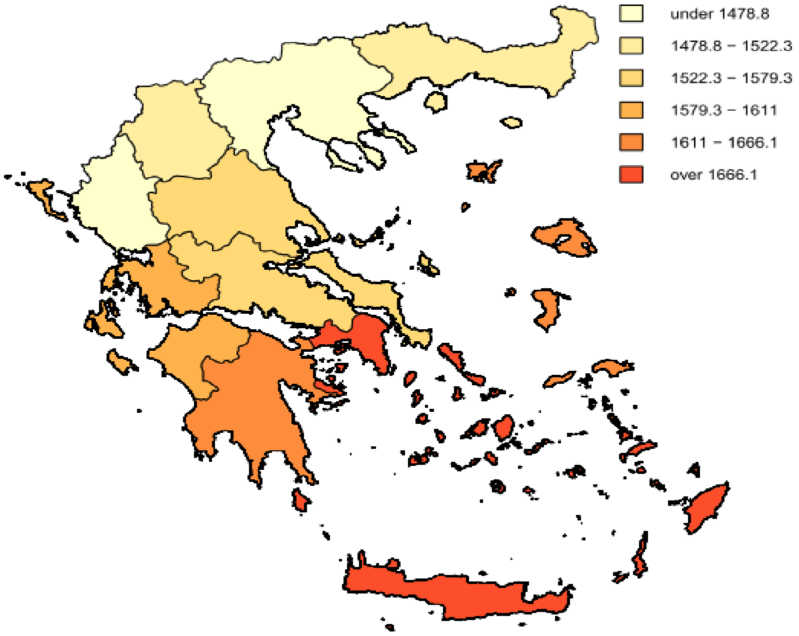


Figure 1: Solar irradiation distribution in 2016 (kWh/m^2)[28]

Economic growth and energy consumption in a country is a causal relationship. In Greece there are few studies concerning this area, even though it is investigated the demand for energy and it's connection with the production, as a function of carbon dioxide emissions [29].

Greece is a country with a large number of islands. Consequently, the utilization and efficiency of renewable energy sources in the islands, has received considerable attention from both academia and industry. Still, however, the price of oil for the production of electricity is 3-4 times higher than that on the mainland, due to the difficult accessibility and the dispersion of the islands, making them vulnerable to fluctuations in oil prices. The price of oil, with an annual growth rate of 5% during the last two decades will grow at an average annual rate of 3% over the next 20 years. The European Union is studying and developing the electrification of islands 100% of endogenous renewable energy sources. Crete is a typical and representative example of development of RES projects, with a total potential solar energy of 16,5 GWh/year, high wind potential with a production that reached 336,7 GWh/year and biomass potential approximately equal to 360 GWh/year of residue of agricultural production [30].

2.3 The energy policy background

It becomes a concerted effort for the penetration of RES in the residential sector to meet energy needs until 2020, in particular for new buildings, putting in the game more and more solar panels, as the most effective and practical form of residential energy production. Previously, one of the most widespread programs to support this policy was the Feed-in-Tariff (FiT) that provided safe investments, becoming very popular in the EU over the last decade. However, the FiT program has unwanted effects, one of which is the reduction of competitiveness among the various renewable energy technologies. Specifically, in the period of 2012-2013 in Greece, the FiT failed the objectives of the program, leading to additional taxation of energy production from solar panels, creating a significant deficit in the special account of RES (used for the financing of FiT), rather than the achievement of the energy targets for the country for 2020, as a result of poor management policy of the official reduction in the FiT price of the existing contracts. In the same period in the EU, this phenomenon has caused a vicious circle and has drastically reduced the development of photovoltaic systems, despite the significant reduction of their cost. To compensate for this problem has arisen the net-metering program, which takes advantage of grid parity and gives solutions with a wide range of options, making it at the same time also quite complex in it’s design [31].

The net-metering policy determines basically if a house accepts or returns electrical current to the network, in case of lack or surplus, respectively. In the case that the house gives power to the network from the installed RES, takes credit for the portion of the electricity it produces [32].

The net-metering applies in practice a policy of “green energy” and encourages the use and development of renewable energy and therefore, allows the spread of the network of distributed generation. This mechanism offsets the units consumed by the consumer from the grid and hence, a reduced electricity bill is achieved with the use of green energy [33].

By definition, net-metering is an electricity policy that allows utility customers to offset some or all of their electricity consumption by using their own generating system, mainly by rooftop PV systems. A net-metering investment may, however, inevitably be affected by the variation of taxes on the sale of electricity, retail charges and to cause a variation of the present value of the life-cycle of the installation project [34].

Another criticism refers to the fact that this policy has recently been criticized on the grounds that it provides a subsidy for residential and commercial solar installations, a subsidy that is paid for by all ratepayers, despite the fact that it grows worldwide in the residential and industrial sector [35].

Despite the positive effects of RES development in Europe, made a concerted effort to coordinate and become more profitable at cogeneration of electricity from RES, in response to the requirements of the Kyoto protocol for environmental protection (promote the use of sustainable energy sources and measures to reduce CO_2 emissions). So, there is the need for continuous improvement of the production of the RES as the energy is the cornerstone of economic development. Statistically, the energy consumption in Europe in 2014 was 1.777 Mtoe (Million tons of oil equivalent) or 3.226 TWh (32,7% of which was covered by RESs) while at global level was around 13.737 Mtoe, 0,5% more than in 2013 from PV energy production, representing around 42,3% of the worldwide installed capacity only from Europe. PV energy contributes around 1,3% of the global electricity demand, 3,5% of the electricity demand in Europe. This energy accounts for only 0,05% of the free solar energy that the earth receives from the sun, which comes with zero CO_2 emissions. In 2015, Germany, Italy, United Kingdom, France, Spain, Belgium and Greece had 85,7% of the total installed capacity in Europe, with the addition of 8,5 GW, representing a total installed capacity of 97,14 GW from PV generation [36].

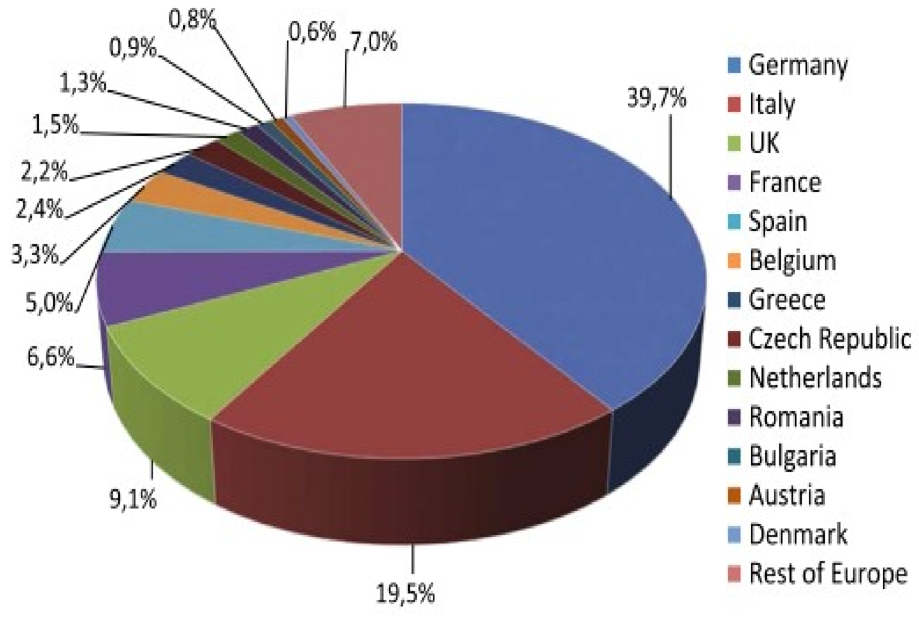


Chart 1: European solar PV cumulative installed capacity 2000–2015 (in percentage by country) [36].

2.4 The dispersed production

With the development of RES comes to the fore the importance of distributed generation (DG), considering the load distribution in the network, for safe operation and protection of equipment. Because of the increasing distributed generation, it becomes imperative for successful and coordinated mix of sources of electricity load to operate as a single controllable system to provide the required energy to the local area network [37].

The greatest challenge of researchers is to regulate the stability of the system through scenarios of inactivity due to the intermittent nature of RES and economic efficiency of the entire system [38].

An energy strategy is important for the management and coordination of the control systems for the production, storage and distribution of electric energy through a set of RESs, setting as main goal the reliability and performance of these systems [39].

The variation of energy production from RES causes great difficulty in the sale of wholesale energy in real-time in connection with the price that is determined at the national level. The dispersed production, however, creates at the same time opportunities for producers and consumers and an innovative and secure network of information. In the field of distribution of information have emerged with a variety of technologies that provide the ability, the plans and the applications for the user, thus participating in the organization of central and decentralized energy market. A central system is defined by a large number of consumers (for example a city) and operates in accordance with a central mechanism of production, distribution and coordination coming from a large power plant. In contrast, the decentralized system works with the co-production of small scale energy systems, typically RESs and includes small groups of consumers, such as small settlements. In a decentralized system, there is the possibility of autonomous operation and interconnection, providing opportunities to professionals and consumers in the energy market and therefore, promotion of the sustainability and the efficient use of local resources [40].

2.5 The microgrid concept

With the spread of distributed generation has emerged the concept of microgrid. A microgrid (MG) is a group of multiple distributed generation (DG) power sources, operating as a coordinated system, connected to the main electrical grid at a single point (typically, at the distribution level) and is able to function in parallel with the grid or in island mode. As of 2015, 12.031 MW of total microgrid capacity have been either planned, proposed, under construction or in operation, worldwide [41].

In the process of decentralization of energy production, microgrids are emerging as a promising solution for combining RESs with smart energy management technologies. Despite the challenges of their many disadvantages, such as high capital costs, irregular power supply and variable power quality, microgrids possess advantages that have continued to drive microgrid development. Many advantages of which are:

- Higher energy supply reliability
- Lower greenhouse gas (GHG) emissions through a higher penetration of RESs
- Higher energy efficiencies using local waste heat and the avoidance of losses in transmission and distribution
- Ability to provide power generation units closer to the end users and to integrate combined heat and power (CHP) technologies
- Increased overall efficiency
- Fewer customer interruptions and improved reliability
- Higher power quality
- Reduced operation costs, either connected to or disconnected from the utility grid [42], [43].

There is a correlation between microgrid and distributed generation, so it adopts the problems-objectives of it, such as maintaining and ensuring the stability of the network, the production and distribution of energy at the lowest possible cost, fulfilling the demand in total and the time that is desirable [44].

Based on the above, the successful design of a system such as the microgrid, requires a more systemic design for improving the reliability. The interchange between the load, the information technology, operation and maintenance costs are some parameters of dimensioning process. The biggest challenge is the prediction of the energy demand, which is extremely difficult because of the large variance due to human activities and environmental conditions [45].

The heterogeneity in the production of energy from dispersed sources can be handled with the interconnection of one or more microgrids. When acting together, microgrids cover the deficits of one of the surplus of the other, reducing the risk of power failure [46].

Of course, in the scenario of the interconnection shall apply regulations and strict controls that prohibit the irregular penetration of RES in the core network. The core network operates always and strictly under specific provisions of frequency and voltage of the power supply [47].

However, the policy of these systems is growing and encouraged along with the evolution of communication and information technologies, even though that contradicts centralized generation schemes that benefit from economies of scale [48].

Another key feature of the microgrid is it’s ability during a utility grid disturbance to separate and isolate itself from the utility grid with little or no disruption to the loads within the microgrid [49].

In a microgrid often appear and other benefits, such as the reduction of energy losses due to the short distances on transmission lines and the possibility of the cut-out operation in the event of damage, making them effective in their maintenance. From the perspective of the network, the microgrid operates as a controlled entity with a variety of financial and investment activities, while offering all the necessary for the network technical specifications in compliance with environmental constraints/objectives [50].

Many studies have focused on the automation of microgrids, missing element from the central power plants. For this reason, it is an immediate need for the introduction of “smart” technologies for the management of distributed generation [51].

It is quite challenging to design a structured approach to the problem with innovative and sophisticated technologies in the field of energy trade for the creation of a smart network management. By definition, a smart grid (SG) is an electricity network that can intelligently integrate the actions of all users connected to it in order to efficiently deliver sustainable, economic and secure electricity supplies. It employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies [52].

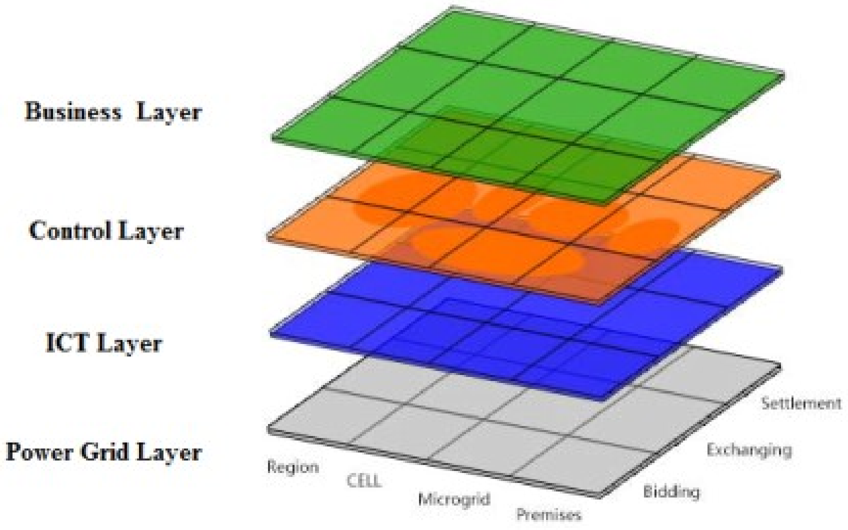
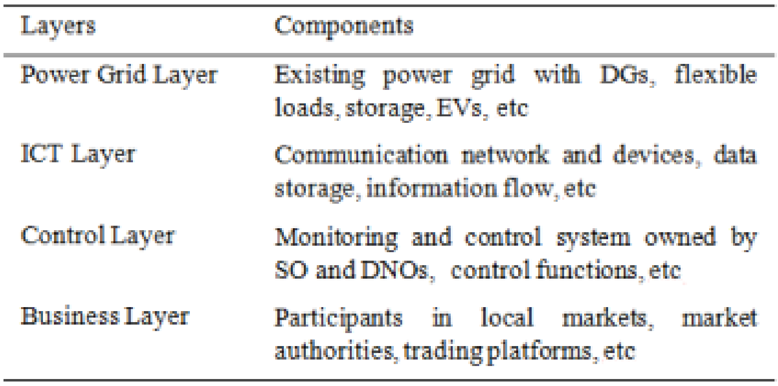


Figure 2: Four-Layer Architecture Model of Peer-to-Peer Energy Trading [52].



Layers	Components
Power Grid Layer	Existing power grid with DGs, flexible loads, storage, EVs, etc
ICT Layer	Communication network and devices, data storage, information flow, etc
Control Layer	Monitoring and control system owned by SO and DNOs, control functions, etc
Business Layer	Participants in local markets, market authorities, trading platforms, etc

Table 1: Components of Each Layer in the Four-Layer Architecture Model of P2P Energy Trading [52].

In distribution networks there is a lack of possibility of monitoring of the consumer in real-time along with the power losses that exist in distribution. The physical structure of the smart grid is an interactive solution to the problem even in remote areas or islands, where the power supply is a great challenge. In this scenario, the central energy production has the role of support, providing a stable base load. There are already several guides that ensure the proper organization and operation of smart grids, which ensure flexibility in the allocation level. In conclusion, smart grids define a variety of characteristics in modern systems of production and supply of electricity and share common features with the microgrids, such as interconnection of distributed generation to the main grid and demand management in real-time, using sophisticated systems of communication [53].

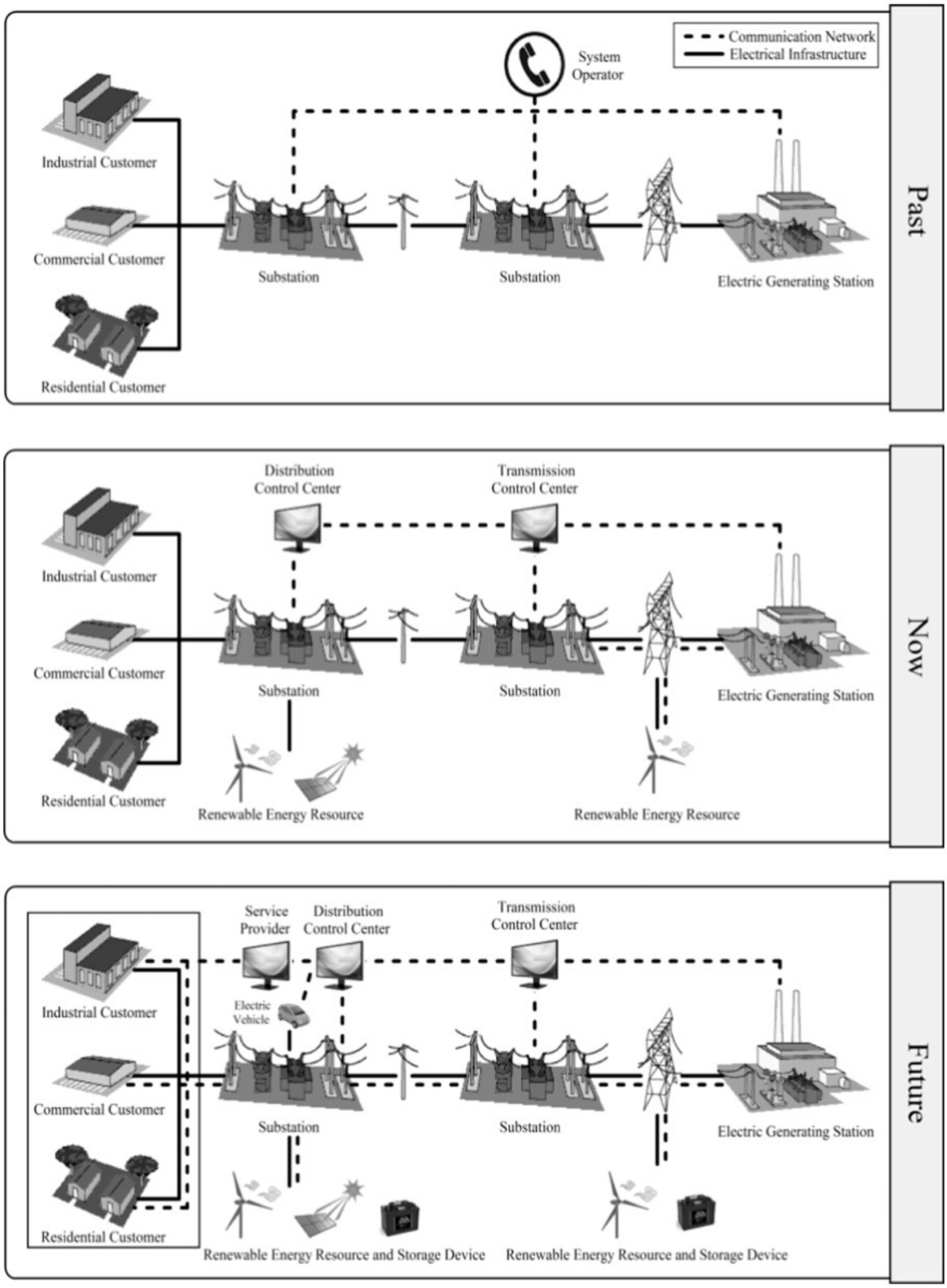


Figure 3: The evolution of power systems [53].

In the interconnected operation of microgrid emerges the need for a “central controller” for the safe and efficient coordination of distributed energy resources, in cooperation with the basic principle of operation of the core network [54].

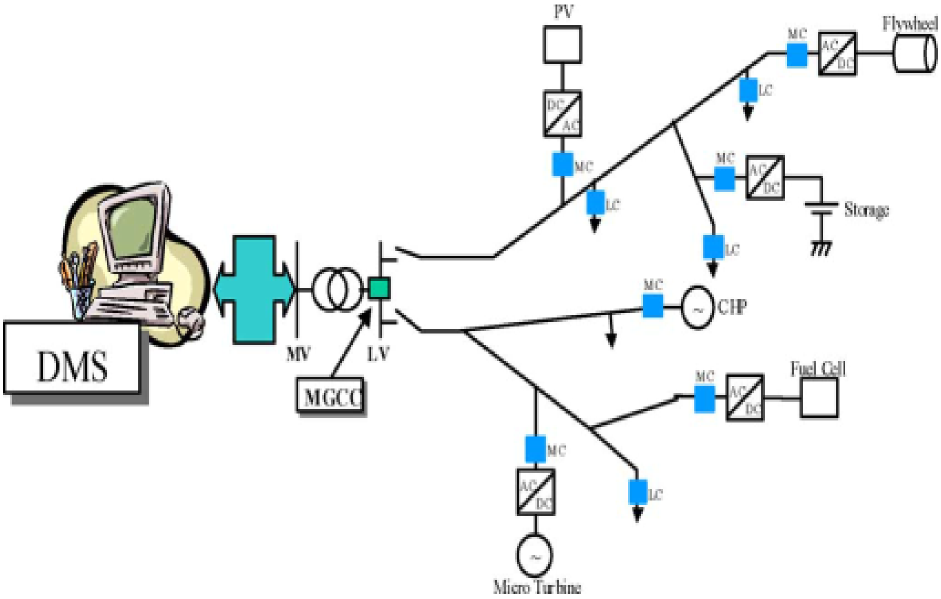


Figure 4: Typical microgrid structure, where contained local micro source controllers (MC) and load controllers (LC), microgrid system central controller (MGCC) and distribution management system (DMS) [54].

2.6 The Geographical Information Systems (GIS)

The purpose of the use of GIS is the combination of the multi-criteria analysis (MCA) for the development of an integrated framework for the research areas of RES potential in the siting of facilities for either wind turbines or solar panels. The GIS tend to be increasingly necessary tool to facilitate the acquisition, management, manipulation, analysis, modeling representation and output of spatially referenced data for solving complex planning and management problems, generating maps with high geographic resolution, taking into account technical, economic, environmental and social criteria in the effective design of energy and non-projects. Greece has recently established a special regulatory framework regarding the siting of renewable energy facilities in general, based on proper land use planning and sustainable development. Some of the parameters that is also invited to consider the MCA is the complexity of the mapping of renewable energy, especially in remote areas such as islands with a strong presence of antiquities, limited areas of land use and special protection areas "Natura 2000", characteristic examples of the island of Crete [55].

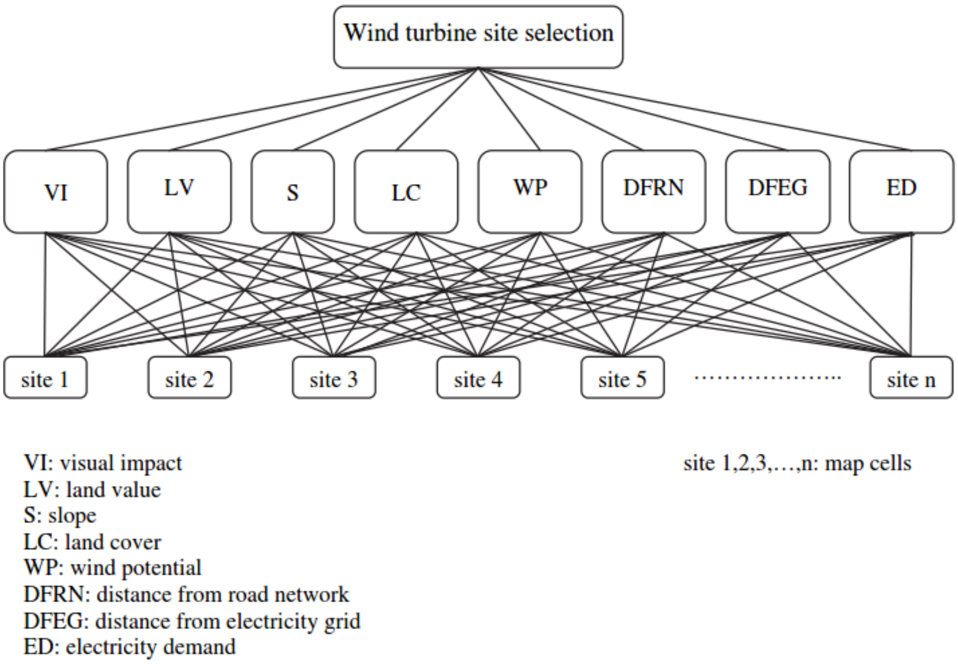


Figure 5: Hierarchy structure of the wind farm siting problem [55].

Regarding the use and application of GIS, it is necessary to describe the reality or the accuracy of that portion of the natural and man-made world that is of interest to us. Basic bridge, however, between reality and the description is the way that we perceive reality. The design approach focuses on the ability of the GIS to contribute to solving spatial problems, i.e. to participate actively in spatial planning [56].

Aerial photographs, satellite images and the images from radar are several forms of log data from a distance, with most characteristic and widespread of these derived from detectors which treat from satellites (satellite remote sensing) [57].

These photos are an integral part of the science of cartography. The cartography is defined as the art, science and technology that deals with the compilation and construction of maps with increased efficiency of communication, or more in detail, the efficient presentation of information corresponding to a specific geographical position on paper, plastic, or other surface such as the screen of the PC (two-dimensional or three-dimensional surface). In the field of digital design, the most prevalent software is ArcGIS. ArcGIS is a complete system that allows people to collect, organize, manage, analyze, communicate and distributing geographical information. As the world's leading platform for construction and use of geographical information systems, ArcGIS is used by people all over the world to put geographic knowledge to work in government, business, science, education and the media. ArcGIS allows geographical information to be published, so that they can have access and used by anyone. The system is available everywhere using web browsers, mobile devices such as smartphones and desktop computers [58].

3 METHODOLOGY

With load profile data (kWh) separately for every settlement in the AOI, acquired by the Hellenic Electricity Distribution Network Operator (HEDNO) between period 2014-2016, calculation procedure of the project's viability includes three stages:

- Manual calculations using excel document for every aspect of the study, with the purpose of the comparison of the results and agreement of GIS systems
- Energy, economic and environmental performance of the system, using RETScreen 4 software
- Wind and solar potential mapping output, using ArcMap GIS software

Figure 6: Specular view of Vorias village (AOI) from Google Earth.

3.1 Project's viability through manual calculations in excel

Sizing of photovoltaic:

For the calculation of the power of the PV modules are taken as data:

- The total days for each month of the year
- The percentage of daytime hours per 24-hour period (t_d)
- The total monthly solar energy, H_t (kWh/m^2)
- The monthly average ambient temperature

3.1.1 Intensity of solar radiation, G_t

$$G_t = \frac{H_t}{t_m}$$

Equation 1

Where:

- H_t, the total monthly energy
- t_m, the total hours for each month

3.1.2 Reason performance, PV overall efficiency

$$PR_S = PR_{opt} * PR_{NIT} * PR_T * n_{trans}$$

Equation 2

Where:

- PR_{opt}, the reason performance of optical losses (reflections, range radiation, shading)
- PR_{NIT}, the reason performance referred to the non-coincidence of the PV point operation with the point of maximum power of the PV array
- PR_T, the reason performance due to the modulation of the temperature of the cell from the reference temperature at STC conditions (25°C)
- n_{trans}, transfer performance due to ohmic losses

$$PR_T = 1 + \gamma_{mp} * \left(\theta_{c,wa} - \theta_{STC}\right)$$

Equation 3

Where:

- $\gamma_{mp} = -0{,}0045K^{-1}$, temperature coefficient efficiency for the silicon
- $\theta_{STC} = 25°C$, reference temperature for standard conditions of operation
- $\theta_{c,wa}$, average monthly active temperature of cell

$$\theta_{c,wa} = \theta_{a,D} + F * k(W_{SD}) * G_{t,D}$$

Equation 4

Where:

- $\theta_{a,D}$, monthly average ambient temperature
- F, empirical parameter given by the equation: $F = (2{,}32 * 0{,}0017) * G_{t,D}$
- $G_{t,D}$, average monthly intensity of solar radiation during the day, given by the equation: $G_{t,D} = \frac{G_{t,D}}{t_D}$
- t_D, the percentage of time of the day per 24-hour period
- $k(W_{SD})$, the coefficient of heat transfer via solar radiation to the PV module:

$$k(W_{SD}) = \frac{T_1 * e^{B*W_{SD}} + T_2 + \Delta\theta}{G_{STC}}$$

Equation 5

Where:

- $T_1 = 19{,}6°C$
- $T_2 = 11{,}5°C$
- $\Delta\theta = 3°C$
- $B = -0{,}223(m/s)^{-1}$
- W_{SD}, average monthly wind speed in (m/s), given by CRES (www.cres.gr/kape/index.htm)

∗Are empirical constants for C-Si PV panels with successive layers of device: glass plate cell C-Si, insulating coating of Tedlar.

For the conditions of solar radiation of southern Greece, the remaining characteristic values of the reason performance will be:

- $PR_{opt} = 0{,}96$
- $PR_{NIT} = 0{,}95$
- $n_{trans} = 0{,}95$

3.1.3 Power factor of photovoltaic, C_{PV}

$$C_{PV} = PR_S * \frac{G_t}{G_{STC}}$$

Equation 6

Where:

- G_t, the average intensity of solar radiation per 24-hour period (W/m^2)
- G_{STC}, the intensity of solar radiation in the standard operating conditions, equal to 1kW/m^2
- PR_S, the reason performance of PV

3.1.4 Power output from the photovoltaic, P_{PV} (Watts)

$$P_{PV} = C_{PV} * P_{PV,nominative}$$

Equation 7

Where:

- P_{PV}, the generated electric power of the installed photovoltaic
- C_{PV}, the power factor of photovoltaic
- $P_{PV,nominative}$, the nominal power of the PV

3.1.5 Dimensioning of wind energy resources (wind energy)

To serve the needs of the substation in wind energy since this is for domestic and industrial use, it was chosen a wind turbine of vertical-axis type, Ropatec T30 proS (30kW). The selection of vertical-axis wind turbine was based on the following criteria-advantages:

- They produce electrical energy regardless of the direction of the wind
- The tower does not have strong support (foundation), as well as the generator, gearbox and other accessories are placed on the ground
- Have low production cost compared to horizontal-axis wind turbines
- Mechanism for rotation in the direction of the wind is not required

- Easy installation compared to horizontal-axis wind turbines
- Easy transportation compared to horizontal-axis wind turbines
- Low maintenance cost
- Indicated for domestic use in densely populated areas
- Greater safety for humans and birds
- Require less space compared to horizontal-axis wind turbines
- Are suitable for areas with extreme weather conditions such as the sudden gusts of southern winds, which prevail in the island of Crete

3.1.6 Distribution probability density of Weibull

The Weibull distribution describes the wind characteristics in the areas of temperate zone for a height of up to 100m from the ground and expresses the probability of the wind speed V (m/s) to be located in the area, (V-dV)/2 & (V+dV)/2. In particular:

$$P(V) = \left(\frac{k}{C}\right) * \left(\frac{V}{C}\right)^{k-1} * e^{-\left(\frac{V}{C}\right)^{k}}$$

Equation 8

Where:

- The parameters C and k, characterize the probability distribution of the wind, therefore, characterize the wind potential, so are determined by the parameters that define the wind potential
- The parameter C is called the size parameter and determines the position of the curve relative to the horizontal axis. Given $C = 8{,}11\ m/s$
- The parameter k is called the parameter of the shape, or slope and determines the dispersion of prices. Also given $k = 1{,}72$
- V, is the wind speed in meters per every second (m/s)

3.1.7 Wind turbine capacity factor

- The ratio of the actual production of electricity from the W/T in a time interval to the theoretical maximum in the same period of time
- If E_{actual} is the real electric energy that is produced by a W/T in time t and $P_{nominative}$ is the nominal power of the W/T, then the capacity factor $C_{f,W/T}$ will be equal:

$$C_{f,W/T} = \frac{E_{actual}}{P_{nominative} * t}$$

Equation 9

$*C_{f,W/T}$ will change monthly, depending on the total number of days each month.

3.1.8 Economic dimensioning

The economic dimensioning of the project is considered for 20-25 years of operation. The optimal economical sizing of a hybrid power plant, is characterized mainly of two components:

- The optimization of investment indicators of the project
- Minimization of the construction and operation costs of the project

The investment indicators of the project are analyzed in the internal rate of return (IRR), the net present value (NPV), in non-interest-bearing and discounted payback period and return on total investment or on equity (ROI, ROE).

3.1.8.1 Economic indicators

- The net present value (NPV) expresses the cumulative profits of the project in total of years of operation, opened in the present value. Is calculated from the equation:

$$NPV = \sum_{t=1}^{N} (\frac{C_t}{(1+i)^t} - C_0$$

Equation 10

Where:

- N, total years of operation of the project
- C_t, net cash flow during the period *t*
- i, discount rate
- C_0, total initial investment costs

- The return on investment (ROI) expresses the percentage of earnings of the investment per unit of capital investment. Is calculated from the equation:

$$ROI = \frac{\sum_{t=1}^{N}(\frac{C_t}{(1+i)^t})}{C_0}$$

Equation 11

- The performance of the equity capital of the investment (ROE) expresses the percentage gains of the investment per unit of equity investment. Is calculated, respectively:

$$ROE = \frac{\sum_{t=1}^{N}(\frac{C_t}{(1+i)^t})}{Equity}$$

Equation 12

∗Regarding the specific costs of production, it is worth noting that the calculation depends in relation to the cost of fuel-price sales of kWh. In large projects, the specific cost of production can be 0,02-0,05 €/kWh.

∗It is calculated a replacement cost for power inverters, once per 10 years of operation of the substation, referring also to the present value. To the costs of the project is also added the maintenance cost on the NPV of the current year.

- From the individual costs of the installation, occurs the life cost (LCC):

$$LCC = C_{RES} + C_{inst} + C_{maint} + C_{inv} - S$$

Equation 13

Where:

- C_{RES}, the initial cost of equipment provision of RES units
- C_{inst}, the installation cost of the substation
- C_{maint}, the total maintenance cost of the substation
- C_{inv}, the cost of power inverters
- S, the residual value of the substation at the end of it's life. The price of the residual value is usually considered as a small percentage around 10% of the initial value of substation's equipment.

- Supplementary Calculations
- $C_{inst} = (5-8)\% * C_{RES}$
- $C_{maint} = \sum_{t=1}^{N} \frac{a_{maint} * C_{RES}}{(1+i)^t} = C_{inst} * \sum_{t=1}^{N} (1+i)^{-t}$

3.1.9 Environmental footprint

Estimated calculation of greenhouse gases (GHG), (CO_2, NO_X, SO_X), that would have been released without any production from RES units, in the environment. In particular:

- Carbon dioxide (↑CO_2) is estimated approximately: 0,76 kg/kWh
- Sulphur oxide (↑SO_X) is estimated about: 0,009334 kg/kWh
- Nitrogen oxide (↑NO_X) is also calculated: 0,001967 kg/kWh

- Calculation of the quantity of oil that would have consumed the main factory for the production of electricity from conventional thermoelectric units, to produce the energy offered by the RES units of the substation. It is known that 1 kg of oil (common diesel) gives of 42.000 kJ of thermal energy. The 30% will be converted ultimately into electrical energy ((60-70) % losses). Therefore:

$$42.000\ kJ * 30\% = 12.000\ kJ\ per\ 1\ kg\ of\ diesel$$

Equation 14

Also known,

$$1kWh = 3{,}6\ MJ/kWh \Rightarrow$$

Equation 15

$$((energy\ of\ substation)\ in\ (kwh/year) * 3{,}6\ MJ/kWh)/12{,}6MJ = amount\ of\ diesel\ in\ tons/year$$

Equation 16

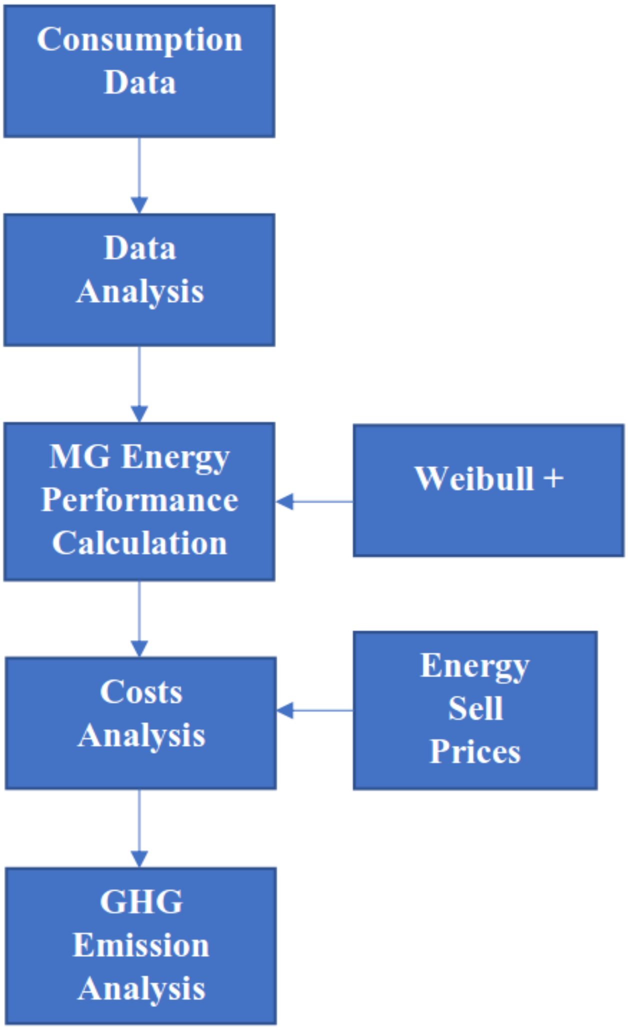


Chart 2: Excel calculation process flowchart.

3.2 Energy, economic and environmental performance of the system, using RETScreen 4 software

The process in RETScreen 4 software includes all of the data used in the excel processing, with a more automated method with the purpose of verification of the results, for both wind and solar PV project feasibility analysis. The procedure includes 6 stages/steps:

1. Settings & Site Conditions
2. Energy Model
3. Cost Analysis
4. Emission Analysis
5. Financial Analysis
6. Sensitivity & Risk Analysis

RETScreen is a clean energy management software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis. RETScreen empowers professionals and decision-makers to rapidly identify, assess and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities and helps find additional energy savings/production opportunities.

Chart 3: RETScreen 4 project research flow chart

3.3 GIS analysis process

- In wind and solar potential map producing process, it is crucial to obtain meteorological data (speed in m/s and direction of wind, air temperature in °C, solar radiation in kWh/m^2, etc.).
- Data obtained by RETScreen 4 software and Hellenic National Meteorological Service (HNMS) from nearby stations of the area of interest (AOI), where data was available, gathered and processed in excel document.
- ArcGIS (ArcMap) software was used in mapping process under linear and logistic functions in three major forms: Raster (pixels), that contains specific desired information according to geographic location of AOI, Vector, which is digitized geometric figures (points, lines and polygons) and three-dimensional Digital Elevation Models (DEM), containing information for geomorphology (relief, slopes, etc.) and elevation, with the aim of meeting the needs of engineering and infrastructure design.

3.3.1 Wind resource mapping

The purpose at this stage is the coordination of the characteristics of the meteorological conditions of the wind prevailing in the area, which were acquired by the HNMS and RETScreen 4 database. The gained knowledge of the wind is the central part in this analysis, as it is used in empirical formulas for making a digitized form of wind distribution map, with parallel processing of digital elevation model and light detection and ranging (LiDAR) forms of data in spatial interpolation methods. The method can be implemented in both raster and vector GIS environments. In this case a raster GIS was selected, considering it’s wider mathematical capabilities:

3.3.1.1 Wind speed at different heights

$$\frac{\bar{V}_Z}{\bar{V}_G} = \left[\frac{\bar{Z}}{Z_G}\right]^a$$

Equation 17

Where:

- $\bar{V}_Z$, the known mean wind speed at height Z in (m/s) in the study area

- $\bar{V}_G$, the mean wind speed at height Z_G, which needs to be extrapolated in (m/s)
- Z, the height for which the wind speed $\bar{V}_Z$ is computed in (m)
- Z_G, the height at which $\bar{V}_G$ is first observed in the same terrain
- a, an empirical exponent, which depends on the roughness of the surface

3.3.1.2 Buffered zones of wind distribution

Formulas for the slipstream calculation:

- $$x_{new} = x_{old} + \left(\left(\frac{height}{1° \ latitude \ in \ meters}\right) * f + \left(\sqrt{\frac{area}{\pi}}\right)\right) * \sin\left(wind \ direction * \frac{\pi}{180}\right)$$

Equation 18

- $$y_{new} = y_{old} + \left(\left(\frac{height}{1° \ longitude \ in \ meters}\right) * f + \left(\sqrt{\frac{area}{\pi}}\right)\right) * \cos\left(wind \ direction * \frac{\pi}{180}\right)$$

Equation 19

Where:

- f, is a factor which is multiplied by the transformed height, depending on the type of obstacle that is in the wind’s way

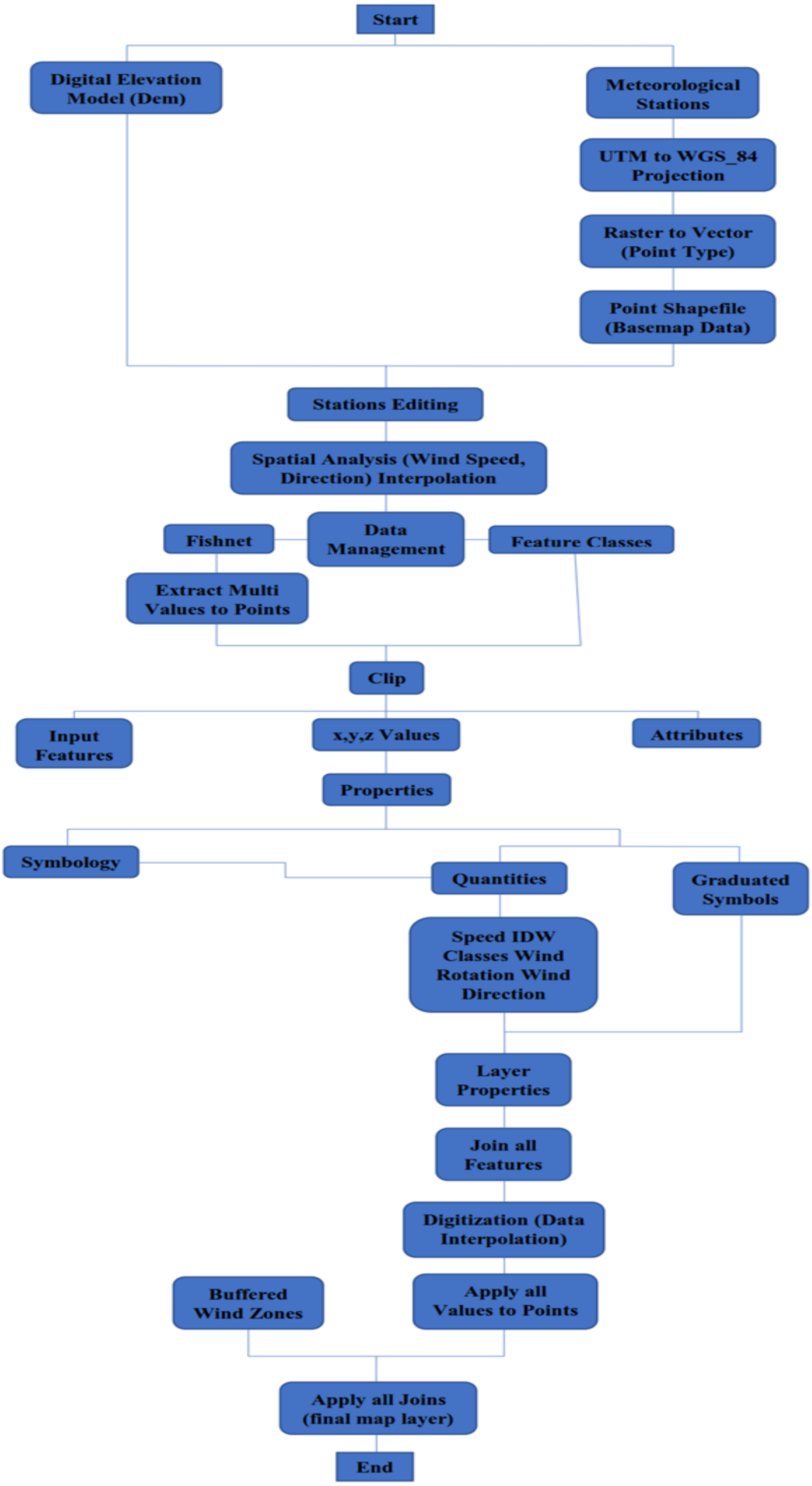


Chart 4: Flowchart for calculating wind potential, especially applied for this study.

3.3.2 Solar photovoltaic resource mapping

The main input data for this analysis are a digital elevation model (DEM) and a digital surface model (DSM). In this case, 2-meter resolution LiDAR provides coordinates for the AOI, the slope and the aspect for each cell, included x,y,z point files for all points, ground points and extracted points (extracted points were selected to create the DSM).

- Using tools in ArcMap 3D Analyst extension, the raw LiDAR extracted point files were processed into terrain rasters that served as the DSM for input into the solar radiation analysis.
- The Esri point file information tool was used to generate a summary of the characteristics for each tile including the number of points, average point spacing, *z* min and *z* max.

Using GIS to model solar radiation, provides a convenient way to generate insolation maps and relate them to other spatial data, in function with the use of satellite imagery which allowed the critical evaluation of the total reliability of the project. Considering average incoming solar radiation, the spatial join tool was used to create a final feature class layer containing the average elevation, slope and solar radiation for each rooftop. This tool joins the attributes from one feature (the join feature class) to another (the target feature class), based on their spatial relationship. The join operation was set to join one-to-one with the merge rule specified as average. In conclusion, a number of conditions were determined for the incoming solar radiation:

Input	**Description**	**Value**
DEM	Input elevation parameters from surface raster layers	2-meter Lidar
Latitude	Latitude of site area, units are in decimal degrees	e.g. 19,5° N(Automatic input
Sky Size	Resolution of the viewshed, skymap amd sun map, upward looking representation of the sky	200
Time Configuration	Specifies the time configuration period used for calculating solar radiation within a day, multiple days, special days or whole year	e.g. Year period 2013-2017
Day Interval	Time interval through the year (units: days) used for the calculation of sky sectors for the sun map	(monthly)
Hour Interval	Time interval through the year (units: hours) used for the calculation of sky sectors	.5
Each Interval	Specifies whether to calculate a single total insolation value for all locations or multiple values for the specified hour and day interval	No Interval
Z Units	Number of ground x,y units in one surface	1
Slope Aspect Input Type	How slope and aspect information are derived (either from DEM or Flat surface)	From DEM
Calculations Directions	Number of azimuth directions used when calculating the viewshed (multiples of 8, 32 are default)	32
Zenith Divisions	Number of divisions used to create sky sectors in the sky map, default is 8 divisions relative to zenith	8
Azimuth Divisions	Number of divisions used to create sky sectors in the sky map, dafault is 8 divisions relative to North	8
Diffuse Model Type	Type of diffuse model-uniform sky, the incoming diffuse radiation is same from all directions or sky-standard overcast diffuse model varies with zenith angle	Standard Overcast Sky
Diffuse Proportion	The proportion of global normal radiation fuse	0,3
Transmittivity	Relates to cloud cover fraction of radiation that passes through the atmosphere averaged over all wavelengths, values range from 0-1, 0 is no transmission and 1 is all transmission, .5 for a generally clear sky	.5

Table 2: Solar conditions, data set for calculating solar radiation.

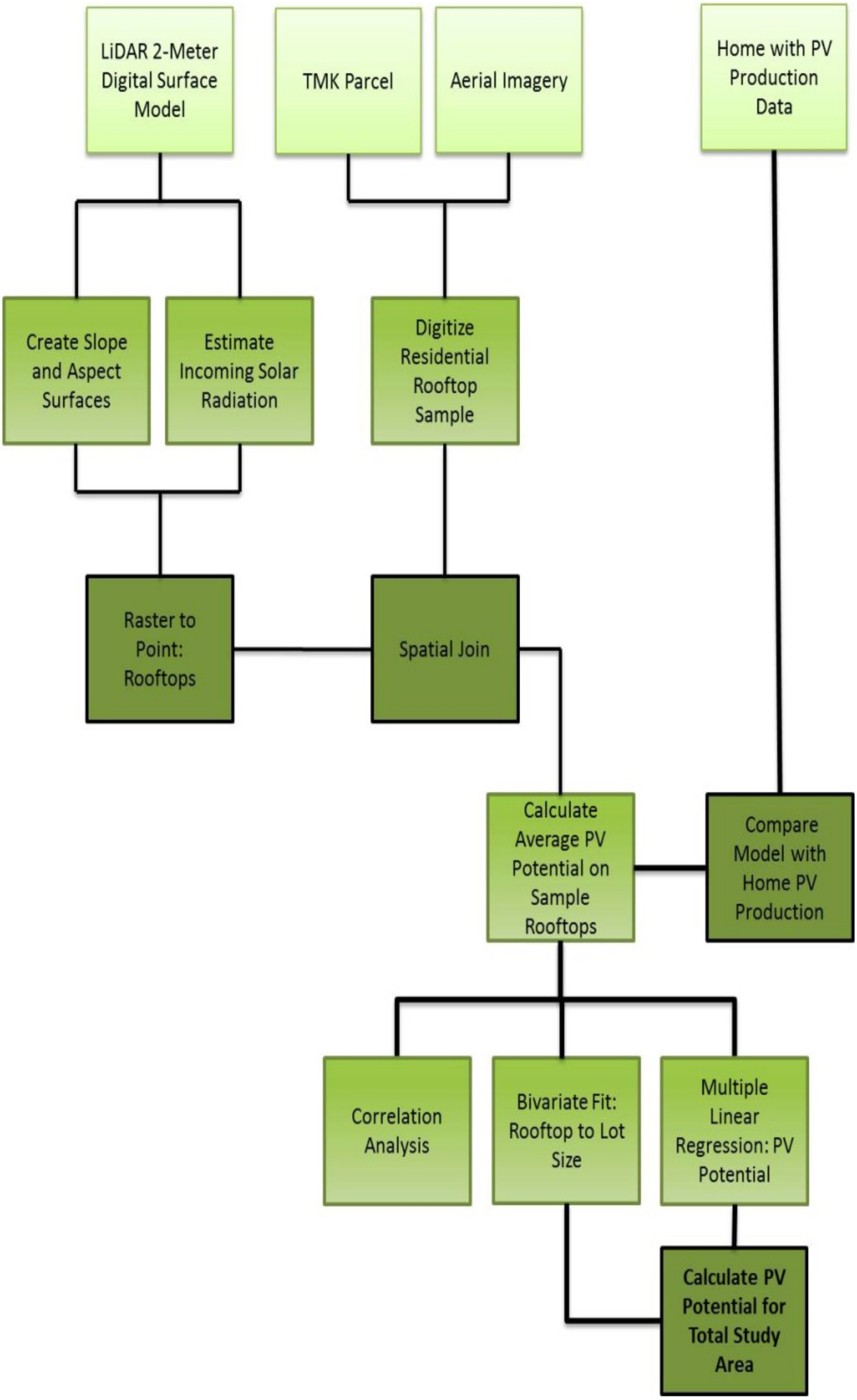


Chart 5: Flowchart for calculating PV potential on the rooftops in the AOI [59].

4 RESULTS

4.1 Results export procedure in excel

4.1.1 Consumption data/data type analysis

P.S.N	INVOICE	FROM	TO	DAYS	ΩXB (kWh)
HOUSE 1	21	12/4/2016	12/12/2016	244	10143
HOUSE 1	21	10/8/2015	12/4/2016	246	10136
HOUSE 1	21	15/4/2015	10/8/2015	117	3317
HOUSE 1	21	12/12/2014	15/4/2015	124	6114
HOUSE 2	33	24/6/2016	20/10/2016	118	0
HOUSE 2	33	20/10/2015	24/6/2016	248	0
HOUSE 2	33	22/6/2015	20/10/2015	120	0
HOUSE 2	33	22/6/2014	22/6/2015	365	0
HOUSE 3	54	10/8/2016	12/12/2016	124	2598
HOUSE 3	54	12/4/2016	10/8/2016	120	2089
HOUSE 3	54	14/12/2015	12/4/2016	120	2748
HOUSE 3	54	10/8/2015	14/12/2015	126	5200
HOUSE 3	54	15/4/2015	10/8/2015	117	2601
HOUSE 3	54	12/12/2014	15/4/2015	124	1298
HOUSE 4	10	10/8/2016	12/12/2016	124	1171
HOUSE 4	10	12/4/2016	10/8/2016	120	1266
HOUSE 4	10	10/8/2015	12/4/2016	246	3180
HOUSE 4	10	12/12/2014	10/8/2015	241	3307
HOUSE 5	10	10/8/2016	12/12/2016	124	350
HOUSE 5	10	12/4/2016	10/8/2016	120	766
HOUSE 5	10	14/12/2015	12/4/2016	120	1518
HOUSE 5	10	10/8/2015	14/12/2015	126	1849
HOUSE 5	10	15/4/2015	10/8/2015	117	2358
HOUSE 5	10	12/12/2014	15/4/2015	124	7609
HOUSE 6	10	10/8/2016	12/12/2016	124	1581
HOUSE 6	10	12/4/2016	10/8/2016	120	1601
HOUSE 6	10	14/12/2015	12/4/2016	120	1764
HOUSE 6	10	10/8/2015	14/12/2015	126	1582
HOUSE 6	10	15/4/2015	10/8/2015	117	1529
HOUSE 6	10	12/12/2014	15/4/2015	124	2101
HOUSE 7	11	10/8/2016	12/12/2016	124	625
HOUSE 7	11	12/4/2016	10/8/2016	120	1548
HOUSE 7	11	14/12/2015	12/4/2016	120	2845
HOUSE 7	11	10/8/2015	14/12/2015	126	1713
HOUSE 7	11	15/4/2015	10/8/2015	117	1476
HOUSE 7	11	12/12/2014	15/4/2015	124	5079
HOUSE 8	10	10/8/2016	12/12/2016	124	0
HOUSE 8	10	12/4/2016	10/8/2016	120	0

HOUSE 8	10	14/12/2015	12/4/2016	120	0
HOUSE 8	10	10/8/2015	14/12/2015	126	0
HOUSE 8	10	15/4/2015	10/8/2015	117	0
HOUSE 8	10	12/12/2014	15/4/2015	124	0
HOUSE 9	10	10/8/2016	12/12/2016	124	54
HOUSE 9	10	12/4/2016	10/8/2016	120	400
HOUSE 9	10	14/12/2015	12/4/2016	120	366
HOUSE 9	10	10/8/2015	14/12/2015	126	416
HOUSE 9	10	15/4/2015	10/8/2015	117	346
HOUSE 9	10	12/12/2014	15/4/2015	124	591
HOUSE 10	10	10/8/2016	12/12/2016	124	1312
HOUSE 10	10	12/4/2016	10/8/2016	120	1475
HOUSE 10	10	14/12/2015	12/4/2016	120	2842
HOUSE 10	10	10/8/2015	14/12/2015	126	1804
HOUSE 10	10	15/4/2015	10/8/2015	117	1330
HOUSE 10	10	12/12/2014	15/4/2015	124	2761
HOUSE 11	21	12/4/2016	9/1/2017	272	3099
HOUSE 11	21	14/12/2015	12/4/2016	120	1568
HOUSE 11	21	15/9/2015	14/12/2015	90	1121
HOUSE 11	21	12/12/2014	15/9/2015	277	3256
HOUSE 12	10	10/8/2016	12/12/2016	124	1507
HOUSE 12	10	12/4/2016	10/8/2016	120	1540
HOUSE 12	10	14/12/2015	12/4/2016	120	1383
HOUSE 12	10	10/8/2015	14/12/2015	126	1103
HOUSE 12	10	15/4/2015	10/8/2015	117	850
HOUSE 12	10	12/12/2014	15/4/2015	124	1364
HOUSE 13	11	10/8/2016	12/12/2016	124	4130
HOUSE 13	11	12/4/2016	10/8/2016	120	5214
HOUSE 13	11	14/12/2015	12/4/2016	120	3617
HOUSE 13	11	10/8/2015	14/12/2015	126	4191
HOUSE 13	11	15/4/2015	10/8/2015	117	4227
HOUSE 13	11	12/12/2014	15/4/2015	124	5804
HOUSE 14	10	10/8/2016	12/12/2016	124	0
HOUSE 14	10	12/4/2016	10/8/2016	120	0
HOUSE 14	10	14/12/2015	12/4/2016	120	0
HOUSE 14	10	10/8/2015	14/12/2015	126	0
HOUSE 14	10	15/4/2015	10/8/2015	117	0
HOUSE 14	10	12/12/2014	15/4/2015	124	0
HOUSE 15	10	10/8/2016	12/12/2016	124	294
HOUSE 15	10	12/4/2016	10/8/2016	120	288
HOUSE 15	10	14/12/2015	12/4/2016	120	394
HOUSE 15	10	10/8/2015	14/12/2015	126	295
HOUSE 15	10	15/4/2015	10/8/2015	117	203
HOUSE 15	10	12/12/2014	15/4/2015	124	407
HOUSE 16	21	10/8/2016	12/12/2016	124	0
HOUSE 16	21	12/4/2016	10/8/2016	120	0
HOUSE 16	21	14/12/2015	12/4/2016	120	0
HOUSE 16	21	10/8/2015	14/12/2015	126	0

HOUSE 16	21	15/4/2015	10/8/2015	117	0
HOUSE 16	21	12/12/2014	15/4/2015	124	0
HOUSE 17	10	12/12/2016	5/1/2017	24	149
HOUSE 17	10	10/8/2016	12/12/2016	124	798
HOUSE 17	10	12/4/2016	10/8/2016	120	1022
HOUSE 17	10	14/12/2015	12/4/2016	120	1082
HOUSE 17	10	10/8/2015	14/12/2015	126	848
HOUSE 17	10	15/4/2015	10/8/2015	117	924
HOUSE 17	10	12/12/2014	15/4/2015	124	1042
HOUSE 17	10	12/12/2016	5/1/2017	24	149
HOUSE 18	11	10/8/2016	12/12/2016	124	1767
HOUSE 18	11	12/4/2016	10/8/2016	120	922
HOUSE 18	11	14/12/2015	12/4/2016	120	1682
HOUSE 18	11	10/8/2015	14/12/2015	126	1140
HOUSE 18	11	15/4/2015	10/8/2015	117	640
HOUSE 18	11	12/12/2014	15/4/2015	124	2239
HOUSE 19	10	10/8/2016	12/12/2016	124	208
HOUSE 19	10	12/4/2016	10/8/2016	120	247
HOUSE 19	10	14/12/2015	12/4/2016	120	335
HOUSE 19	10	10/8/2015	14/12/2015	126	431
HOUSE 19	10	15/4/2015	10/8/2015	117	223
HOUSE 19	10	12/12/2014	15/4/2015	124	106
HOUSE 20	33	25/6/2016	20/10/2016	117	1565
HOUSE 20	33	20/10/2015	25/6/2016	249	2006
HOUSE 20	33	22/6/2015	20/10/2015	120	1860
HOUSE 20	33	22/6/2014	22/6/2015	365	3937
HOUSE 21	33	24/6/2016	20/10/2016	118	0
HOUSE 21	33	20/10/2015	24/6/2016	248	0
HOUSE 21	33	22/6/2015	20/10/2015	120	0
HOUSE 21	33	22/6/2014	22/6/2015	365	0
HOUSE 22	10	10/8/2016	12/12/2016	124	2417
HOUSE 22	10	12/4/2016	10/8/2016	120	2870
HOUSE 22	10	14/12/2015	12/4/2016	120	2823
HOUSE 22	10	10/8/2015	14/12/2015	126	2906
HOUSE 22	10	15/4/2015	10/8/2015	117	513
HOUSE 22	10	12/12/2014	15/4/2015	124	571
HOUSE 23	25	1/2/2017	1/3/2017	28	2320
HOUSE 23	25	1/1/2017	1/2/2017	31	1120
HOUSE 23	25	1/12/2016	1/1/2017	31	680
HOUSE 23	25	1/11/2016	1/12/2016	30	1440
HOUSE 23	25	1/10/2016	1/11/2016	31	3920
HOUSE 23	25	1/9/2016	1/10/2016	30	5840
HOUSE 23	25	1/8/2016	1/9/2016	31	13920
HOUSE 23	25	1/7/2016	1/8/2016	31	4760
HOUSE 23	25	1/6/2016	1/7/2016	30	3800
HOUSE 23	25	1/5/2016	1/6/2016	31	920
HOUSE 23	25	1/4/2016	1/5/2016	30	680
HOUSE 23	25	1/3/2016	1/4/2016	31	720

HOUSE 23	25	1/2/2016	1/3/2016	29	560
HOUSE 23	25	1/1/2016	1/2/2016	31	680
HOUSE 23	25	1/12/2015	1/1/2016	31	2640
HOUSE 23	25	1/11/2015	1/12/2015	30	3120
HOUSE 23	25	1/10/2015	1/11/2015	31	4480
HOUSE 23	25	1/9/2015	1/10/2015	30	8240
HOUSE 23	25	1/8/2015	1/9/2015	31	7040
HOUSE 23	25	1/7/2015	1/8/2015	31	5080
HOUSE 23	25	1/6/2015	1/7/2015	30	520
HOUSE 23	25	1/5/2015	1/6/2015	31	560
HOUSE 23	25	1/4/2015	1/5/2015	30	440
HOUSE 23	25	1/3/2015	1/4/2015	31	520
HOUSE 23	25	1/2/2015	1/3/2015	28	360
HOUSE 23	25	1/1/2015	1/2/2015	31	360
HOUSE 23	25	1/12/2014	1/1/2015	31	2000
HOUSE 24	33	1/2/2017	1/3/2017	28	2640
HOUSE 24	33	1/1/2017	1/2/2017	31	3200
HOUSE 24	33	1/12/2016	1/1/2017	31	2880
HOUSE 24	33	1/11/2016	1/12/2016	30	3040
HOUSE 24	33	1/10/2016	1/11/2016	31	11360
HOUSE 24	33	1/9/2016	1/10/2016	30	14880
HOUSE 24	33	1/8/2016	1/9/2016	31	24240
HOUSE 24	33	1/7/2016	1/8/2016	31	27040
HOUSE 24	33	1/6/2016	1/7/2016	30	27520
HOUSE 24	33	1/5/2016	1/6/2016	31	9200
HOUSE 24	33	1/4/2016	1/5/2016	30	6080
HOUSE 24	33	1/3/2016	1/4/2016	31	3120
HOUSE 24	33	1/2/2016	1/3/2016	29	3840
HOUSE 24	33	1/1/2016	1/2/2016	31	2800
HOUSE 24	33	1/12/2015	1/1/2016	31	2400
HOUSE 24	33	1/11/2015	1/12/2015	30	1920
HOUSE 24	33	1/10/2015	1/11/2015	31	2320
HOUSE 24	33	1/9/2015	1/10/2015	30	5520
HOUSE 24	33	1/8/2015	1/9/2015	31	11680
HOUSE 24	33	1/7/2015	1/8/2015	31	32320
HOUSE 24	33	1/6/2015	1/7/2015	30	18240
HOUSE 24	33	1/5/2015	1/6/2015	31	13440
HOUSE 24	33	1/4/2015	1/5/2015	30	3040
HOUSE 24	33	1/3/2015	1/4/2015	31	2800
HOUSE 24	33	1/2/2015	1/3/2015	28	4960
HOUSE 24	33	1/1/2015	1/2/2015	31	5520
HOUSE 24	33	1/12/2014	1/1/2015	31	4880

Table 3: Detailed table of electricity consumption for each house in the village of Vorias, with the contents of the type of consumption on the basis of invoice, the amount of total consumption by date and total days and the total consumption for this period of time in kwh, as received from the HEDNO service.

Invoice	**Type of Consumption**	**Total kWh/type**
10	Household 1	143792
11	Household 2	87242
21	Professional-Industrial 1	152614
25	Professional-Industrial 2	76720
54	Professional-Industrial 3	16534
33	Irrigation	487926

Year	**kWh/yr.**	**Hours/Year**	8765
2014	494040		
2015	502613		
2016	408596		
Average	468416		

Table 4: Pivot table of consumption of electricity, separated on the basis of invoice.

4.1.2 Analysis of the calculation of the production of energy from the study's microgrid.

$\kappa_{(wsd)}$ (K*m^2/W)	0,025
G_{STC} (kW/m^2)	1
θ_{STC} (°C)	25
γ_{mp} (K^{-1})	-0,0045
T_1 (°C)	19,6
T_2 (°C)	11,5
$\Delta\theta$ (°C)	3
B (m/s)$^{-1}$	-0,223
PR_{opt}	0,96
PR_{NIT}	0,95
n_{trans}	0,95
$P_{PV,nom}$ (kW)	55
$P_{W/T,nom}$ (kW)	210

Table 5: Table of individual elements for the calculation of the electricity production from RESs.

Months	Days/Month	t_d (%)	H_t (kWh/m^2)	$\theta_{a,D}$ (°C)	G_t (kW/m^2)	$G_{t,D}$ (W/m^2)	F	W_{sd} (m/s)	$k(W_{sd})$ (K*m^2/W
January	31	0,41	115	11,20	0,15	377,00	1,68	9,80	0,0167
February	28	0,45	124	13,60	0,18	410,05	1,62	9,48	0,0136
March	31	0,49	191	13,70	0,26	523,92	1,43	10,08	0,0145
April	30	0,52	198	18,10	0,28	528,85	1,42	8,77	0,0152
May	31	0,55	216	20,20	0,29	527,86	1,42	8,10	0,0157
June	30	0,60	227	25,40	0,32	525,46	1,43	7,93	0,0698
July	31	0,59	232	26,80	0,31	528,52	1,42	7,80	0,2249
August	31	0,58	228	26,50	0,31	528,36	1,42	7,04	0,0156
September	30	0,54	208	23,50	0,29	534,98	1,41	7,59	0,0151
October	31	0,49	181	20,20	0,24	496,49	1,48	7,42	0,0152
November	30	0,45	134	16,00	0,19	413,58	1,62	8,16	0,0147
December	31	0,40	104	12,90	0,14	349,46	1,73	7,90	0,0149
			↑ PVGIS	↑ HNMS				↑ HNMS	

$\theta_{c,wa}$ (°C)	PR_T	PR_S	$C_{W/T}$	$P_{W/T}$ (kW)	C_{PV}	P_{PV} (kW)	Hours/Month	E_{PV} (kWh)	$E_{W/T}$ (kWh)	E_{SS} (kWh)
21,77	1,01	0,8790	0,262148	55,05	0,1359	7,47	744	5559,54	40958,07	46517,61
22,68	1,01	0,8754	0,204367	42,92	0,1615	8,88	672	5970,55	28840,32	34810,86
24,58	1,00	0,8680	0,144521	30,35	0,2228	12,26	744	9118,69	22580,04	31698,73
29,54	0,98	0,8487	0,219825	46,16	0,2334	12,84	720	9242,36	33237,59	42479,95
31,97	0,97	0,8392	0,204644	42,98	0,2436	13,40	744	9970,13	31973,65	41943,79
77,76	0,76	0,6607	0,147574	30,99	0,2083	11,46	720	8248,79	22313,22	30562,01
195,80	0,23	0,2005	0,298815	62,75	0,0625	3,44	744	2558,22	46686,87	49245,10
38,20	0,94	0,8149	0,309732	65,04	0,2497	13,74	744	10219,17	48392,46	58611,64
34,90	0,96	0,8278	0,152366	32,00	0,2391	13,15	720	9470,05	23037,72	32507,77
31,37	0,97	0,8416	0,131768	27,67	0,2047	11,26	744	8377,67	20587,48	28965,14
25,81	1,00	0,8632	0,259812	54,56	0,1607	8,84	720	6361,96	39283,59	45645,54
21,87	1,01	0,8786	0,380764	79,96	0,1228	6,75	744	5025,69	59490,55	64516,23
								90122,82	**417381,56**	**507504,37**
								90,12	417,38	507,50

Table 6: Annual electricity production from the RESs of the study. The selection of the total installed power was taken on the basis of the total consumption of the settlement and includes 55 kW of solar photovoltaic and 210 kW of wind turbine proposed installation, with a total annual power output from both RES's reaching 507.504,37 kWh/year.

4.1.3 Weibull probability distribution

V (m/s)	**P (V) Weibull**	**t** (hours/month)	Ropatec T30 proS (30 kW)	**E** (kWh/V)	Months	**$C_{W/T}$**
1	0,04572	34,018918	0,00	0,00	January	0,2621
2	0,07074	52,630733	0,00	0,00	February	0,2044
3	0,08650	64,358255	0,08	5,15	March	0,1445
4	0,09478	70,517940	0,95	66,99	April	0,2198
5	0,09688	72,082305	2,40	173,00	May	0,2046
6	0,09411	70,019441	4,70	329,09	June	0,1476
7	0,08777	65,297312	7,80	509,32	July	0,2988
8	0,07907	58,829890	12,40	729,49	August	0,3097
9	0,06912	51,423785	18,50	951,34	September	0,1524
10	0,05879	43,742184	25,00	1093,55	October	0,1318
11	0,04878	36,289466	30,00	1088,68	November	0,2598
12	0,03954	29,414103	30,00	882,42	December	0,3808
13	0,03135	23,325047	30,00	699,75		
14	0,02435	18,116207	30,00	543,49		
15	0,01854	13,794105	30,00	413,82		
16	0,01385	10,304864	30,00	309,15		
17	0,01016	7,557983	30,00	226,74		
18	0,00732	5,445508	30,00	163,37		
19	0,00518	3,856226	30,00	115,69		
20	0,00361	2,685195	30,00	80,56		
21	0,00247	1,839310	30,00	55,18		
22	0,00167	1,239821	30,00	37,19		
23	0,00111	0,822683	30,00	24,68		
24	0,00072	0,537534	0,00	0,00		
25	0,00046	0,345941	0,00	0,00		
26	0,00029	0,219346	0,00	0,00		
27	0,00018	0,137055	0,00	0,00		
28	0,00011	0,084409	0,00	0,00		
29	0,00007	0,051251	0,00	0,00		
30	0,00004	0,030685	0,00	0,00		

Weibull C (m/s)	8,11
Weibull k	1,72
Days/Month	31
Hours/Month	744
Ropatec T30 proS Nominal Power (kW)	30
$C_{W/T}$	0,380764
Total Energy Production (kWh)	8498,65

Table 7: Weibull probability distribution, the efficiency of the chosen wind turbine per wind speed as well as the monthly capacity factor of the W/T.

Months	**Weibull C** (m/s)	**Weibull k**
January	6,49	1,62
February	5,68	1,54
March	4,91	1,55
April	5,77	1,43
May	5,79	1,65
June	4,63	1,32
July	6,99	1,67
August	7,15	1,72
September	4,99	1,53
October	4,59	1,44
November	6,39	1,52
December	8,11	1,72

Table 8: Monthly distribution of the parameters C and k, that characterize the probability distribution of the wind.

4.1.4 Special development program

PV SDP (Buildings & Rooftops)	
Month/Year	Sell Price (€/MWh)
February 2013	125
August 2013	125
February 2014	120
August 2014	120
February 2015	115
August 2015	115
February 2016	110
August 2016	110
February 2017	105
August 2017	100
February 2018	95
August 2018	90
February 2019	85
August 2019	80

Table 9: Monthly and annual variation of sales prices of electricity from photovoltaics in €/MWh, on the basis of the special development program.

4.1.5 Costs analysis

Special Costs		
W/T cost Ropatec T30 proS (turbine) (€/turbine)	77000	**7**
W/T cost Ropatec T30 proS (mast) (€/mast)	16500	**7**
PV cost (900 €/kW)	49500	
Total W/T cost (€)	654500	
Transformers total cost (€)	10000	
Transmission wiring (€/meter)	1,5	
Interest rate reduction i	0,08	
Cost of RESs (PV & W/T) C_{RES} (€)	704000	
Maintenance cost C_{maint} (1%*C_{RES}) (€)	7040	
Installation cost $C_{install}$ (8%*C_{RES}) (€)	56320	
Total maintenance cost (20 year) (€)	69119,76	
Life cycle cost L.C.C (€)	839439,76	**755495,78**
Sub-station residual value S (10% of LCC)	83943,976	
PV electricity sales price (€/MWh)	100	←SDP (Buildings & Rooftops)
W/T electricity sales price (€/MWh)	120	←non-interconnected islands
Interest rate of debt	0,05	
Total Installation Cost (€)	770320	
Loan (€)	750000	
Grant on investment (10%) (€)	77032	
Own funds (€)	20000	
Total amount of money (€)	**847032**	
Years of repayment	15	
Net Present Value (NPV)	17037,10	
Internal Rate of Return (IRR)	9,29%	
Return On Investment (ROI)	201,14%	
Return On Equity (ROE)	8518,55%	

Table 10: Summary table of the economic evaluation on the special costs of the project, for the whole of RES and electrical equipment, as well as the individual economic indicators. The total cost of the investment amounts in 704.000 €, approximate.

Year	$1/(1+i)^N$	$C_{maintenance}$ (€)	Annual Revenues (€)	Loan Payment (€)	Depreciation (€)	Taxes (€)	Total Costs (€)	Revenues/Profits (€)	Profits in Present Value (€)
1	0,92593	6518,52	59098,07	72256,72	30800	0	78775,23	-19677,17	-18219,60
2	0,85734	6035,67	59098,07	72256,72	30800	0	78292,38	-19194,31	-16456,03
3	0,79383	5588,58	59098,07	72256,72	30800	0	77845,29	-18747,23	-14882,15
4	0,73503	5174,61	59098,07	72256,72	30800	0	77431,33	-18333,26	-13475,49
5	0,68058	4791,31	59098,07	72256,72	30800	0	77048,02	-17949,95	-12216,44
6	0,63017	4436,39	59098,07	72256,72	30800	0	76693,11	-17595,04	-11087,86
7	0,58349	4107,77	59098,07	72256,72	30800	0	76364,49	-17266,42	-10074,79
8	0,54027	3803,49	59098,07	72256,72	30800	0	76060,21	-16962,14	-9164,12
9	0,50025	3521,75	59098,07	72256,72	30800	0	75778,47	-16680,40	-8344,35
10	0,46319	3260,88	59098,07	72256,72	30800	0	75517,60	-16419,53	-7605,42
11	0,42888	3019,34	59098,07	72256,72	30800	0	75276,05	-16177,98	-6938,46
12	0,39711	2795,68	59098,07	0	30800	2550,239	5345,92	53752,15	21345,72
13	0,36770	2588,59	59098,07	0	30800	2570,948	5159,54	53938,53	19833,08
14	0,34046	2396,85	59098,07	0	30800	2590,122	4986,97	54111,10	18422,72
15	0,31524	2219,30	59098,07	0	30800	2607,877	4827,18	54270,89	17108,45
16	0,29189	2054,91	59098,07	0	30800	2624,316	4679,22	54418,84	15884,34
17	0,27027	1902,69	59098,07	0	30800	2639,538	4542,23	54555,84	14744,75
18	0,25025	1761,75	59098,07	0	30800	2653,632	4415,38	54682,68	13684,29
19	0,23171	1631,25	59098,07	0	30800	2666,682	4297,93	54800,13	12697,85
20	0,21455	1510,42	59098,07	0	30800	2678,765	4189,18	54908,88	11780,60
							Total Profits (€):		**489439,05**
							Total Profits in NPV (€):		**145501,81**

Table 11: Detailed table of revenues/expenses for the total years of operation of the project. The total revenue of the investment amounts in 489.439,05 €, on the basis of selection of the worst possible scenarios and of 20-year of operation.

4.1.6 Project's environmental footprint

GHSs:	**↑CO_2**	**↑SO_X**	**↑NO_X**
Emissions (tons/Year):	**385,70**	**4,74**	**1,00**
E_{RES} (kWh/Year):	507504,37		
↑CO_2: Carbon Dioxide			
↑SO_X: Sulphur Oxide			

↑NO_X: Nitrogen Oxide	

Table 12: Calculating table of GHG in tons/year, that would be emitted into the atmosphere, of the total energy of the project's RESs had produced from conventional thermoelectric diesel units.

1 kg of Oil (kJ) →	42000
30% Losses (MJ/kg) →	12,6
1 kWh (MJ) →	3,6
Total MJoules/Year →	1827016
Tons of Oil/Year →	**145001,2**

Table 13: Table of calculation of the total quantity of conventional diesel oil, saved from the production of project's RESs.

4.1.7 Symbol explanations

Nomenclature	
H_t	Total monthly irradiation per square meter
$\theta_{a,D}$	Monthly average ambient temperature
G_t	Intensity of solar radiation
$G_{t,D}$	Average monthly intensity of solar radiation during the day
F	Empirical parameter given by the equation: F=(2,32-0,0017)*Gt,D
W_{sd}	Monthly average wind speed velocity
$k_{(Wsd)}$	Coefficient of heat transfer through solar radiation to the pv panel
$\theta_{c,wa}$	Average monthly active temperature of cell
PR_T	Reason performance due to the modulation of temperature
PR_S	Reason performance, overall efficiency of PV
$C_{W/T}$	Wind turbine capacity factor
C_{PV}	Photovoltaic capacity factor
$P_{W/T}$	Power output of wind turbine
P_{PV}	Power output of photovoltaic
P_d	Power demand
E_d	Energy demand
E_{PV}	Photovoltaic energy production
$E_{W/T}$	Wind turbine energy production
E_{SS}	Sub-station energy production
G_{STC}	Intensity of solar radiation in standard operating conditions
θ_{STC}	Reference temperature for standard conditions of operation
γ_{mp}	Temperature coefficient efficiency for silicon
PR_{opt}	Reason performance of fiber losses
PR_{NIT}	Reason performance referred to the non-coincidenceof the

	PV point operation with the point of maximum power of the PV array
n_{trans}	Transfer performance due to ohmic losses
$P_{PV,nom}$	Nominal installed power of photovoltaic
$P_{W/T,nom}$	Nominal installed power of wind turbine
t_d	Percentage of time of the day per 24-hour period
HNMS	Hellenic National Meteorological Service
SDP	Special Development Program
P.S.N	Power Supply Nymber

Table 14: Explanation of symbols for the analysis.

4.1.8 Charts

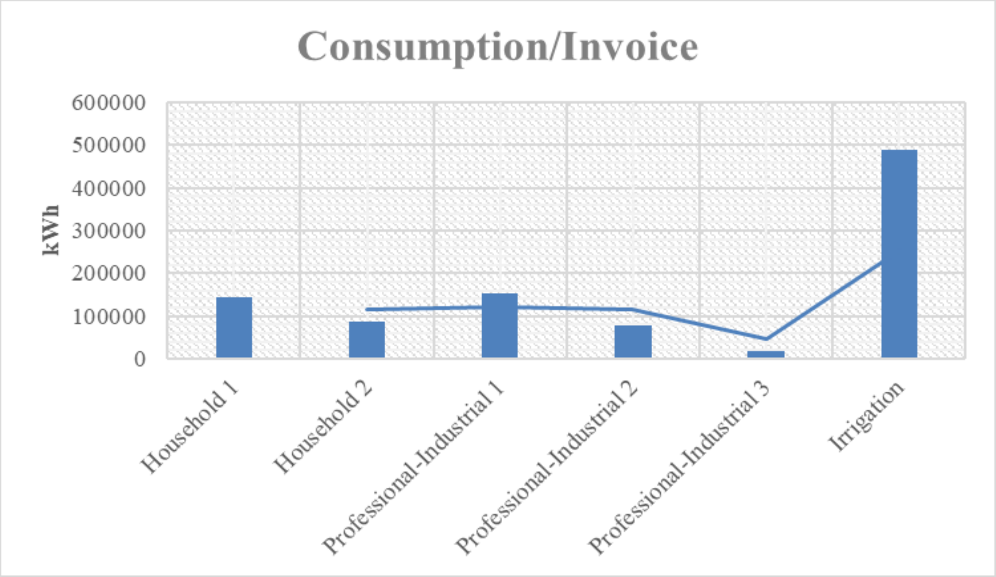


Chart 6: Graph of total energy consumption by category of invoice in kWh, of Vorias's settlement.

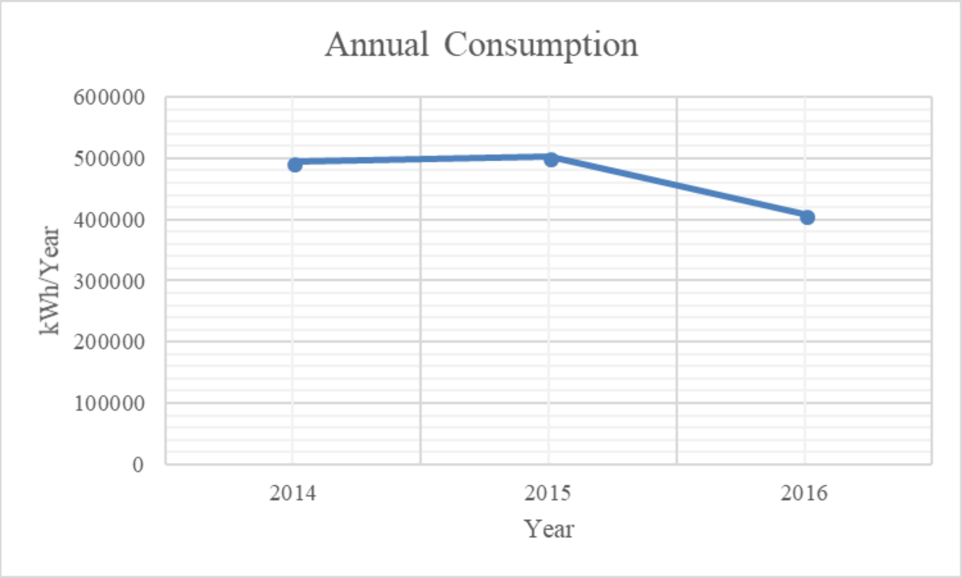


Chart 7: Graph of the annual periodic energy consumption of the Vorias's settlement in kWh/year.

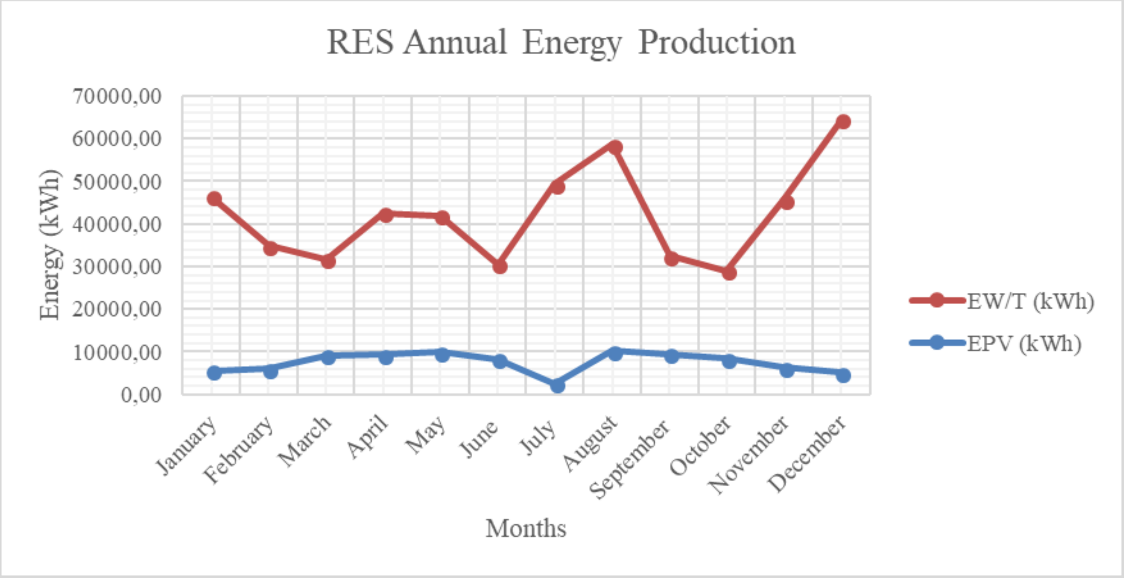


Chart 8: Graph of annual allocation of project's RESs per month, in kWh.

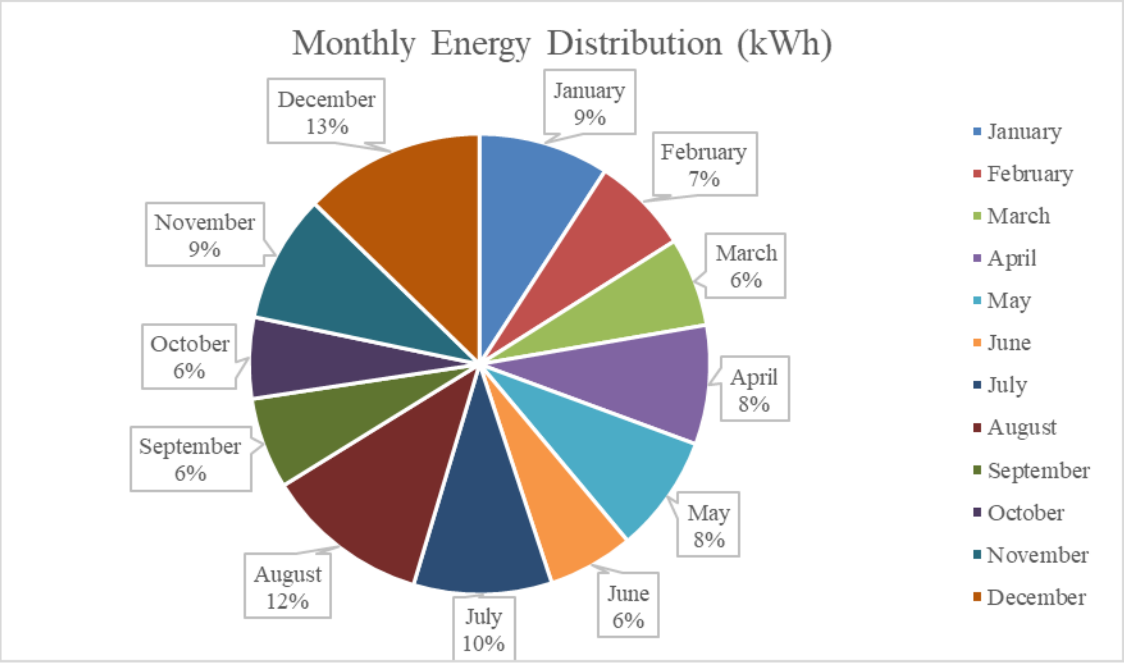


Chart 9: Percentage change of the total energy production per month.

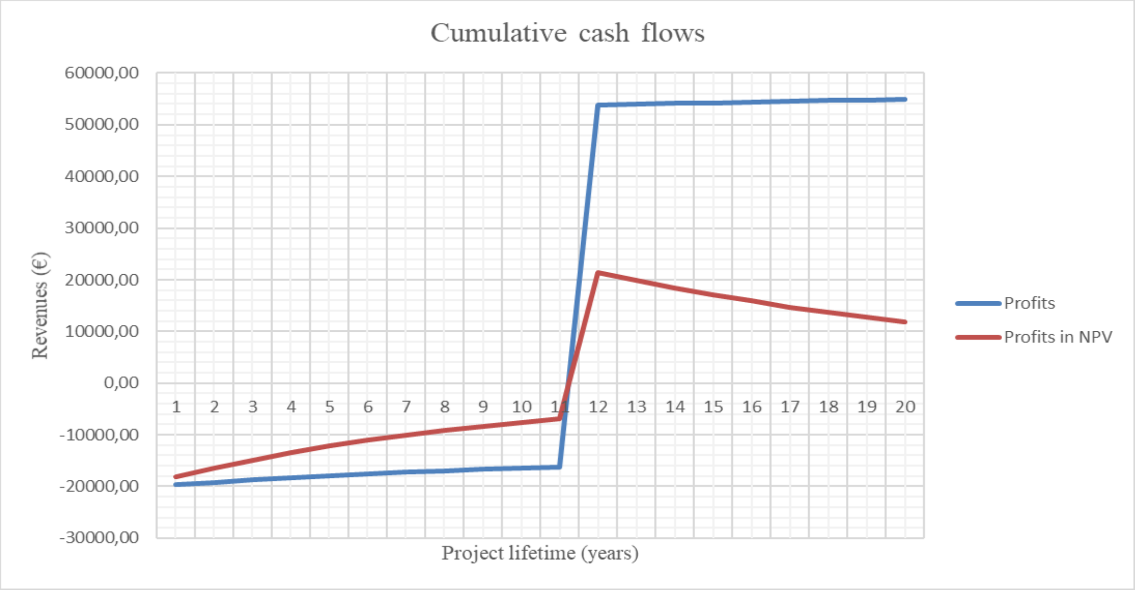


Chart 10: Cumulative cash flows chart for total profits & profits in NPV, that shows in 20-year depth, repayment of the loan and commencement of revenue by the eleventh year of operation of the total RESs of the project.

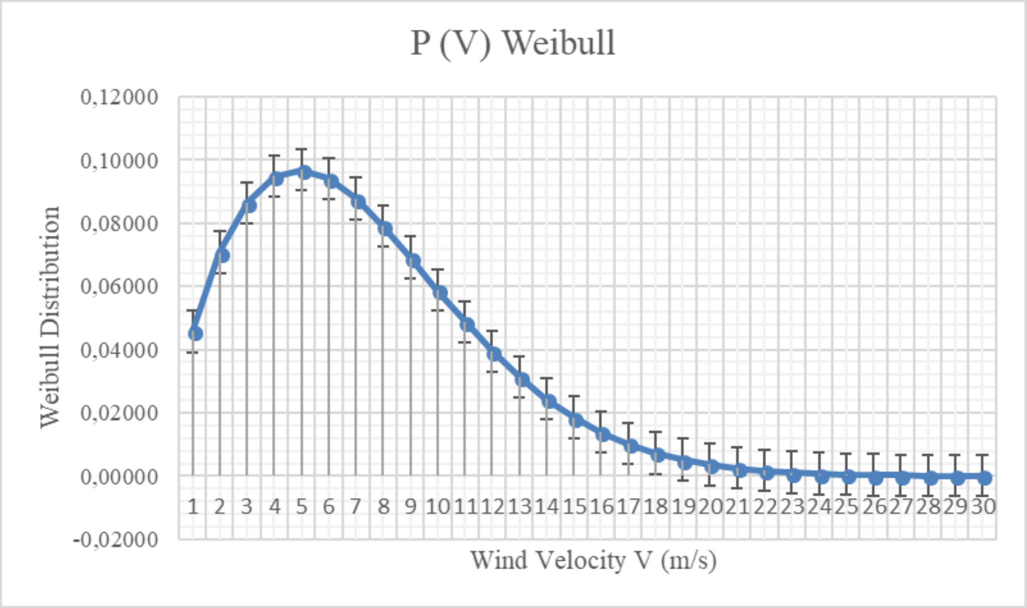


Chart 11: Graph of Weibull probability distribution.

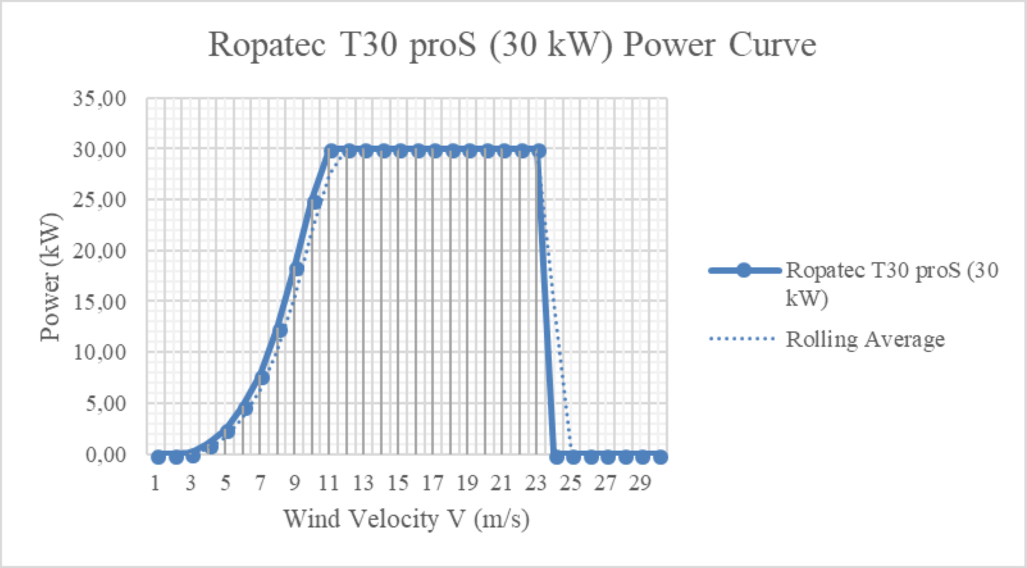


Chart 12: Graph of fluctuation in power curve of the chosen wind turbine, in kW per wind velocity in m/s.

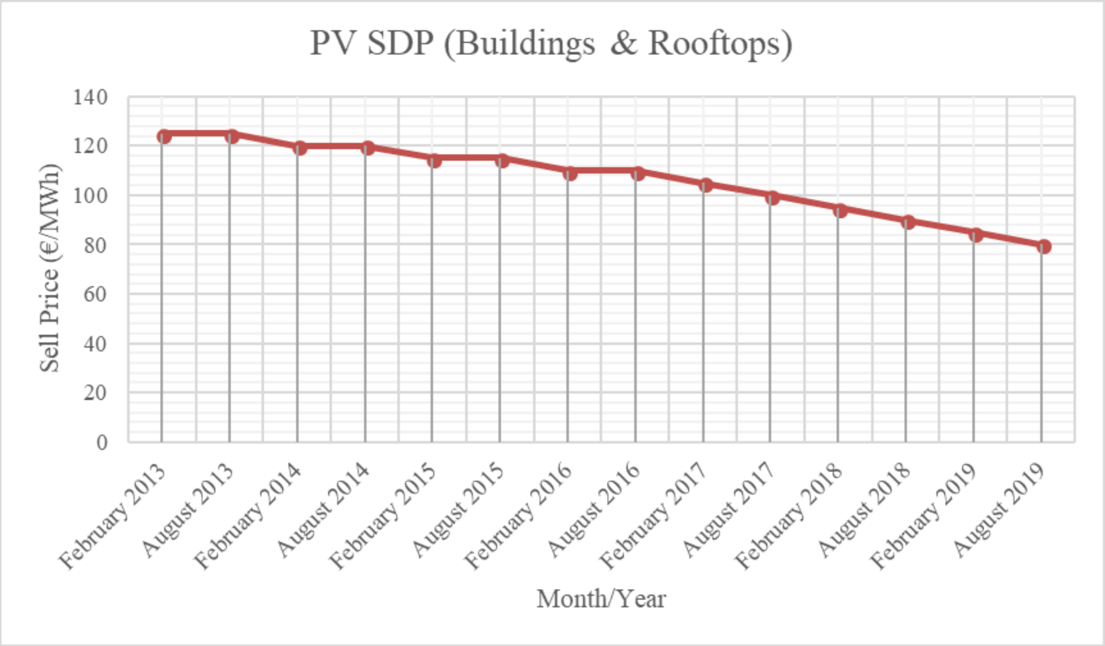


Chart 13: Graph of the annual and monthly fluctuation of the selling price of electricity from photovoltaics, in accordance with the Special Development Program, in €/MWh.

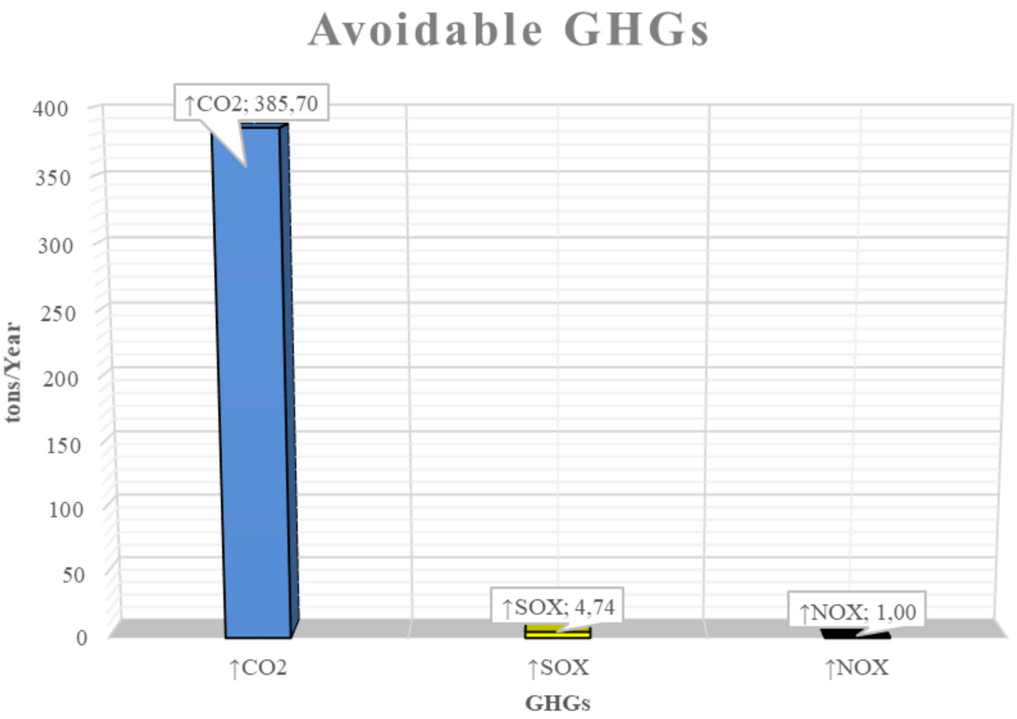
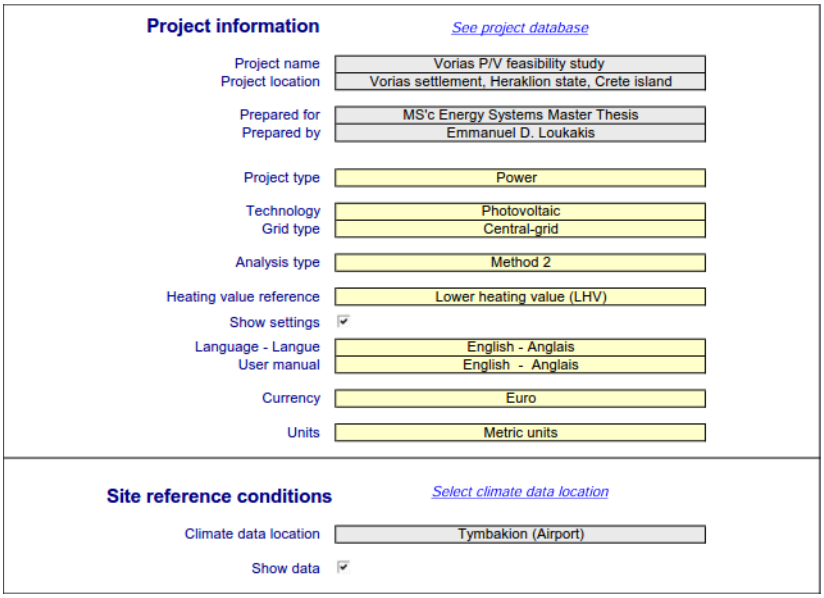


Chart 14: Pivot chart of the greenhouse gases that are avoided, due to the use of RESs of the project, in tons/year.

4.2 RETScreen report analysis

4.2.1 RETScreen photovoltaic feasibility study

4.2.1.1 PV settings & site conditions



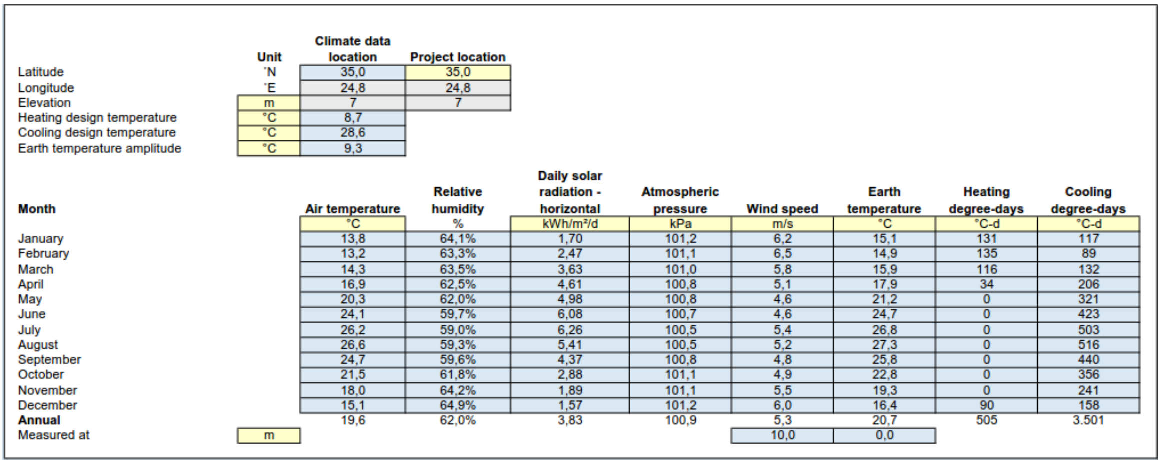
Project information See project database

Project name	Vorias P/V feasibility study
Project location	Vorias settlement, Heraklion state, Crete island
Prepared for	MS'c Energy Systems Master Thesis
Prepared by	Emmanuel D. Loukakis
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☑
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	Euro
Units	Metric units

Site reference conditions Select climate data location

Climate data location	Tymbakion (Airport)
Show data	☑

Table 15: Table of contents of the photovoltaic study.

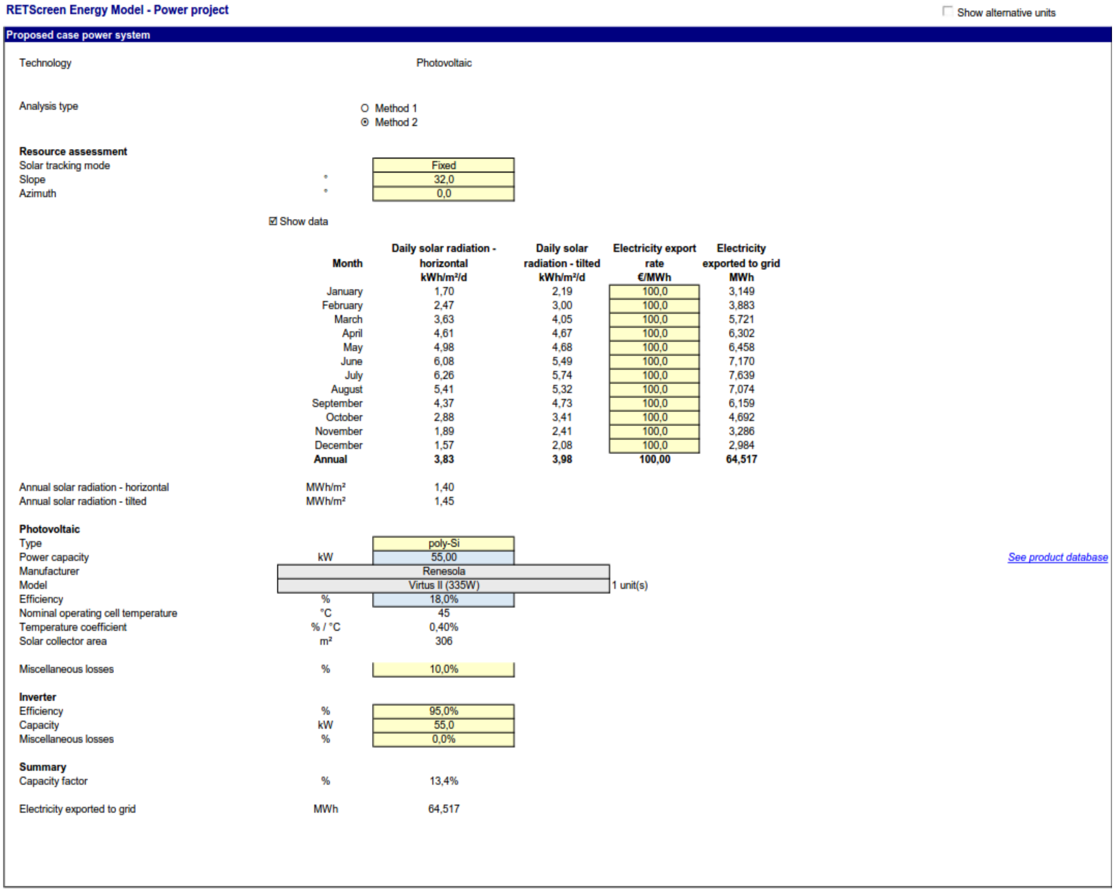


	Unit	Climate data location	Project location
Latitude	°N	35,0	35,0
Longitude	°E	24,8	24,8
Elevation	m	7	7
Heating design temperature	°C	8,7	
Cooling design temperature	°C	28,6	
Earth temperature amplitude	°C	9,3	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		13,8	64,1%	1,70	101,2	6,2	15,1	131	117
February		13,2	63,3%	2,47	101,1	6,5	14,9	135	89
March		14,3	63,5%	3,63	101,0	5,8	15,9	116	132
April		16,9	62,5%	4,61	100,8	5,1	17,9	34	206
May		20,3	62,0%	4,98	100,8	4,6	21,2	0	321
June		24,1	59,7%	6,08	100,7	4,6	24,7	0	423
July		26,2	59,0%	6,26	100,5	5,4	26,8	0	503
August		26,6	59,3%	5,41	100,5	5,2	27,3	0	516
September		24,7	59,6%	4,37	100,8	4,8	25,8	0	440
October		21,5	61,8%	2,88	101,1	4,9	22,8	0	356
November		18,0	64,2%	1,89	101,1	5,5	19,3	0	241
December		15,1	64,9%	1,57	101,2	6,0	16,4	90	158
Annual		19,6	62,0%	3,83	100,9	5,3	20,7	505	3.501
Measured at	m					10,0	0,0		

Table 16: Table of climatic conditions, on the basis of the nearest measurement station that possess the program (Tymbakion airport). The same table applies to the study of wind turbines.

4.2.1.2 PV energy model



RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 ● Method 2
Resource assessment		
Solar tracking mode		Fixed
Slope	°	32,0
Azimuth	°	0,0

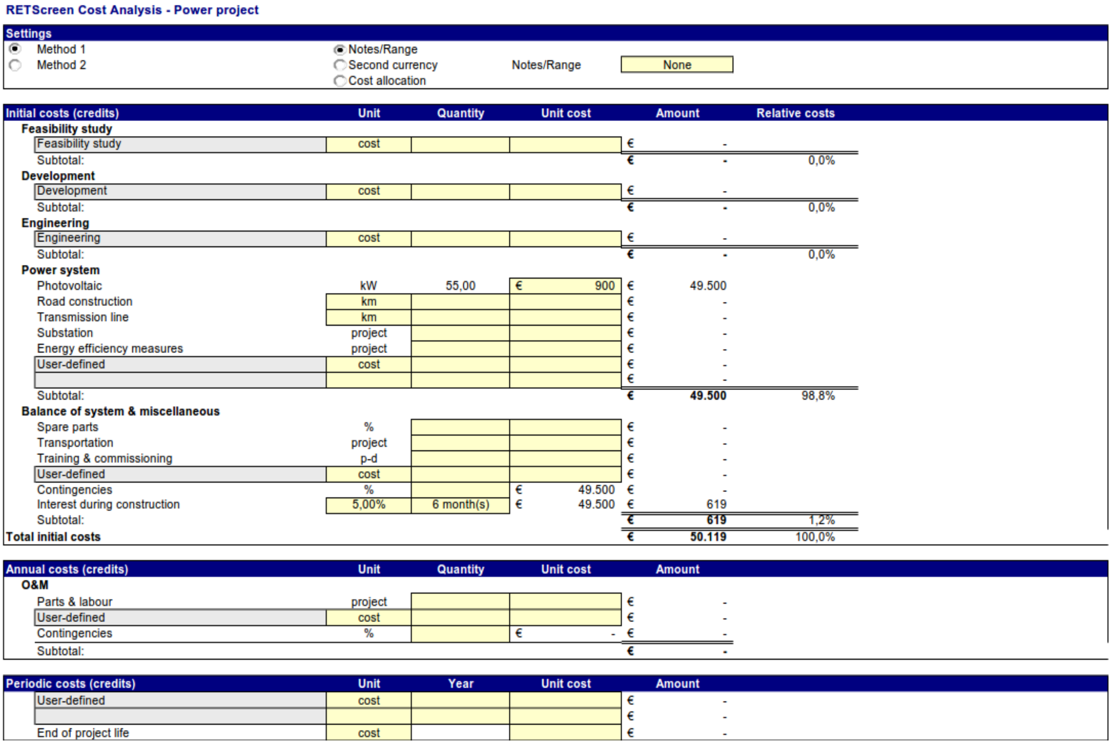
☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate €/MWh	Electricity exported to grid MWh
January	1,70	2,19	100,0	3,149
February	2,47	3,00	100,0	3,883
March	3,63	4,05	100,0	5,721
April	4,61	4,67	100,0	6,302
May	4,98	4,68	100,0	6,458
June	6,08	5,49	100,0	7,170
July	6,26	5,74	100,0	7,639
August	5,41	5,32	100,0	7,074
September	4,37	4,73	100,0	6,159
October	2,88	3,41	100,0	4,692
November	1,89	2,41	100,0	3,286
December	1,57	2,08	100,0	2,984
Annual	**3,83**	**3,98**	**100,00**	**64,517**

Annual solar radiation - horizontal	MWh/m²	1,40
Annual solar radiation - tilted	MWh/m²	1,45
Photovoltaic		
Type		poly-Si
Power capacity	kW	55,00
Manufacturer		Renesola
Model		Virtus II (335W) 1 unit(s)
Efficiency	%	18,0%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0,40%
Solar collector area	m²	306
Miscellaneous losses	%	10,0%
Inverter		
Efficiency	%	95,0%
Capacity	kW	55,0
Miscellaneous losses	%	0,0%
Summary		
Capacity factor	%	13,4%
Electricity exported to grid	MWh	64,517

Table 17: Table of the energy model with the characteristics of the selected photovoltaic panel.

4.2.1.3 PV cost analysis



RETScreen Cost Analysis - Power project

Settings

● Method 1
○ Method 2

● Notes/Range
○ Second currency
○ Cost allocation

Notes/Range: None

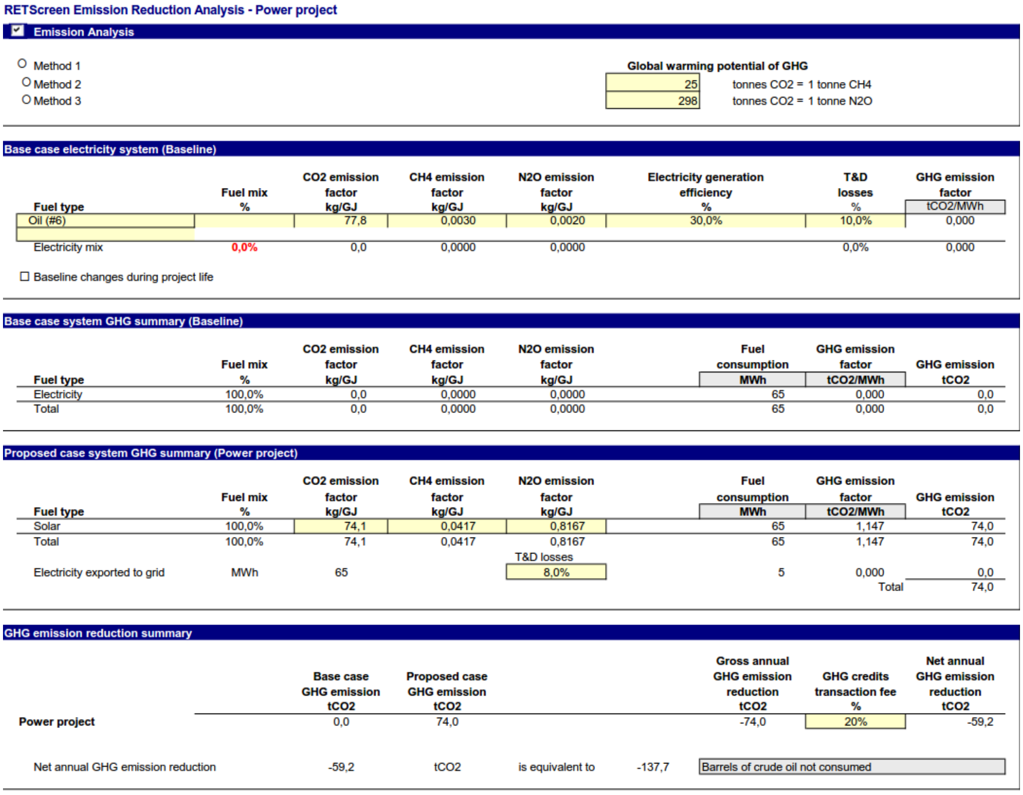
Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost			€ -	
Subtotal:				€ -	0,0%
Development					
Development	cost			€ -	
Subtotal:				€ -	0,0%
Engineering					
Engineering	cost			€ -	
Subtotal:				€ -	0,0%
Power system					
Photovoltaic	kW	55,00	€ 900	€ 49.500	
Road construction	km			€ -	
Transmission line	km			€ -	
Substation	project			€ -	
Energy efficiency measures	project			€ -	
User-defined	cost			€ -	
				€ -	
Subtotal:				€ **49.500**	98,8%
Balance of system & miscellaneous					
Spare parts	%			€ -	
Transportation	project			€ -	
Training & commissioning	p-d			€ -	
User-defined	cost			€ -	
Contingencies	%		€ 49.500	€ -	
Interest during construction	5,00%	6 month(s)	€ 49.500	€ 619	
Subtotal:				€ **619**	1,2%
Total initial costs				€ **50.119**	100,0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project			€ -
User-defined	cost			€ -
Contingencies	%		€ -	€ -
Subtotal:				€ -

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			€ -
				€ -
End of project life	cost			€ -

Table 18: Table of the individual PV installation costs.

4.2.1.4 PV emission analysis



RETScreen Emission Reduction Analysis - Power project

☑ **Emission Analysis**

○ Method 1
○ Method 2
○ Method 3

Global warming potential of GHG

25 tonnes CO2 = 1 tonne CH4
298 tonnes CO2 = 1 tonne N2O

Base case electricity system (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Electricity generation efficiency %	T&D losses %	GHG emission factor tCO2/MWh
Oil (#6)		77,8	0,0030	0,0020	30,0%	10,0%	0,000
Electricity mix	0,0%	0,0	0,0000	0,0000		0,0%	0,000

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100,0%	0,0	0,0000	0,0000	65	0,000	0,0
Total	100,0%	0,0	0,0000	0,0000	65	0,000	0,0

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	100,0%	74,1	0,0417	0,8167	65	1,147	74,0
Total	100,0%	74,1	0,0417	0,8167	65	1,147	74,0
				T&D losses			
Electricity exported to grid	MWh	65		8,0%	5	0,000	0,0
						Total	74,0

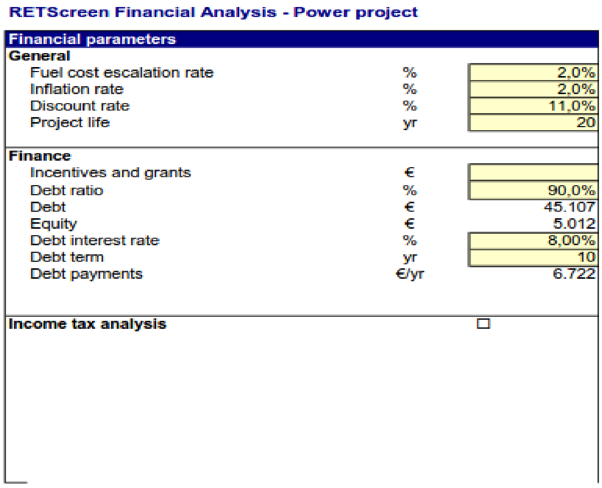
GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	0,0	74,0	-74,0	20%	-59,2

Net annual GHG emission reduction -59,2 tCO2 is equivalent to -137,7 Barrels of crude oil not consumed

Table 19: Analytical table of the greenhouse gases (PV environmental savings)

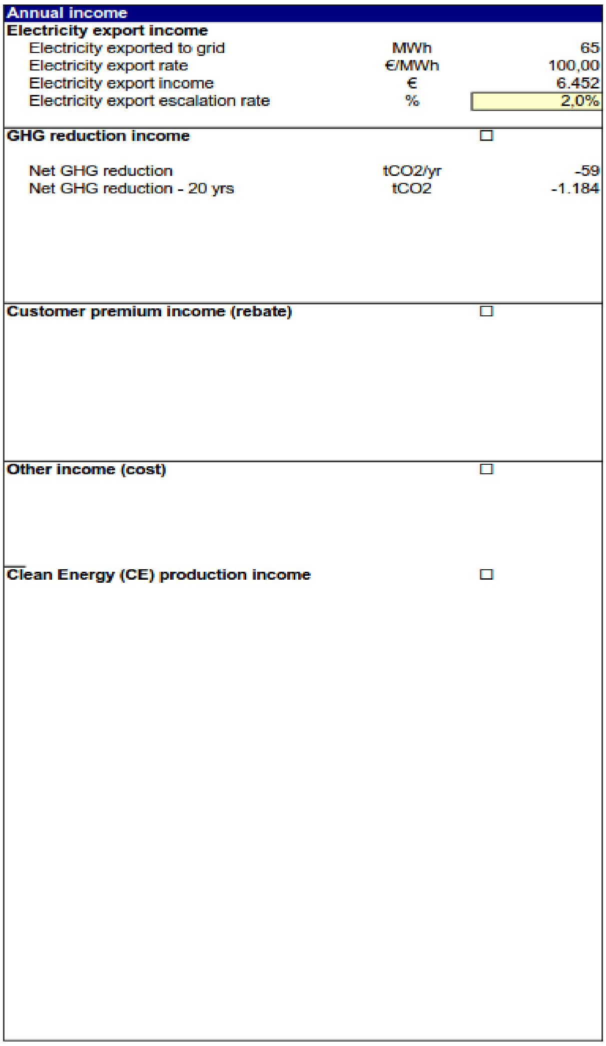
4.2.1.5 PV financial analysis



RETScreen Financial Analysis - Power project

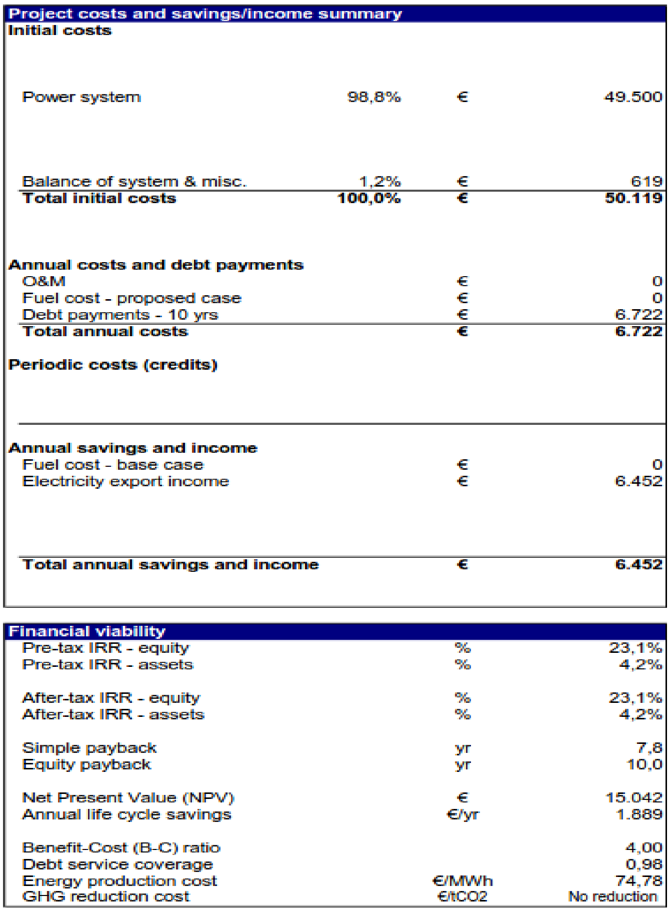
Financial parameters		
General		
Fuel cost escalation rate	%	2,0%
Inflation rate	%	2,0%
Discount rate	%	11,0%
Project life	yr	20
Finance		
Incentives and grants	€	
Debt ratio	%	90,0%
Debt	€	45.107
Equity	€	5.012
Debt interest rate	%	8,00%
Debt term	yr	10
Debt payments	€/yr	6.722
Income tax analysis		☐

Table 20: Table of PV financial parameters.



Annual income		
Electricity export income		
Electricity exported to grid	MWh	65
Electricity export rate	€/MWh	100,00
Electricity export income	€	6.452
Electricity export escalation rate	%	2,0%
GHG reduction income		☐
Net GHG reduction	tCO2/yr	-59
Net GHG reduction - 20 yrs	tCO2	-1.184
Customer premium income (rebate)		☐
Other income (cost)		☐
Clean Energy (CE) production income		☐

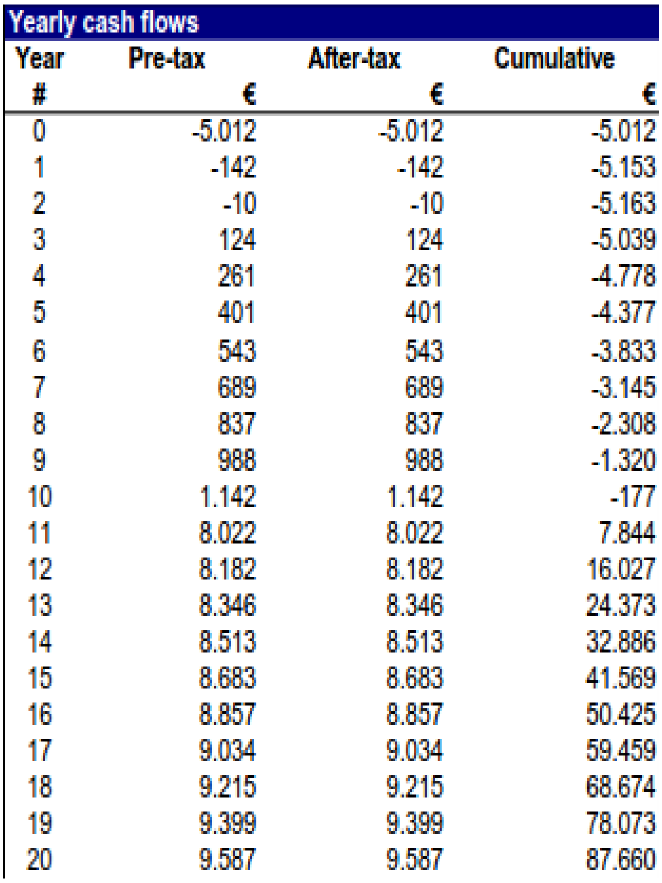
Table 21: Table of PV annual income, based on the selling price of MWh.



Project costs and savings/income summary			
Initial costs			
Power system	98,8%	€	49.500
Balance of system & misc.	1,2%	€	619
Total initial costs	**100,0%**	**€**	**50.119**
Annual costs and debt payments			
O&M		€	0
Fuel cost - proposed case		€	0
Debt payments - 10 yrs		€	6.722
Total annual costs		**€**	**6.722**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		€	0
Electricity export income		€	6.452
Total annual savings and income		**€**	**6.452**

Financial viability		
Pre-tax IRR - equity	%	23,1%
Pre-tax IRR - assets	%	4,2%
After-tax IRR - equity	%	23,1%
After-tax IRR - assets	%	4,2%
Simple payback	yr	7,8
Equity payback	yr	10,0
Net Present Value (NPV)	€	15.042
Annual life cycle savings	€/yr	1.889
Benefit-Cost (B-C) ratio		4,00
Debt service coverage		0,98
Energy production cost	€/MWh	74,78
GHG reduction cost	€/tCO2	No reduction

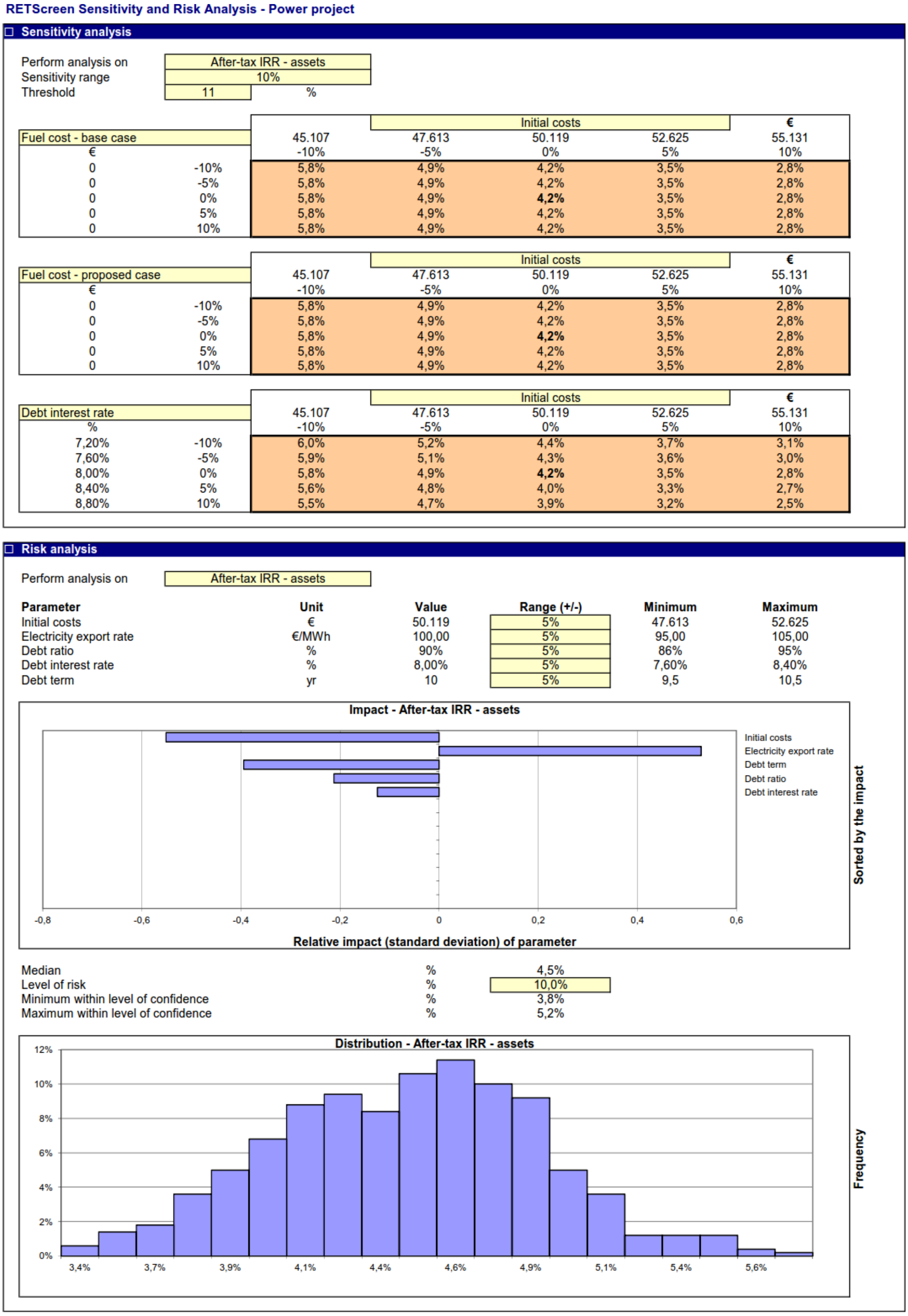
Table 22: Summary table of the economic viability of the PV power project.



Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	€	€	€
0	-5.012	-5.012	-5.012
1	-142	-142	-5.153
2	-10	-10	-5.163
3	124	124	-5.039
4	261	261	-4.778
5	401	401	-4.377
6	543	543	-3.833
7	689	689	-3.145
8	837	837	-2.308
9	988	988	-1.320
10	1.142	1.142	-177
11	8.022	8.022	7.844
12	8.182	8.182	16.027
13	8.346	8.346	24.373
14	8.513	8.513	32.886
15	8.683	8.683	41.569
16	8.857	8.857	50.425
17	9.034	9.034	59.459
18	9.215	9.215	68.674
19	9.399	9.399	78.073
20	9.587	9.587	87.660

Table 23: Table of cash flows at a depth of 20-years for the PV power project.

4.2.1.6 PV sensitivity & risk analysis



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	After-tax IRR - assets
Sensitivity range	10%
Threshold	11 %

Fuel cost - base case		Initial costs				€
		45.107	47.613	50.119	52.625	55.131
€		-10%	-5%	0%	5%	10%
0	-10%	5,8%	4,9%	4,2%	3,5%	2,8%
0	-5%	5,8%	4,9%	4,2%	3,5%	2,8%
0	0%	5,8%	4,9%	**4,2%**	3,5%	2,8%
0	5%	5,8%	4,9%	4,2%	3,5%	2,8%
0	10%	5,8%	4,9%	4,2%	3,5%	2,8%

Fuel cost - proposed case		Initial costs				€
		45.107	47.613	50.119	52.625	55.131
€		-10%	-5%	0%	5%	10%
0	-10%	5,8%	4,9%	4,2%	3,5%	2,8%
0	-5%	5,8%	4,9%	4,2%	3,5%	2,8%
0	0%	5,8%	4,9%	**4,2%**	3,5%	2,8%
0	5%	5,8%	4,9%	4,2%	3,5%	2,8%
0	10%	5,8%	4,9%	4,2%	3,5%	2,8%

Debt interest rate		Initial costs				€
		45.107	47.613	50.119	52.625	55.131
%		-10%	-5%	0%	5%	10%
7,20%	-10%	6,0%	5,2%	4,4%	3,7%	3,1%
7,60%	-5%	5,9%	5,1%	4,3%	3,6%	3,0%
8,00%	0%	5,8%	4,9%	**4,2%**	3,5%	2,8%
8,40%	5%	5,6%	4,8%	4,0%	3,3%	2,7%
8,80%	10%	5,5%	4,7%	3,9%	3,2%	2,5%

☐ **Risk analysis**

Perform analysis on After-tax IRR - assets

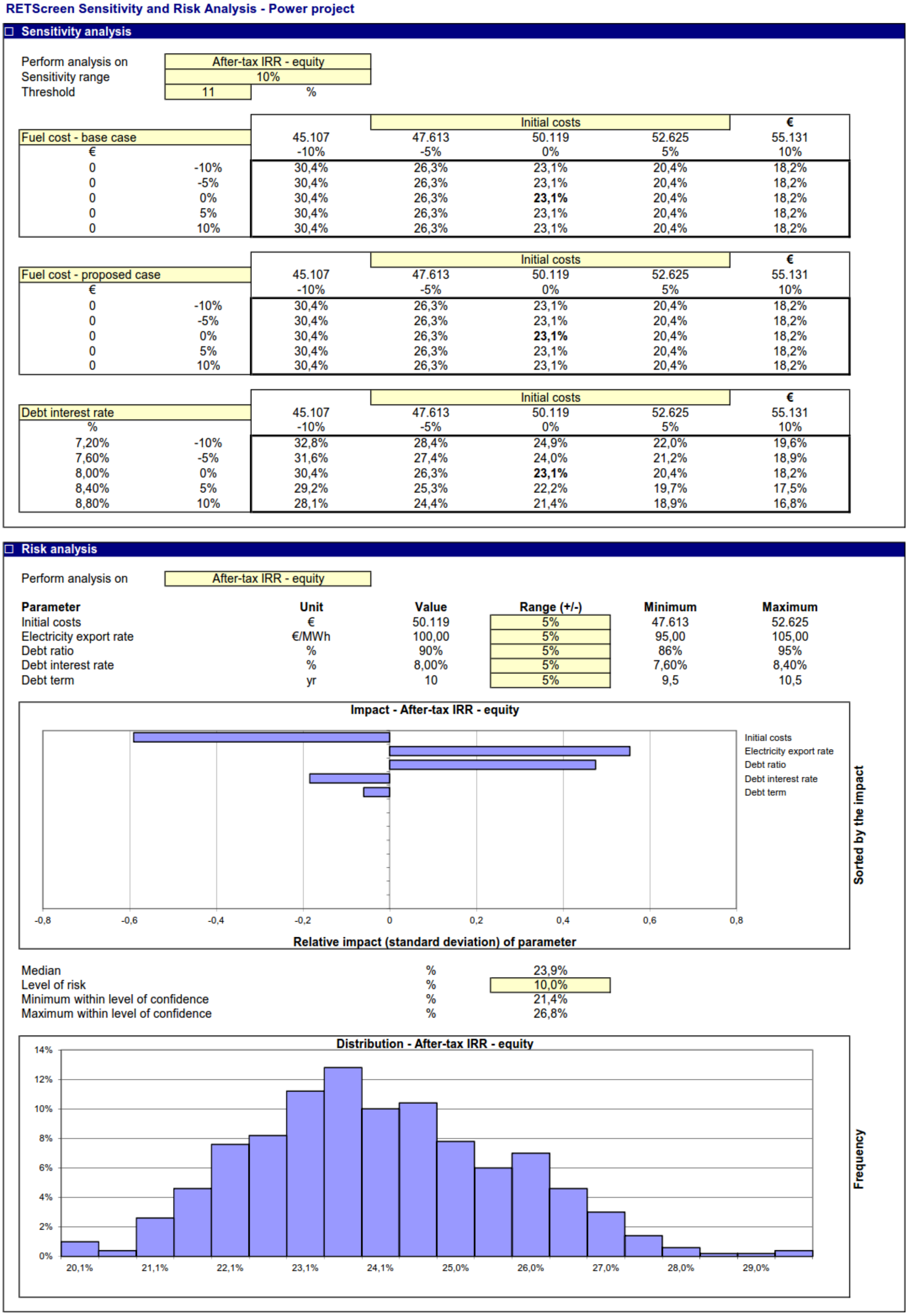
Parameter	**Unit**	**Value**	**Range (+/-)**	**Minimum**	**Maximum**
Initial costs	€	50.119	5%	47.613	52.625
Electricity export rate	€/MWh	100,00	5%	95,00	105,00
Debt ratio	%	90%	5%	86%	95%
Debt interest rate	%	8,00%	5%	7,60%	8,40%
Debt term	yr	10	5%	9,5	10,5

Impact - After-tax IRR - assets

Median	%	4,5%
Level of risk	%	10,0%
Minimum within level of confidence	%	3,8%
Maximum within level of confidence	%	5,2%

Distribution - After-tax IRR - assets

Table 24: PV sensitivity and risk analysis table, after-tax IRR-assets.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	After-tax IRR - equity	
Sensitivity range	10%	
Threshold	11	%

Fuel cost - base case		Initial costs				€
€		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
0	-10%	30,4%	26,3%	23,1%	20,4%	18,2%
0	-5%	30,4%	26,3%	23,1%	20,4%	18,2%
0	0%	30,4%	26,3%	**23,1%**	20,4%	18,2%
0	5%	30,4%	26,3%	23,1%	20,4%	18,2%
0	10%	30,4%	26,3%	23,1%	20,4%	18,2%

Fuel cost - proposed case		Initial costs				€
€		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
0	-10%	30,4%	26,3%	23,1%	20,4%	18,2%
0	-5%	30,4%	26,3%	23,1%	20,4%	18,2%
0	0%	30,4%	26,3%	**23,1%**	20,4%	18,2%
0	5%	30,4%	26,3%	23,1%	20,4%	18,2%
0	10%	30,4%	26,3%	23,1%	20,4%	18,2%

Debt interest rate		Initial costs				€
%		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
7,20%	-10%	32,8%	28,4%	24,9%	22,0%	19,6%
7,60%	-5%	31,6%	27,4%	24,0%	21,2%	18,9%
8,00%	0%	30,4%	26,3%	**23,1%**	20,4%	18,2%
8,40%	5%	29,2%	25,3%	22,2%	19,7%	17,5%
8,80%	10%	28,1%	24,4%	21,4%	18,9%	16,8%

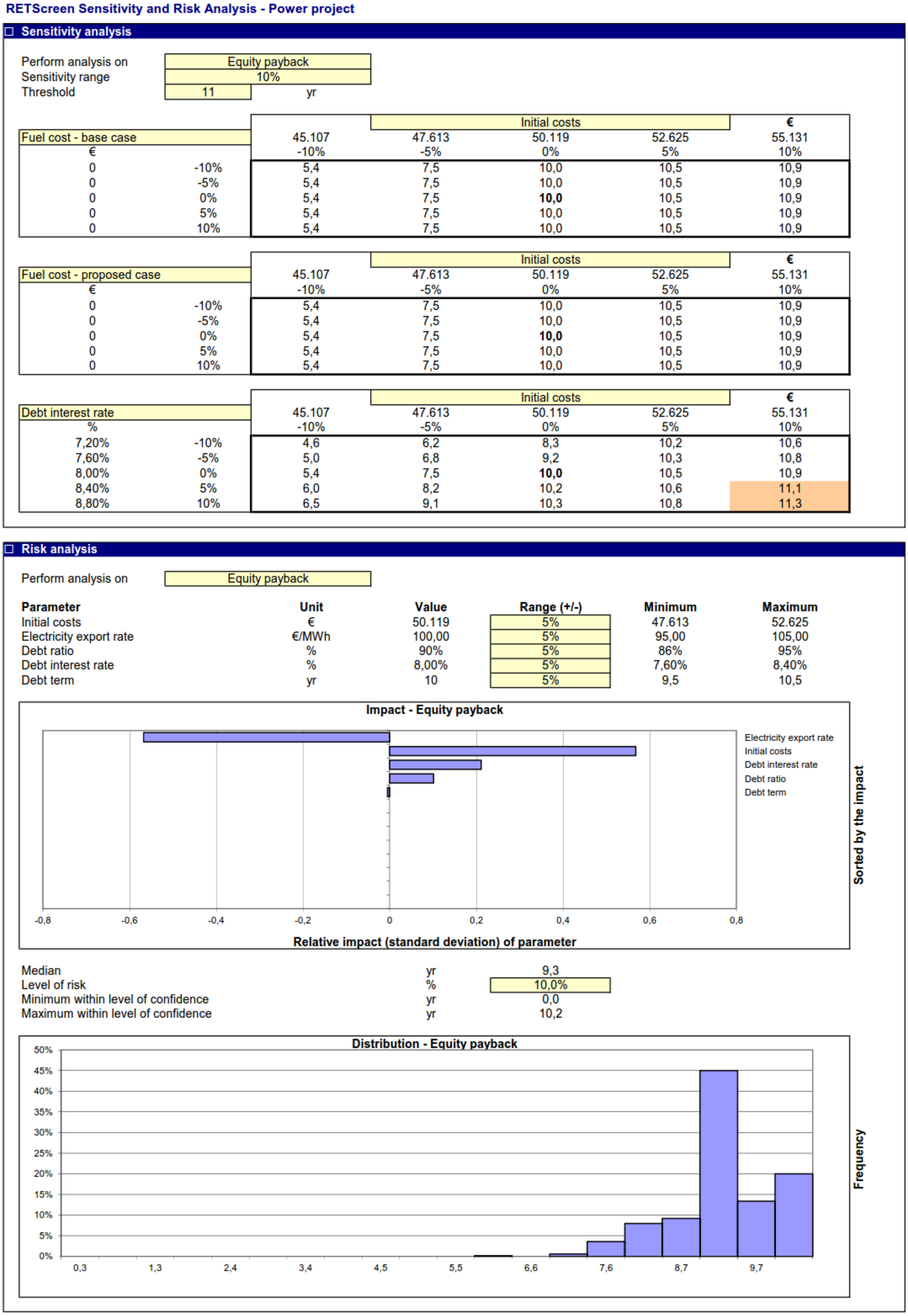
☐ **Risk analysis**

Perform analysis on: After-tax IRR - equity

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	€	50.119	5%	47.613	52.625
Electricity export rate	€/MWh	100,00	5%	95,00	105,00
Debt ratio	%	90%	5%	86%	95%
Debt interest rate	%	8,00%	5%	7,60%	8,40%
Debt term	yr	10	5%	9,5	10,5

Median	%	23,9%
Level of risk	%	10,0%
Minimum within level of confidence	%	21,4%
Maximum within level of confidence	%	26,8%

Table 25: PV sensitivity and risk analysis table, after-tax IRR-equity.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	Equity payback	
Sensitivity range	10%	
Threshold	11	yr

Fuel cost - base case				Initial costs		€
€		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
0	-10%	5,4	7,5	10,0	10,5	10,9
0	-5%	5,4	7,5	10,0	10,5	10,9
0	0%	5,4	7,5	**10,0**	10,5	10,9
0	5%	5,4	7,5	10,0	10,5	10,9
0	10%	5,4	7,5	10,0	10,5	10,9

Fuel cost - proposed case				Initial costs		€
€		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
0	-10%	5,4	7,5	10,0	10,5	10,9
0	-5%	5,4	7,5	10,0	10,5	10,9
0	0%	5,4	7,5	**10,0**	10,5	10,9
0	5%	5,4	7,5	10,0	10,5	10,9
0	10%	5,4	7,5	10,0	10,5	10,9

Debt interest rate				Initial costs		€
%		45.107	47.613	50.119	52.625	55.131
		-10%	-5%	0%	5%	10%
7,20%	-10%	4,6	6,2	8,3	10,2	10,6
7,60%	-5%	5,0	6,8	9,2	10,3	10,8
8,00%	0%	5,4	7,5	**10,0**	10,5	10,9
8,40%	5%	6,0	8,2	10,2	10,6	11,1
8,80%	10%	6,5	9,1	10,3	10,8	11,3

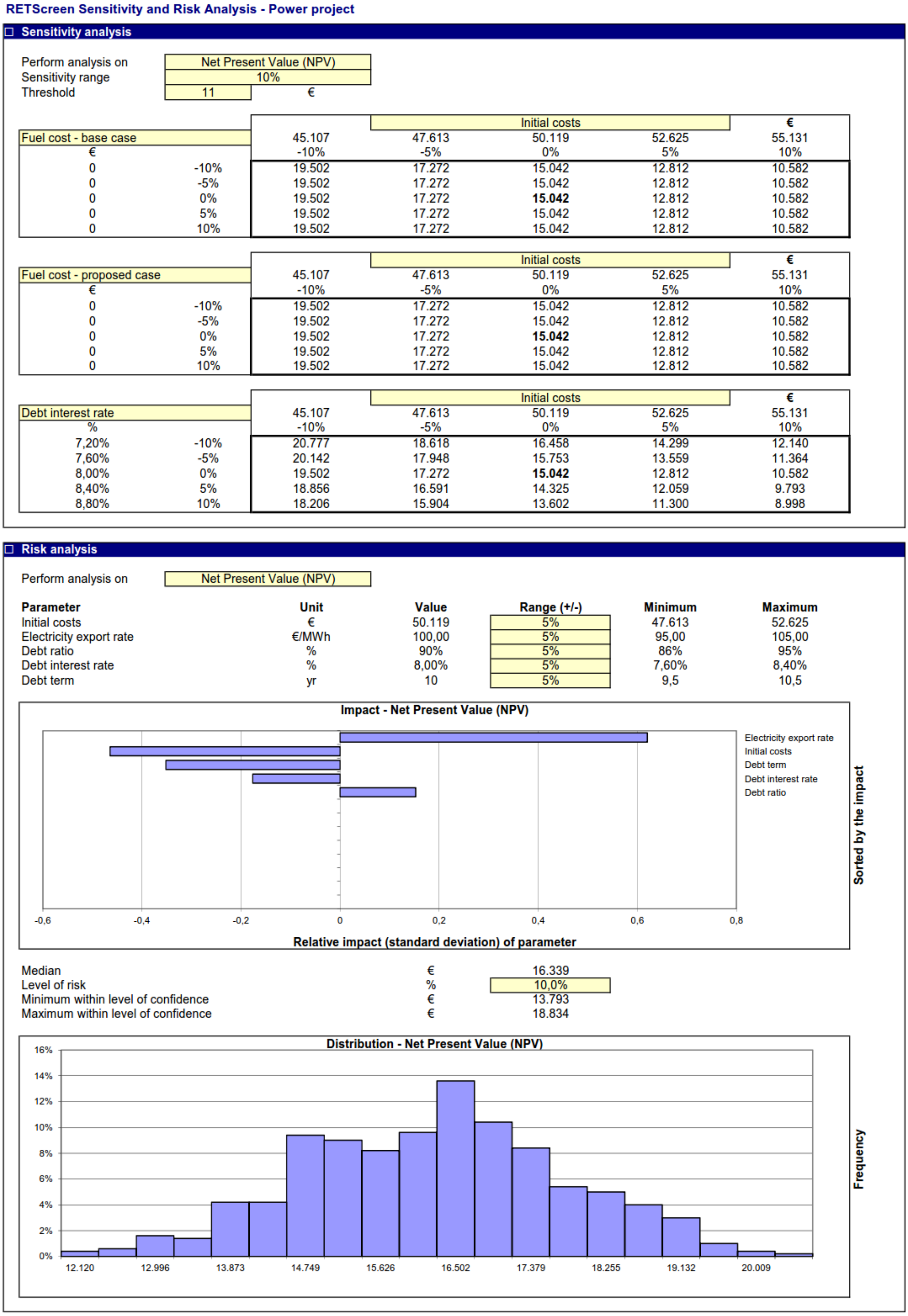
☐ **Risk analysis**

Perform analysis on Equity payback

Parameter	**Unit**	**Value**	**Range (+/-)**	**Minimum**	**Maximum**
Initial costs	€	50.119	5%	47.613	52.625
Electricity export rate	€/MWh	100,00	5%	95,00	105,00
Debt ratio	%	90%	5%	86%	95%
Debt interest rate	%	8,00%	5%	7,60%	8,40%
Debt term	yr	10	5%	9,5	10,5

Median	yr	9,3
Level of risk	%	10,0%
Minimum within level of confidence	yr	0,0
Maximum within level of confidence	yr	10,2

Table 26: PV sensitivity and risk analysis table, on equity payback.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	Net Present Value (NPV)	
Sensitivity range	10%	
Threshold	11	€

			Initial costs			€
Fuel cost - base case		45.107	47.613	50.119	52.625	55.131
€		-10%	-5%	0%	5%	10%
0	-10%	19.502	17.272	15.042	12.812	10.582
0	-5%	19.502	17.272	15.042	12.812	10.582
0	0%	19.502	17.272	**15.042**	12.812	10.582
0	5%	19.502	17.272	15.042	12.812	10.582
0	10%	19.502	17.272	15.042	12.812	10.582

			Initial costs			€
Fuel cost - proposed case		45.107	47.613	50.119	52.625	55.131
€		-10%	-5%	0%	5%	10%
0	-10%	19.502	17.272	15.042	12.812	10.582
0	-5%	19.502	17.272	15.042	12.812	10.582
0	0%	19.502	17.272	**15.042**	12.812	10.582
0	5%	19.502	17.272	15.042	12.812	10.582
0	10%	19.502	17.272	15.042	12.812	10.582

			Initial costs			€
Debt interest rate		45.107	47.613	50.119	52.625	55.131
%		-10%	-5%	0%	5%	10%
7,20%	-10%	20.777	18.618	16.458	14.299	12.140
7,60%	-5%	20.142	17.948	15.753	13.559	11.364
8,00%	0%	19.502	17.272	**15.042**	12.812	10.582
8,40%	5%	18.856	16.591	14.325	12.059	9.793
8,80%	10%	18.206	15.904	13.602	11.300	8.998

☐ **Risk analysis**

Perform analysis on Net Present Value (NPV)

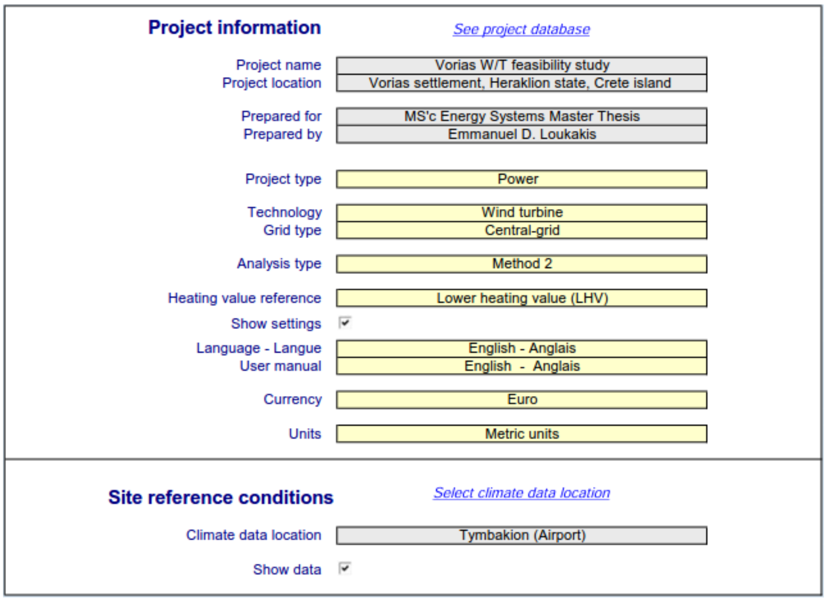
Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	€	50.119	5%	47.613	52.625
Electricity export rate	€/MWh	100,00	5%	95,00	105,00
Debt ratio	%	90%	5%	86%	95%
Debt interest rate	%	8,00%	5%	7,60%	8,40%
Debt term	yr	10	5%	9,5	10,5

Median	€	16.339
Level of risk	%	10,0%
Minimum within level of confidence	€	13.793
Maximum within level of confidence	€	18.834

Table 27: PV sensitivity and risk analysis table, on net present value (NPV).

4.2.2 RETScreen wind turbine feasibility study

4.2.2.1 W/T settings & site conditions



Project information *See project database*

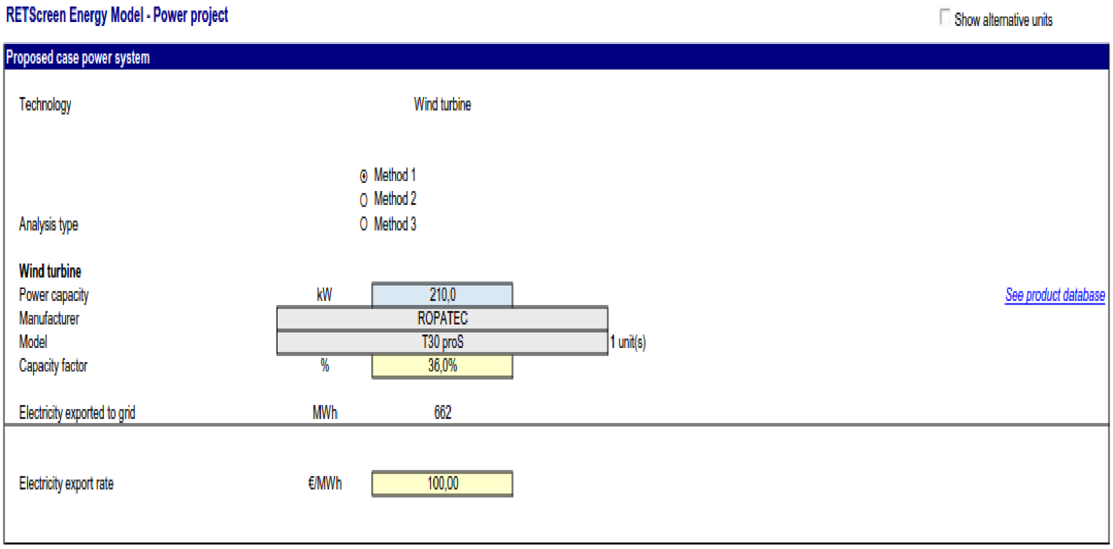
Project name	Vorias W/T feasibility study
Project location	Vorias settlement, Heraklion state, Crete island
Prepared for	MS'c Energy Systems Master Thesis
Prepared by	Emmanuel D. Loukakis
Project type	Power
Technology	Wind turbine
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☑
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	Euro
Units	Metric units

Site reference conditions *Select climate data location*

Climate data location	Tymbakion (Airport)
Show data	☑

Table 28: Table of contents of the wind turbine study.

4.2.2.2 W/T energy model



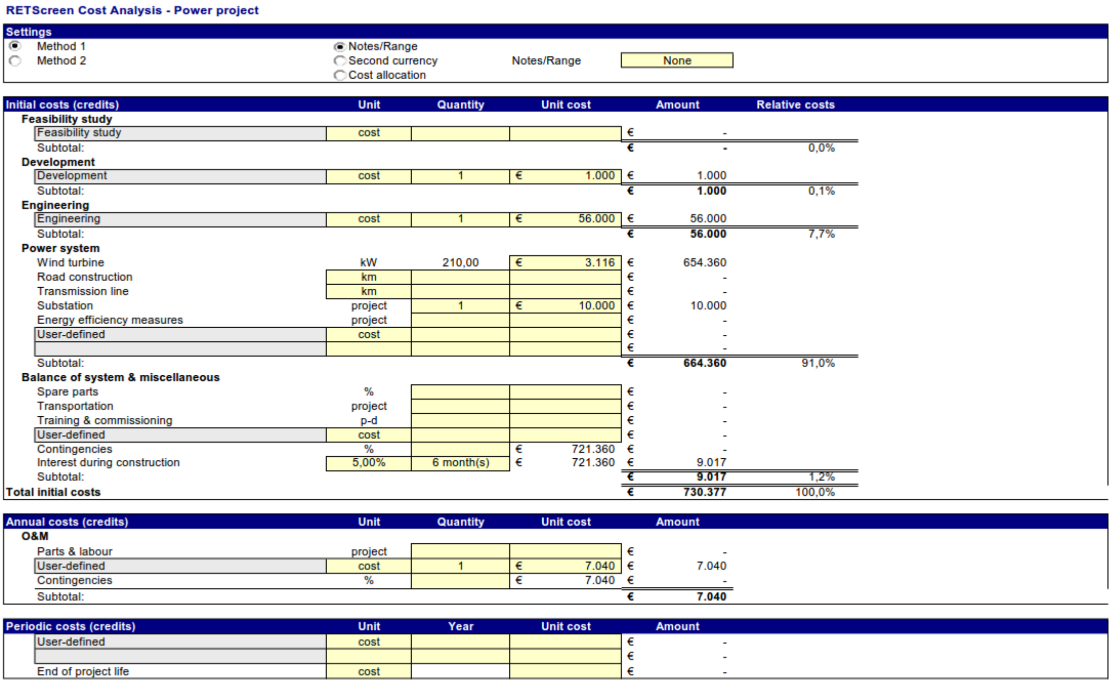
RETScreen Energy Model - Power project ☐ Show alternative units

Proposed case power system

Technology		Wind turbine	
Analysis type		● Method 1 ○ Method 2 ○ Method 3	
Wind turbine			
Power capacity	kW	210,0	*See product database*
Manufacturer		ROPATEC	
Model		T30 proS	1 unit(s)
Capacity factor	%	36,0%	
Electricity exported to grid	MWh	662	
Electricity export rate	€/MWh	100,00	

Table 29: Table of the energy model with the characteristics of the selected wind turbine.

4.2.2.3 W/T cost analysis



RETScreen Cost Analysis - Power project

Settings

● Method 1
○ Method 2

● Notes/Range
○ Second currency
○ Cost allocation

Notes/Range: None

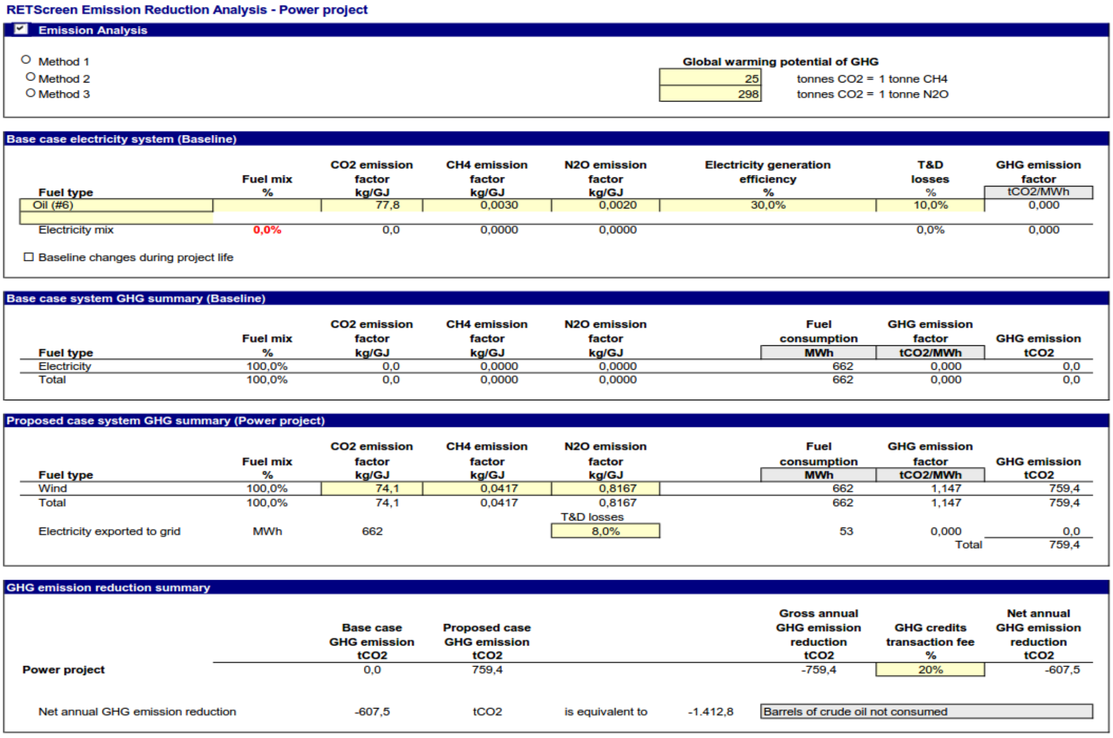
Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost			€ -	
Subtotal:				€ -	0,0%
Development					
Development	cost	1	€ 1.000	€ 1.000	
Subtotal:				€ **1.000**	0,1%
Engineering					
Engineering	cost	1	€ 56.000	€ 56.000	
Subtotal:				€ **56.000**	7,7%
Power system					
Wind turbine	kW	210,00	€ 3.116	€ 654.360	
Road construction	km			€ -	
Transmission line	km			€ -	
Substation	project	1	€ 10.000	€ 10.000	
Energy efficiency measures	project			€ -	
User-defined	cost			€ -	
				€ -	
Subtotal:				€ **664.360**	91,0%
Balance of system & miscellaneous					
Spare parts	%			€ -	
Transportation	project			€ -	
Training & commissioning	p-d			€ -	
User-defined	cost			€ -	
Contingencies	%		€ 721.360	€ -	
Interest during construction	5,00%	6 month(s)	€ 721.360	€ 9.017	
Subtotal:				€ **9.017**	1,2%
Total initial costs				€ **730.377**	100,0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project			€ -
User-defined	cost	1	€ 7.040	€ 7.040
Contingencies	%		€ 7.040	€ -
Subtotal:				€ **7.040**

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			€ -
				€ -
End of project life	cost			€ -

Table 30: Table analysis of the individual W/T installation costs.

4.2.2.4 W/T emission analysis



RETScreen Emission Reduction Analysis - Power project

☑ **Emission Analysis**

○ Method 1
○ Method 2
○ Method 3

Global warming potential of GHG

25	tonnes CO2 = 1 tonne CH4
298	tonnes CO2 = 1 tonne N2O

Base case electricity system (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Electricity generation efficiency %	T&D losses %	GHG emission factor tCO2/MWh
Oil (#6)		77,8	0,0030	0,0020	30,0%	10,0%	0,000
Electricity mix	0,0%	0,0	0,0000	0,0000		0,0%	0,000

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100,0%	0,0	0,0000	0,0000	662	0,000	0,0
Total	100,0%	0,0	0,0000	0,0000	662	0,000	0,0

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Wind	100,0%	74,1	0,0417	0,8167	662	1,147	759,4
Total	100,0%	74,1	0,0417	0,8167	662	1,147	759,4
				T&D losses			
Electricity exported to grid	MWh	662		8,0%	53	0,000	0,0
						Total	759,4

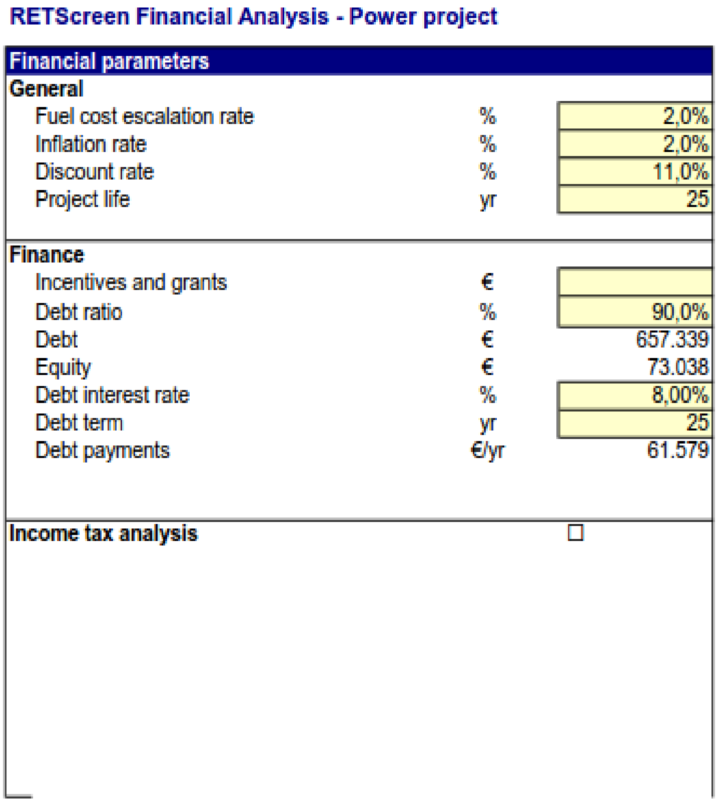
GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	0,0	759,4	-759,4	20%	-607,5

Net annual GHG emission reduction -607,5 tCO2 is equivalent to -1.412,8 Barrels of crude oil not consumed

Table 31: Analytical table of the greenhouse gases (W/T environmental savings).

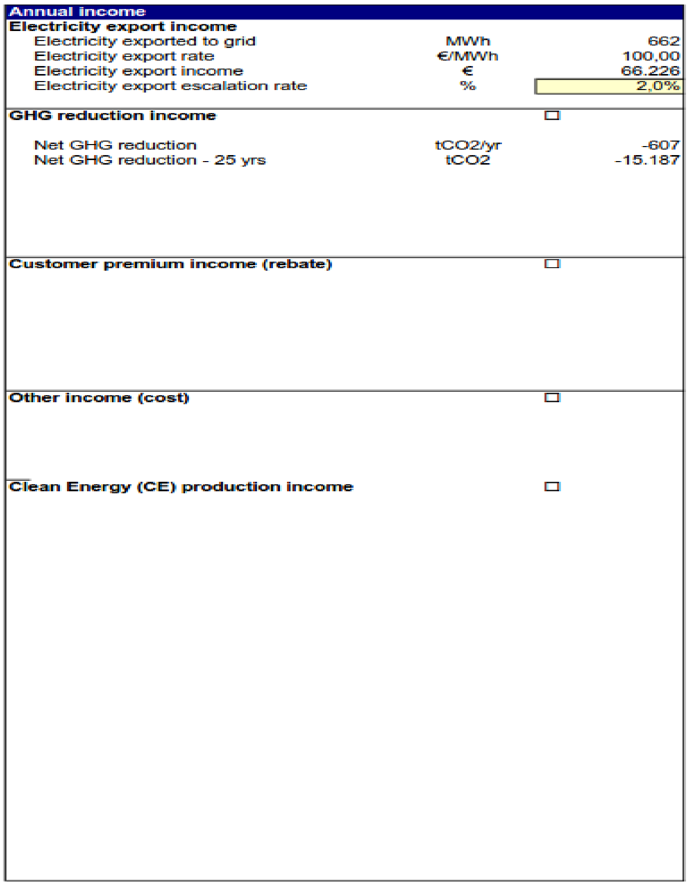
4.2.2.5 W/T financial analysis



RETScreen Financial Analysis - Power project

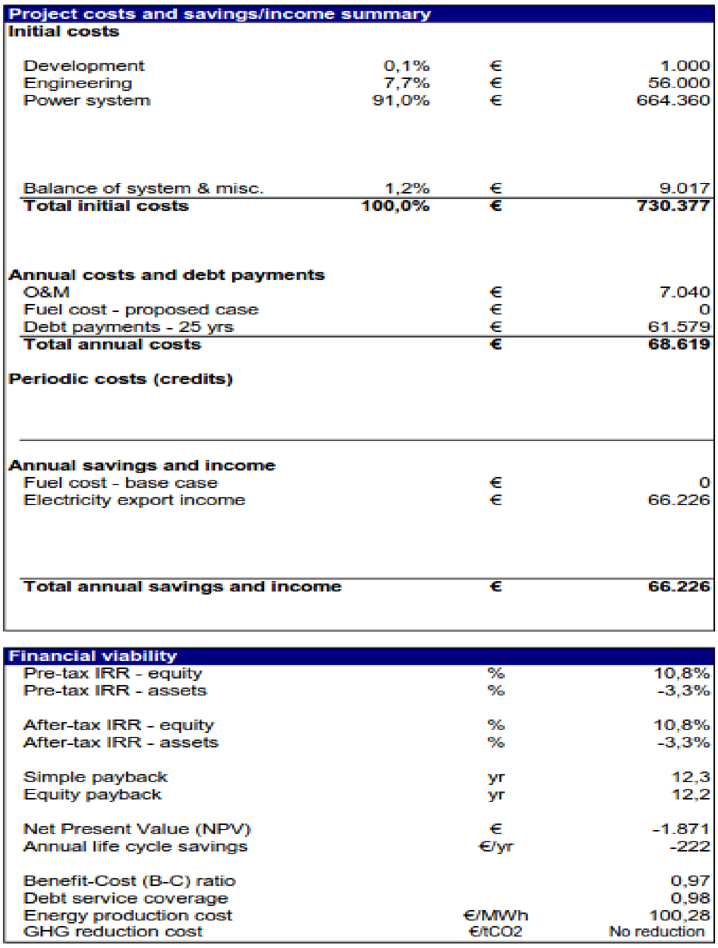
Financial parameters		
General		
Fuel cost escalation rate	%	2,0%
Inflation rate	%	2,0%
Discount rate	%	11,0%
Project life	yr	25
Finance		
Incentives and grants	€	
Debt ratio	%	90,0%
Debt	€	657.339
Equity	€	73.038
Debt interest rate	%	8,00%
Debt term	yr	25
Debt payments	€/yr	61.579
Income tax analysis		☐

Table 32: Table of W/T financial parameters



Annual income			
Electricity export income			
Electricity exported to grid	MWh		662
Electricity export rate	€/MWh		100,00
Electricity export income	€		66.226
Electricity export escalation rate	%		2,0%
GHG reduction income		☐	
Net GHG reduction	tCO2/yr		-607
Net GHG reduction - 25 yrs	tCO2		-15.187
Customer premium income (rebate)		☐	
Other income (cost)		☐	
Clean Energy (CE) production income		☐	

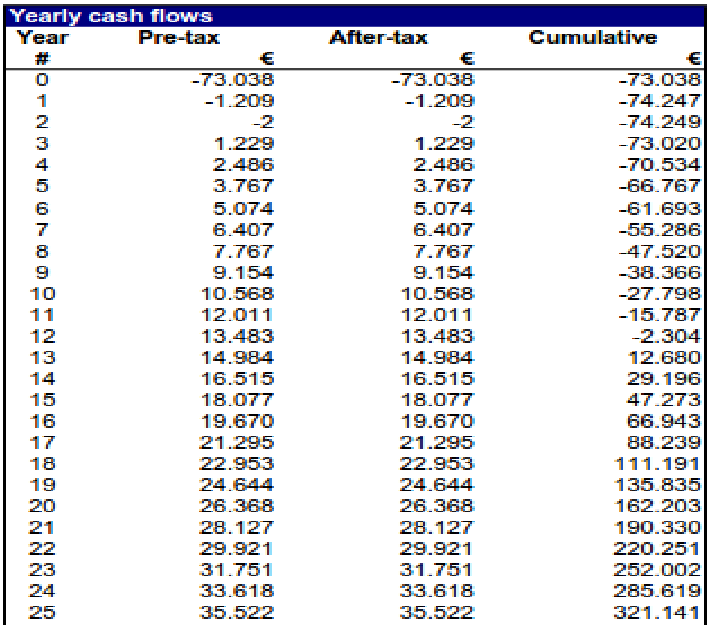
Table 33: Table of W/T annual income, based on the selling price of MWh.



Project costs and savings/income summary			
Initial costs			
Development	0,1%	€	1.000
Engineering	7,7%	€	56.000
Power system	91,0%	€	664.360
Balance of system & misc.	1,2%	€	9.017
Total initial costs	**100,0%**	**€**	**730.377**
Annual costs and debt payments			
O&M		€	7.040
Fuel cost - proposed case		€	0
Debt payments - 25 yrs		€	61.579
Total annual costs		**€**	**68.619**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		€	0
Electricity export income		€	66.226
Total annual savings and income		**€**	**66.226**

Financial viability		
Pre-tax IRR - equity	%	10,8%
Pre-tax IRR - assets	%	-3,3%
After-tax IRR - equity	%	10,8%
After-tax IRR - assets	%	-3,3%
Simple payback	yr	12,3
Equity payback	yr	12,2
Net Present Value (NPV)	€	-1.871
Annual life cycle savings	€/yr	-222
Benefit-Cost (B-C) ratio		0,97
Debt service coverage		0,98
Energy production cost	€/MWh	100,28
GHG reduction cost	€/tCO2	No reduction

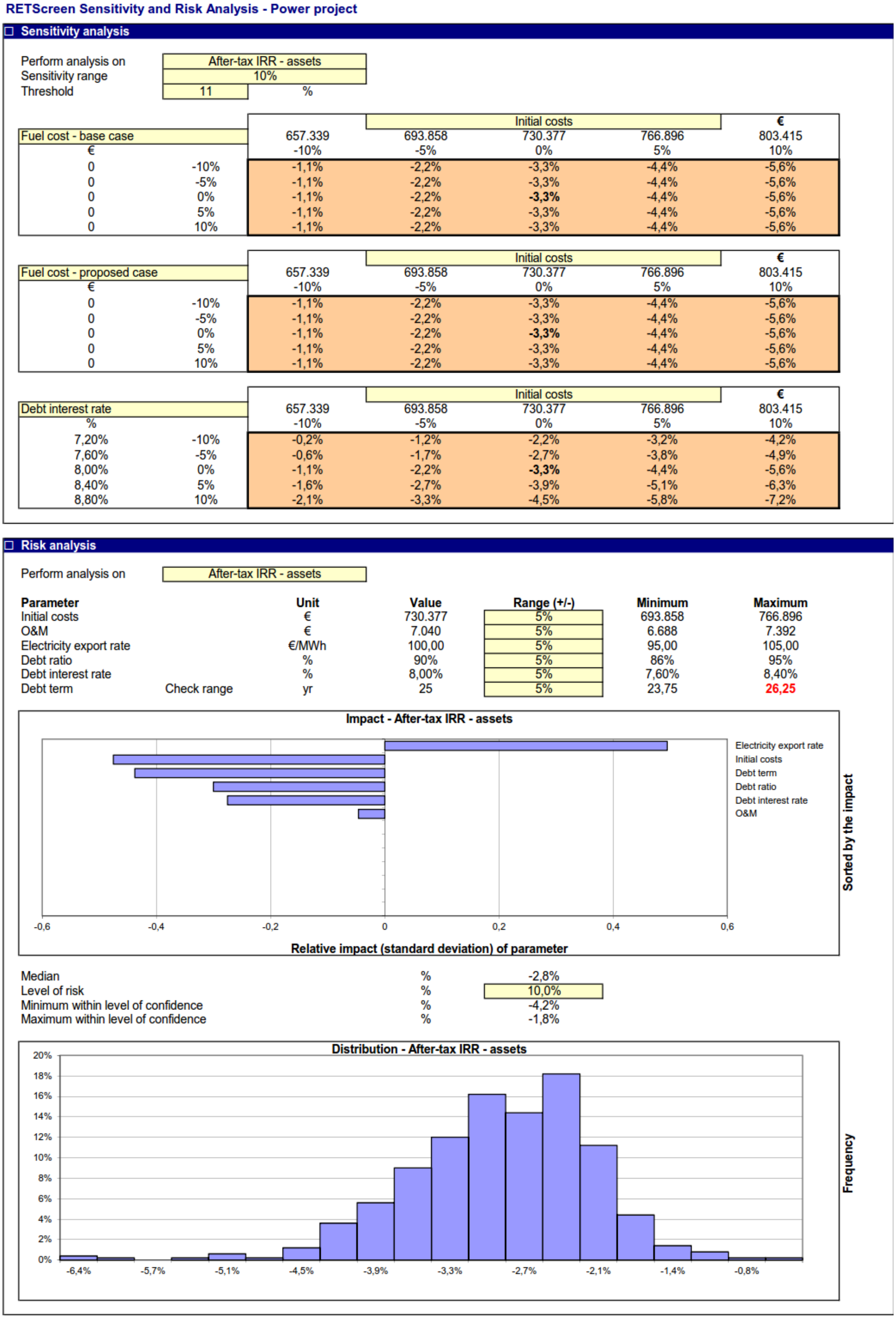
Table 34: Summary table of the economic viability of the W/T power project.



Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	€	€	€
0	-73.038	-73.038	-73.038
1	-1.209	-1.209	-74.247
2	-2	-2	-74.249
3	1.229	1.229	-73.020
4	2.486	2.486	-70.534
5	3.767	3.767	-66.767
6	5.074	5.074	-61.693
7	6.407	6.407	-55.286
8	7.767	7.767	-47.520
9	9.154	9.154	-38.366
10	10.568	10.568	-27.798
11	12.011	12.011	-15.787
12	13.483	13.483	-2.304
13	14.984	14.984	12.680
14	16.515	16.515	29.196
15	18.077	18.077	47.273
16	19.670	19.670	66.943
17	21.295	21.295	88.239
18	22.953	22.953	111.191
19	24.644	24.644	135.835
20	26.368	26.368	162.203
21	28.127	28.127	190.330
22	29.921	29.921	220.251
23	31.751	31.751	252.002
24	33.618	33.618	285.619
25	35.522	35.522	321.141

Table 35: Table of cash flows at a depth of 20-years for the W/T power project.

4.2.2.6 W/T sensitivity & risk analysis



RETScreen Sensitivity and Risk Analysis - Power project

☐ Sensitivity analysis

Perform analysis on	After-tax IRR - assets
Sensitivity range	10%
Threshold	11 %

Fuel cost - base case		Initial costs				€
		657.339	693.858	730.377	766.896	803.415
€		-10%	-5%	0%	5%	10%
0	-10%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	-5%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	0%	-1,1%	-2,2%	**-3,3%**	-4,4%	-5,6%
0	5%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	10%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%

Fuel cost - proposed case		Initial costs				€
		657.339	693.858	730.377	766.896	803.415
€		-10%	-5%	0%	5%	10%
0	-10%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	-5%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	0%	-1,1%	-2,2%	**-3,3%**	-4,4%	-5,6%
0	5%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%
0	10%	-1,1%	-2,2%	-3,3%	-4,4%	-5,6%

Debt interest rate		Initial costs				€
		657.339	693.858	730.377	766.896	803.415
%		-10%	-5%	0%	5%	10%
7,20%	-10%	-0,2%	-1,2%	-2,2%	-3,2%	-4,2%
7,60%	-5%	-0,6%	-1,7%	-2,7%	-3,8%	-4,9%
8,00%	0%	-1,1%	-2,2%	**-3,3%**	-4,4%	-5,6%
8,40%	5%	-1,6%	-2,7%	-3,9%	-5,1%	-6,3%
8,80%	10%	-2,1%	-3,3%	-4,5%	-5,8%	-7,2%

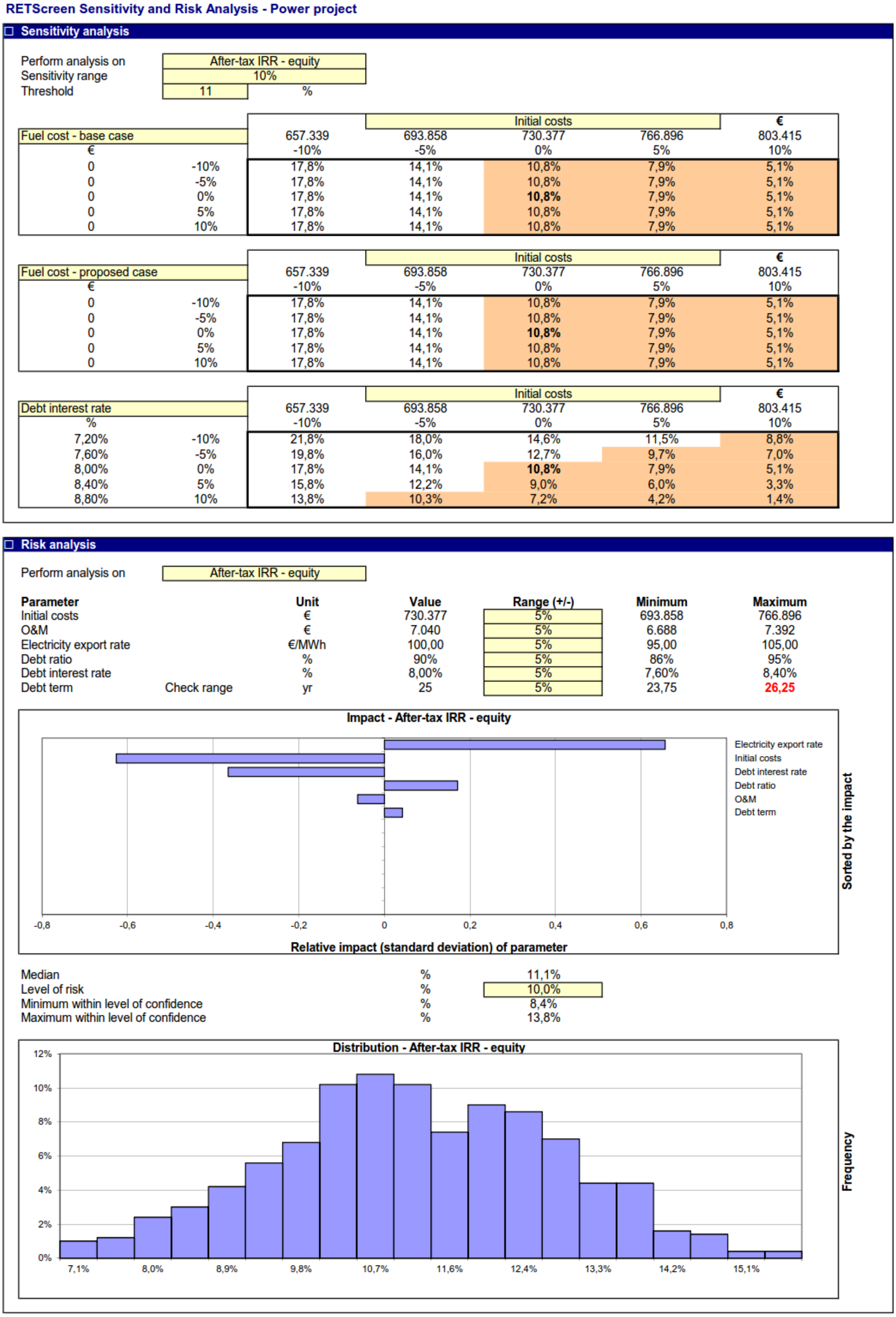
☐ Risk analysis

Perform analysis on: After-tax IRR - assets

Parameter		**Unit**	**Value**	**Range (+/-)**	**Minimum**	**Maximum**
Initial costs		€	730.377	5%	693.858	766.896
O&M		€	7.040	5%	6.688	7.392
Electricity export rate		€/MWh	100,00	5%	95,00	105,00
Debt ratio		%	90%	5%	86%	95%
Debt interest rate		%	8,00%	5%	7,60%	8,40%
Debt term	Check range	yr	25	5%	23,75	26,25

Median	%	-2,8%
Level of risk	%	10,0%
Minimum within level of confidence	%	-4,2%
Maximum within level of confidence	%	-1,8%

Table 36: W/T sensitivity and risk analysis table, after-tax IRR assets.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	After-tax IRR - equity	
Sensitivity range	10%	
Threshold	11	%

Fuel cost - base case				Initial costs		€
€		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
0	-10%	17,8%	14,1%	10,8%	7,9%	5,1%
0	-5%	17,8%	14,1%	10,8%	7,9%	5,1%
0	0%	17,8%	14,1%	**10,8%**	7,9%	5,1%
0	5%	17,8%	14,1%	10,8%	7,9%	5,1%
0	10%	17,8%	14,1%	10,8%	7,9%	5,1%

Fuel cost - proposed case				Initial costs		€
€		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
0	-10%	17,8%	14,1%	10,8%	7,9%	5,1%
0	-5%	17,8%	14,1%	10,8%	7,9%	5,1%
0	0%	17,8%	14,1%	**10,8%**	7,9%	5,1%
0	5%	17,8%	14,1%	10,8%	7,9%	5,1%
0	10%	17,8%	14,1%	10,8%	7,9%	5,1%

Debt interest rate				Initial costs		€
%		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
7,20%	-10%	21,8%	18,0%	14,6%	11,5%	8,8%
7,60%	-5%	19,8%	16,0%	12,7%	9,7%	7,0%
8,00%	0%	17,8%	14,1%	**10,8%**	7,9%	5,1%
8,40%	5%	15,8%	12,2%	9,0%	6,0%	3,3%
8,80%	10%	13,8%	10,3%	7,2%	4,2%	1,4%

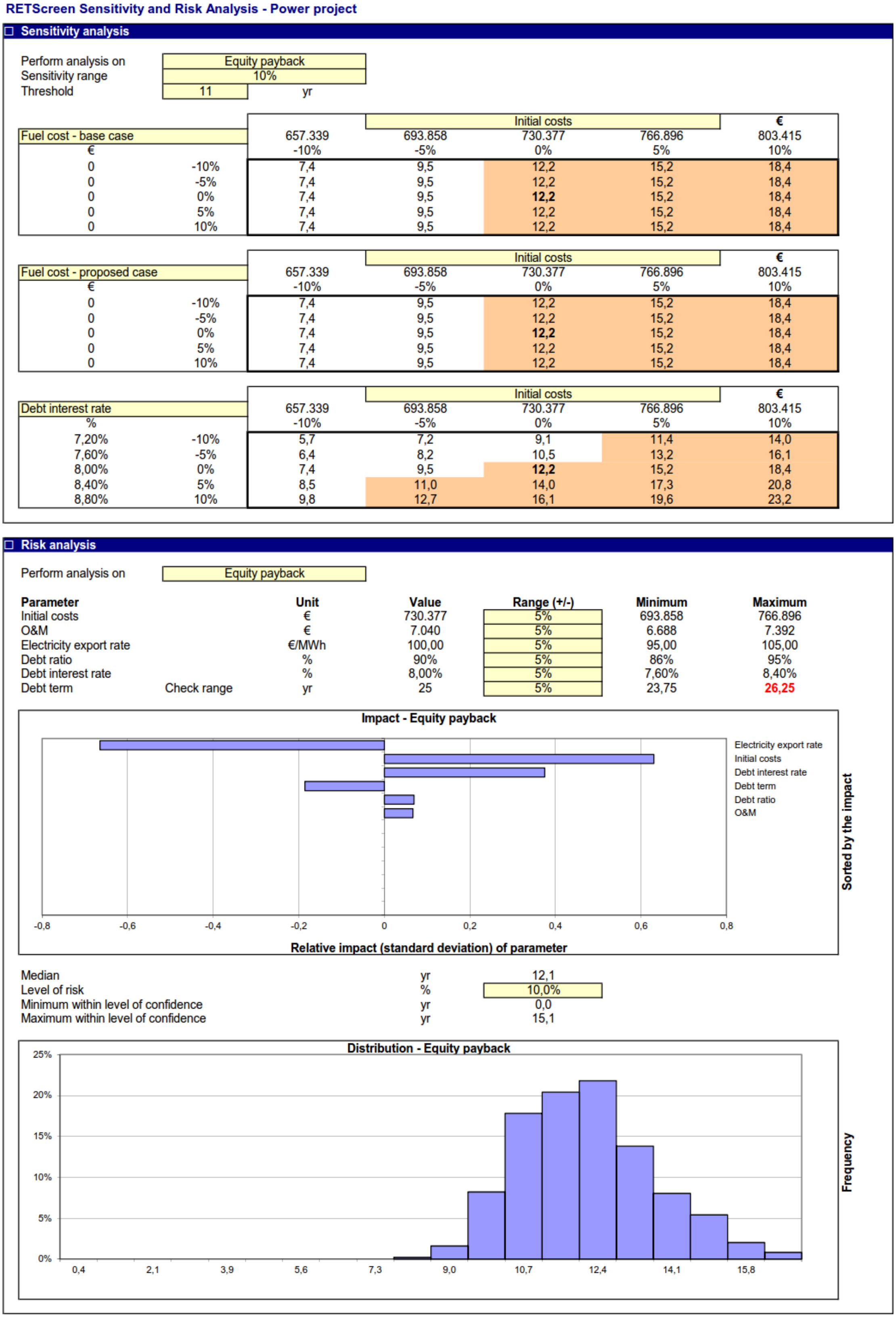
☐ **Risk analysis**

Perform analysis on: After-tax IRR - equity

Parameter		Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs		€	730.377	5%	693.858	766.896
O&M		€	7.040	5%	6.688	7.392
Electricity export rate		€/MWh	100,00	5%	95,00	105,00
Debt ratio		%	90%	5%	86%	95%
Debt interest rate		%	8,00%	5%	7,60%	8,40%
Debt term	Check range	yr	25	5%	23,75	26,25

Median	%	11,1%
Level of risk	%	10,0%
Minimum within level of confidence	%	8,4%
Maximum within level of confidence	%	13,8%

Table 37: W/T sensitivity and risk analysis table, after-tax IRR equity.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	Equity payback	
Sensitivity range	10%	
Threshold	11	yr

Fuel cost - base case				Initial costs		€
€		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
0	-10%	7,4	9,5	12,2	15,2	18,4
0	-5%	7,4	9,5	12,2	15,2	18,4
0	0%	7,4	9,5	**12,2**	15,2	18,4
0	5%	7,4	9,5	12,2	15,2	18,4
0	10%	7,4	9,5	12,2	15,2	18,4

Fuel cost - proposed case				Initial costs		€
€		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
0	-10%	7,4	9,5	12,2	15,2	18,4
0	-5%	7,4	9,5	12,2	15,2	18,4
0	0%	7,4	9,5	**12,2**	15,2	18,4
0	5%	7,4	9,5	12,2	15,2	18,4
0	10%	7,4	9,5	12,2	15,2	18,4

Debt interest rate				Initial costs		€
%		657.339	693.858	730.377	766.896	803.415
		-10%	-5%	0%	5%	10%
7,20%	-10%	5,7	7,2	9,1	11,4	14,0
7,60%	-5%	6,4	8,2	10,5	13,2	16,1
8,00%	0%	7,4	9,5	**12,2**	15,2	18,4
8,40%	5%	8,5	11,0	14,0	17,3	20,8
8,80%	10%	9,8	12,7	16,1	19,6	23,2

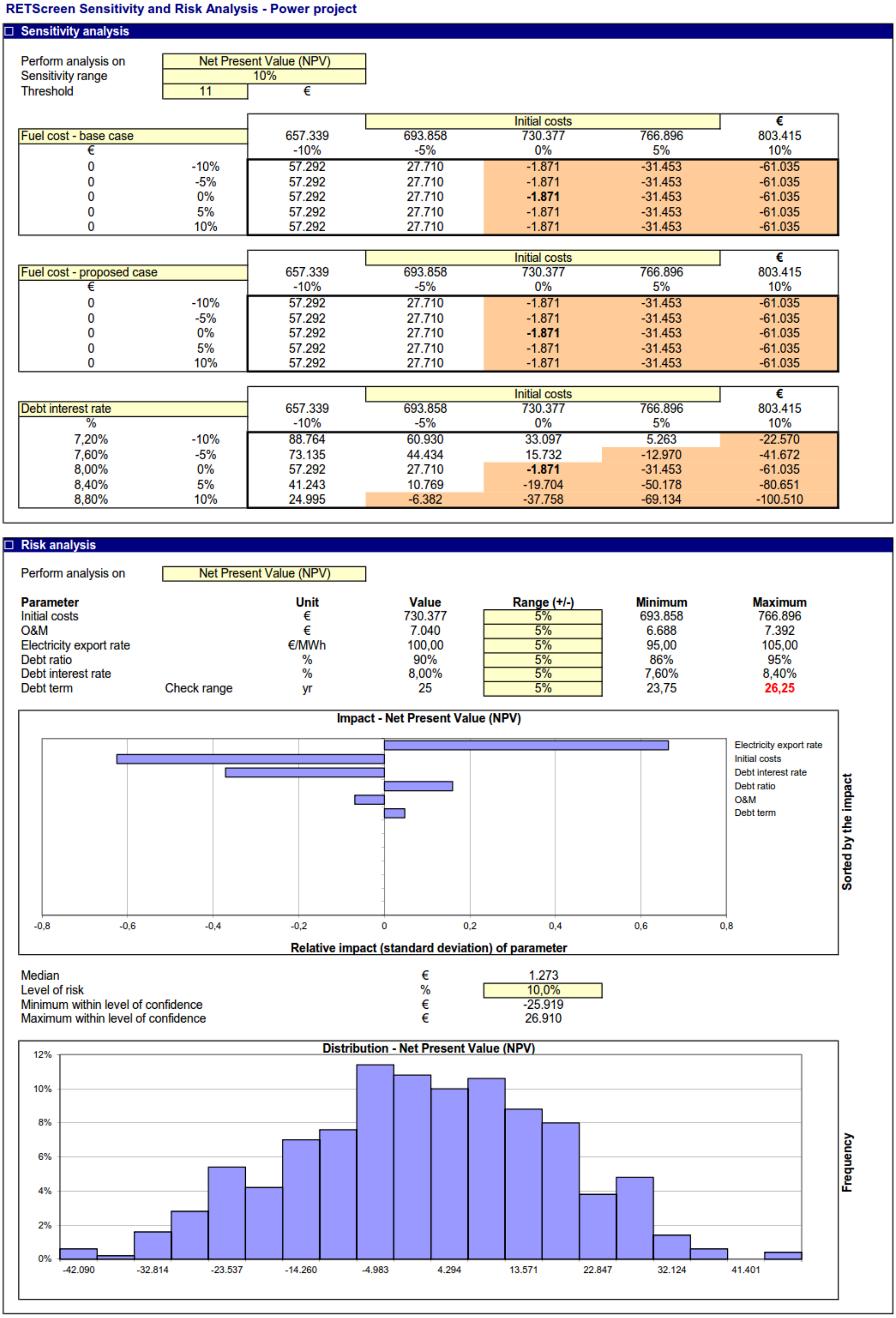
☐ **Risk analysis**

Perform analysis on: Equity payback

Parameter		**Unit**	**Value**	**Range (+/-)**	**Minimum**	**Maximum**
Initial costs		€	730.377	5%	693.858	766.896
O&M		€	7.040	5%	6.688	7.392
Electricity export rate		€/MWh	100,00	5%	95,00	105,00
Debt ratio		%	90%	5%	86%	95%
Debt interest rate		%	8,00%	5%	7,60%	8,40%
Debt term	Check range	yr	25	5%	23,75	26,25

Median	yr	12,1
Level of risk	%	10,0%
Minimum within level of confidence	yr	0,0
Maximum within level of confidence	yr	15,1

Table 38: W/T sensitivity and risk analysis table, on equity payback.



RETScreen Sensitivity and Risk Analysis - Power project

☐ **Sensitivity analysis**

Perform analysis on	Net Present Value (NPV)	
Sensitivity range	10%	
Threshold	11	€

				Initial costs		€
Fuel cost - base case		657.339	693.858	730.377	766.896	803.415
€		-10%	-5%	0%	5%	10%
0	-10%	57.292	27.710	-1.871	-31.453	-61.035
0	-5%	57.292	27.710	-1.871	-31.453	-61.035
0	0%	57.292	27.710	**-1.871**	-31.453	-61.035
0	5%	57.292	27.710	-1.871	-31.453	-61.035
0	10%	57.292	27.710	-1.871	-31.453	-61.035

				Initial costs		€
Fuel cost - proposed case		657.339	693.858	730.377	766.896	803.415
€		-10%	-5%	0%	5%	10%
0	-10%	57.292	27.710	-1.871	-31.453	-61.035
0	-5%	57.292	27.710	-1.871	-31.453	-61.035
0	0%	57.292	27.710	**-1.871**	-31.453	-61.035
0	5%	57.292	27.710	-1.871	-31.453	-61.035
0	10%	57.292	27.710	-1.871	-31.453	-61.035

				Initial costs		€
Debt interest rate		657.339	693.858	730.377	766.896	803.415
%		-10%	-5%	0%	5%	10%
7,20%	-10%	88.764	60.930	33.097	5.263	-22.570
7,60%	-5%	73.135	44.434	15.732	-12.970	-41.672
8,00%	0%	57.292	27.710	**-1.871**	-31.453	-61.035
8,40%	5%	41.243	10.769	-19.704	-50.178	-80.651
8,80%	10%	24.995	-6.382	-37.758	-69.134	-100.510

☐ **Risk analysis**

Perform analysis on Net Present Value (NPV)

Parameter		**Unit**	**Value**	**Range (+/-)**	**Minimum**	**Maximum**
Initial costs		€	730.377	5%	693.858	766.896
O&M		€	7.040	5%	6.688	7.392
Electricity export rate		€/MWh	100,00	5%	95,00	105,00
Debt ratio		%	90%	5%	86%	95%
Debt interest rate		%	8,00%	5%	7,60%	8,40%
Debt term	Check range	yr	25	5%	23,75	26,25

Median	€	1.273
Level of risk	%	10,0%
Minimum within level of confidence	€	-25.919
Maximum within level of confidence	€	26.910

Table 39: W/T sensitivity and risk analysis table, on net present value (NPV).

4.2.3 PV & W/T cumulative cash flows graphs

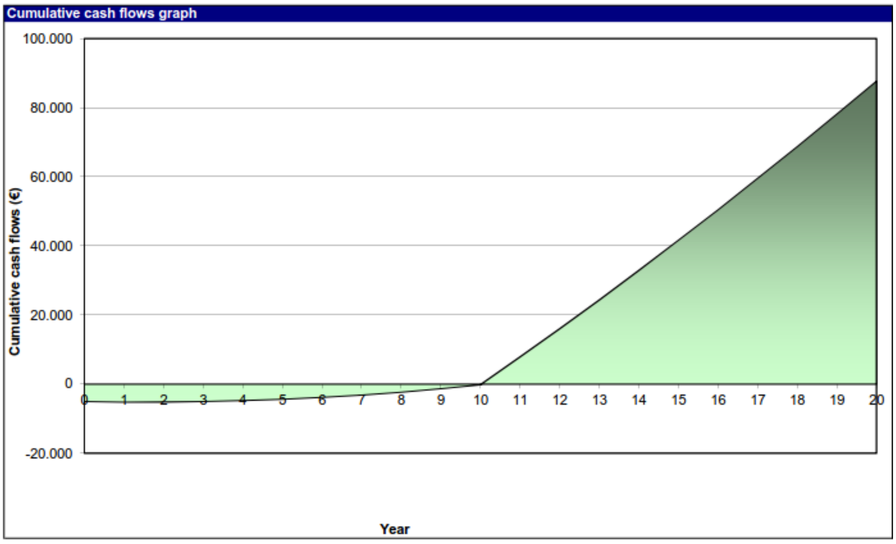


Chart 15: Cumulative cash flows graph that shows in 20-year depth, repayment of the loan and commencement of revenue by the tenth year of operation of the PV project.

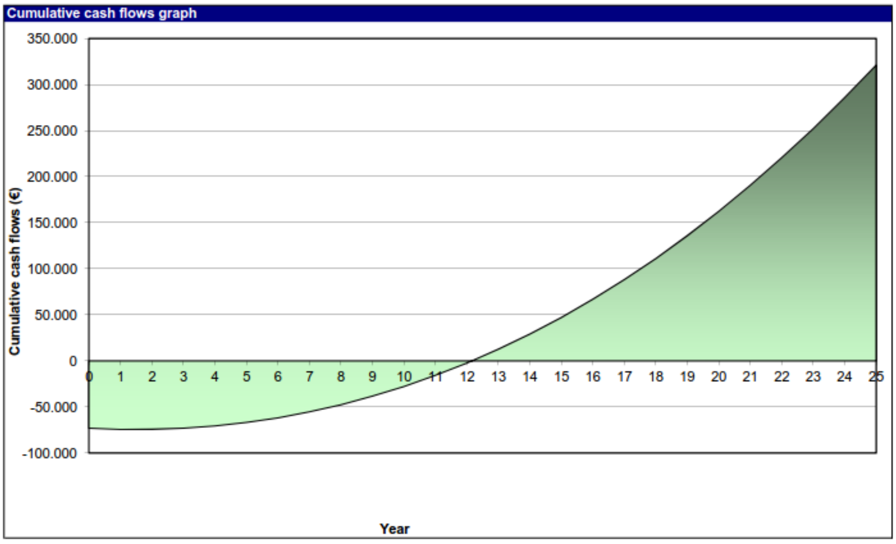


Chart 16: Cumulative cash flows graph that shows in 25-year depth, repayment of the loan and commencement of revenue by the twelfth year of operation of the W/T project.

4.3 Wind and solar potential maps (GIS report)

Before the digitization of the maps of wind potential, it is important to classify the information of meteorological data, speed and direction of wind, as well as the geographical location of the measurement stations of such data.

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	9	8,9	9,7	11,8	15	19,1
Monthly Average Temperature (°C)	12,1	12,2	13,5	16,5	20,3	24,4
Monthly Max Temperature (°C)	15,3	15,5	16,7	20	23,5	27,3
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	21,6	21,8	19,3	16,5	13,4	10,8
Monthly Average Temperature (°C)	26,1	26	23,5	20	16,6	13,7
Monthly Max Temperature (°C)	28,7	28,5	26,4	23,4	20	17
Data Period:	1955-1997					
Heraklion (Civ/AFB):	Longitude 25°10'55" / Latitude 35°20'07"/ Alt 39m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	S	S	NW	NW	NW	NW
Monthly Average Wind Speed (m/s)	5,20	5,60	4,90	4,40	4,00	4,20
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	NW	NW	NW	NW	S	S
Monthly Average Wind Speed (m/s)	5,30	5,10	4,40	4,50	4,80	5,00

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	7,5	7,3	8,3	10,5	14	17,6
Monthly Average Temperature (°C)	11,7	11,7	13,4	16,4	20,6	24,8
Monthly Max Temperature (°C)	15,9	15,9	17,5	20,5	24,5	28,6
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	20,3	20,4	17,9	14,9	11,7	9,2
Monthly Average Temperature (°C)	27,6	27,4	24,3	20,2	16,3	13,2
Monthly Max Temperature (°C)	31,6	31,6	28,7	24,9	21,1	17,5
Data Period:	1959-1997					
Tympakion (Airport):	Longitude 24°45'43" / Latitude 35°03'59"/ Alt 6m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	W	W	W	W	W	W
Monthly Average Wind Speed (m/s)	6,20	6,50	5,80	5,10	4,60	4,60
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	N	N	N	N	E	W
Monthly Average Wind Speed (m/s)	5,40	5,20	4,80	4,90	5,50	6,00

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	0,6	3,8	5,1	9,1	11,1	15,4
Monthly Average Temperature (°C)	9,7	12,8	12,3	18,1	19,2	25,2
Monthly Max Temperature (°C)	18,4	23,5	21,9	29,4	33,4	38,6
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	18,9	19,2	15,6	11	6,4	1,3
Monthly Average Temperature (°C)	25,5	25,5	22,2	19,3	14,8	8,3
Monthly Max Temperature (°C)	35,8	35,2	34,3	30,2	24,7	17,9
Data Period:	2015-2016					
Metaxochori:	Longitude 25°08'32" / Latitude 35°07'48"/ Alt 418m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	W	W	W	W	W	W
Monthly Average Wind Speed (m/s)	10,30	9,05	10,40	9,42	8,70	7,75
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	W	W	W	W	W	W
Monthly Average Wind Speed (m/s)	8,55	7,30	6,60	7,65	7,80	8,25

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	3,9	5,6	7,3	11,4	12,7	17,1
Monthly Average Temperature (°C)	12,8	15,6	14,9	19,3	20,9	25,6
Monthly Max Temperature (°C)	23,1	27,3	24,7	32,9	35,3	35,3
2nd Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Min Temperature (°C)	20,5	20,8	17,4	13,1	8,5	3,8
Monthly Average Temperature (°C)	26,7	26,3	24,2	21,1	17,3	17,3
Monthly Max Temperature (°C)	34,8	34,3	36,9	30,9	27,8	27,8
Data Period:	2015-2016					
Knossos:	Longitude 25°12'00" / Latitude 35°18'00"/ Alt 115m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	N	SSW	NW	N	NNW	NNW
Monthly Average Wind Speed (m/s)	11,50	10,75	14,40	11,25	11,60	9,75
2nd Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Average Wind Direction	NW	NNW	NNW	NNW	S	N
Monthly Average Wind Speed (m/s)	7,95	7,25	12,15	9,20	10,05	8,60

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	3,0	4,7	6,3	9,2	11,7	16,1
Monthly Average Temperature (°C)	11,2	13,6	13,7	18,1	20,2	25,4
Monthly Max Temperature (°C)	19,3	23,3	21,9	28,0	32,5	36,4
2nd Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Min Temperature (°C)	19,0	19,2	16,0	12,5	8,4	3,6
Monthly Average Temperature (°C)	26,8	26,5	23,5	20,2	16,0	12,9
Monthly Max Temperature (°C)	34,8	34,1	33,2	29,4	24,7	22,1
Data Period:	2015-2016					
Vorias:	Longitude 25° 6'54,52" / Latitude 35° 5'59,07"/ Alt 316m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	-	-	-	-	-	-
Monthly Average Wind Speed (m/s)	9,80	9,48	10,08	8,77	8,10	7,93
2nd Semester	JUL	AUG	SEP	OCT	NOV	DEC
Monthly Average Wind Direction	-	-	-	-	-	-
Monthly Average Wind Speed (m/s)	7,80	7,04	7,59	7,42	8,16	7,90

1st Semester	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
Monthly Min Temperature (°C)	0,7	0,3	4,5	6	9,3	14,2
Monthly Average Temperature (°C)	11,4	13,8	14,4	18,6	20,8	26,6
Monthly Max Temperature (°C)	21,1	26,3	24,3	30,3	36,4	43,2
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	16,8	15,3	10,4	9,4	6,6	-0,40
Monthly Average Temperature (°C)	28,8	27,8	24,1	21,3	16,4	16,4
Monthly Max Temperature (°C)	38,5	37,3	35,2	30,9	27,2	27,2
Data Period:	2015-2016					
Moires:	Longitude 24°52'22,9" / Latitude 35°3'5,5"/ Alt 90m.					

1st Semester	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
Monthly Average Wind Direction	WSW	WSW	WSW	WSW	WSW	WSW
Monthly Average Wind Speed (m/s)	9,00	7,85	8,00	7,70	7,10	7,00
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	WSW	ENE	WSW	ENE	ENE	ENE
Monthly Average Wind Speed (m/s)	6,50	6,05	6,00	5,80	7,24	6,33

1st Semester	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
Monthly Min Temperature (°C)	1,1	3,5	5,5	8,7	10,7	15,3
Monthly Average Temperature (°C)	10,2	13,2	12,8	18,3	19,4	25,1
Monthly Max Temperature (°C)	19,2	24,6	22,3	30,4	35,1	39,6
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	18,7	18,9	15,6	11,1	7,2	1,3
Monthly Average Temperature (°C)	25,6	25,6	22,6	19,7	15,2	15,2
Monthly Max Temperature (°C)	37,7	35,3	34,5	31,8	24,7	24,7
Data Period:	2015-2016					
Pyrathi:	Longitude 25°08'32" / Latitude 35°07'48"/ Alt 418m.					

1st Semester	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**
Monthly Average Wind Direction	NE	NE	W	ENE	NE	NE
Monthly Average Wind Speed (m/s)	11,26	12,88	11,58	10,96	9,46	9,56
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	NE	NE	NE	NE	NE	NE
Monthly Average Wind Speed (m/s)	9,64	8,67	8,525	9,14	9,62	9,72

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	2,1	5,3	6,7	9,8	11,9	16,1
Monthly Average Temperature (°C)	11,3	14,3	13,7	18,7	20,4	25,5
Monthly Max Temperature (°C)	21,6	25,6	22,9	29,7	32,9	35,7
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	18,9	20,7	16,4	11,1	6,6	1,3
Monthly Average Temperature (°C)	26,5	26,2	23,3	20	16	9,4
Monthly Max Temperature (°C)	34,7	34,2	35,2	32,2	26,2	26,2
Data Period:	2015-2016					
Stavrakia:	Longitude 25°03'45" / Latitude 35°15'12"/ Alt 245m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	NNW	SSE	SE	S	NW	NNW
Monthly Average Wind Speed (m/s)	15,75	14,69	16,77	13,22	12,71	12,52
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	N	N	N	NNW	NW	N
Monthly Average Wind Speed (m/s)	9,40	8,28	9,67	9,17	12,45	10,49

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Min Temperature (°C)	-0,60	2,6	2,9	6,2	8,7	13,2
Monthly Average Temperature (°C)	10,6	13,4	13,3	18,1	19,7	25,7
Monthly Max Temperature (°C)	19,4	25,6	23,3	29,5	35,6	39,6
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Min Temperature (°C)	15,9	16,2	15,3	12,6	7,1	1,7
Monthly Average Temperature (°C)	27,4	26,9	23,4	20,3	15,5	9,4
Monthly Max Temperature (°C)	36,2	36,7	34,3	31	25,8	18,7
Data Period:	2015-2016					
Vagionia:	Longitude 24°59'56" / Latitude 35°00'41"/ Alt 196m.					

1st Semester	JAN	FEB	MAR	APR	MAY	JUN
Monthly Average Wind Direction	WSW	ENE	WSW	W	ENE	ENE
Monthly Average Wind Speed (m/s)	9,975	10,165	10,905	9,21	7,665	8,96
2nd Semester	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Monthly Average Wind Direction	ENE	ENE	ENE	ENE	ENE	ENE
Monthly Average Wind Speed (m/s)	9,665	8,5	8,545	9	7,86	8,805

Table 40: Table of meteorological data from measurement stations (cities and airports) of the HNMS service.

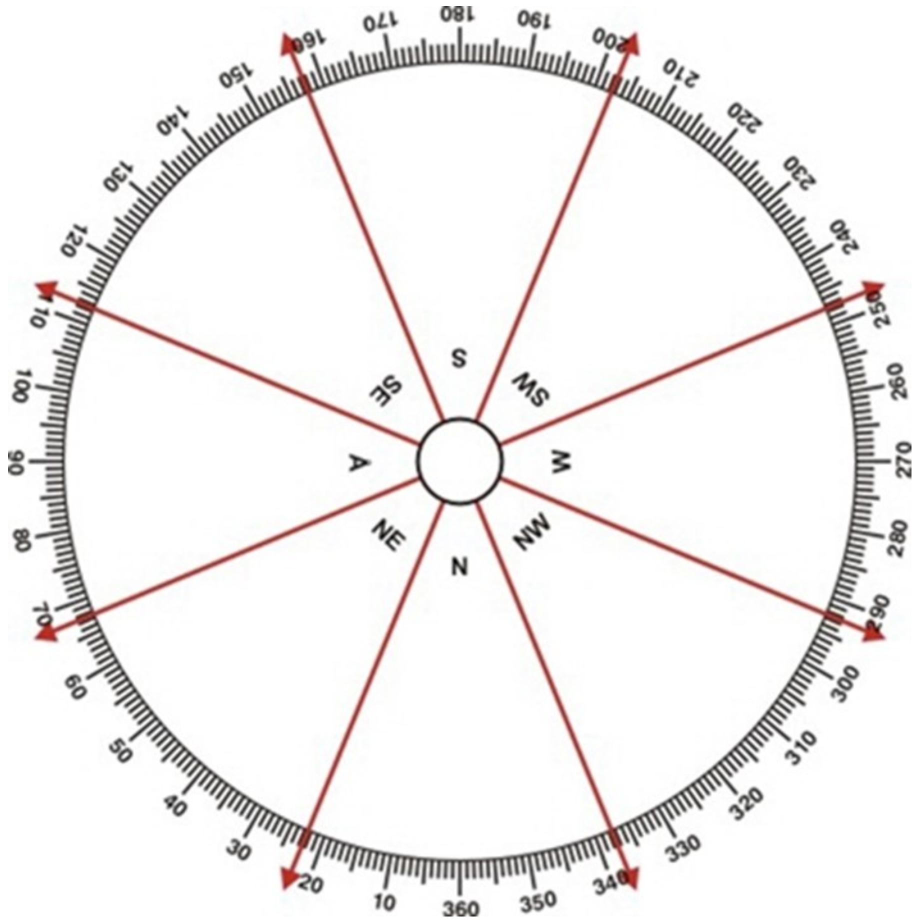


Figure 7: Histogram of dispersion of the direction of the wind in degrees (°).

Station	UTMX (°)	UTMY (°)	Direction (°)	Speed (m/s)
Heraklion	331341	3912158	273,3	5
Tymbakion	296539	3883383	285,0	5
Metaxochori	330754	3889035	270,0	8
Knossos	332657	3907692	315,8	10
Moires	302154	3871424	190,0	7
Pyrathi	334965	3885351	65,8	10
Stavrakia	323669	3902823	297,1	12
Vagionia	317579	3876454	116,7	9
Vorias	**328202**	**3885731**	**226,7**	**8**

Table 41: Table of wind speed and direction, also containing information about the geographical location of the meteorological stations, in Universal Transverse Mercator (UTM) coordinate system, for the purpose of creating a digital map of wind resources.

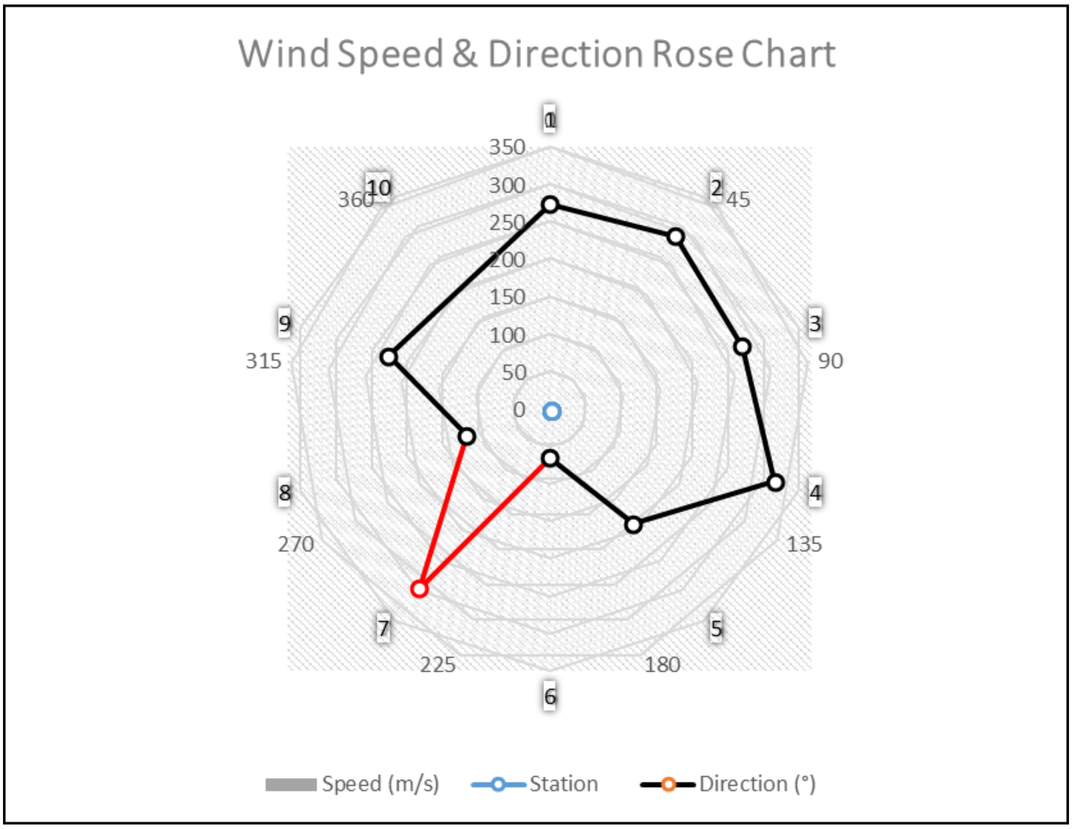


Chart 17: Radar chart of wind speed and direction. Red colored section represents the AOI, with estimated of Northeastern wind direction annually, on average basis.

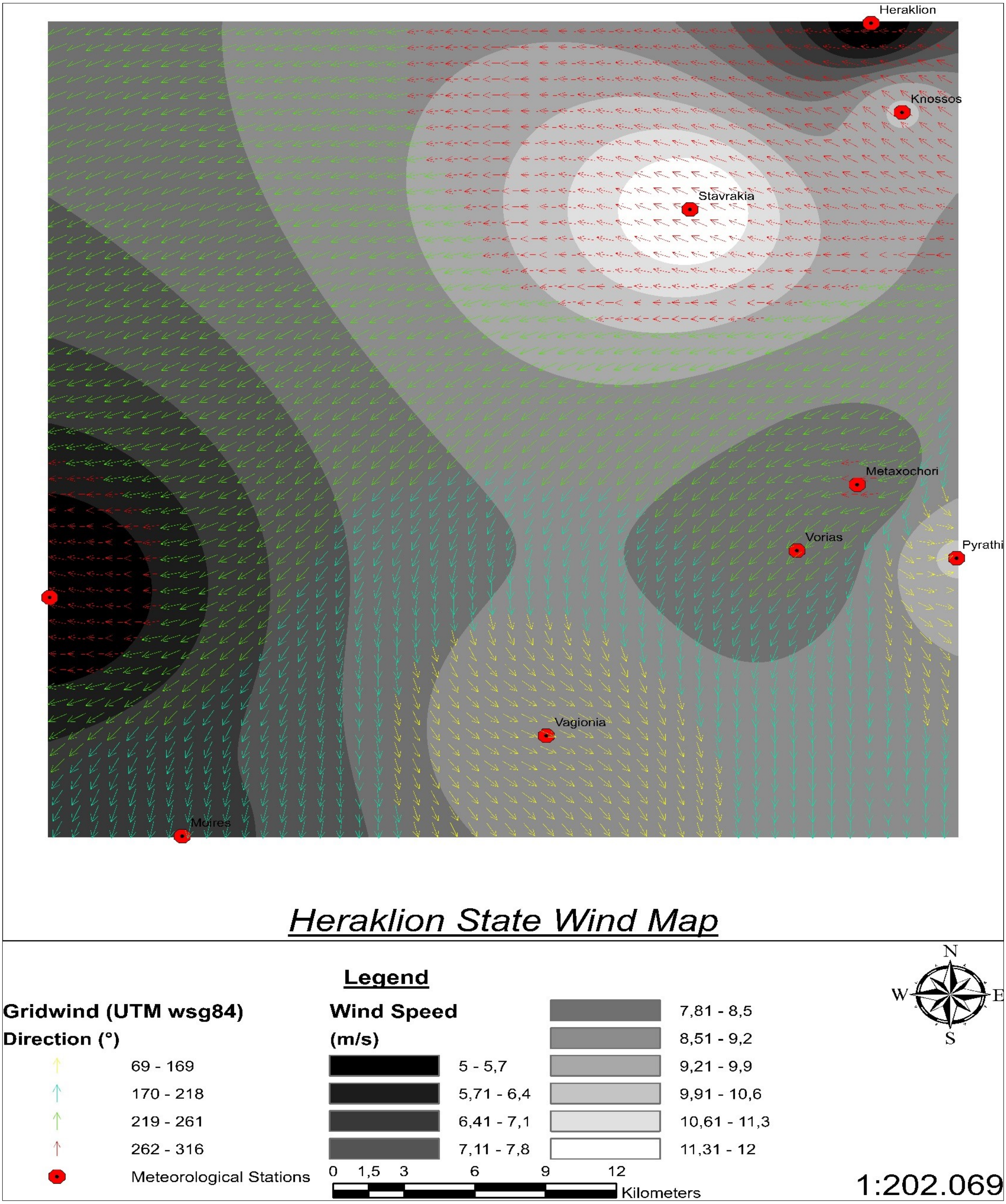


Figure 8: Wind speed and direction map by ArcGIS software. The AOI of Vorias village wind speed values are between 7-9 m/s with Northeastern wind direction on average, annually.

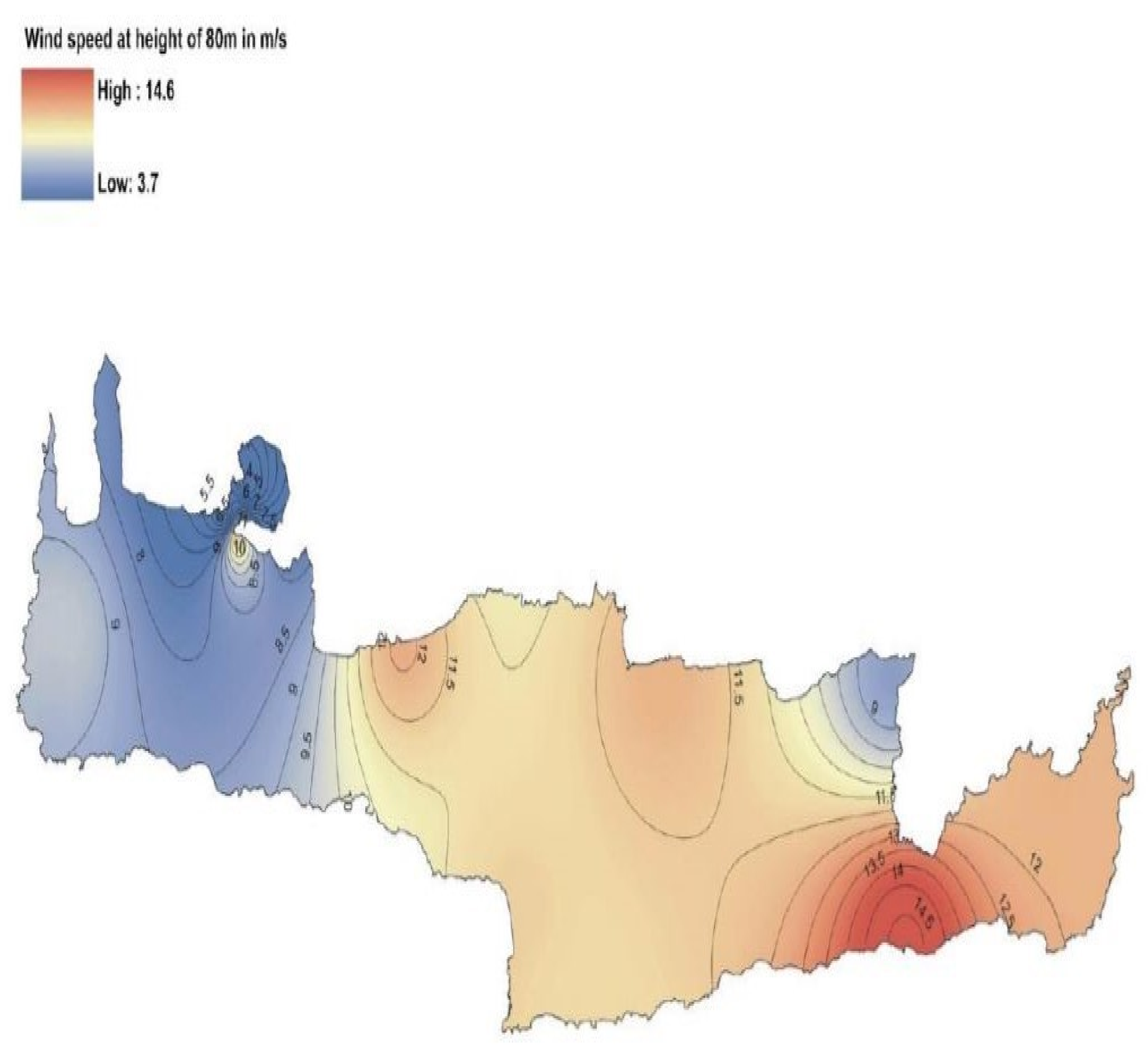


Figure 9: Correlation map of wind potential in Crete island [63].

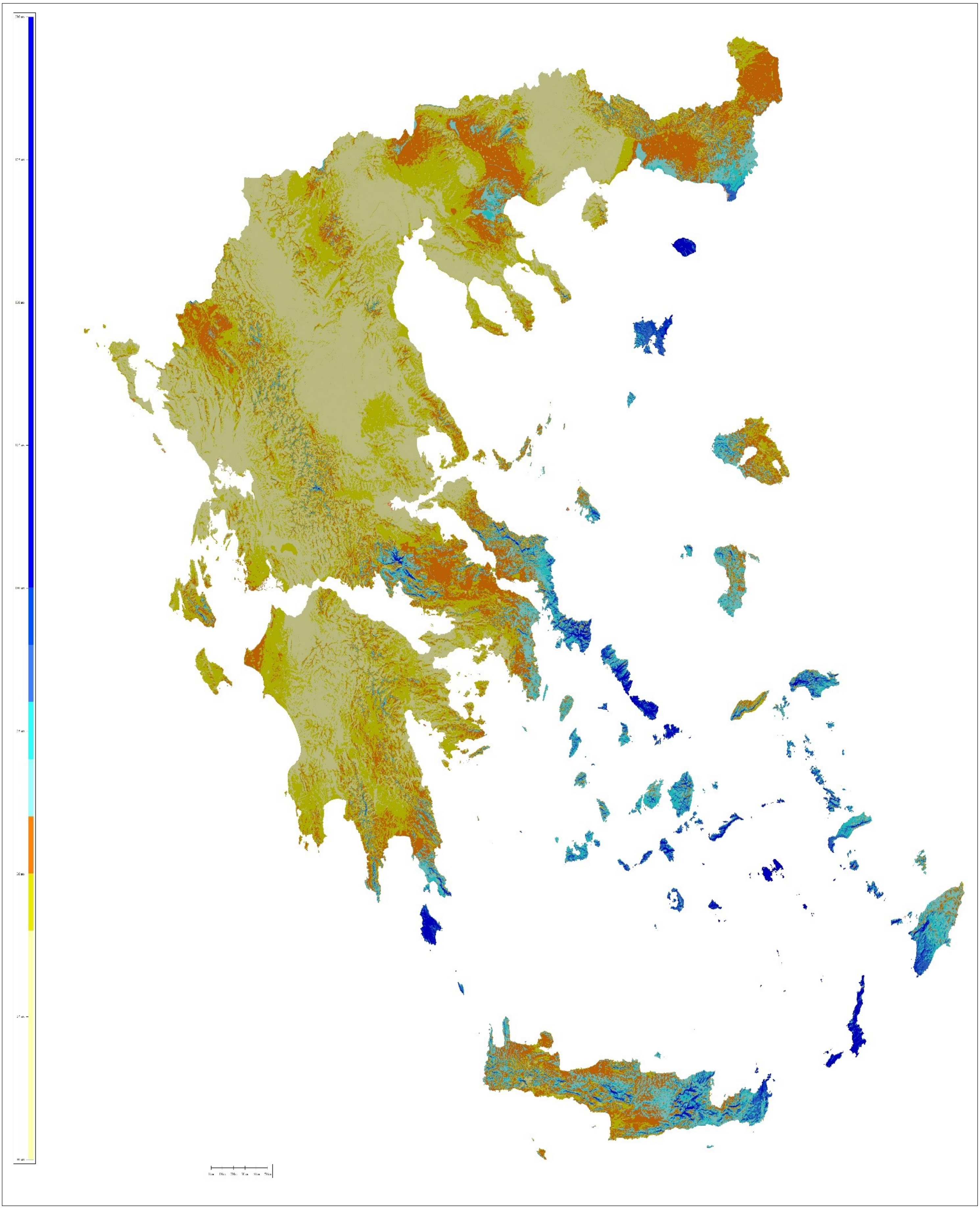


Figure 10: Total wind potential of Greece.

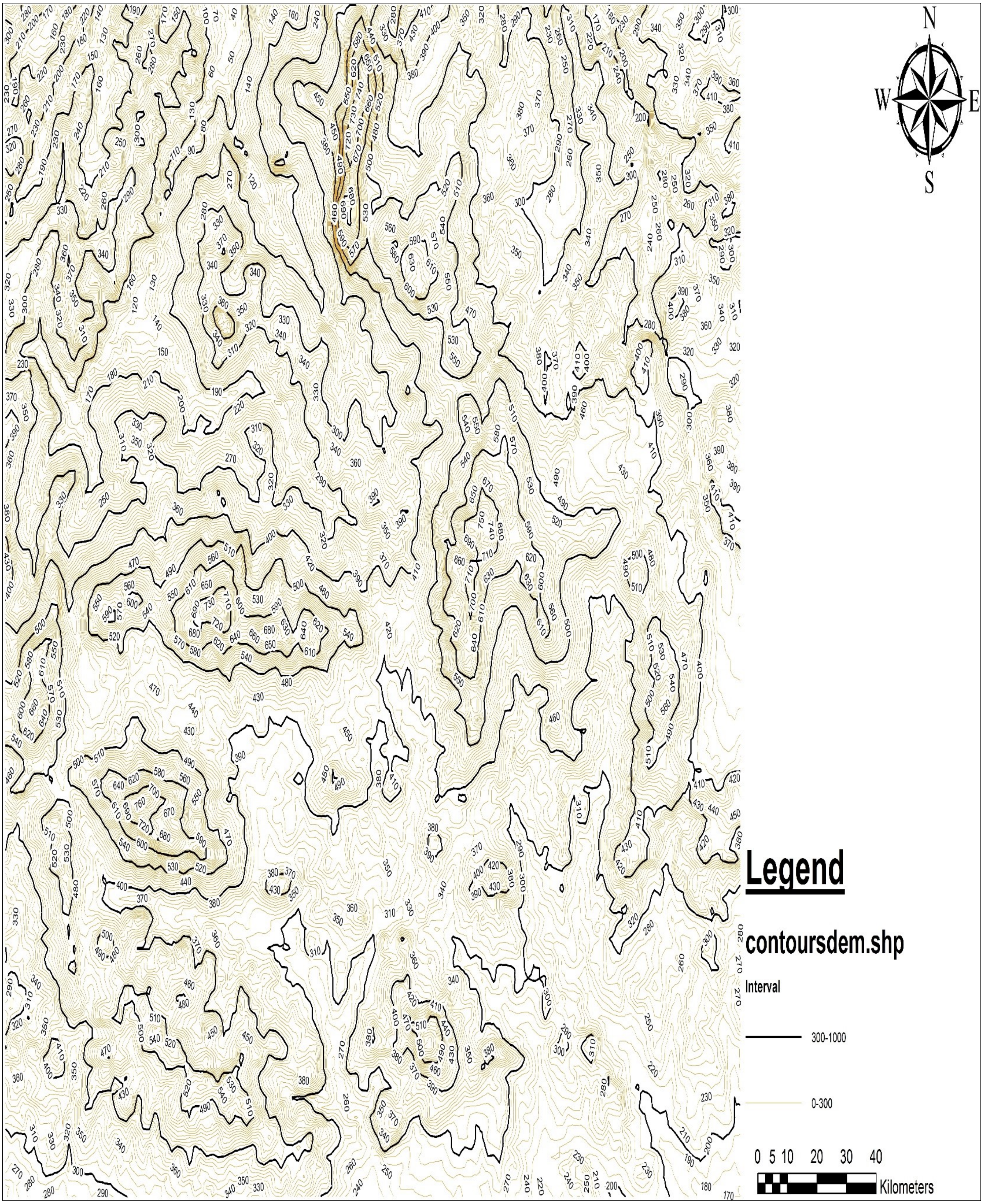


Figure 11: Topographic map of the AOI in meters. Higher elevation points between 700-760 meters, represent possible wind turbine installation.

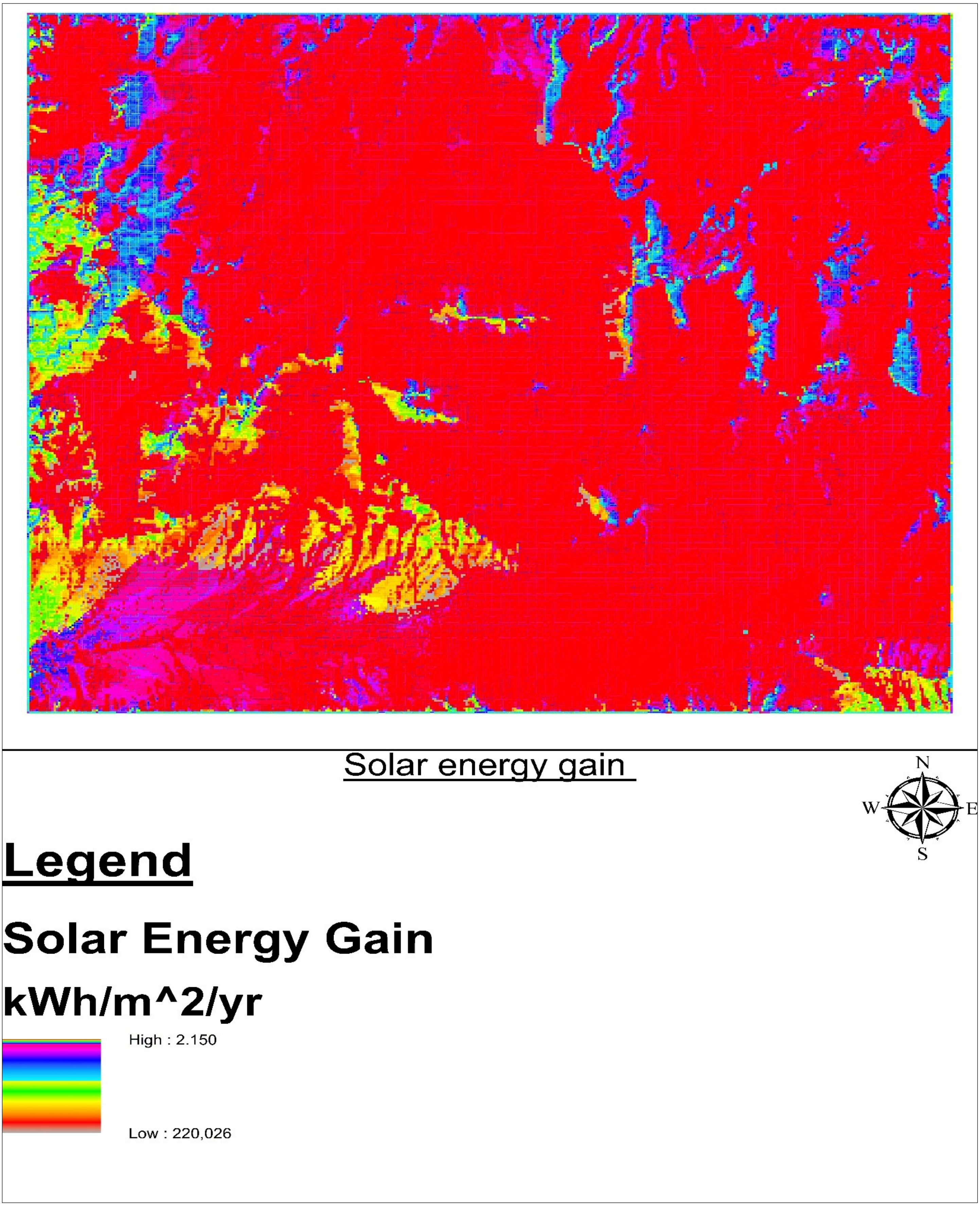


Figure 12: Average Direct Normal Irradiation (DNI) of the surrounding area in kWh/m^2/year. Solar radiation was set in annually measurement of year 2016, counting average monthly interval. Incoming solar radiation in this example, displays a minimum of 220,026 kWh/m^2/year and maximum of 2.150 kWh/m^2/year.

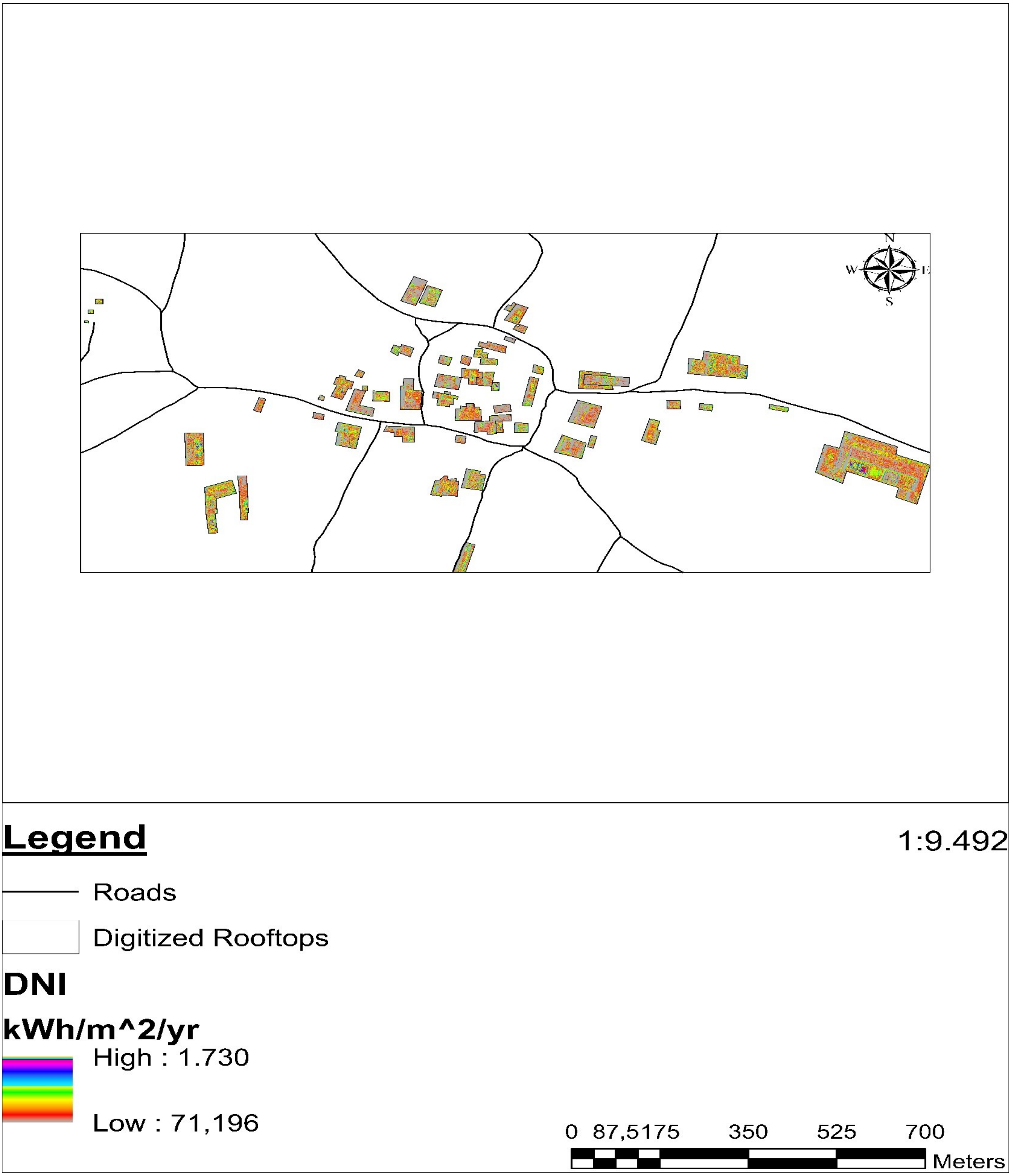


Figure 13: Digitized features of the study area with DNI calculation, specified analysis conducted in Figure 12. Incoming solar radiation on rooftops displays a minimum of 71,196 kWh/m^2/year and maximum of 1.730 kWh/m^2/year.

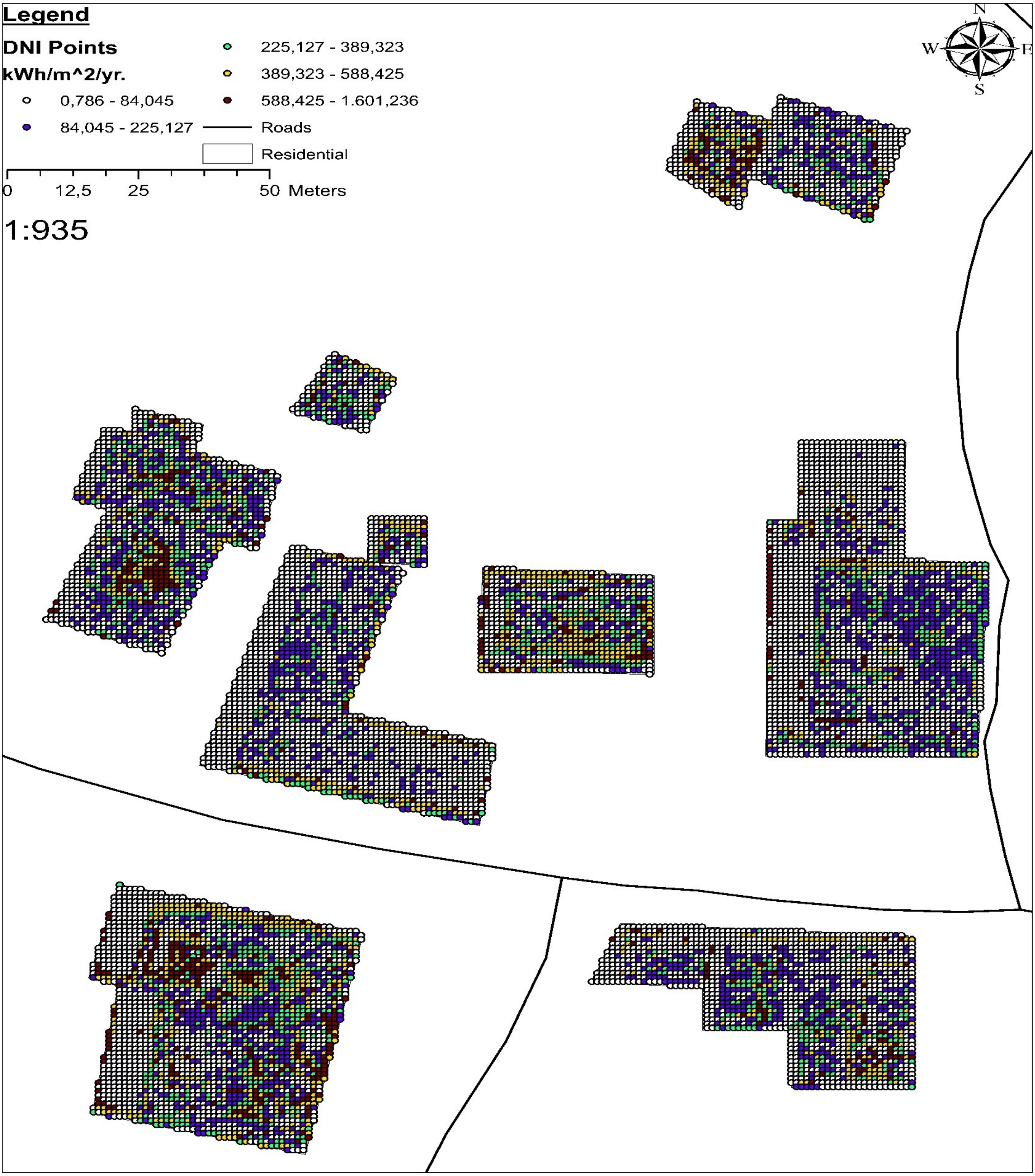


Figure 14: Point DNI on digitized rooftops. In this step, the solar radiation analysis is concentrated on point level, taking into account south orientation at 32° inclination, as optimum given parameters for PV installation for Crete. Incoming solar radiation in this sample of the total rooftops displays a minimum of 0,786 kWh/m^2/year and maximum of 1.601,236 kWh/m^2/year. The entire analysis presented a total of 428.432 kWh/m^2/year incoming radiation from rooftops, without considering technical specifications of PV installation.

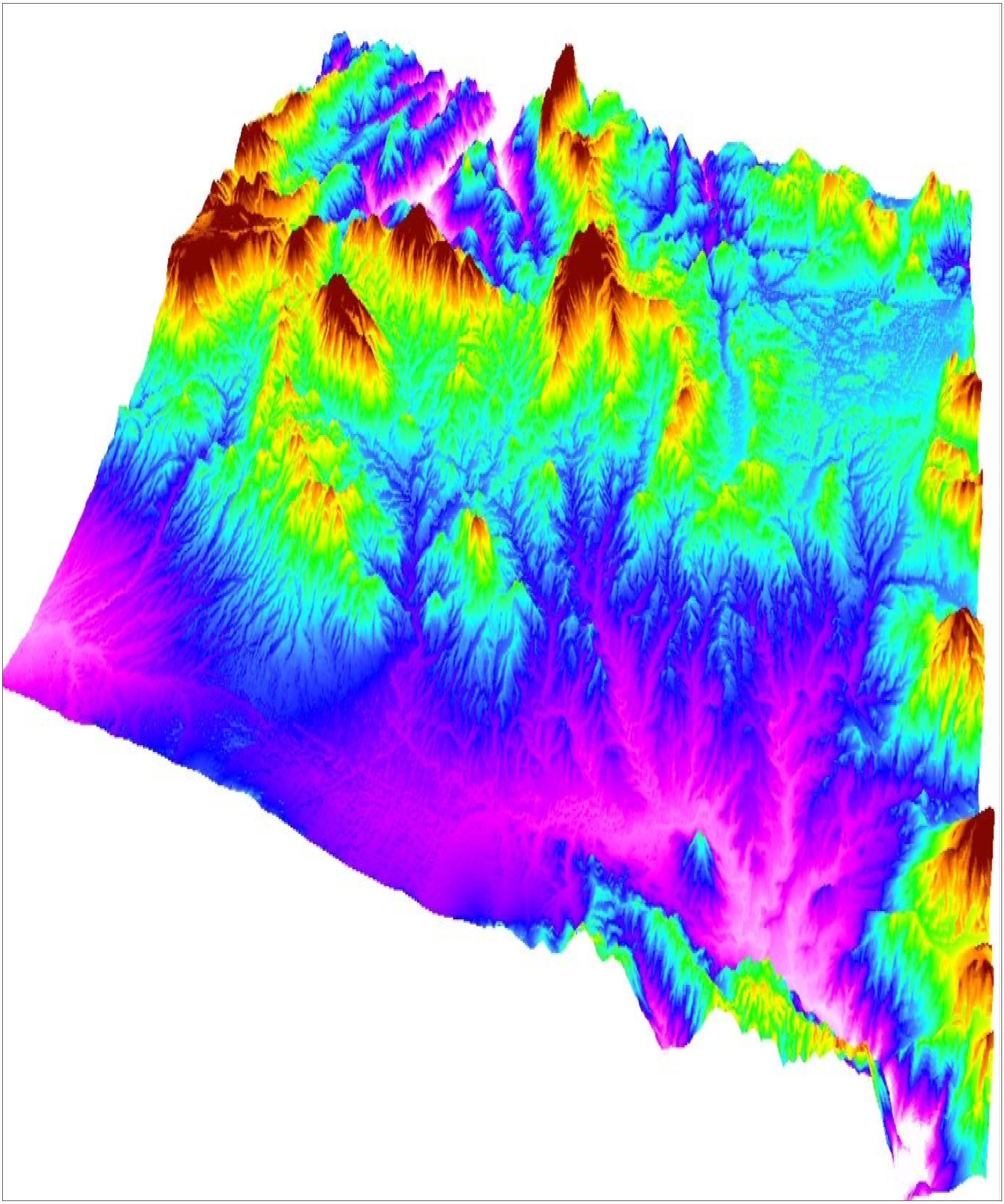


Figure 15: Three-dimensional imaging of the region of the study. As shown in the figure, the red parts of the map represent the points with the highest altitude.

5 CONCLUSION & DISCUSSION

This study sought out to answer the question if the design of a microgrid with renewable energy sources is feasible/viable, even in conditions of low energy efficiency and high installation cost (worst case scenarios). This work provides a high-level overview and proposes a method to model the tasks associated with energy, economic and environmental issues. The findings presented in this document are based on a methodology that has simplifications about system design and overall feasibility. Based on the findings, the microgrid of the present study is considered to be feasible (both techno-economically and environmentally) and attractive to investment. In summary, settlement of Vorias is considered as one "energy community" that can profit:

- Total average energy demand of the settlement, 468.416 kWh/year
- Total potential RES energy production, 507,50 MWh/year
- Total profits of RES energy sale, in accordance with excel calculations, 489.439,05 € & 145.501,81 € in NPV
- Total profits of PV energy sale in accordance with RETScreen software, 466.990 €
- Total profits of W/T energy sale in accordance with RETScreen software, 1.922.903 €
- Net GHG reduction, in accordance with excel calculations, 385,70 tons of ↑CO_2/year, 4,74 tons of ↑SO_X/year, 1 ton of ↑NO_X/year and 145.001,2 tons of oil/year not consumed
- Net GHG reduction, in accordance with RETScreen software, 59 tons of ↑CO2/year from PV, with 137,7 barrels of crude oil not consumed & 607 tons of ↑CO2/year from W/T, with 1.412,8 barrels of crude oil not consumed, respectively

∗This study was carried out with zero cost, as it used free access software and high-resolution satellite imagery.

5.1 Recommendations

What is the necessity of the use of GIS?

- Ability of improving the organizational integration (capture, analyze, manage, interpret and display all forms of information)
- Cost effective

- Rapid analysis
- Remote control (minimization of rural work)
- High level of quality analysis (controlled desired accuracy and therefore great reliability)
- Open to largely automation

In addition to the general properties of GIS, in the present study have a dominant role in the innovative development of RES and the microgrid in general. In parallel with the creation of maps of probability and dispersion of RES, the GIS offer alternative activities in the design and digital imaging in real time, in conjunction with social restrictions that may exist in the area. The use of GIS has shown that the ability was not limited only in the connection of geographical information between different levels of digitization, but also to activate/deactivate the various levels, depending on the desired analysis and the specific information we want to render. Regardless of their appearance or not, the digital maps of the study taken into account various constraints (technical, economical and environmental) which are listed below:

- Digital imaging of the existing electrical network
- Creation of the electrical network of the study's microgrid
- Quick faults identification and effective expansion of networks for future needs under constraints, through efficient management of assets
- Definition of zones of influence or exclusion (i.e. special protection areas "Natura 2000" and archaeological sites)
- Location of specific social security regulations (i.e. distance from cities, settlements, coastline, military zones and airports)
- Digitization of planning data (i.e. roads, houses and public domain buildings)
- Topographic maps that include data of the slope of terrain and altitude difference, for the selection of the possible location of wind farms installation, in accordance with the restrictions referred above (Figure 11, Figure 15)
- Although solar radiation is one of the largest factors in calculating photovoltaic generation potential, other factors like technology, orientation and maintenance play important roles as well. Considering average incoming solar radiation on rooftops, the spatial join tool was used to create a final feature class layer containing the average elevation, slope and solar radiation for each rooftop. In Figure 12, Figure 13 and Figure 14, this method also serves to identify the exact spot where the incoming solar radiation is more intense, for the selection of the best possible installation of photovoltaic panels in the rooftop buildings.
- It is important to notice that the specific methodology for the calculation of the wind and solar potential is based on free data and maps, analysis of

5-15 meters. The results could have been obtained with a different and much more detailed way, of the map of the AOI was purchased. Buying a map cost 360 € per 25 km^2 and offers a high resolution (0,5 cm on the surface and 100 meters underground), as well as providing data from at least 9 different frequencies (bands of light) that can yield maps of high-definition, both for the calculation of the wind and solar potential of the region under specific remote-sensed methods, in comparison with the conventional time-consuming and expensive analyses with are usually made in such projects

5.2 Other GIS applications in power systems in Greece

In accordance with the study development of transmission system of the Hellenic Transmission System Operator (HTSO) and the Regulatory Authority for Energy (RAE), occurs with regard to the interconnection projects of the Cyclades islands with the continental system, that has been completed already an important part of the planned projects. The islands to be interconnected with the mainland are Andros, Tinos, Syros, Mykonos, Paros and Naxos, with the construction of aerial and underwater components of the interconnection. During the year 2003 was completed the installation of a provisional substation (150/20 kV) in Andros, while in 2005 was completed the work for the installation of the permanent substation in Andros. The underwater cable between Andros-Tinos works on 20 kV for powering of the loads of Tinos. These interconnection projects were further examined through GIS analysis [60], [61].

Figure 16: Distribution of RES installations in Greece [61].

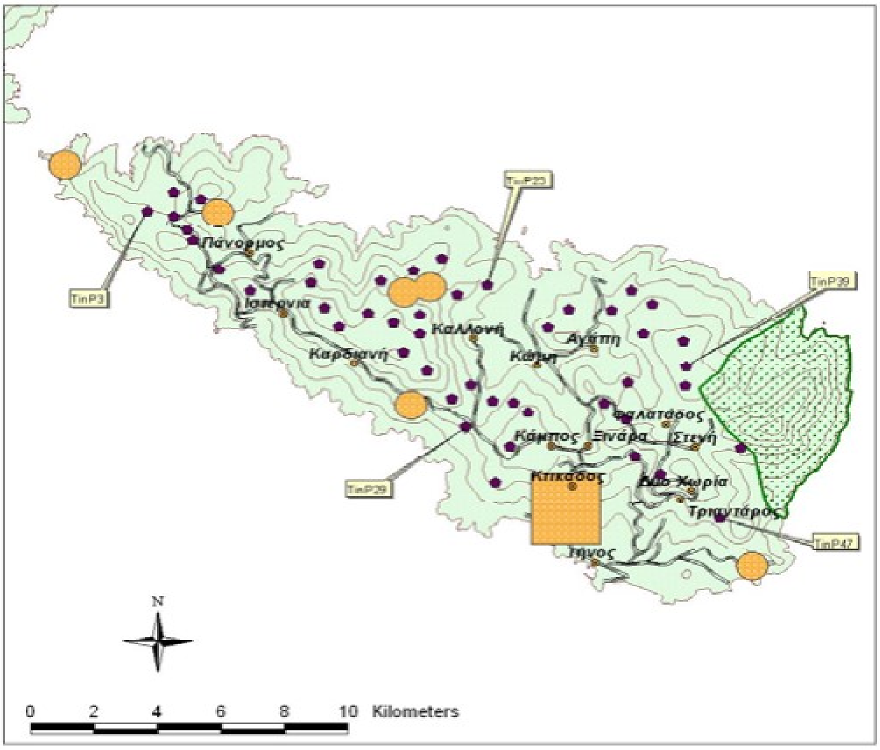


Figure 17: GIS-possible W/P on Tinos Island [61].

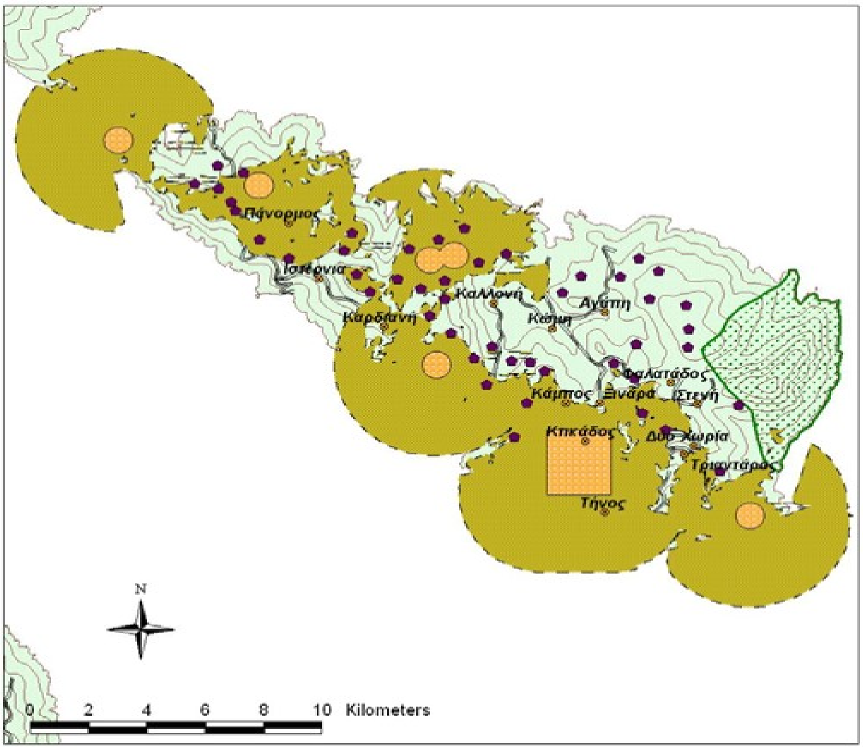


Figure 18: GIS-possible W/P on Tinos Island with visibility from ancient monuments filter enabled [61].

5.3 Area of application: location & characteristics

Figure 19: Location of Vorias village from Google Maps.

Vorias is a small village of the prefecture of Heraklion with 73 residents (national statistical service census of population). It is located at an altitude of 310 m, at a distance of 35 km from Heraklion city and belongs to the local community of Charaki, at the municipality of Asterousia. The residents deal mainly with agriculture of olive trees and vineyards. The choice of this particular settlement was made on the basis of intense relief that presents the region (mountain ranges suitable for the installation of wind farms and plains for the installation of photovoltaic systems), as well as the surrounding area does not fall within specific constraints (special protection areas “Natura 2000” and archaeological zones etc.).

In the area are already installed or under assessment of photovoltaic parks, which are represented in the next map of the regulatory authority for energy (RAE):

Figure 20: RAE map of installed or under assessment of interconnected photovoltaic parks (marked polygon areas) in the wider area of the implementation of the study, with installed power capacity >=1 MW.

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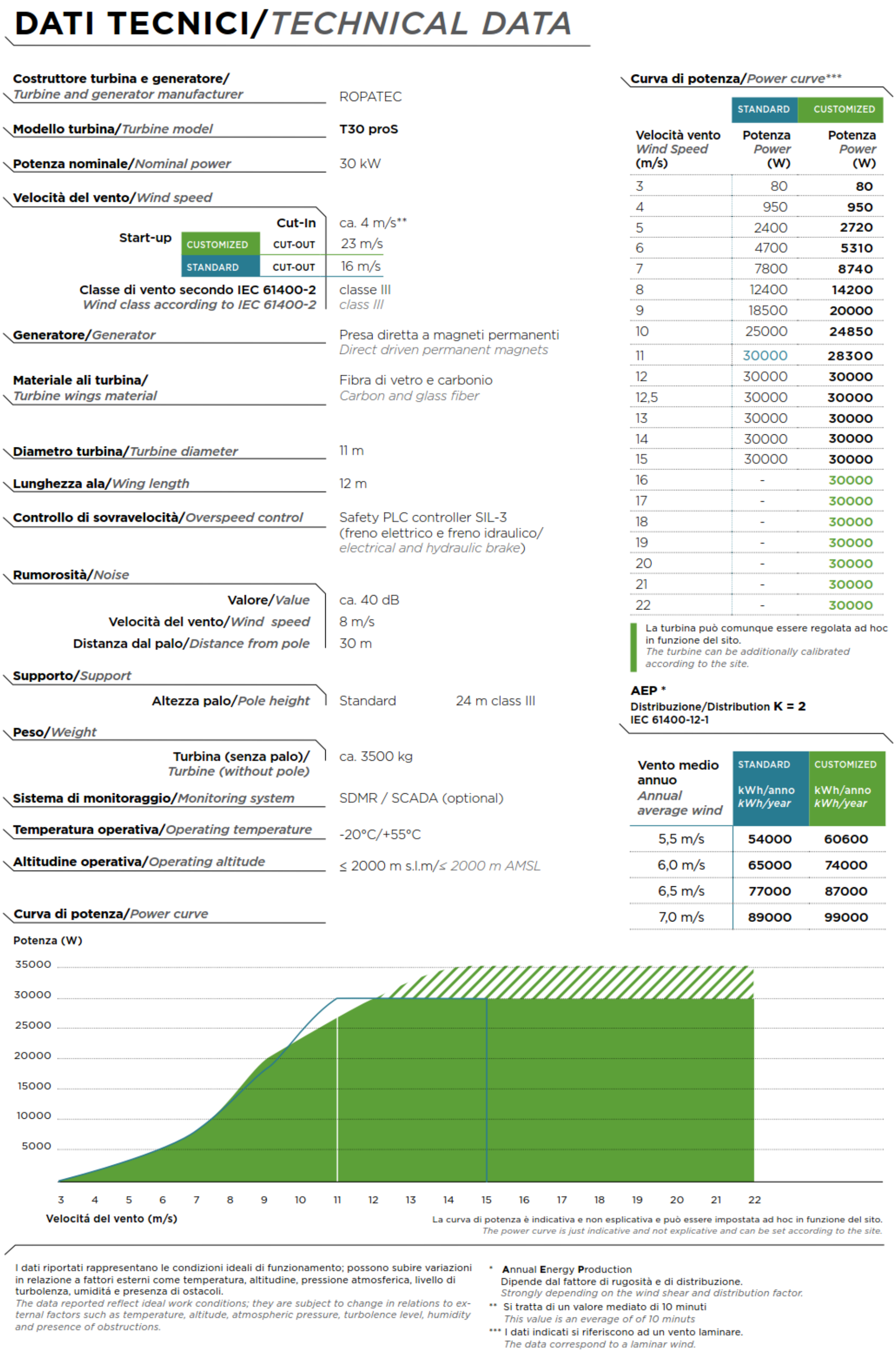
7 APPENDIX

Figure 21: Chosen vertical wind turbine of the study, Ropatec T30 proS.



DATI TECNICI/*TECHNICAL DATA*

Costruttore turbina e generatore/ *Turbine and generator manufacturer*	ROPATEC	
Modello turbina/*Turbine model*	**T30 proS**	
Potenza nominale/*Nominal power*	30 kW	
Velocità del vento/*Wind speed*		
Start-up **Cut-In**	ca. 4 m/s**	
CUSTOMIZED CUT-OUT	23 m/s	
STANDARD CUT-OUT	16 m/s	
Classe di vento secondo IEC 61400-2 *Wind class according to IEC 61400-2*	classe III *class III*	
Generatore/*Generator*	Presa diretta a magneti permanenti *Direct driven permanent magnets*	
Materiale ali turbina/ *Turbine wings material*	Fibra di vetro e carbonio *Carbon and glass fiber*	
Diametro turbina/*Turbine diameter*	11 m	
Lunghezza ala/*Wing length*	12 m	
Controllo di sovravelocità/*Overspeed control*	Safety PLC controller SIL-3 (freno elettrico e freno idraulico/ *electrical and hydraulic brake*)	
Rumorosità/*Noise*		
Valore/*Value*	ca. 40 dB	
Velocità del vento/*Wind speed*	8 m/s	
Distanza dal palo/*Distance from pole*	30 m	
Supporto/*Support*		
Altezza palo/*Pole height*	Standard	24 m class III
Peso/*Weight*		
Turbina (senza palo)/ *Turbine (without pole)*	ca. 3500 kg	
Sistema di monitoraggio/*Monitoring system*	SDMR / SCADA (optional)	
Temperatura operativa/*Operating temperature*	-20°C/+55°C	
Altitudine operativa/*Operating altitude*	≤ 2000 m s.l.m/*≤ 2000 m AMSL*	

Curva di potenza/*Power curve****

	STANDARD	CUSTOMIZED
Velocità vento *Wind Speed* **(m/s)**	**Potenza** *Power* **(W)**	**Potenza** *Power* **(W)**
3	80	**80**
4	950	**950**
5	2400	**2720**
6	4700	**5310**
7	7800	**8740**
8	12400	**14200**
9	18500	**20000**
10	25000	**24850**
11	30000	**28300**
12	30000	**30000**
12,5	30000	**30000**
13	30000	**30000**
14	30000	**30000**
15	30000	**30000**
16	-	**30000**
17	-	**30000**
18	-	**30000**
19	-	**30000**
20	-	**30000**
21	-	**30000**
22	-	**30000**

La turbina può comunque essere regolata ad hoc in funzione del sito.
The turbine can be additionally calibrated according to the site.

AEP *
Distribuzione/Distribution K = 2
IEC 61400-12-1

Vento medio annuo *Annual average wind*	STANDARD kWh/anno *kWh/year*	CUSTOMIZED kWh/anno *kWh/year*
5,5 m/s	**54000**	**60600**
6,0 m/s	**65000**	**74000**
6,5 m/s	**77000**	**87000**
7,0 m/s	**89000**	**99000**

Curva di potenza/*Power curve*

La curva di potenza è indicativa e non esplicativa e può essere impostata ad hoc in funzione del sito.
The power curve is just indicative and not explicative and can be set according to the site.

I dati riportati rappresentano le condizioni ideali di funzionamento; possono subire variazioni in relazione a fattori esterni come temperatura, altitudine, pressione atmosferica, livello di turbolenza, umiditá e presenza di ostacoli.
The data reported reflect ideal work conditions; they are subject to change in relations to external factors such as temperature, altitude, atmospheric pressure, turbolence level, humidity and presence of obstructions.

* **A**nnual **E**nergy **P**roduction
Dipende dal fattore di rugosità e di distribuzione.
Strongly depending on the wind shear and distribution factor.

** Si tratta di un valore mediato di 10 minuti
This value is an everage of of 10 minuts

*** I dati indicati si riferiscono ad un vento laminare.
The data correspond to a laminar wind.

Table 42: Technical data/characteristics of Ropatec T30 proS wind turbine.

ReneSola

Virtus® II (5BB)

Virtus®II Module

315W/320W/325W/330W/335W

Efficiency — **High Module Conversion Efficiencies**

Easy & Quick — **Easy Installation and Handling for Various Applications**

2400Pa - 5400Pa — **Mechanical Load Capability up to 5400 Pa**

IEC & — **Conforms with IEC 61215:2005, IEC 61730:2004, UL 1703 PV Standards**

Certification — **ISO9001, ISO14001, OHSAS18001 Certified**

Safety & Fire — **Application Class A, Safety Class II, Fire Rating Class C**

Applicable For Modules With Black Frame and Diamond Wire Slicing Wafer

Guarantee

10-year material& workmanship

25-year linear power output

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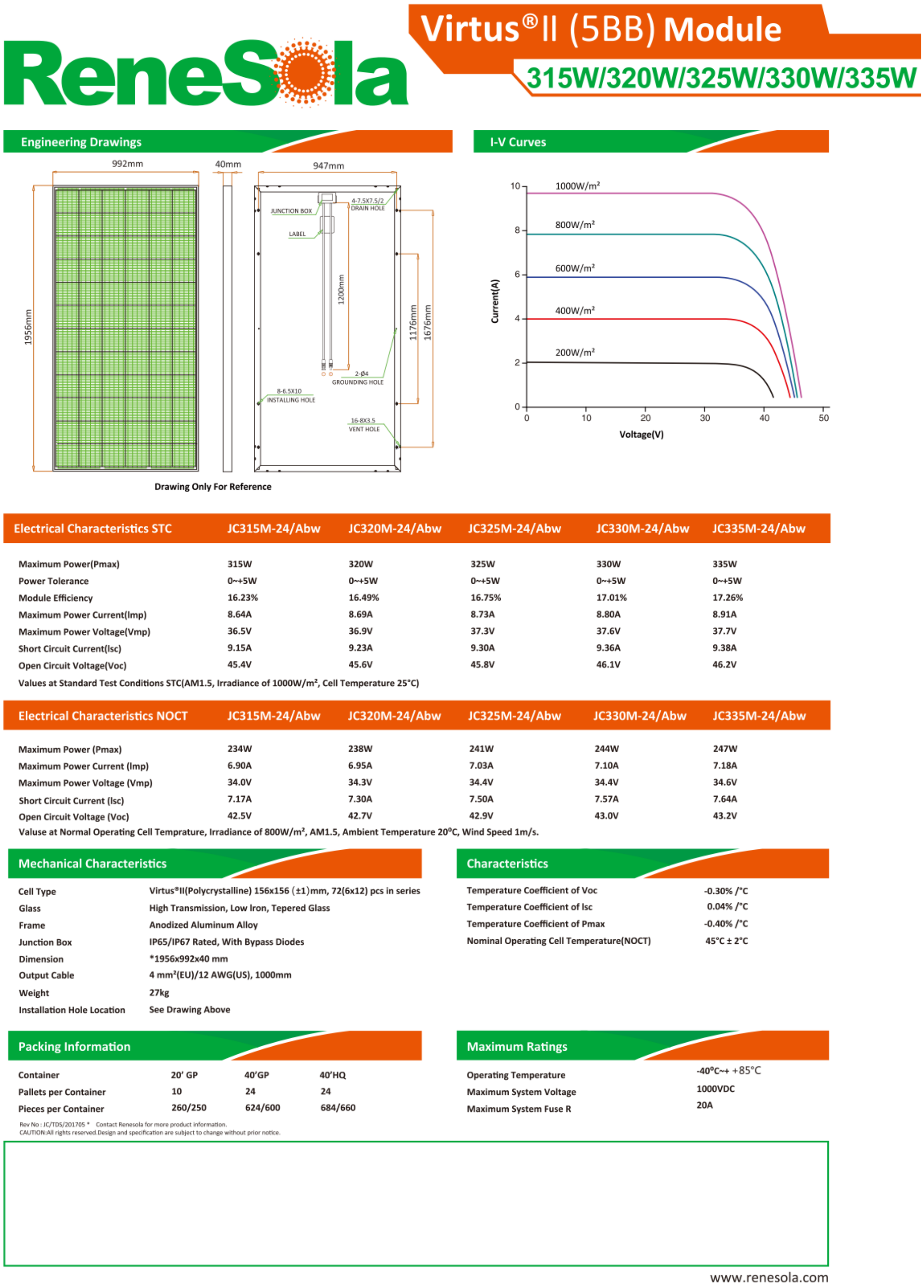
Figure 22: Chosen photovoltaic panel of the study, ReneSola Virtus 2 module (335 W).



ReneSola

Virtus®II (5BB) Module

315W/320W/325W/330W/335W

Engineering Drawings

Drawing Only For Reference

I-V Curves

Electrical Characteristics STC	JC315M-24/Abw	JC320M-24/Abw	JC325M-24/Abw	JC330M-24/Abw	JC335M-24/Abw
Maximum Power(Pmax)	315W	320W	325W	330W	335W
Power Tolerance	0~+5W	0~+5W	0~+5W	0~+5W	0~+5W
Module Efficiency	16.23%	16.49%	16.75%	17.01%	17.26%
Maximum Power Current(Imp)	8.64A	8.69A	8.73A	8.80A	8.91A
Maximum Power Voltage(Vmp)	36.5V	36.9V	37.3V	37.6V	37.7V
Short Circuit Current(Isc)	9.15A	9.23A	9.30A	9.36A	9.38A
Open Circuit Voltage(Voc)	45.4V	45.6V	45.8V	46.1V	46.2V

Values at Standard Test Conditions STC(AM1.5, Irradiance of 1000W/m², Cell Temperature 25°C)

Electrical Characteristics NOCT	JC315M-24/Abw	JC320M-24/Abw	JC325M-24/Abw	JC330M-24/Abw	JC335M-24/Abw
Maximum Power (Pmax)	234W	238W	241W	244W	247W
Maximum Power Current (Imp)	6.90A	6.95A	7.03A	7.10A	7.18A
Maximum Power Voltage (Vmp)	34.0V	34.3V	34.4V	34.4V	34.6V
Short Circuit Current (Isc)	7.17A	7.30A	7.50A	7.57A	7.64A
Open Circuit Voltage (Voc)	42.5V	42.7V	42.9V	43.0V	43.2V

Valuse at Normal Operating Cell Temprature, Irradiance of 800W/m², AM1.5, Ambient Temperature 20°C, Wind Speed 1m/s.

Mechanical Characteristics

Cell Type	Virtus®II(Polycrystalline) 156x156 (±1)mm, 72(6x12) pcs in series
Glass	High Transmission, Low Iron, Tepered Glass
Frame	Anodized Aluminum Alloy
Junction Box	IP65/IP67 Rated, With Bypass Diodes
Dimension	*1956x992x40 mm
Output Cable	4 mm²(EU)/12 AWG(US), 1000mm
Weight	27kg
Installation Hole Location	See Drawing Above

Characteristics

Temperature Coefficient of Voc	-0.30% /°C
Temperature Coefficient of Isc	0.04% /°C
Temperature Coefficient of Pmax	-0.40% /°C
Nominal Operating Cell Temperature(NOCT)	45°C ± 2°C

Packing Information

Container	20' GP	40'GP	40'HQ
Pallets per Container	10	24	24
Pieces per Container	260/250	624/600	684/660

Maximum Ratings

Operating Temperature	-40°C~+ +85°C
Maximum System Voltage	1000VDC
Maximum System Fuse R	20A

Rev No : JC/TDS/201705 * Contact Renesola for more product information.
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Table 43: Technical data/characteristics of ReneSola Virtus 2 module (335 W).