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RESEARCH AND DESIGN OF POWER INFRASTRUCTURE FOR THE TRANSFORMATION OF A GREEK ISLAND INTO A SMART ISLAND

DISSERTATION

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ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ ΑΘΗΝΑΣ
ΣΧΟΛΗ ΧΗΜΙΚΩΝ ΜΗΧΑΝΙΚΩΝ

ΤΟΜΕΑΣ ΙΙ
ΕΡΓΑΣΤΗΡΙΟ ΒΙΟΜΗΧΑΝΙΚΗΣ & ΕΝΕΡΓΕΙΑΚΗΣ ΟΙΚΟΝΟΜΙΑΣ

ΕΡΕΥΝΑ ΚΑΙ ΣΧΕΔΙΑΣΜΟΣ ΕΝΕΡΓΕΙΑΚΗΣ ΥΠΟΔΟΜΗΣ ΓΙΑ ΜΕΤΑΤΡΟΠΗ ΕΛΛΗΝΙΚΟΥ ΝΗΣΙΟΥ ΣΕ ΕΞΥΠΝΟ ΝΗΣΙ

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Preface

The current dissertation has been conducted in the School of Chemical Engineering in the department of Economics and Business Administration during the year of 2020-2021, under the supervision of Associate Professor Mr. Aggelos Tsakanikas.

The basis for this research originally stemmed from my passion for developing sustainable methods and scenarios to power remote areas and communities that face serious electrification and other relevant to power supply issues. As the world moves further into the digital-eco-friendly age, and new technologies arise, there will be a greater need to put them in action and give those communities access to green and zero-emission, reliable energy to power their residences and businesses.

The topic and the relevant study points came after my working experience in Gommyr Power Networks, a renewable energy systems advisor and project developer company with a focus on solar PV microgrids and battery energy storage. While working there I gained experience and knowledge to support and study the idea of transforming distant islands with electrification issues into smart and intelligent hubs that can be sustained through the exploitation of local renewable energy sources.

For this research I would like to thank my supervisor Mr. Aggelos Tsakanikas for the trust and support for this initiative. Moreover, I could not have achieved my current level of success without the support of Dr. Aimilia Protogerou – Laboratory Teaching Stuff who provided patient advice and guidance throughout the research process. I would also like to thank Gommyr Power Networks, for sharing their knowledge and sources for this study.

Last but not least, I would like to thank my fellow colleagues that were a good companion on this journey that has finally come to an end. Thanks again to all the aforementioned contributors, I now can be called a Graduate Chemical Engineer of National Technical University of Athens.

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Table of Abbreviations

Abbreviation	Meaning
AC	Alternative Current
AMPIG	Average Marginal Price of the Interconnected Electricity Grid
AVC	Average Variable Cost
BO	Back Office
CAPEX	Capital Expenditure
CE	Civil Engineer
CEEP	European Centre of Employers and Enterprises
CHP	Combined Heat and Power
CO2	Carbon Dioxide
DC	Direct Current
DCDB	Direct Current Distribution Box
ELSTAT	Hellenic Statistical Authority
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gas
H2	Hydrogen
HEDNO	Hellenic Electricity Distribution Network Operator
ICT	Information of Communications Technology
ID	Identity Document
IEA	International Energy Agency
IEG	Interconnected Electricity Grid
IT	Information Technology
LED	Light Emitting Diode

Li-ion	Lithium-Ion
LPG	Liquefied Petroleum Gas
LVAC	Low Voltage Alternative Current
MPPT	Maximum Power Point Tracking
N/A	Not Available
NIIS	Non-Interconnected Islands
O&M	Operation & Maintenance
OPEX	Operating Expense
PD	Project Director
PM	Project Manager
PPC	Public Power Corporation
PSO	Public Service Obligation
PV	Photovoltaics
QR	Quick Response
RAE	Regulatory Authority for Energy
RES	Renewable Energy Sources
RFQ	Request for Quotation
RME	Rapeseed methyl ester
SCU	Service for common Utilities
SE	Supporting Engineer
SES	Scenario Exploration System
SLD	Single Line Diagram
SM	Site Manager
TFEC	Total Final Energy Consumption
TPES	Total Energy Supply
US	United States

VAC	Ventilation and Air-Conditioning
Wi-Fi	Wireless Fidelity
WP	Work Package

Units of measurement

Units	Meaning
EJ	Exajoules
GJ	Gigajoules
Gt	Giga tonnes
GW	Gigawatt
h/hr	hours
K	Kelvin
kW	Kilowatt
kWh	Kilowatt-hour
L	Litres
m/s	Meter per second
min	minutes
MW	Megawatt
MWh	Megawatt hours
PW	Petawatt
RPM	Revolutions per minute
TW	Terawatt
W	Watt

Abstract

The principal aim of this research is to investigate the possible scenarios which are adequate to substitute the current energy system in the Greek islands and identify the most feasible scenarios contributing to the development plans for specific islands that have high costs of connecting their electricity supply system to the mainland. Therefor the development of a microgrid solution under the umbrella of smart islands initiative is researched.

Before getting in depth on the analysis of the scenarios, a general research is conducted to understand the current energy status worldwide and in Greece. Moreover, a breakdown of the technologies is being analysed in order to understand and choose the most fit technologies for this investigation.

The first stage of the analysis is the creation and modelling of a reference scenario which represents as realistic as possible the current energy system in Astypalea and the energy balance characteristics. These concern the fuel utilization types, energy sources mostly used and the profiles in the demand and supply side.

The second stage includes the development and modelling of one suggested alternative scenario which is capable to fulfil the existing demands, substituting the reference scenario and respond to the goals set in the research question. This alternative scenario is created based on the reference scenario data and according to the Smart Energy System concept.

The third stage includes the workplan for the development of the alternative scenario, including detailed workforce and table of work packages and deliverables.

The fourth stage is the financial aspect of the project that includes a detailed budget regarding development and operation.

The results of the simulations for the alternative scenario are presented and analysed, following by a discussion regarding the uncertainties and the need for sensitivity analysis to test the robustness of the results and identify connections between inputs and outputs. In this way crucial information is obtained regarding the factors which may alter the results in case of being changed even though the sensitivity analysis is not realized. It stands though as a better understanding of the results and conclusions made and how these might change.

Finally, the sensitivity factors and uncertainties in calculations are outlined and discussed regarding possible influences, followed by a general discussion.

Keywords: Smart Islands, Renewable Energy, Energy Storage Technologies, Solar Systems, Battery Storage, Smart Technologies, Greek Islands, Project Development, Project Management, Project Budgeting

Περίληψη

Κύριος στόχος της παρούσας έρευνας είναι η διερεύνηση των πιθανών σεναρίων που επαρκούν για την αντικατάσταση του σημερινού ενεργειακού συστήματος στην Αστυπάλαια.

Πριν εμβαθύνουμε στην ανάλυση των σεναρίων, διεξάγεται μια γενική έρευνα για την κατανόηση της τρέχουσας ενεργειακής κατάστασης παγκοσμίως και στην Ελλάδα. Επιπλέον, γίνεται ανάλυση των τεχνολογιών προκειμένου να κατανοηθούν και να επιλεγούν οι πλέον κατάλληλες τεχνολογίες για την έρευνα αυτή.

Το πρώτο στάδιο της έρευνας είναι η δημιουργία και μοντελοποίηση ενός σεναρίου αναφοράς το οποίο αντιπροσωπεύει όσο το δυνατόν πιο ρεαλιστικά το σημερινό ενεργειακό σύστημα στην Αστυπάλαια και τα χαρακτηριστικά του ενεργειακού ισοζυγίου. Αυτά αφορούν τους τύπους χρήσης καυσίμων, τις πηγές ενέργειας που χρησιμοποιούνται ως επί το πλείστον και τα προφίλ στην πλευρά της ζήτησης και της προσφοράς.

Το δεύτερο στάδιο περιλαμβάνει την ανάπτυξη και μοντελοποίηση ενός προτεινόμενου εναλλακτικού σεναρίου το οποίο είναι ικανό να εκπληρώσει τις υπάρχουσες απαιτήσεις, αντικαθιστώντας το σενάριο αναφοράς και ανταποκρινόμενο στους στόχους που τίθενται στην ερευνητική ερώτηση. Αυτό το εναλλακτικό σενάριο δημιουργείται με βάση τα δεδομένα σεναρίου αναφοράς και σύμφωνα με την έννοια του έξυπνου ενεργειακού συστήματος.

Το τρίτο στάδιο περιλαμβάνει το σχέδιο εργασίας για την ανάπτυξη του εναλλακτικού σεναρίου, συμπεριλαμβανομένου λεπτομερούς εργατικού δυναμικού και πίνακα πακέτων εργασίας και παραδοτέων.

Το τέταρτο στάδιο είναι η οικονομική πτυχή του έργου που περιλαμβάνει λεπτομερή προϋπολογισμό για την ανάπτυξη (CAPEX) και τη λειτουργία (OPEX) του εναλλακτικού σεναρίου.

Τα αποτελέσματα των προσομοιώσεων για το εναλλακτικό σενάριο παρουσιάζονται και αναλύονται, μετά από μια συζήτηση σχετικά με τις αβεβαιότητες και την ανάγκη για ανάλυση ευαισθησίας για να ελεγχθεί η ευρωστία των αποτελεσμάτων και να προσδιοριστούν οι συνδέσεις μεταξύ εισροών και εκροών. Με τον τρόπο αυτό λαμβάνονται κρίσιμες πληροφορίες σχετικά με τους παράγοντες που μπορούν να μεταβάλουν τα αποτελέσματα σε περίπτωση αλλαγής, παρόλο που η ανάλυση ευαισθησίας δεν πραγματοποιείται. Στέκεται όμως ως μια καλύτερη κατανόηση των αποτελεσμάτων και των συμπερασμάτων που έγιναν και πώς αυτά μπορεί να αλλάξουν.

Τέλος, περιγράφονται και συζητούνται οι παράγοντες ευαισθησίας και οι αβεβαιότητες στους υπολογισμούς σχετικά με τις πιθανές επιρροές, ακολουθούμενη από μια γενική συζήτηση.

Εκτεταμένη Περίληψη

Εισαγωγή

Η παρούσα διπλωματική αρχικά κάνει μια ανάλυση του τομέα ενέργειας ο οποίος έχει αρχίσει να αλλάζει με πολλά υποσχόμενους τρόπους με την παγκόσμια υιοθέτηση τεχνολογιών ανανεώσιμων πηγών ενέργειας (ΑΠΕ) με στόχο ένα βιώσιμο και πιο πράσινο μέλλον. Ήταν η δεκαετία του 1970, όταν οι περιβαλλοντολόγοι προώθησαν την ανάπτυξη ανανεώσιμων πηγών ενέργειας τόσο ως αντικατάσταση της ενδεχόμενης εξάντλησης των ορυκτών καυσίμων, όσο και ως απόδραση από την εξάρτηση από το πετρέλαιο [1]. Τώρα, οι τεχνολογίες ανανεώσιμων πηγών ενέργειας κυριαρχούν στην παγκόσμια αγορά για νέα δυναμικότητα παραγωγής ενέργειας. Η ηλιακή-φωτοβολταϊκή και η αιολική ενέργεια είναι όλο και περισσότερο οι φθηνότερες πηγές ηλεκτρικής ενέργειας σε πολλές αγορές και οι περισσότερες από τις άλλες ανανεώσιμες πηγές ενέργειας θα είναι πλήρως ανταγωνιστικές μέσα στην επόμενη δεκαετία.

Μετά από εκτεταμένη ανάλυση των κύριων ανανεώσιμων πηγών ενέργειας στο Κεφάλαιο 1, καταλήξαμε στα παρακάτω συμπεράσματα όσον αφορά το κόστος και την αποδοτικότητα τους.

Ενέργεια βιομάζας:

Η ενέργεια της βιομάζας δεν μπορεί να χαρακτηριστεί ως ένας αποτελεσματικός τρόπος παραγωγής ενέργειας για ένα πολύπλοκο περιβάλλον, όπως τα ελληνικά νησιά, καθώς τα εδάφη είναι στεγνά με αυξημένη αλατότητα που καθιστά δύσκολη την καλλιέργεια ενεργειακών φυτειών. Επιπλέον, τα απόβλητα που παράγουν οι ντόπιοι δεν επαρκούν για την κάλυψη όλων των ενεργειακών απαιτήσεων. Ωστόσο, η ενέργεια της βιομάζας μπορεί να χρησιμοποιηθεί ως δευτερεύουσα πηγή ηλεκτρικής ενέργειας σε μεταγενέστερο στάδιο στα πλαίσια της ανάπτυξης του «έξυπνου νησιού» και μιας πιο πράσινης λύσης για την ανακύκλωση των αποβλήτων.

Αιολική ενέργεια:

Η αιολική ενέργεια δεν είναι επίσης μια αποτελεσματική ενεργειακή λύση για τα κατοικημένα ελληνικά νησιά, καθώς όπως αναφέρθηκε είναι δαπανηρές επενδύσεις με περιβαλλοντικές επιπτώσεις και όχι κατάλληλες λύσεις για κατοικημένες περιοχές, όπως τα νησιά που στοχεύουμε σε αυτήν την έρευνα. Μια καλύτερη χρήση αυτής της τεχνολογίας θα ήταν στα ακατοίκητα ξηρά νησιά όπου το κόστος για υποθαλάσσιες συνδέσεις δεν θα είναι υψηλό και οι αποστάσεις θα έχουν νόημα στο να επενδύσουμε σε αυτού του είδους τη λύση. Ωστόσο, ακόμη και με αυτό το ενεργειακό σενάριο, μπορεί να χαρακτηριστεί ως μη οικονομικά αποδοτική λύση, καθώς υπάρχουν και άλλες λύσεις όπως τα φωτοβολταϊκά ενεργειακά συστήματα που ταιριάζουν καλύτερα στο σενάριό μας.

Φωτοβολταϊκή ηλιακή ενέργεια:

Συμπερασματικά, η φωτοβολταϊκή ενέργεια είναι το καλύτερο σενάριο που χρησιμοποιείται για τα απομακρυσμένα ελληνικά νησιά, δεδομένου ότι αποτελούν μια πολλά υποσχόμενη οικονομική λύση και ιδανική για τα νησιά-στόχους και ως εκ τούτου θα χρησιμοποιηθεί στην ανάλυση αυτής της έρευνας. Εκτός από την τεχνική προοπτική, χάρη στην ταχεία μείωση του κόστους και των υλικών, το καθιστά μία από τις πιο προσιτές και αξιόπιστες λύσεις για το συγκεκριμένο περιβάλλον στο οποίο εστιάζει αυτή η έρευνα.

Για τις ανάγκες αυτής της έρευνας θα χρησιμοποιηθούν για τον σχεδιασμό οι τεχνολογίες της ηλιακής ενέργειας, συγκεκριμένα των φωτοβολταικών συστημάτων σε συνδυασμό με τεχνολογίες αποθήκευσης, συγκεκριμένα μπαταρίες λιθίου καθώς τα τελευταία χρόνια η χρήση τους είναι συνηθής και οι πιο οικονομικές τεχνολογίες στην αγορά.

Επίσης έγινε και μια μικρή ανάλυση σχετικά με τις έξυπνες τεχνολογίες που μπορούν να εφαρμοσθούν για και να ενσωματωθούν στο σύστημα ενέργειας προκειμένου να διασφαλιστεί η ομαλή παραγωγή και παροχή ηλεκτρικού ρεύματος για την ικανοποίηση των απαιτήσεων του νησιού.

Τέλος, προκειμένου λοιπόν για να αποκτήσουμε μια εικόνα για την ανάπτυξη των συγκεκριμένων συστημάτων στην Ελλάδα, γίνεται μια ανάλυση του τομέα ενέργειας και των συστημάτων που λειτουργούν αυτή την στιγμή στην χώρα στο επόμενο Κεφάλαιο.

Ενέργεια στην Ελλάδα

Στο Κεφάλαιο 2 γίνεται αρχικά μια ανάλυση του τομέα ενέργειας στην Ελλάδα με τα εξής ευρήματα. Το καύσιμο που επικρατεί στον Ελληνικό ενεργειακό τομέα είναι το πετρέλαιο, αντιπροσωπεύοντας περίπου το 51% του TPES (Total Primary Energy Supply) για το έτος 2019. Η Ελλάδα κατέχει τη δεύτερη θέση στη χρήση πετρελαίου μεταξύ των χωρών μελών της IEA (International Energy Agency) και εξαρτάται σχεδόν αποκλειστικά από τις εισαγωγές πετρελαίου. Ο άνθρακας είναι το δεύτερο πιο κυρίαρχο καύσιμο με μερίδιο 23% στο TPES κατά το έτος 2019 και χρησιμοποιείται κυρίως στην παραγωγή ηλεκτρικής ενέργειας και ένα μικρό μερίδιο για βιομηχανικούς σκοπούς. Το φυσικό αέριο καταλαμβάνει την τρίτη θέση του πλέον χρησιμοποιούμενου καυσίμου στο συνολικό εφοδιασμό πρωτογενούς ενέργειας για το έτος 2019, με μερίδιο 11%. Σε γενικές γραμμές, τα ορυκτά καύσιμα συμβάλλουν στον Ελληνικό συνολικό εφοδιασμό ενέργειας σε σημαντικό επίπεδο, καθώς το ποσοστό έφθασε το 84% το έτος 2016, γεγονός που οδήγησε την Ελλάδα στην έβδομη θέση μεταξύ των χωρών του IEA [32].

Η παραγωγή ενέργειας που προέρχεται από ΑΠΕ παρουσίασε διττή αύξηση σε διάστημα 10 ετών, κλιμακούμενη από 5,9% το 2006 σε 12,5% το 2019, με τα βιοκαύσιμα και τα απόβλητα να ευθύνονται για το ήμισυ περίπου της παραγωγής ΑΠΕ στα TPES. Είναι σημαντικό να αναφέρουμε ότι η Ελλάδα κατέχει τη δεύτερη θέση μεταξύ των χωρών της IEA στο μερίδιο της ηλιακής ενέργειας.

Μελετώντας το ελληνικό δίκτυο ηλεκτρικής ενέργειας, είναι δυνατή η διάκριση και η διαίρεση του εθνικού δικτύου ηλεκτρικής ενέργειας με το ηπειρωτικό δίκτυο ηλεκτρικής ενέργειας της Στερεάς Ελλάδας και το σύστημα ηλεκτροδότησης των ελληνικών νησιών μέσω μικρότερων τοπικών δικτύων. Τα νησιά που δεν τροφοδοτούνται από το ηπειρωτικό δίκτυο ηλεκτρικής ενέργειας, ονομάζονται Μη Διασυνδεδεμένα Νησιά (ΜΔΝ) της Ελλάδας. Τα περισσότερα από τα ελληνικά νησιά τροφοδοτούνται από αυτόνομα ηλεκτρικά συστήματα με ηλεκτρική ενέργεια που παράγεται κυρίως από τοπικούς θερμοηλεκτρικούς σταθμούς και σε ορισμένες περιπτώσεις από ΑΠΕ. Οι θερμοηλεκτρικοί σταθμοί χρησιμοποιούν αργό πετρέλαιο, βαρύ πετρέλαιο (μαζούτ) και ελαφρύ πετρέλαιο (ντίζελ). Τα τελευταία χρόνια, τα ελληνικά νησιά δεν έχουν ακόμη συνδεθεί με το ηπειρωτικό ηλεκτρικό δίκτυο λόγω τεχνικών και οικονομικών περιορισμών που θέτουν το επενδυτικό κόστος σημαντικά υψηλό.

Επίσης αξίζει να αναφερθεί πως ο σημερινός τρόπος ενεργειακής παροχής στα ΜΔΝ παρουσιάζει ξεχωριστά προβλήματα τα οποία μπορούν να ταξινομηθούν σε οικονομικά, τεχνικά και περιβαλλοντικά και παρουσιάζονται στις επόμενες παραγράφους.

Από οικονομική άποψη, συνολικά, τα ΜΔΝ χαρακτηρίζονται από αυξημένο κόστος σε σύγκριση με το ηπειρωτικό ηλεκτρικό δίκτυο. Αναλυτικά, το μέσο μεταβλητό κόστος (AVC) είναι δύο έως οκτώ φορές υψηλότερο από τη μέση οριακή τιμή του συστήματος του Ηπειρωτικού ηλεκτρικού δικτύου [35]. Το μέσο κόστος παραγωγής των αυτόνομων σταθμών ηλεκτροπαραγωγής που λειτουργούν με πετρέλαιο τον Αύγουστο του 2017, σύμφωνα με επίσημα στοιχεία του διαχειριστή του Ελληνικού Δικτύου Διανομής Ηλεκτρικής Ενέργειας (ΔΕΔΔΗΕ), διαμορφώθηκε στα 336,96 € ανά μεγαβατώρα, περίπου επτά φορές υψηλότερο από την οριακή τιμή της ηπειρωτικής χώρας, γύρω στα 50 € μεγαβατώρα [37].

Από τεχνική άποψη, οι υφιστάμενοι σταθμοί ηλεκτροπαραγωγής που λειτουργούν με πετρέλαιο λειτουργούν σε μέγιστο επίπεδο, ιδίως κατά την υψηλή περίοδο (θερινή περίοδος), για να καλύψουν την αυξημένη ζήτηση ηλεκτρικής ενέργειας λόγω του τουρισμού. Πρόκειται για μια σημαντική δυσκολία που σήμερα δεν μπορεί να αντιμετωπίσει αποτελεσματικά ο νησιωτικός ενεργειακός τομέας. Οι σταθμοί ηλεκτροπαραγωγής που λειτουργούν σε μέγιστο βαθμό ενδέχεται να έχουν αρνητικές επιπτώσεις, όπως διακοπές ρεύματος. Η πρόκληση της κάλυψης των καλοκαιρινών φορτίων και της αιχμής της ζήτησης σε ορισμένα νησιά παρακάμπτεται από άλλες λύσεις, όπως είναι η ενοικίασης φορητών μονάδων ντίζελ ή η μέσω μεταφοράς παραγωγής από άλλα δίκτυα όπου υπάρχει πλεονάζουσα παραγωγική ικανότητα [37] [36].

Επιπλέον, ένα άλλο τεχνικό εμπόδιο που πρέπει να ληφθεί υπόψη είναι η τεχνική διάρκεια ζωής και η χαμηλή απόδοση των σημερινών σταθμών ηλεκτροπαραγωγής. Η παροχή ηλεκτρικού ρεύματος στα 32 μη διασυνδεδεμένα νησιά της χώρας εξασφαλίζεται από σταθμούς χαμηλής χωρητικότητας (ντίζελ και μαζούτ) που έχουν εγκατασταθεί από τη δεκαετία του 1960 και του 1970 [37].

Από τα παραπάνω, είναι σαφές ότι υπάρχει εντεινόμενη ανάγκη αλλαγής στον ενεργειακό τομέα των ελληνικών νησιών και στον προσδιορισμό αποτελεσματικότερων τρόπων εξασφάλισης ενέργειας για κάλυψη των αναγκών. Τα τελευταία χρόνια, υλοποιήθηκαν δράσεις και πρωτοβουλίες με στόχο την αντιμετώπιση του ζητήματος της παροχής ενέργειας σε όλα τα νησιά της ΕΕ και την προώθηση της διαδικασίας μετάβασης του ενεργειακού τους τομέα από ορυκτά καύσιμα σε καθαρή ενέργεια. Αρκετοί οργανισμοί και ερευνητικοί φορείς έχουν μελετήσει και αναπτύξει πιλοτικά έργα έξυπνων νησιών και πόλεων που έχουν ως βάση την πράσινη ενέργεια προκειμένου να εξετάσουν και να επικυρώσουν τη σκοπιμότητα και τις θετικές περιβαλλοντικές επιπτώσεις που μπορούν να προκαλέσουν. Στην Ευρώπη και με έμφαση στην Ελλάδα βρίσκουμε 3 τέτοιους οργανισμούς:

Ονοματεπώνυμο Οργανισμού	**Περιοχή εστίασης**
DAFNI (Δίκτυο Βιώσιμων Ελληνικών Νησιών)	Ελλάδα – Νησιά Αιγαίου
Smart Islands Initiative	Ευρωπαϊκά Νησιά
Pact of Islands	Ευρωπαϊκά Νησιά

Πίνακας 1 Οργανισμοί που συνδέονται με έξυπνα νησιά και τομέα εστίασης

Μέσω αυτής της έρευνας, έχουμε ως βάση την ιδεολογία των έξυπνων νησιών και διερευνούμε τις επιλογές για το επόμενο νησί που έχει τις απαραίτητες απαιτήσεις και προδιαγραφές ώστε να λάβει μέρος σε αυτή τη μετάβαση. Είναι γεγονός ότι πρέπει να αναπτυχθούν περισσότερα πιλοτικά έργα με υψηλότερες δυνατότητες, χρησιμοποιώντας νησιά που χρειάζονται άλλο ενεργειακό σύστημα σε συνδυασμό με έξυπνες τεχνολογίες. Έτσι, τα ελληνικά νησιά είναι μια καλή αρχή καθώς όπως αναφέρθηκε έχουν την ανάγκη για αντικατάσταση του τρέχοντος ενεργειακού τους συστήματος.

Μελέτη για την ανάπτυξη υποδομής στα ΜΔΝ

Στο κεφάλαιο 3 γίνεται μια πιο εκτεταμένη ανάλυση τον νησιών για να εξακριβωθεί και να επιλεχθεί ένα νησί για αυτή την έρευνα που θα ήταν κατάλληλο για την ανάπτυξη μιας τέτοιας υποδομής που περιεγράφηκε στα παραπάνω κεφάλαια. Το σύμπλεγμα παραγωγής ενέργειας των ΜΔΝ αποτελείται από 32 αυτόνομα ηλεκτρικά συστήματα, τα οποία παρέχουν ηλεκτρική ενέργεια σε 61 νησιά. Συνολικά, κατά τη διάρκεια του 2017, η εγκατεστημένη ισχύς ήταν 1808,35 MW . Επιπλέον, οι εγκαταστάσεις ανανεώσιμων πηγών ενέργειας λειτουργούν σε πολλά από τα ΜΔΝ. Η συνολική χωρητικότητα των σταθμών ΑΠΕ στα ΜΔΝ ήταν 459,59 MW το πρώτο τετράμηνο του 2018. Όσον αφορά τα μερίδια κατανάλωσης ενέργειας, το 81,5% καλύπτεται από θερμικούς σταθμούς και το 18,5% από σταθμούς ΑΠΕ. Το μερίδιο ΑΠΕ κατανέμεται ως εξής [54]:

- 60,7% αιολική ενέργεια
- 34,3% ηλιακή ενέργεια (φωτοβολταϊκοί σταθμοί)
- 4,7% ηλιακή ενέργεια (φωτοβολταϊκά στην σκεπή και net-metering)
- 0,3% από άλλες ΑΠΕ (αυτή είναι η εκτιμώμενη συνεισφορά στην Ενέργεια ΑΠΕ από ένα μικρό υδροηλεκτρικό σταθμό ονομαστικής ισχύος 0,3 MW και μια μικρή μονάδα βιοαερίου ονομαστικής ισχύος 0,5 MW, που λειτουργούν στην Κρήτη)

Σημειώνεται ότι ένα σημαντικό χαρακτηριστικό των ενεργειακών συστημάτων των ΜΔΝ είναι η χρήση γεννητριών (κυρίως ντίζελ) για την κάλυψη επιπλέον, εποχιακών αναγκών σε ηλεκτρική ενέργεια. Οι γεννήτριες ενοικιάζονται κατά κανόνα από τους παραγωγούς ενέργειας και μεταφέρονται στα νησιά. Αυτό, φυσικά, προκαλεί αυξήσεις στο κόστος παραγωγής ενέργειας και θα αναλυθεί περαιτέρω.

Σύμφωνα με τις παρεχόμενες πληροφορίες, επισημαίνεται και πάλι η ανάγκη για την Ελλάδα να λάβει σοβαρά υπόψη την οικονομική ζημία που προκαλούν τα σημερινά συστήματα παροχής ηλεκτρικής ενέργειας στο έθνος. Η ανάγκη μετάβασης σε πιο φιλικές προς το περιβάλλον λύσεις είναι σαφής. Η Ελλάδα πρέπει να λάβει υπόψη τις δυνατότητες των πηγών ΑΠΕ και να επωφεληθεί από τις τρέχουσες επενδύσεις και χρηματοδότηση που παρέχονται από την Ευρώπη. Ένα καλό ξεκίνημα είναι οι πρωτοβουλίες που εστιάζουν στα ελληνικά μη διασυνδεδεμένα νησιά - εξ ου και το επίκεντρο αυτής της έρευνας.

Για τους σκοπούς αυτής της έρευνας το νησί της Αστυπάλαιας θα εξεταστεί καθώς καλύπτει όλα τα κύρια χαρακτηριστικά και είναι ένα από τα πρώτα νησιά που πρόκειται να μετατραπούν στο πλαίσιο της πρωτοβουλίας «έξυπνων νησιών». Στις ακόλουθες ενότητες, η έρευνα εστιάζει στο παρασκήνιο του νησιού της Αστυπάλαιας και με την χρήση κάποιων άλλων παρόμοιων ερευνών θα σκιαγραφηθούν οι τρέχουσες ανάγκες, πιθανές λύσεις και ενεργειακά συστήματα που μπορούν να αντικαταστήσουν το υπάρχον.

Το νησί της Αστυπάλαιας

Η Αστυπάλαια είναι μια ιδανική και αντιπροσωπευτική μελέτη περίπτωσης για τη διερεύνηση μελλοντικών προοπτικών μικρών, αυτόνομων ηλεκτρικών συστημάτων στα ελληνικά νησιά. Βρίσκεται στη μέση του Αιγαίου, και οι αποστάσεις μεταξύ του νησιού και άλλων μεγάλων νησιών, καθώς και από την ηπειρωτική χώρα είναι αρκετά μεγάλες [69].

Ως εκ τούτου, πρακτικά, η λειτουργία ενός αυτόνομου ηλεκτρικού συστήματος στην Αστυπάλαια είναι υποχρεωτική, διότι η σύνδεσή του με άλλα, μεγαλύτερα ηλεκτρικά συστήματα (ή με το διασυνδεδεμένο ηλεκτρικό δίκτυο της ηπειρωτικής χώρας) είναι δύσκολη.

Ο μόνιμος πληθυσμός του νησιού, σύμφωνα με την τελευταία απογραφή, είναι 1334 κάτοικοι. Το εμβαδόν του νησιού είναι 96,9 χλμ2. Η Αστυπάλαια είναι ένας αρκετά δημοφιλής τουριστικός προορισμός, ειδικά τους καλοκαιρινούς μήνες και έτσι κατά συνέπεια η ζήτηση ενέργειας αυξάνεται κατά τη διάρκεια του καλοκαιριού.

Σύμφωνα με πληροφορίες του ΔΕΔΔΗΕ ο παρακάτω πίνακας έχει εξαχθεί σχετικά με τη ζήτηση ηλεκτρικής ενέργειας:

Total annual electricity demand	6.56 GWh
Hourly maximum demand value	2224 kW
Hourly minimum value	241 kW
Annual average load value	748.90 kW

Table 17 Info concerning Astypalea electricity demands and loads

Προκειμένου να εκτιμηθεί και να σχεδιαστεί το σύστημα στην Αστυπάλαια, διεξάγεται ξεχωριστή έρευνα για κάθε τομέα, ώστε να έχουμε πιο ρεαλιστικά και ακριβή αποτελέσματα για τον σχεδιασμό. Συγκεκριμένα έχουν αναλυθεί οι παρακάτω τομείς:

- Οικιστικός Τομέας
- Τομέας Ξενοδοχείων και άλλων υπηρεσιών διαμονής
- Τομέας Επιχειρήσεων φαγητού
- Τομέας Εκπαίδευσης
- Αεροδρόμιο και άλλα κτίρια.
- Τομέας Οδικού Φωτισμού
- Τομέας Ύδρευσης

Συμπερασματικά, τα αυτόνομα ηλεκτρικά συστήματα των ΜΔΝ, ιδιαίτερα τα απομακρυσμένα, αποτελούν την ιδανική περίπτωση για τη χρήση ανανεώσιμων πηγών ενέργειας υπέρ των τοπικών κοινωνιών, βάσει αποκεντρωμένων εφαρμογών. Η αποκεντρωμένη εκμετάλλευση ΑΠΕ σε απομακρυσμένα νησιά είναι ένας ήπιος, βιώσιμος τρόπος αξιοποίησης της πράσινης ενέργειας. Οι κυβερνητικές πολιτικές θα πρέπει να υποστηρίζουν πιο ενεργά αυτό το είδος ενεργειακού μέλλοντος για τα ΜΔΝ.

Μετατροπή του νησιού της Αστυπάλαιας σε Έξυπνο Νησί

Όπως προαναφέρθηκε, αν και η διασύνδεση με το ηλεκτρικό δίκτυο αποτελεί στρατηγική επιλογή της Ελληνικής κυβέρνησης, η Αστυπάλαια απέχει πολύ από την ηπειρωτική χώρα και άλλα μεγαλύτερα ενεργειακά συστήματα (Ρόδος, Κως, Κρήτη, Νάξος). Το κόστος για την επέκταση των ενεργειακών δικτύων με υποβρύχια καλώδια είναι αρκετά υψηλό. Συνδυάζοντας δεδομένα από σχετικούς πόρους [80] [81] [82], εκτιμάται ότι το απαραίτητο κόστος για την επέκταση του δικτύου προς αυτόνομα νησιωτικά συστήματα ανέρχεται σε 1.000.000€/km.

Άλλα σενάρια για την ηλεκτροδότηση του νησιού που ερευνήθηκαν είναι τα ακόλουθα [60]:

• **Σενάριο Α:** Περαιτέρω χρήση ανανεώσιμης ενέργειας χωρίς την προσθήκη αποθηκευτικού χώρου

- Α1: Φωτοβολταϊκά και μικρός υδροηλεκτρικό σταθμό.

- Α2: Φωτοβολταϊκά, ανεμογεννήτριες και μικρός σταθμός υδροηλεκτρικής ενέργειας.

• **Σενάριο Β:** Περαιτέρω χρήση ανανεώσιμων πηγών ενέργειας με την προσθήκη μπαταριών συστημάτων αποθήκευσης ενέργειας (Li-Ion)

- Β1: Φωτοβολταϊκά και συστοιχία μπαταριών.

- Β2: Φωτοβολταϊκά, ανεμογεννήτριες και συστοιχία μπαταριών.

- Β3: Φωτοβολταϊκά, ανεμογεννήτριες, μικρός σταθμός υδροηλεκτρικής ενέργειας και συστοιχία μπαταριών.

Έχοντας τις πιο πάνω πληροφορίες και από την ανάλυση στα προηγούμενα κεφάλαια εκτιμάται πως η καλύτερη επιλογή για το νησί της Αστυπάλαιας είναι η ανάπτυξη φωτοβολταικών πάρκων σε συνδυασμό με αποθήκευση ενέργειας σε μπαταρίες για την ικανοποιητική λειτουργεία του νησιού. Μερικά από τα προτερήματα για την χρήση των φωτοβολταικών είναι τα εξής:

Τεράστια χωρητικότητα

Όσον αφορά το ανθρώπινο χρονοδιάγραμμα, είναι μια αιώνια πηγή ενέργειας.

Περιβαλλοντικά ασφαλές

Όπως και άλλες ανανεώσιμες πηγές ενέργειας, η ηλιακή ενέργεια είναι ασφαλής για το περιβάλλον. Δεν θα προκαλέσει ρύπανση ή υποβάθμιση του περιβάλλοντος.

Ευπροσάρμοστο

Αν και συχνά τοποθετούνται στις στέγες, τα ηλιακά πάνελ μπορούν να τοποθετηθούν οπουδήποτε.

Οικονομικά αποδοτικό

Η τιμή των ηλιακών συλλεκτών σημείωσε δραστική πτώση τα τελευταία χρόνια και το κόστος εγκατάστασης είναι προσιτό για επενδύσεις. Επιπλέον, είναι πιο αποδοτικό από πλευράς κόστους μακροπρόθεσμα.

Λίγο έως καθόλου κόστος συντήρησης

Τα ηλιακά πάνελ συνήθως διαρκούν έως και 30 χρόνια, επομένως δεν συνεπάγονται έξοδα συντήρησης.

Για το νησί της Αστυπάλαιας και το σχεδιασμό των ηλιακών αγροκτημάτων θα διαιρέσουμε τις 2 κύριες περιοχές που απέχουν μεταξύ τους για να μειώσουν τη σύνδεση και άλλα έξοδα. Τα δύο τμήματα είναι επομένως:

- Τμήμα Α (η δυτική πλευρά του νησιού)
- Τμήμα Β (η ανατολική πλευρά του νησιού)

	Section A (West)	Section B (East)
Residential sector	1.8491 GWh	0.2809 GWh
Hotels and other accommodation types sector	1.7557 GWh	0.0443 GWh
Dinning businesses and food catering services sector	0.9502 GWh	0.1798 GWh
Public Buildings	0,4700 GWh	0.3000 GWh
Street Light and other public lights sector	0.3820 GWh	0.1660 GWh
Other	0.23 GWh	
Total	**5.64 GWh**	**1 GWh**

Table 35 Data for Section A and Section B Solar Farms

Σύμφωνα με την ανάλυση παραπάνω γίνεται και ο υπολογισμός του εξοπλισμού και το κάθε Section.

	Section A (West)	Section B (East)
Total (annual)	5.64 GWh	1 GWh
Daily	0.015 GWh/day	0.003 GWh/day
9 hours irradiation	1,7 MW	0.3 MW
Battery Capacity	400 kWh Li-ion	100 kWh Li-ion
455W/panel	3496 panels	617 panels
Total panels	**4113 panels**	
Total Battery Capacity	**500 kWh Li-ion**	

Table 39 Data for total Sizing of Solar Farms

Πλάνο εργασιών για την ανάπτυξη του Έξυπνου Νησιού της Αστυπάλαιας

Σε αυτό το κεφάλαιο έχει διεξαχθεί ένα πλάνο εργασιών καθώς και μια ανάλυση κατάλληλου προσωπικού. Για αυτό το έργο εντοπίζουμε τρεις κύριες φάσεις και δεκατρία πακέτα εργασίας τα οποία συνοψίζονται παρακάτω:

- **Φάση 1** - Τοπική προετοιμασία, Τελικός Σχεδιασμός και Προμήθεια
  - ΠΕ1 - Τελική μηχανική
  - ΠΕ2 - Κοινοτική διαχείριση
  - ΠΕ3 - Συμβάσεις
  - ΠΕ4 – Logistics και Μεταφορές
- **Φάση 2** - Κατασκευή και θέση σε λειτουργία
  - ΠΕ5 - Τεχνική εποπτεία
  - ΠΕ6 - Εγκατάσταση Ενεργειακών Συστημάτων
  - ΠΕ7 – Εγκατάσταση άλλων συστημάτων
  - ΠΕ8 - Back-office Management
  - ΠΕ9 - Εγχειρίδιο λειτουργίας

- ΠΕ10 - Εκπαίδευση τοπικών ομάδων

- **Φάση 3** - Λειτουργία και βελτιστοποίηση

  - ΠΕ11 – Διαχείριση Συστημάτων
  - ΠΕ12 - Λειτουργία και Συντήρηση
  - ΠΕ13 - Προετοιμασία τελικής έκθεσης

Σύμφωνα και με τον σχεδιασμό ενός Gantt chart που δημιουργήθηκε για αυτή την έρευνα, εκτιμάται πως ολόκληρο το έργο θα διαρκέσει 24 μήνες για να παραδώθει με επιτυχία υποθέτοντας ότι αρχίζει πρώτη εβδομάδα Απριλίου 2022 και ολοκληρώνεται την τελευταία εβδομάδα του Μαρτίου 2024. Συγκεκριμένα:

- Η Φάση 1 θα περιλαμβάνει τους πρώτους τέσσερις μήνες του χρονοδιαγράμματος (Απρίλιος 2022 - Ιούλιος 2022)
- Η Φάση 2 θα περιλαμβάνει τον μήνα 5 έως τον 17ο μήνα του χρονοδιαγράμματος (Αύγουστος 2022 - Ιούλιος 2023)
- Η Φάση 3 θα διαρκέσει από τον 18ο έως τον 24ο μήνα του χρονοδιαγράμματος (Αύγουστος 2023 - Μάρτιος 2024)

Όσον αφορά την ακρίβεια, οι εκτιμώμενοι χρόνοι για την ολοκλήρωση κάθε εργασίας θα μπορούσαν να διαφέρουν στην πραγματικότητα, καθώς υπάρχουν διάφοροι λόγοι και κίνδυνοι που θα μπορούσαν να τους επηρεάσουν. Μερικοί από αυτούς που αναλύονται σε αυτή την έρευνα είναι πολιτικοί, οικονομικοί, τεχνολογικοί κοινωνικοί κλπ.

Οικονομική Ανάλυση του Έξυπνου Νησιού της Αστυπάλαιας

Σε αυτό το κεφάλαιο γίνεται μια ανάλυση όλων των κοστών για την ανάπτυξη του συγκεκριμένου έργου (CAPEX) καθώς και τα λειτουργικά έξοδα (OPEX) . Συνοπτικά παρακάτω είναι τα αποτελέσματα.

Description CAPEX	**Price (Euros/year)**
Total	**1,475,844**
General preparation and project development	42,250
Personnel (project management, engineering and commissioning)	106,225
Energy system - Procurement, Installation and Interconnection	**915,175**
Solar PV plant	682,900
Battery Energy Storage System	196,125
System Integration	35,825
Street Lights and Distribution Network	325
Desalination System	20,519
EV Station	11,100
Installation and labor	31,625
Shipping and logistics	66,075

Duties and customs clearance	166,725
Training and support	7,000
Travel to Site	15,100
Contingency	92,050

Table 47 Budget for Project Development – CAPEX

Description OPEX	**Price (Euros/year)**
Total	**183,575**
Personnel	83,075
Spare replacements	7,500
Asset management	20,800
Security	28,800
Admin, insurance and other	43,400

Table 48 Budget for Project Operation - OPEX

Σύμφωνα με τα δεδομένα και το εκτιμώμενο κόστος κάθε παράγοντα εκτιμάται ότι μια τέτοια προσέγγιση για την ανάπτυξη (CAPEX) των προαναφερθέντων συστημάτων στην Αστυπάλαια θα κοστίσει περίπου 1,5 εκατ. € και για τη λειτουργία (OPEX) περίπου 200 χιλ. Ευρώ ετησίως. Όσον αφορά την ακρίβεια των αποτελεσμάτων και τους ευαίσθητους παράγοντες και αβεβαιότητες - θα συζητηθούν στο επόμενο κεφάλαιο.

Συμπεράσματα

Η έρευνα που παρουσιάστηκε σε αυτή την διπλωματική εστίασε :

1) στα χαρακτηριστικά και τα προβλήματα που σχετίζονται με την ηλεκτροδότηση των ελληνικών νησιών που δεν συνδέονται με το IEG, και
2) παρείχε στοιχεία για το σχεδιασμό ενός καλύτερου ενεργειακού μέλλοντος για το μικρό απομακρυσμένο νησί της Αστυπάλαιας

Επίσης η έρευνα περιγράφει και κατηγοριοποιεί δύο ευαίσθητους παράγοντες:

i) τις αβεβαιότητες των εκτιμώμενων δεδομένων από την πλευρά της ζήτησης και τη μοντελοποίηση σεναρίων αναφοράς
ii) τις αβεβαιότητες σχετικά με τα δεδομένα που εφαρμόζονται στη μοντελοποίηση των σεναρίων

Επίσης αξίζει να αναφερθεί ότι σε αυτή την έρευνα οι παράγοντες που έχουν σημαντικό ρόλο στα αποτελέσματα και τα συμπεράσματα είναι οι εξής:

- Επιλογή εργαλείου μοντελοποίησης για τις αρχικές προσομοιώσεις
- Πολιτικό πλαίσιο στην Ελλάδα και πιθανή επιρροή στην επιλογή τεχνολογιών ΑΠΕ

Εν κατακλείδι - Η Ελλάδα έχει δεσμευτεί να προωθήσει την αειφόρο ανάπτυξη, την πράσινη ενέργεια και τις σύγχρονες τεχνολογίες για τη βελτίωση των κοινωνικών, οικονομικών και περιβαλλοντικών συνθηκών στη χώρα. Ως εκ τούτου, η Ελλάδα είναι έτοιμη να υποστηρίξει τοπικά έργα και συνεργασίες με στόχο να βοηθήσει τις πόλεις και τις κοινότητες με τις στρατηγικές τοπικής ανάπτυξης. Η κυβέρνηση λαμβάνει υπόψη τις παγκόσμιες προκλήσεις και ευκαιρίες που προσφέρουν οι εξελίξεις στους τομείς της πράσινης ενέργειας και των ηλεκτρικών οχημάτων. Αυτό επιβεβαιώνει το ενδιαφέρον και τις δυνατότητες μετατροπής του νησιού της Αστυπάλαιας σε ένα έξυπνο νησί που υπόσχεται γρήγορες αλλαγές τα επόμενα χρόνια.

Τα αποτελέσματα και τα συμπεράσματα που έγιναν για αυτή την ερευνητική περίπτωση βασίζονται σε μια διάταξη πρωτογενών δεδομένων από αξιόπιστες πηγές και από εκτιμώμενα δεδομένα που βασίζονται σε δευτερογενή δεδομένα που λαμβάνονται από τη βιβλιογραφία και προσαρμόζονται στις ανάγκες αυτής της έρευνας. Τρία βασικά στάδια μπορούν να συμπεριληφθούν σε μελλοντικές ερευνητικές εργασίες με σκοπό τη βελτιστοποίηση των μοντέλων που περιγράφονται στην παρούσα έρευνα.

Ένα στάδιο που πρέπει να ολοκληρωθεί σε περαιτέρω έρευνα είναι η διεξαγωγή εκτεταμένης και λεπτομερούς ανάλυσης σε κάθε τομέα της Αστυπάλαιας και ο συνδυασμός ποιοτικών και ποσοτικών μεθόδων που θα παρέχουν ρεαλιστικά δεδομένα. Οι ποιοτικές και ποσοτικές μέθοδοι αναφέρονται σε ερωτηματολόγια σε κάθε τομέα, εστιασμένες συνεντεύξεις, αποδεικτικά στοιχεία και παρατήρηση και αλληλογραφία με τις αρμόδιες αρχές στην Ελλάδα. Ο σκοπός αυτού θα ήταν να εξετάσει τα δεδομένα εισόδου που εφαρμόζονται σε αυτή την έρευνα και να εξετάσει την εγκυρότητα και την ακρίβειά τους. Εφόσον ολοκληρωθεί αυτό το βήμα, μπορεί να επιτευχθεί βελτιστοποίηση του σεναρίου αναφοράς και των ενεργειακών ισορροπιών. Αυτό θα επηρεάσει τη δημιουργία και την ανάπτυξη των εναλλακτικών σεναρίων και τελικά θα προσφέρει πιο ρεαλιστικά, ακριβή και δυναμικά αποτελέσματα.

Το δεύτερο στάδιο που πρέπει να ολοκληρωθεί σε περαιτέρω έρευνα, η οποία θα μπορούσε επίσης να δοκιμάσει την ευρωστία των αποτελεσμάτων και να ενδυναμώσει τα συμπεράσματα αυτής της έρευνας, είναι μια ανάλυση ευαισθησίας. Λόγω περιορισμένου χρόνου και λόγω του γεγονότος ότι η ανάλυση ευαισθησίας σε όλα τα εξεταζόμενα σενάρια και για κάθε συνδυασμό τεχνολογίας θα ήταν απαιτητική και χρειάζεται ακρίβεια, η έρευνα αυτή επιλέγει να συμπεριλάβει μόνο μια συζήτηση σχετικά με τους παράγοντες ευαισθησίας. Έτσι, το επόμενο στάδιο και η υποστήριξη του πρώτου έργου περαιτέρω έρευνας που περιεγράφηκε παραπάνω θα ήταν μια λεπτομερής ανάλυση ευαισθησίας.

Τέλος, το τρίτο τελικό στάδιο σε περαιτέρω έρευνα θα ήταν μια έρευνα πολιτικής στην Ελλάδα που θα εξετάζει πώς τα υπάρχοντα πολιτικά πλαίσια, θεσμοί, χρηματοδοτικά συστήματα και άλλοι σχετικοί παράγοντες θα μπορούσαν να επιτρέψουν ή να παρεμποδίσουν την υλοποίηση έργων που αφορούν την ενεργειακή μετάβαση στα ελληνικά νησιά. Η συμβολή του έργου αυτού στην παρούσα έρευνα θα ήταν να σκιαγραφήσει ένα συγκεκριμένο σύνολο τεχνολογιών και υποδομών, συστημάτων οικονομικής στήριξης και χρηματοδότησης που θα μπορούσαν να οδηγήσουν τη διαδικασία μοντελοποίησης των σεναρίων και των επιλεγμένων τεχνολογιών ΑΠΕ.

1

Introduction

1.1 Global Energy Transition

The energy sector has started changing in promising ways, with worldwide adoption of renewable energy technologies (RES) in the aim of having a well sustainable greener future. It was the 1970s when environmentalists promoted the development of renewable energy both as a replacement for the eventual depletion of fossil fuels, as well as an escape from dependence on oil [1]. Now, renewable energy technologies are dominating the global market for new power generation capacity. Solar PV and Wind are increasingly the cheapest sources of electricity in many markets, and most of the other renewable power sources will be fully competitive within the next decade.

Renewable energy technologies offer significant potential economic, security, environmental and social benefits. There is no doubt why the RES are now growing faster than the overall power demand. A new milestone was reached in 2019 when renewable electricity generation increased by more than the increase in electricity demand, while fossil-fuel electricity generation decreased. This is the first time in decades that fossil-fuel-based generation declined when overall electricity generation increased [2].

Wind and solar generation rose by 15% in 2019, generating 8% of the world's electricity. Compound growth rate of 15% of wind and solar generation is needed every year to meet the Paris climate agreement. This was achieved in 2019 and lower prices provide hope it can be sustained. However, maintaining this high growth rate as volumes scale up will require a concerted effort from all regions [3].

On the other side, fossil fuels and specifically coal has seen one of the lowest reductions since the past decade. Global coal-fired electricity generation fell by 3% in 2019, leading to a 2% fall of CO2 power sector emissions. Both of these are the biggest falls since at least 1990. Coal collapsed in the EU and the US, but Chinese coal generation rose and for the first time was responsible for half of global coal generation. The carbon-intensity of global electricity is now 15% lower than in 2010 [4].

The US coal collapse is undermined by a switch to gas, whereas the EU is leapfrogging from coal to wind and solar. Coal generation collapsed by 24% in the EU and 16% in the US in 2019, and is now half the level of 2007 in both the EU and US. Since 2007, US CO2 power sector emissions fell by 19-32%, whereas they fell by 43% in the EU [4].

Indicator	**Historical Progress**		**Where we are heading**		**Where we need to be**	
	2015	**2019**	**2030**	**2050**	**2030**	**2050**
Energy-related CO2 emissions (Gt)	32	34	35	33	25	9.5
Energy demand (EJ TPES)	571	599	647	710	556	538
Fossil-fuel use (EJ TPES)	468	485	450	440	313	130

Table 2The changing nature of energy and fossil fuel use (Based on Irena scenarios (PES and TES), along with IAE (2019a, 2019b) for 2015-2018 historical progress of energy demand and fossil fuel use [5].

One reason for the fall of fossil fuel is that investments to expand the supply infrastructure are short-sighted and increasingly risky. Such investments will lead to significant stranded assets and will lock in fossil-fuel emissions for decades to come that will also risk achieving the aims of the Paris Agreement.

While climate change is appearing as a global threat, many countries take different paths in order to transform the energy sector. Finding are presented in Table 2, where Europe aims to increase renewable energy power generation share up to 55% by 2030 [5].

Regions	**Emissions (GT CO2/yr)**				**Electrification in end-use consumption (% in TFEC)**		
	2017	2030	2050		2017	2030	2050
East Asia	11.2	8.4	2.2		25%	37%	58%
European Union	3.4	1.9	0.6		22%	30%	49%

Latin America and the Caribbean	1.2	1	0.6		18%	26%	39%
Middle East and North Africa	2.5	2	1.1		19%	20%	38%
North America	6.2	3.7	1.4		20%	28%	52%
Oceania	0.4	0.4	0.1		23%	22%	45%
Rest of Asia	3.5	3.8	2		18%	26%	47%
Rest of Europe	2	1.6	0.7		18%	23%	38%
Southeast Asia	1.4	1.6	0.8		18%	20%	42%
Sub-Saharan Africa	0.8	0.6	0.3		7%	23%	48%

Regions	**Renewable Energy share in TPES (%)**				**Renewable Energy share in power generation (%)**		
	2017	2030	2050		2017	2030	2050
East Asia	7%	27%	65%		23%	60%	90%
European Union	15%	39%	71%		31%	55%	86%
Latin America and the Caribbean	30%	53%	73%		65%	85%	93%
Middle East and North Africa	1%	9%	26%		3%	27%	53%
North America	10%	30%	67%		23%	60%	85%
Oceania	10%	39%	85%		25%	66%	93%
Rest of Asia	8%	27%	58%		18%	52%	81%
Rest of Europe	6%	19%	54%		27%	42%	82%
Southeast Asia	13%	41%	75%		20%	53%	85%
Sub-Saharan Africa	7%	43%	89%		26%	67%	95%

Table 3 Different transition paths for different regions. [5]

1.2 Renewable Energy Sources (RES)

Renewable energy sources have been important for humans since the beginning of civilisation. For centuries and in many ways our ancestors used different kinds of today's Renewable energy sources to correspond to their need. One example is the biomass that has been used for heating, cooking, steam raising, and power generation. Hydropower and wind

energy have been used for centuries to complete various types of works such as windmills and watermills that demanded the power of movement.
Renewable energy sources generally depend on energy flows through the Earth's ecosystem from the insolation of the sun and the geothermal energy of the Earth. One can distinguish:

- Biomass energy
- Wind energy
- Direct use of solar energy
- Hydropower
- Marine energy
- Geothermal energy

Each of these technologies have their own specific characteristics and different ways to produce the energy product, as well as for different application as listed below:

Technology	Energy product	Application
Biomass Energy		
Combustion (domestic scale)	Heat (cooking, space heating)	Widely applied; improved technologies available
Combustion (industrial scale)	Process heat, steam, electricity	Widely applied; potential for improvement
Gasification/power production	Electricity, heat (CHP)	Demonstration phase
Gasification/fuel production	Hydrocarbons, methanol, H2	Development phase
Hydrolysis and fermentation	Ethanol	Commercial applied for sugar / starch corps; production from wood under development
Pyrolysis/productio n of liquid fuels	Bio-oils	Pilot phase; some technical barriers
Pyrolysis/productio n of solid fuels	Charcoal	Widely applied; wide range of efficiencies
Extraction	Biodiesel	Applied; relatively expensive
Digestion	Biogas	Commercially applied
Wind Energy		
Water pumping and battery charging	Movement, power	Small wind machines, widely applied
Onshore wind turbines	Electricity	Widely applied commercially
Offshore wind turbined	Electricity	Development and demonstration phase
Solar Energy		
Photovoltaic solar energy conversion	Electricity	Widely applied; rather expensive; further development needed
Solar thermal electricity	Heat, steam, electricity	Demonstrated; further development needed
Low-temperature solar energy use	Heat (water and space heating), cold	Solar collectors commercially applied; solar cookers applied

	Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and applications; no active parts
	Artificial photosynthesis	H2 or hydrogen rich fuels	Fundamental and applied research
Hydropower		Power, electricity	Commercially applied; small and large scale
Geothermal energy		Heat, steam, electricity	Commercial applied
Marine Energy			
	Tidal Energy	Electricity	Applied; relatively expensive
	Wave Energy	Electricity	Research, development and demonstration phase
	Current energy	Electricity	Research, development phase
	Ocean thermal energy conversion	Heat, electricity	Research, development and demonstration phase
	Salinity gradient / osmotic energy	Electricity	Theoretical option
	Marine biomass production	Fuels	Research, development phase

Table 4 Categories of renewable energy conversion technologies [6]

If applied in a modern way, renewable energy sources are considered highly responsive to overall energy policy guidelines and environmental, social, and economic goals [6]:

- Diversifying energy carriers for the production of heat, fuels, and electricity
- Improving access to clean energy sources
- Balancing the use of fossil fuels, saving them for other applications and for future generations
- Increasing the flexibility of power systems as electricity demand changes
- Reducing pollution and emissions from conventional energy systems
- Reducing dependency and minimising spending on imported fuels.

Furthermore, many renewable technologies are suited to small off-grid applications, good for rural, remote areas, where energy is often crucial in human development. At the same time, such small energy systems can contribute to the local economy and create local jobs.

The natural energy flows through the Earth's ecosystem are immense, and the theoretical potential of what they can produce for human needs exceeds current energy consumption by many times. For example, solar power plants on 1 percent of the world's desert area would generate the world's entire electricity demand today.

Analysing the current findings and information scientists globally have concentrated in three types of RES with big potential and more advanced developed systems. These are Biomass Energy, Wind Energy and Photovoltaic Solar Energy.

1.2.1 Biomass Energy

Biomass is a rather simple term for all organic material that stems from plants including algae, trees, and crops. Biomass sources are therefore diverse, including organic waste streams, agricultural and forestry residues, as well as crops grown to produce heat, fuels, and electricity (energy plantations).

Biomass contributes significantly to the world's energy supply probably accounting for 52 ± 10 EJ a year (9–13% of the world's energy supply) [7]. Its largest contribution to energy consumption on average between a third and a fifth is found in developing countries.

Dominating the traditional use of biomass, particularly in developing countries, is firewood for cooking and heating. The modern use of biomass, to produce electricity, steam, and biofuels, is estimated at 7 EJ a year. This is considered fully commercial, based on bought biomass or used for productive purposes. That leaves the traditional at 45 ± 10 EJ a year [7].

Since the early 1990s biomass has gained considerable interest world-wide. It is carbon neutral when produced sustainably. Its geographic distribution is relatively even. It has the potential to produce modern energy carriers that are clean and convenient to use. It can make a large contribution to rural development. And its attractive costs make it a promising energy source in many regions. With various technologies available to convert biomass into modern energy carriers, the application of commercial and modern biomass energy systems is growing in many countries [8].

Analysing the biomass processes, two types can be distinguished, the thermochemical conversion and the biochemical conversion. These two conversion methods are broken down in different ways of using the biomass with different processes and end-products as represented in figure 1 [9].

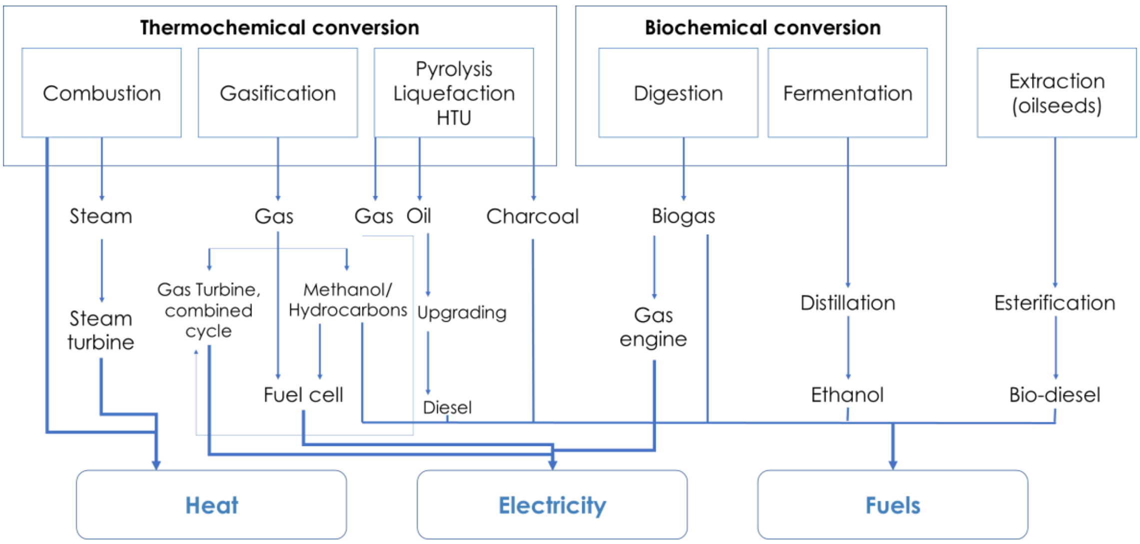

Figure 1 Main Biomass Energy Conversion Routes [9]

Biomass energy can be carbon neutral when all biomass produced is used for energy (short carbon cycle). But sustained production on the same surface of land can have considerable negative impacts on soil fertility, water use, agrochemical use, biodiversity, and landscape. Seen world-wide, climatic, soil, and socioeconomic conditions set strongly variable demands for what biomass production can be sustainable or not.

Problems Occurred	
Erosion	Caused by extensive cultivation of crops. Erosion can increase pollution and sedimentation in streams and rivers, clogging these waterways and

	causing declines in fish and other species. Degraded lands are also often less able to hold onto water, which can worsen flooding
Agrochemicals	Pesticides affect the quality of groundwater and surface water and thus plants and animals. Specific effects depend on the type of chemical, the quantity used, and the method of application [10].
Nutrients	The abundant use of fertilisers and manure in agriculture has led to considerable environmental problems in various regions: nitrification of groundwater, saturation of soils with phosphate, eutrophication, and unpotable water. Phosphates have also increased the heavy metal flux of the soil [11].

Table 5 Problems occurred with extensive use of biomass

On the economic aspect of the energy systems, biomass is a profitable alternative mainly when cheap or even negative cost biomass residues or wastes are available. To make biomass competitive with fossil fuels, the production of biomass, the conversion technologies, and total bio-energy systems require further optimisation. In Table 5 popular processes are listed including the conversion efficiency, costs of short- and long-term production.

	RME (bio-diesel)	**Ethanol from sugar or starch crops**	**Ethanol from ligno-cellulosic biomass**	**Hydrogen from ligno-cellulosic biomass**	**Methanol from ligno-cellulosic biomass**	**Bio-oil from lignocellulosic biomass**
Concept	Extraction and esterification	Fermentation	Hydrolysis, fermentation and electricity production	Gasification	Gasification	Flash pyrolysis
Net energy efficiency at conversion	75% based on all energy inputs	50% for sugar beel; 44% percent for sugar cane	60-70% (longer term with power generation included)	55-65%, 60-70% (longer term)	50-60%, 60-70% (longer term)	70% (raw bio-oil)
Cost range, short term	€12-20/GJ (northwest Europe)	€12-20/GJ for sugar beel; €7-8/GJ for sugar cane	€8-12/GJ	€7-8/GJ	€9-11/GJ	N/A
Cost range long term	N/A	N/A	€5-6/GJ	€5-7/GJ	€6-8/GJ	Unclear

Table 6 Main performance data for some conversion routes of biomass to fuels [6]

Note: Diesel and gasoline production costs vary widely on the oil price. Longer-term projections give estimations of roughly €0.20-0.30 a litre, or €7-9 a gigajoule. Retail prices are usually dominated by taxes of €0.40-1.10 a litre depending on the country [86]

Concerning the biomass production, plantation biomass costs already are favourable in some developing countries. Eucalyptus plantations in northeast Brasil supply wood chips at prices between €1.2–1.6 a GJ [12]. Costs are much higher in industrialised countries, such as €3.3 a GJ in parts of northwest Europe [13]. It is expected for large areas in the world that low-cost biomass can be produced in large quantities. Its competitiveness will depend on the prices of coal (and natural gas), but also on the costs and net returns from alternative, competing uses of productive land.

Modern use of biomass is important in the energy systems of a number of countries (table 6). Other countries can be mentioned as well—as in Asia, where biomass, mainly traditional biomass, can account for 50–90% of total energy. India has installed more than 2.9 million biomass digesters in villages and produces biogas for cooking—and is using small gasifier diesel systems for rural electrification.

Country	**Role of Biomass in the Energy System**
Austria	Modern biomass accounts for 17,6% of the national energy supply. Forest residues are used for heating, largely in systems of relatively small scale
Brasil	Biomass accounts for about a third of energy supply. Main modern applications are ethanol for vehicles produced from sugar cane (13-14 billion litres a year) and substantial use of charcoal in steel industry.
Denmark	Biomass accounts for 22.9% of the national energy supply. A programme is to use 1.2 million tonnes of straw as well as use forest residues. Various concepts have been devised for co-firing biomass in large-scale combined heating and power plants, district heating, and digestion of biomass residues
Finland	20% of its primary energy demand comes from modern biomass. The pulp and paper industry makes a large contribution through efficient residue and black liquor use of energy production
Sweden	Modern biomass accounts for 21.7% of national energy demand. Use of residues in the pulp and paper industry and district heating (CHP) and use of wood for space heating are dominant.
United States	About 10,700 megawatts electric biomass fired capacity 2 % of national energy supply
Zimbabwe	Forty million litres of ethanol are produced a year. Biomass satisfies 75% of national energy

Table 7 Biomass in the energy systems of selected countries [14]

To conclude, biomass can make a large contribution to the future world's energy supply. Land for biomass production should not be a bottleneck, if the modernisation of conventional agricultural production continues. Modernised biomass use can be a full-scale player in the portfolio of energy options for the longer term.

1.2.2 Wind Energy

Wind energy, in common with other renewable energy sources, is broadly available but diffuse. Wind energy was widely used as a source of power before the industrial revolution, but later displaced by fossil fuel use because of differences in costs and reliability. The oil crises of the 1970s, however, triggered renewed interest in wind energy technology for grid-connected electricity production, water pumping, and power supply in remote areas [1].

In recent decades enormous progress has been made in the development of wind turbines for electricity production. Around 1980 the first modern grid-connected wind turbines were installed. In 1990 about 2,000 megawatts of grid-connected wind power was in operation world-wide, at the beginning of 2000, about 13,500 megawatts. In addition, more than 1 million water-pumping wind turbines, manufactured in many developing countries, supply water for livestock, mainly in remote areas. Wind power capacity worldwide reached 650,8 GW in 2019 [15].

On the economic aspect, the energy generation costs of wind turbines are basically determined by five parameters [16]:

1. **Turnkey project cost**

Initial investment costs, project preparation, and infrastructure make up the turnkey project costs. The costs of European wind turbines are typically €400 a square metre (machine cost, excluding foundation). Project preparation and infrastructure costs depend heavily on local circumstances, such as soil conditions, road conditions, and the availability of electrical substations. Turnkey costs vary from €400 a square metre to €550 a square metre.

2. **Energy output of the system**

The energy output of a wind turbine can be estimated by:

$\boldsymbol{E} = \boldsymbol{b} \cdot \boldsymbol{V}^{3}$ where:

E is the annual energy output (kilowatt-hours a square metre),
b is the performance factor, and
V is the average wind speed at hub height.

The factor b depends on the system efficiency of the wind turbine and the statistical distribution of wind speeds. In coastal climates in Europe a value of 3.15 for b is representative for modern wind turbines and not too far away from the theoretical maximum. On good locations in Denmark, northern Germany, and the Netherlands annual outputs of more than 1,000 kilowatt-hours a square metre are often achieved.

3. **Local average wind speed**

In general, local average wind speed should exceed five metres a second at a height of 10 metres to allow economic exploitation of grid-connected wind turbines.

4. **Availability of the system**

The technical availability of modern wind farms exceeds 96%.

5. **Lifetime of the system**

Design tools have improved so much that designing on the basis of fatigue lifetime has become possible. As a result, one can confidently use lifetimes of 15–20 years for economic calculations.

For Europe a state-of-the-art reference calculation uses the following values:

Turnkey cost per m³	€500
Interest	5%
Economic lifetime	15 years
Technical availability	93%
O&M costs (€/kWh)	€0.004
Average wind speed (m/s)	5.6-7.5
Electricity production cost €/kWh	€0.12-0.04

Table 8: European calculations for the development of wind energy infrastructure [16]

Because the energy of the wind is proportional to the third power of the wind speed, the economic calculations are very sensitive to the local average annual wind speed. Overall, the investment for wind farms tends to be high but has potential for reduction in long-term period.

Regarding implementation issues, manufacturers and project developers usually identify the following items as serious barriers for efficient implementation of wind turbine projects [16]:

- Fluctuating demand for wind turbines as a result of changing national policies and support schemes.
- Uncertainties leading to financing costs as a result of changing governmental policies.
- Complicated, time-consuming, and expensive institutional procedures, resulting from a lack of public acceptance, which varies considerably from country to country.
- Project preparation time often longer than the 'time to market' of new wind turbine types.
- Lack of sufficient international acceptance of certification procedures and standards.

To conclude, the potential of wind energy is large, with the technical potential of generating electricity onshore and off-shore. Costs have to come down further, requiring development of advanced flexible concepts and dedicated offshore wind energy systems. Cost reductions up to 45% are feasible within 15 years. Ultimately wind electricity costs might come down to about €0.03 a kWh. The environmental impacts of wind turbines are limited, with noise and visibility causing the most problems, increasing public resistance against the installation of new turbines in densely populated countries [16].

1.2.3 Photovoltaic solar energy

Photovoltaic solar energy conversion is the direct conversion of sunlight into electricity. This can be done by flat plate and concentrator systems. An essential component of these systems is the solar cell, in which the photovoltaic effect—the generation of free electrons using the energy of light particles—takes place. These electrons are used to generate electricity.

Solar radiation is available at any location on the surface of the Earth. The maximum irradiance (power density) of sunlight on Earth is about 1,000 W a square metre, irrespective of location. It is common to describe the solar source in terms of insolation—the energy available per unit of area and per unit of time (such as kilowatt-hours per square metre a year). Measured in a horizontal plane, annual insolation varies over the Earth's surface by a factor of 3—from roughly 800 kWh per square metre a year in northern Scandinavia and Canada to a maximum of 2,500 kWh per square metre a year in some dry desert areas [17].

The differences in average monthly insolation (June to December) can vary from 25% close to the equator to a factor of 10 in very northern and southern areas determining the annual production pattern of solar energy systems. The ratio of diffuse to total annual insolation can range from 10% for bright sunny areas to 60% or more for areas with a moderate climate, such as Western Europe. The actual ratio largely determines the type of solar energy technology that can be used (non-concentrating or concentrating).

The average power density of solar radiation is 100–300 W a square metre. The net conversion efficiency of solar electric power systems (sunlight to electricity) is typically 10–15%. So substantial areas are required to capture and convert significant amounts of solar energy to fulfil energy needs (especially in industrialised countries, relative to today's energy consumption). For instance, at a plant efficiency of 10 percent, an area of 3–10 square kilometres is required to generate an average of 100 MW of electricity—0.9 TWh of electricity or 3.2 PJ of electricity a year—using a photovoltaic (or solar thermal electricity) system [18].

The total average power available at the Earth's surface in the form of solar radiation exceeds the total human power consumption by roughly a factor of 1,500. Although these numbers provide a useful rough picture of the absolute boundaries of the possibilities of solar energy, they have little significance for the technical and economic potential. Because of differences in the solar energy supply pattern, energy infrastructure, population density, geographic conditions, and the like, a detailed analysis of the technical and economic potential of solar energy is best made regionally or nationally. The global potential is then the sum of these national or regional potentials.

The economic potential of solar energy, a matter of debate, depends on the perspectives for cost reduction. In the recent past several scenario studies have assessed the potential application of solar energy technologies.

The technical potential of photovoltaics has been studied in some detail in several countries. In densely populated countries with a well-developed infrastructure, there is an emphasis on applications of grid-connected photovoltaic systems in the built environment (including infrastructural objects like railways and roads). These systems are necessarily small- or medium-sized, typically 1 kW to 1 MW. The electricity is generated physically close to the place where electricity is also consumed. In less densely populated countries, there is also considerable interest in 'ground-based' systems, generally larger than 1 MW. In countries or rural regions with a weak or incomplete grid infrastructure, small standalone systems and modular electric systems may be used for electrification of houses or village communities [6].

On the economic aspect the turnkey cost of a photovoltaic system is determined by the module cost and by the balance-of-system (BOS) costs, which contains the cost of all other system components, electrical installation costs, and costs associated with building integration, site preparation, erection of support structures, and so on. In 2010 the prices of utility scale solar per kWh was in the range of 0.32-0.21 euros per kWh. In 2020 new milestone has being achieved with the depletion of the solar costs dropping by a factor of 5 since 2010, having prices in the range of €0.04-0.08 per kWh, unlocking the potential for more exploitation of the sector [19].

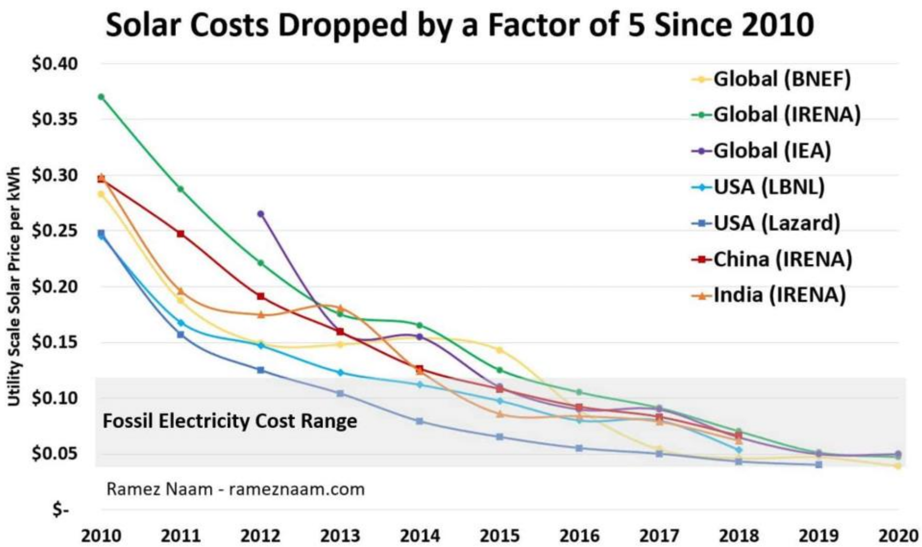

Figure 2 Solar Costs Reduction according to RES organisation reports [19]

Turnkey cost (PV euro/kWp)	200 euros
Interest rate	5%
Economic lifetime	30 years
Technical availability	98%
O&M costs (€/kWh)	€0.001
Average radiation	varies
Electricity production cost €/kWh	€0.03-0.07

Table 9 Calculations in Europe for solar energy infrastructure [20]

Photovoltaic market development through government programs in industrialised countries applies mainly to systems integrated in the built environment. The aim of these programs is to boost the development and application of photovoltaic technology as an essential step towards future large-scale use. They provide market volume to the photovoltaics industry to achieve economies of scale and experience with a completely new way of sustainable (decentralised) electricity generation. Clearly, this policy-driven market depends on public support and high expectations for photovoltaics as a major electricity source for the future.

A variety of instruments can achieve a self-sustained market: rate-based measures (favourable feed-in tariffs), fiscal measures, investment subsidies, soft loans, building codes. Another instrument is the removal of barriers related, say, to building design and material use. In addition to these incentives, the added value of photovoltaics— like aesthetics in building integration, combining electricity generation and light transmission, and generating part or all of one's own electricity consumption—are used in marketing photovoltaics. Green electricity and green certificates for the use of renewables are also expected to be important in the further development of a self-sustained market for grid-connected systems. They enable selling electricity from photovoltaics (or other renewables) to environmentally conscious electricity consumers.

Several countries have set targets or formulated programs for renewable energy technologies, specifically solar. In countries with a well-developed electricity infrastructure, the long-term aim is to achieve a substantial contribution to the electricity generation from solar energy. In developing countries and countries with a less-developed electricity infrastructure, efforts are focused on the large-scale implementation of smaller standalone solar photovoltaic systems. In these cases, the dissemination of solar energy is a tool for social and economic development.

1.2.4 Conclusions

Having analysed the three major renewable energy production solutions in terms of costs and efficiency, the following conclusions are extracted:

Biomass Energy:
Biomass energy cannot be characterised as an efficient way to produce energy for a complex environment such as the Greek islands since the lands are dry with an increased soil salinity which makes it hard to grow energy plantations. Furthermore, the wastes produced by the locals are not enough to cover all energy demands. However, biomass energy can be used as a sub-source of electricity in a later stage under the terminology of the smart island initiative and a greener solution to recycle wastes.

Wind Energy:
Wind energy is also not an efficient energy solution for the inhabited Greek islands since as mentioned are expensive investments with environmental impacts and not proper solutions for inhabited areas such as the islands we target in this research. A better use of this technology would be in uninhabited dry islands close the the supply communities where the costs for undersea connections would not be high and the distances will make sense to invest in this kind of solution. However, even with this energy scenario, it can be still labelled as a non-cost-effective solution since there are other solutions like photovoltaic energy systems that fit better in our case scenario.

Photovoltaic solar energy:
To conclude, photovoltaic energy is the best-case scenario to be used for the distant Greek islands since they are a promising cost-efficient investment and perfect fit for the target islands and therefore will be used in the analysis of this research. Apart from the technical perspective, thanks to the rapid drop of costs and materials, it makes it one of the most affordable and reliable solutions for the specific environment that this research focuses on.

1.3 Energy Storage Technologies

Ever since the human started using the various forms of energy for his comfort and necessities one of the widely researched topics till today in energy management. The term energy management includes the production of energy and efficient utilisation of the energy and finally storing the energy for future use. The energy can be utilised effectively by incorporating proper storage methods.

Energy storage devices are “charged” when they absorb energy, either directly from renewable generation devices or indirectly from the electricity grid. They “discharge” when they deliver the stored energy back into the grid. Charge and discharge normally require power conversion devices, to transform electrical energy (AC or DC) into a different form of chemical, electrochemical, electrical, mechanical and thermal [21].

Energy storage can store surplus energy from intermittent renewable sources, such as solar PV and wind power, until it is required – allowing therefore for the integration of additional renewable energy into the system.

Different energy storage systems – centralised and decentralised – consider different technological possibilities, which EASE organises in 5 energy storage classes: chemical, electrochemical, electrical, mechanical and thermal.

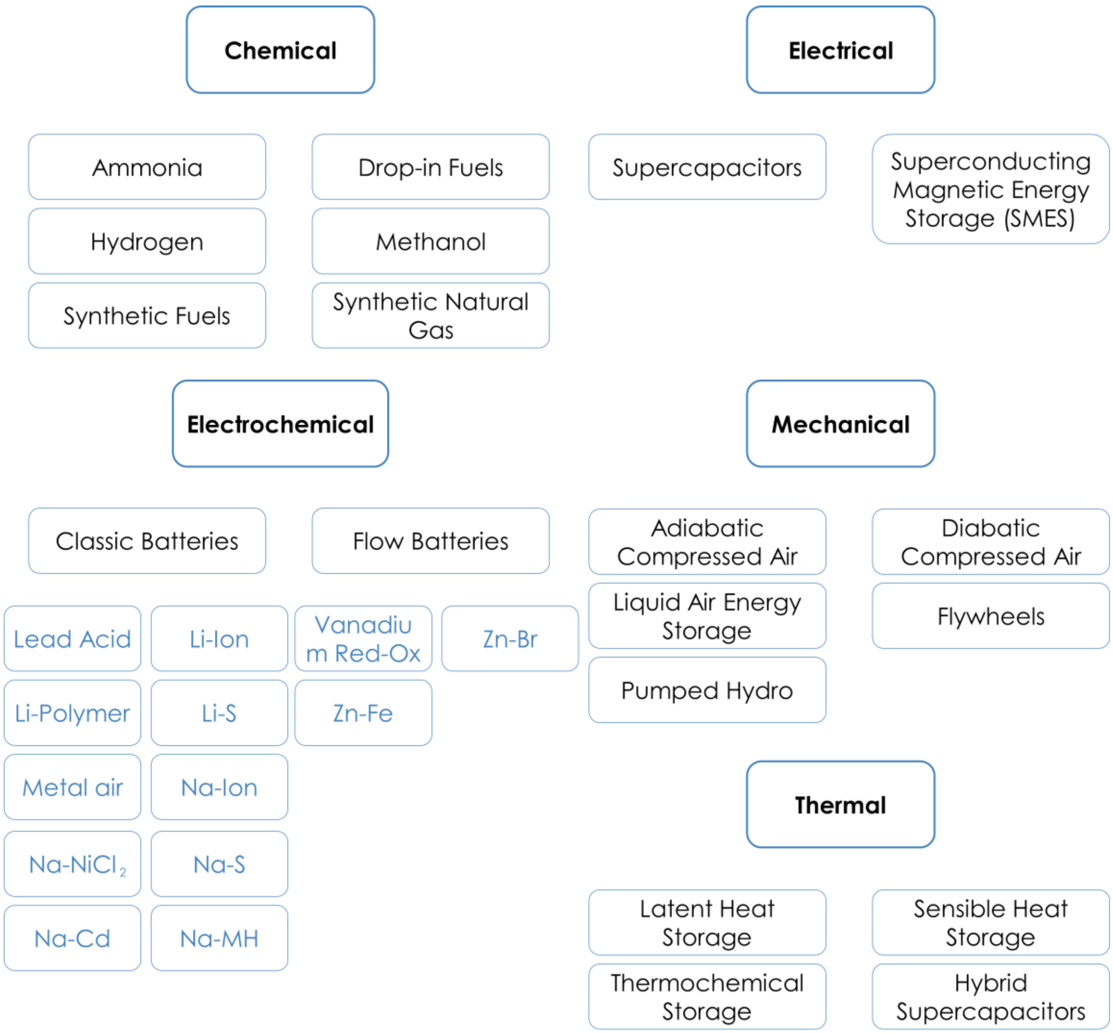

Figure 3 Energy storage systems categorisation [22]

Based on the storage period, the energy storage system can be classified as follows.

Long-term energy storage system:

1. Compressed air energy storage
2. Battery
3. Hydrogen storage

Short-term energy storage system:

1. Super capacitor
2. Flywheel
3. Inductor-Superconducting magnetic storage

Each of the above-mentioned technology has its own properties regarding to storage capacity, power, response time and cost.

For the purpose of this research some of the main popular methods that are used for storing energy are briefly analysed below.

1.3.1 Battery Energy Storage System

A rechargeable battery is a type of electrical battery made of stacked electrochemical cell and the operation is based on electrochemical energy storage. Rechargeable batteries have a higher initial cost but can be recharged inexpensive and reused many times. Batteries are modular and non-polluting and have less environmental impacts. The energy conversion in secondary battery is reversible.

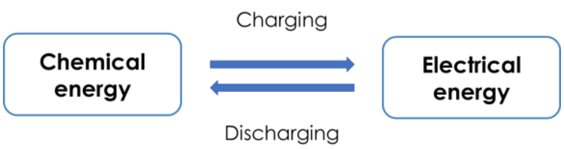

Figure 10 Energy conversion in battery energy storage

Technology	Moving Part	Flammable	Toxic Material	Rare Metal
Flow Battery	Yes	No	Yes	No
Liquid Metal	No	Yes	No	No
Sodium Ion	No	Yes	No	No
Lead-Acid	No	No	Yes	No
Na-S Battery	No	No	Yes	No
Ni-Cd	No	No	Yes	Yes
Lithium-Ion	No	yes	No	No

Table 11 Technology comparison of various types of battery for grid connected applications [22]

The energy flow in the battery energy storage system is based on the charging and discharging process. In the grid energy storage applications rechargeable batteries are used for load levelling. The unused excess electric energy during the low load levelling. The unused excess electric energy during the low demand period are stored in the batteries and are supplied to the grid during peak load periods such as storing power generated from photovoltaic arrays during the day to be used at night.

Some of the available battery technologies include Lead-Acid battery, Nickel-Cadmium, Sodium-Ion, Sodium-Sulphur batteries, Lithium-Ion batteries and flow batteries like Hydrogen Vanadium Redox, and Regenesys Redox.

The Li-ion batteries are suitable for portable devices and applications requiring high energy density and high overall efficiency. Due to low investment and maintenance costs, the

Li-ion batteries are currently the predominant technology. The Vanadium and Flow Batteries can be used for application where high power is required for long duration [22].

The efficiency of the rechargeable batteries can be 60 to 80% and it varies with the factors like recharge cycle, depth of discharge and temperature effect [22].

Batteries are sensitive to environment. During an electrical charge and discharge cycle the temperature charge in the battery must be controlled or it can cause adverse effects in battery's life expectancy. The type of battery used will determine how resistant it is to life degradation due to temperature. The battery's life cycle can be defined as the number of charge/discharge cycles that a battery can supply depending on the depth of discharge. The battery cycle application requires the battery energy storage system to charge and discharge multiple times a day. The battery's life cycle varies with the depth of charge. The battery's life cycle will be high until the depth of discharge is relatively low. However, if the depth of discharge is large, then the battery's life cycle can be degraded.

1.3.2 Hydrogen Based Energy Storage System

Hydrogen based energy storage systems are one of the best electrical energy storages. Hydrogen energy system can be easily integrated with renewable power sources like solar and wind. Even though the efficiency of hydrogen energy is not very high, their cost of storage capacity is very less when compared to the other energy storage techniques.

Hydrogen energy storage is there for economically best suited to situations where the total amount of energy stored is more valuable than efficiency. There essential elements compromise an electrolyser unit to convert the electrical energy into hydrogen, a reservoir where the chemical energy is stored and a hydrogen energy conversion system such as fuel cell to convert the stored chemical energy into electrical energy. Hydrogen is produced, then compressed or liquified, stored, and then converted back to electrical energy or heat energy. The major advantage of hydrogen is that it can replace all the fossil fuel applications without emission of harmful gases [23].

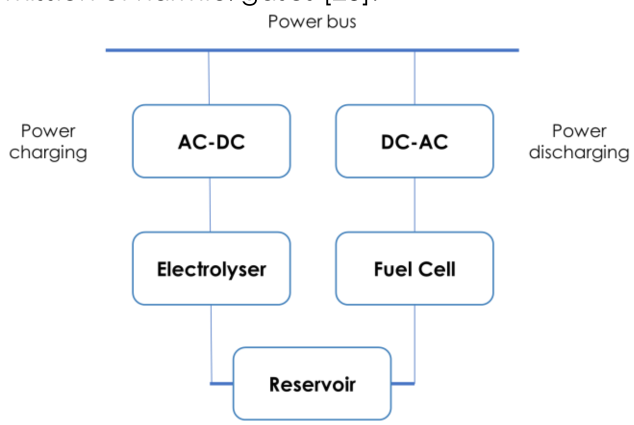

Figure 4 Energy flow in hydrogen energy storage system [23]

The different hydrogen storage mechanisms are as follows [23]:

1)Liquid hydrogen storage

Hydrogen is cooled and liquefied then kept in an insulated tank. Liquid hydrogen storage is one of the bulk storage methods. This method has high safety record. The method does not hold good for large application as the cost of liquefaction is very high because of the cryogenic storage technology.

2)Compressed and stored in pressure tank

Compressed gaseous hydrogen storage is suitable for both large and small-scale applications as long-term storage where the hydrogen liquefaction method fails due to the high cost behind the liquefaction process. This method has some safety issues and initial cost of implementation is high due to the high cost of compressors and pressure vessels.

3) Physical adsorption in carbon

The hydrogen is stored in gaseous form in the carbon through the adsorption process. The gaseous hydrogen can be adsorbed onto the surface of carbon to attain storage volumetric densities greater than liquid hydrogen. The Carbon nanofiber is used as adsorbent as it has improved hydrogen storage capability. Storage by absorption as chemical compounds or by adsorption on carbon materials have definite advantages from the safety perspective such that some form of conversion or energy input is required to release the hydrogen for use carbon materials such as activated carbons, carbon nanotubes and carbon nanofiber have been the subject of intensive research.

4) Complex compounds – Microsphere hydrogen storage

Microsphere hydrogen storage is well suitable for vehicular hydrogen storage. This system consists of hollow glass spheres that are charged with hydrogen for an hour, and discharged by heating and reducing pressure. The microspheres can be easily transferred from one tank to another. The disadvantages of this system are immature system characterisation and lower storage period.

The greatest challenge for hydrogen production, particularly from renewable resources, is providing hydrogen at lower cost. For transportation fuel cells, hydrogen must be cost-competitive with conventional fuels and technologies on a per-mile basis. This means that the cost of hydrogen—regardless of the production technology—must be less than €1.12/L gasoline equivalent. To reduce overall hydrogen cost, research is focused on improving the efficiency and lifetime of hydrogen production technologies as well as reducing the cost of capital equipment, operations, and maintenance.

1.3.3 Compressed air Energy Storage System

Compressed air energy storage is a way to store energy generated at one time for use at another time using compressed air. In compressed air energy storage systems, off-peak grid power is used to pump air underground until it reaches a high pressure. The compressed air remains in the underground reservoir or surface vessel. During peak demand the compressed air is released and heated with a fuel and is allowed to pass through turbine to generate electricity. Compressed air energy storage systems are high-efficiency turbine plants and can be easily integrated with the existing power networks. This technology has direct environmental impacts as this system produces emissions from combustion and the construction of caverns involve some sort of digging and mining operation that can have impacts on the surrounding environment, such as erosion, underground habitat destruction and increased noise levels [24].

The three main types of caverns are salt dome, hard-rock, and aquifers. Aquifers are porous underground regions usually composed of sandstone or fractured rock that has been used for the storage of water, oil and natural gas. A salt dome is a cavity created by salt mining, in which water is pumped into the rock and is used to dissolve the salt. Then the water is pumped into the rock and is used to dissolve the salt. Then the water is pumped out and a porous cavity is left, which then can be used to store air. The last type of cavern is the hard-rock cavern. This cavern is created by using more conventional mining tools such as drills, picks, and mining carts [24].

The major advantage in this method is long lifetime and provides good efficiency of nearly 85%. In order to achieve a higher efficiency or remove the need for an additional conventional fuel there are many new hybrid Compressed air energy storage technologies like interfacing with supercapacitors, oil-hydraulics and pneumatics to increase efficiency of design. On the other hand, the main disadvantage is the limited site selection and the boundaries on developing these underground reservoirs that may have an impact on the surrounding environment. [25]

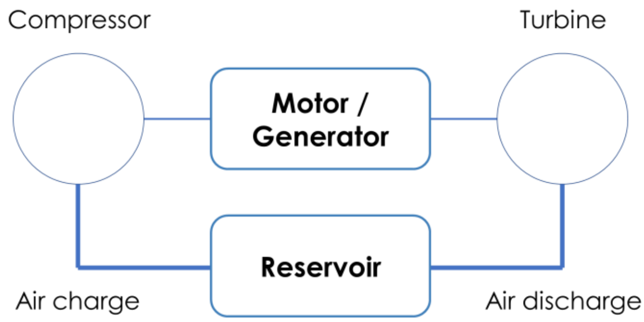

Figure 5 Energy flow in compressed air energy storage systems [24]

1.3.4 Pumped Hydroelectric Energy Storage System

Pumped hydroelectric energy storage system is a mature technology with high efficiency and long storage period. The Pumped Hydroelectric energy storage system in an existence for more than 70 years and is a clean, fast way to store energy. The working principle is as same as the hydro-electric power. Pumped hydroelectric systems comprises of a generation unit and a storage unit. The system consists of two reservoirs with pipe a pipe interconnecting them. The height difference between the reservoirs, controls the power and energy rating of the system. During the off-peak hours the surplus power is used to pump and store water in the high reservoir and during the peak demand water in the high reservoir to the low reservoir which in turns the turbine to produce electricity. The efficiency ranges between 70-85%. [26]

One of the main advantages of hydroelectric power is that it is renewable and generates no atmospheric pollution during operation reducing our reliance on expensive oil to meet peak energy demand. It also has relatively low operational and maintenance costs. Another positive attribute of hydro storage plants is that it can be used where there is little natural water available to draw upon. Also, the upper or lower dams and reservoirs that hold the resulting water could be used as recreational facilities if their water levels do not rise and fall quickly or by too much in response to generation or pumping. However, due to its size, lack of suitable locations and use of precious resources, as well as its direct damaging of the environment, it is hard technology to implement as a universal storage system. [26]

To conclude hydro power is a very flexible method of electricity generation and pumped hydro storage adds to this flexibility by using and storing large quantities of energy.

With today's state of the art turbine-pumps, pumped hydro storage plants are an interesting option for larger scale applications of energy storage allowing a way to store large quantities of electrical energy in the form of potential energy and using water as its fuel also has one of the highest cycle efficiencies of any energy storage process. Areas and environments that already have water reservoirs could consider this option, however developing this solution from zero is high-priced with many barriers that could delay or even terminate the project [27].

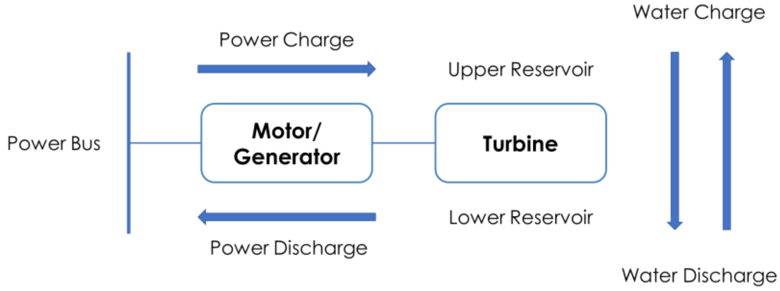

Figure 6 Energy flow in pumped hydro energy storage system [26]

1.3.5 Flywheel

The Flywheel energy storage system is one of the oldest energy storage methods and serves as an efficient method to bulk energy storage. Flywheel systems are made up to rotating cylinder, a bearing system, a motor or generator and a container to house the flywheel.

The working of Flywheels energy storage is in the form of angular momentum. The flywheel comprises of rotating discs and kinetic energy is stored by spinning a disk or rotor about its axis. Amount of energy stored in disk or rotor is directly proportional to the square of the wheel speed and rotor's mass moment of inertia. Whenever power is required, flywheel uses the rotor inertia and converts stored kinetic energy into electricity. To charge this device, energy is used to power a motor which spins the disc, and the disc remains spinning until the energy is needed. At that point the disc is allowed to turn a generator, which produces electricity. The speed of the flywheel increases during charging and decreases during discharging. Based on the speed of the rotating flywheel the system can be classified as Low speed and High-speed device. The low-speed type is designed to operate below 10,000RPM and the high-speed type can operate above 10,000 RPM [28].

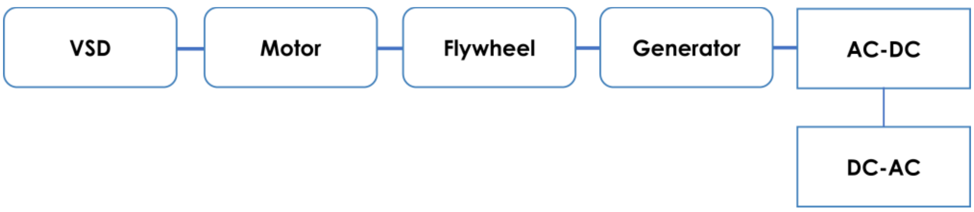

Figure 7 Motor-generator with flywheel and power electronics [28]

Recent Advances in power electronics conversion and control technology as shown in the above figure resulted in DC flywheel energy storage system. The Flywheel can be used as substitute for Batteries. Though the initial cost of installation of the flywheel is higher it has no environmental impacts like the battery energy storage which are toxic. Flywheels are not as adversely affected by temperature changes, can operate at a much wider temperature range, and are not subject to many of common failures of chemical rechargeable batteries. Depending on winding losses, bearing losses and cycling process, the round-trip efficiency of flywheel modules varies from 80% to 85%. They have high energy density compared to other storage systems. The main advantage of flywheel energy storage is long life and low maintenance. [28] In addition, they can be built with harmless materials and without hazardous chemicals.

One main disadvantage is the potential safety risks that arise if a flywheel is loaded up with more energy than its components can handle. Such a scenario could result in an almost explosion-like event, which requires security walls thus increasing the weight of the unit [29].

1.3.6 Conclusion

The efficient storage of the produced energy can be improved by the implementation of proper energy storage system. Several energy storage systems are discussed above and the overview comparison of the system are tabulated below. The table shows the general characteristics of the above discussed energy storage system. The proper utilisation of energy storage systems is possible by considering the following parameters to choose the best one for the specific application. It is clear that the compressed air energy storage and pumped hydro energy storage are well suited for centred energy storage due to their high energy storage capacity. The battery and hydrogen energy storage systems are ideal for distributed energy storage. At present - batteries are widely used due to their low maintenance and high efficiency. However, several research projects are under process for increasing the efficiency of hydrogen energy storage system for making hydrogen a promising future energy storage system.

Energy Storage System	**Power Rating**	**Discharge Time**	**Deployment time**	**Life time Efficiency**
Pumped hydro energy storage system	100-400 MW	1hr-24hr	30 years	70-85%
Flywheel energy storage system	<750 KW	milliseconds to 40 Min	20 years	90-95%
Compressed air energy storage system	50-300 MW	1hr-24hr	30 years	70-80%
Battery	<50 MW	Sec-hours	5-10 years	80-90%
Hydrogen	<250 KW	14hr-24hr	10-20 years	20-50%

Table 12 Comparison of different energy storage technologies [30]

To conclude, for the purpose of this research, battery storage will be used for the energy system design as they are highly compatible with solar microgrid projects and they are the most efficient and cost-effective proven solution in the recent years.

1.4 Energy Smart Technologies

Energy smart technologies are products and services that increase the connection and dialogue between electricity producers and end users. They are the heart of a smart grid – a combination of parts plus a process for using information and communication technologies to integrate the components of each electric system – and are contributing to one of the first major foundational changes to the global power system since its inception a century ago. The growth of this market presents a critical opportunity for generators and end users across a vast array of industries to develop new products and improve efficiency and resiliency in the evolving grid. [31]

Energy smart products and devices can be deployed in the residential, commercial, institutional and industrial sectors. By increasing the analytic data available to grid operators and energy users, smart technologies create an information bridge liking generation, transmission, and distribution with consumers. For example, digital technologies that enable two-way communications are helping to better match the generation of power with demand. These capabilities allow grid managers and end users to make more informed decisions about how and when to use energy based on grid requirements and price signals. And the additional information helps utilities manage their increasingly diverse generation portfolios.

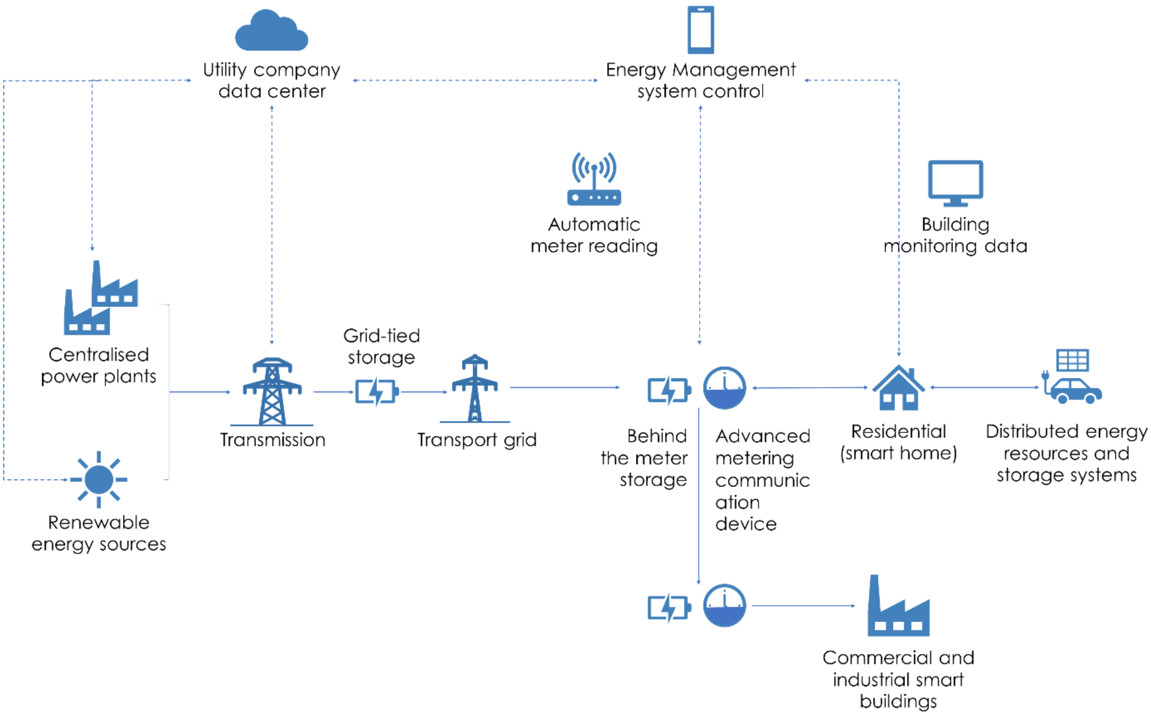

Figure 8 Digital Products and Processes Integrate Electrical Grid Components, sample system design and interconnection [31] ; [1]

Other new products are making the grid more interconnected and responsive. These include advanced metering infrastructure, automated feeder switches, voltage regulators, and other innovative controls that enable grid stability and resilience. Similarly, smart meters allow utilities and consumers to communicate digitally and make more informed decisions about energy demand, production, and use. Such sharing of data is emblematic of these emerging capabilities. Since 2007, deployment of these meters has grown rapidly, surpassing traditional automated installations for the first time, with over 51.9 million meters in 2013. [31]

New smart devices are providing residential customers with a greater understanding of their energy use and, in turn, driving changes in individual behaviour. For example, smart

[1] Note: connected line=energy flow, dashed line= information flow

thermostats provide customers with data about what time of day their appliances are cycling on and off and how their energy use compares with that of their neighbours. The thermostats are also a source of tips for saving more power—for example, doing laundry at night when the price of electricity is lower. Some utilities are offering customers digital meters and incentives to temporarily reduce their homes' power use when the grid experiences high demand.

As innovations in energy smart technologies enhance communication between producers and consumers, the role of these products in the power system will continue to evolve. National recognition of the economic and security benefits offered by smart products will be essential to support further deployment and market growth.
Establishment of open standards will unify the technologies and drive interconnection. Continued financing of innovation will help to lower costs and increase market adoption, resulting in a cleaner, cheaper, and stronger grid.

In the cases of microgrids, such energy smart technology (platform) must be integrated in the system in order to ensure smooth production and supply of electricity to satisfy the island's demands. Furthermore, it will be a basis more innovative technologies and solutions can be added in the later future such as recycling system, desalination system, EV charging stations etc.. Through this system every action is monitored and is the best way to detect errors in order to immediately resolve them.

2

Energy Sector in Greece

2.1 Energy Mix in Greece

The fuel which prevails in the Greek energy sector is oil, accounting for approximately 51% of the TPES (Total Primary Energy Supply) for the year 2019. Greece holds the second place in oil utilisation between the IEA (International Energy Agency) member countries and is almost exclusively dependent on oil imports. Coal is the second most dominant fuel with a share of 23% in the TPES in the year 2019 and utilized mostly in electricity production and a small share for industrial purposes. Natural gas occupies the third place of the most utilized fuel in the total primary energy supply for the year 2019, with a share of 11%. In general, fossil fuels contribute in the Greek total primary energy supply at a significant level, as the percentage reached 84% in the year 2016, fact which led Greece in the seventh position among the IEA countries [32].

The energy production deriving from RES experienced a double-fold increase over a 10year period, escalating from 5.9% in 2006 to 12.5% in 2019, with bio-fuels and waste being responsible for approximately half of the RES production in the TPES. It is important to mention that Greece occupies the second position among the IEA countries in the share of solar energy. The aforementioned data are illustrated in figure 9.

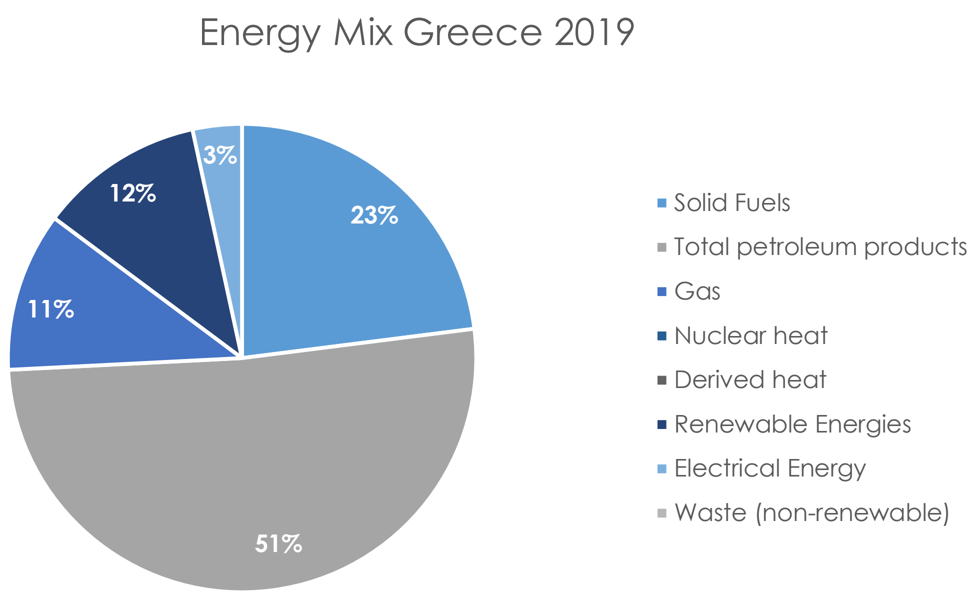

Figure 9 Energy Mix Greece 2019 [33]

2.2 Grid Connection, Non-Interconnected Islands (NIIs) and Challenges

Studying the Greek electricity network, it is possible to distinguish and divide the national power grid to the mainland power grid of central Greece and the electrification system of the Greek islands through smaller local grids. Greece can be geographically sub-divided in the mainland region, the Peloponnese peninsula (separated from the mainland) and approximately 6000 islands and islets, of which only 227 are inhabited. [32]

The islands which are not powered by the mainland power grid, termed as the Non-Interconnected Islands (NIIs) of Greece, have an electricity market which consists of thirty-two autonomous systems and of islands complexes. These thirty-two autonomous systems are categorized according to the peak load demand into three distinct systems. There are 19 small-scale autonomous systems with a peak load up to 10 MW, 11 medium-scale autonomous systems with a peak load ranging from 10 MW to 100 M, and lastly 2 large-scale autonomous systems with a peak load higher than 100 MW (islands of Crete and Rhodes) [34]. In 2020 Mykonos and Syros systems have been connected to the mainland Grid.

Most of the Greek islands are powered by autonomous electrical systems with electricity generated mostly by local thermal power stations and in some cases by RES. The thermal power stations utilize crude oil, heavy oil (mazut) and light oil (diesel). Over the last years, the Greek islands have not yet been connected to the mainland power grid due to technical and economical restrictions which set the investment costs significantly high.

The autonomous island network of Greece is accounted for the significant share of oil utilization in power generation. Greece has a large share of oil use in power production with the oil-fuelled power plants to generate approximately 11% of the total electricity production in 2015, fact which places Greece in the first place between the IEA member countries [32]. This fact is associated with numerous challenges and negative impacts towards the society and the technical performance of the energy system.

The NIIs (Non-Interconnected Islands) are principally situated in the Aegean Sea. Approximately 15% of the Greek population live on the islands and 10% of the total national electricity consumption originates from the islands [35].The current energy path way demonstrates distinct problems which can be classified to financial, technical and environmental and are presented in the following paragraphs.

Figure 10 The interconnected and non-interconnected islands in Greece [34]

From a financial perspective, overall, the NIIs are characterised by an elevated cost in comparison to the mainland power grid. In detail, the Average Variable Cost (AVC) is two to eight times higher than the average system marginal price of the mainland power grid [35]. The average variable cost is defined as the total variable cost per unit including material and labour which represents 'the average of all costs on a per unit basis that change with production levels.

After research, several articles in the Greek press where found which validate the significant difference of the AVC and the average system marginal cost of the mainland power grid [36] [37]. The average production cost of autonomous oil-fuelled power plants in August 2017, according to official data from the Hellenic Electricity Distribution Network Operator (HEDNO), stood at 336.96 € per megawatt hour, about seven times higher than the mainland limit value, around 50 € megawatt hour [37]. These elevated energy costs (generation costs, import costs, operation and maintenance O&M, fuel cost, variable operating cost) resulted in the creation and implementation of a policy measure called Public Service Obligation (PSO). According to this policy measure Greek consumers all over Greece are charged for the energy issues and thus this policy measure adds an economic burden to the Greek consumers. [36]

From a technical point of view, the existing oil-fuelled power plants operate at a maximum level particularly during the high season (summer period) to meet the increased electricity demand due to tourism. This is an important difficulty that currently the island energy sector cannot efficiently confront. The power plants operation at a maximum extent may present negative impacts such as energy blackouts. The challenge of covering the summer loads and peak demand in some islands is by-passed by ad-hoc solutions, such are rental capacity of portable diesel units or transfer of production unit from other networks where surplus capacity is available. [37] [36]

Furthermore, another technical bottleneck which should be considered is the technical lifetime and the low efficiency of the current power plants. The electricity supply of the 32 non-interconnected islands in the country is secured by low-capacity (diesel and fuel oil) stations installed since the 1960s and 1970s. [37]

As far as the energy and climate and according to the International Energy Agency, the elevated reliance on coal and diesel in electricity production (especially on the NIIs) results in a high carbon intensity of the economy. As part of EU, Greece has implemented measures which foresee the reduction in greenhouse gas emissions (GHG) and the decarbonization of the national economy. Fossil fuels were accounted for 70% of the electricity production in 2015 and the share in the NIIs was even higher [32].

After the implementation of the EU legislation on pollutant emissions, Public Power Corporation (PPC) is obliged to withdraw the polluting oil-fuelled power plants by 2020 and maintain them as an emergency back-up. Furthermore, and according to the criteria of the MoU requirements, Greece should consider and assess alternative ways for fulfilling the energy demand of the Greek islands and assess the cost of interconnection of the islands based on a socio-economic analysis, concluding to proposals for the economically non-viable interconnection of islands.

To achieve that, a national development plan for the period 2017-2026 has been published and is examined in section 2.5. In general, it includes plans for interconnections of the islands, where there is such a possibility, and for those that the connection is not viable, the process of replacing existing units with new low-environmental footprint technologies is examined, without having to lead to an increase in the cost of electricity generation by 2020. This energy transition and investigation of alternative scenarios for energy provision on the Greek islands is a requirement of the country within the EU [38].

From the above, it is clear that there is an intensified need for a transition in the energy sector of the Greek islands and identification of more efficient ways for securing the energy supply. From a higher political point of view and within the EU, actions and initiatives have been implemented with the scope to address the issue of the energy provision of all the EU islands and spur up the process for the transition of their energy sector from fossil-fuels to clean energy.

2.3 Actions promoting energy transition in EU Islands

In the EU, initiatives have been developed with an objective to decarbonize geographical islands and achieve a transition from fossil-fuel based technologies to clean energy systems. A key political priority is to establish the EU as the Energy Union, with a strategy to improve the EU economy, boost job creation, increase growth and attract more investments.

In 2016, the European Commission introduced the 'Clean Energy for All Europeans' plan with the scope to define a legislative framework able to assist the progress of clean energy transition. The initiative 'Clean Energy for All Europeans' aims to increase the GDP up to 1% over the next 10-year period and create 900.000 jobs. Additionally, for 2030 it is projected a decrease by approximately 43% of the carbon intensity of the EU's economy comparing to present [39]. A component of this plan is the 'Clean Energy for EU Islands' which sets a long-term legislative framework for spurring up the clean energy transition in Europe's islands. The islands within the EU confront several problems which this plan aims to address, while also functioning as a knowledge sharing platform of best practices and pilot projects.

The significant current challenges that the EU islands confront are the following. Most of the EU islands suffer from significantly increased energy expenses, weak security of energy supply, dependency on imports, small economies of scale and weak access to the EU energy market. The energy sector of the EU islands is heavily relied on diesel fuel and oil for electricity production. This poses a threat for the environment and it negatively affects the market competitiveness [40].

In addition, it is noteworthy that the local consumers are exposed to high electricity prices which is a burden for the economy. This is due to the constant need for implementing administrative measures and financial assistance plans to alleviate these elevated electricity costs. Lastly, during the touristic season is observed an increased electricity demand which puts pressure in the local infrastructure and natural reserves. Under the light of this evidence and according to, the decarbonization of the island energy sector seems necessary and of immense importance.

On the other hand, there are several arguments which justify the need and adequacy for projects on a smaller scale as in the context of an island. The objective is the transition of the EU islands energy sector to a decarbonised system with less dependence on imports.

The populated EU islands constitute an ideal system for implementing modernized energy solutions and engage greater investment capital which consolidates local renewable energy generation, storage resources and efficient response to the energy demand. Furthermore, due to several characteristics within the context of the EU islands, such as the geographic location, the climate potential, the size and population, available indigenous resources, they offer a favourable environment for implementation and testing of innovative energy solutions and business models.

These characteristics are 'important drivers for sustainable and resilient economic growth and the development of local skills and jobs for the communities on EU islands'. The islands may efficiently strengthen the EU's energy and climate targets and assist in the establishment of the EU. In Greece political actions have been taken which aim to support this energy transition and introduce larger amounts of RES in the energy mix. Furthermore, the Smart Islands terminology has been introduced and currently there are several attempts in order to introduce this ideology and transform the current islands into a next generation green communities.

2.4 Terminology of Smart Islands

Smart Islands are the newest trend that according to scientists and energy analysts are a key point for the transitioning to renewable energy. Specifically, smart islands can be described as autonomous, green with the potential of development and high quality of life to the local population, protecting the natural resources and equipping the grid with smart modern energy systems with smart technologies and software that provides innovative solutions to the current problems that they face [41]. All characteristics of a smart island are depicted as follows in figure 11.

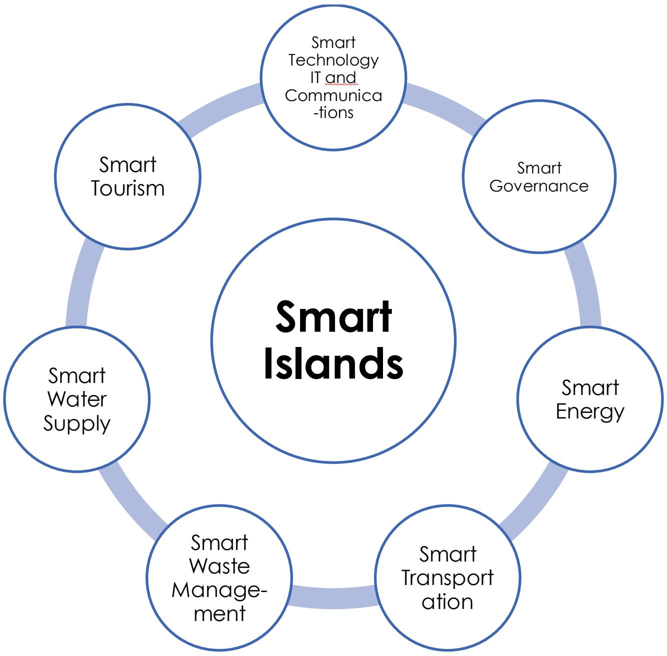

Figure 11 Basic characteristics that define a Smart Island [42]

Smart Technology IT and Communications

These are now an integral part of our daily lives and are associated with our working and social life but also with institutions and society. They have introduced new ways of communicating, teaching and working, helping significantly many daily routines, and are essentially the basis for one's infrastructure
smart island.

Smart Governance

E-government includes the application of ICT (Information and Communications Technology) for the delivery of services, the exchange of information, the communication and integration of individual systems and services between government, citizens, businesses, civil servants and intergovernmental governments. With the use of e-government it is possible to provide government services to citizens in a convenient, efficient and transparent way.

Smart Energy

For the development of a smart island, an important structural element is its sector energy. Much work is being done towards this goal in order to reduce carbon dioxide emissions and increase the use of renewable sources energy (RES). Other steps include setting up a smart grid, with the installation of smart meters in the electricity network, the use of renewable sources energy and biomass for the production of electricity and heating for buildings and the storage of energy at the building or area level using batteries.

The Greek islands play a very important role in the economic development of the country. A large number of these islands are electrically autonomous, producing energy with the use of fossil fuels and renewable energy sources. It would be desirable to increase energy production through RES, as the largest Part of the electricity supply to the islands is made using oil transported by oil tankers.

Smart Transportation

The transport sector can be improved in a variety of ways. Purchase and use electric vehicles, for the needs of the municipality, as well as the installation of power stations Charging is an important step. Smart grids can help with this electricity, which will help the penetration of renewable energy sources, in saving it, improving the service provided but also the best customer service. With the use of electric cars new generation vehicles, which will be powered by RES and will be in continuous communicate with the smart grid so that they charge at times when power requirements are reduced. This change, however, depends on the growth rate of RES in each case island, as the increase in energy demand should not be to his detriment environment, i.e., by increasing energy production through fossil fuels. It must the network can support electric vehicles through its RES. May also set up a bicycle rental or lending platform, provided there are appropriate infrastructure and if the morphology of the soil allows. All of the above are important for the creation and development of sustainable tourism.

Smart Waste Management

Waste management in a smart and efficient way is also key typical of a smart island. Smart bins can be installed, which have a much larger capacity from the conventional bins and at the same time notify via Wi-Fi the responsible service for when they need to be emptied. Recycling and biomass production is also an efficient one waste management technique, which can be used to generate electricity energy but also the heating of buildings.

Smart Water Supply

Water is a necessity for human kind. A large number of islands do not have significant water reserves, and often this water is not even drinkable. This problem is most pronounced in the summer months when the tourist traffic is launched. Installation desalination plants in Aegean islands, which will be supplied by RES. Based on them in their calculations, water production by this method is significantly cheaper than the cost of transporting drinking water to the island.

Smart Tourism

The main source of income of most islands is tertiary sector, therefore every step towards a smart island should take into account upgrade the quality of services to tourists but also to residents, with always respect for the environment.

Taking into account the different components that can structure a smart island, this research will focus on the Smart Energy and Smart Water Supply aspect as they can be characterised as the basis and the most important features that have to be developed in the islands. Following the development of those, it is easier to focus on other smart technologies and systems that can make the island smarter, cost-efficient and environmentally friendly.

2.5 Smart Island Reference Organisations

In the past decade, several organisations and research entities have studied and developed pilot project of smart islands and cities in order to examine and validate the feasibility and positive environmental impact they can cause. In Europe and with focus in Greece we find 3 entities:

Name of Organisation	**Area of focus**
Dafni (Network of Sustainable Greek Islands)	Greece – Aegean Islands
Smart Islands Initiative	European Islands
Pact of Islands	European Islands

Table 13 Organisations associated with smart islands and area of focus

These entities are briefly analysed below.

2.5.1 Dafni (Network of Sustainable Greek Islands)

DAFNI is a civil non-profit company. According to its official website, it appears that the company wishes to contribute to:

• preservation and protection of the environment of the Aegean islands, which is basic financial resource for our country
• strengthening the role of the local community but also the self-government of the islands, creating the basis for participatory decision making
• creating the conditions for healthy competition between the islands, especially concerns tourism
• creation of the basis for communication and cooperation between the islands on issues protection of the environment and protection of their cultural heritage.

The DAFNI network includes 32 islands in the Aegean Sea. Provided to member islands scientific and technical support to achieve the objectives as well as information on projects and programs. From all the member islands we see that the island of Samos is missing. At the initiative of the company, the first took place on 21 and 22 June 2016 smart islands forum [43].

2.5.2 Smart Islands Initiative

The Smart Islands initiative is an effort by local European authorities to highlight the potential of these islands to function as laboratories technological, social, economic and political innovations. They consider the islands can host pilot technologies and applications and generate knowledge on efficient management of resources and infrastructure, which in turn can be implemented in mountainous, lowland or generally isolated areas, or even in large cities.

The first Smart Islands forum, organized at the initiative of the Network Sustainable Islands DAFNI, took place in Athens in June 2016. At the conference More than 40 representatives from 13 different European countries participated in the constructive exchange of experiences between them. On March 2017 was the second meeting of the Smart Islands Initiative, this time in Brussels.

2.5.3 Pact of Islands

The Islands Pact is an initiative aimed at achieving this goal of Europe 2020 concerning the reduction of carbon dioxide emissions in the islands by at least 20% through the development of RES. It lists 150 members, divided into clusters, the which clusters work together exchanging ideas and know-how on them energy sectors. In 2014, the study of the Network was completed Sustainable Islands for the installation of smart grids on the islands of Lesvos, Lemnos, Santorini, Kythnos and Milos. Funding will be provided by its ELENA program European Investment Bank and the European Commission. The project includes installation of smart meters that will be managed through energy control centers, units RES and charging stations for electric vehicles. [43]

2.6 Smart Islands and Cities - Developed Projects

2.6.1 Samso

Samso is an island in Denmark, with 3724 inhabitants. Due to connectivity issues in Internet from the available providers, the residents decided from 2012 to provide themselves High speed internet co-financed by the Danish government. Until April of 2016 the network already had 1199 subscribers, in a population of about 3700 inhabitants [44].
The island is also 100% energy autonomous, producing a surplus of energy. The 1998 Samso wins a government-sponsored tender to run model renewable energy island. Then began a long transformation, leaving back the dependence on fossil fuels which were imported from the mainland. Most the island generates 100% of the required electricity from wind turbines. The surplus electricity is sold in the national electricity network of the country, through an electricity pipeline connecting the island with the mainland. [44]

2.6.2 Kythnos

The geography of Kythnos favors the use of renewable energy sources. It is ideal candidate for an autonomously powered island, as there is sunshine and wind throughout over time, helping to detach from diesel engines that feed the island so far. The Aegean Energy and Environment Service, in collaboration with the municipality of Kythnos, promote the island as an ideal candidate for innovative technologies, thanks in the technology used so far.

The first wind turbines were installed on the island in 1982, being the first wind turbine park created in Europe. 5 wind turbines of 20 kW were installed. The 1983 a 100kW photovoltaic system was installed with batteries that had the ability to store 400kWh. In 1989 the existing wind turbines were installed with newer ones, which had the ability to produce larger amounts of energy (33kW). In 1992 An inverter was installed in the photovoltaic system, while in 1998 an additional one was installed Vestas 500kW wind turbine [41].

In 2000 a fully automated management system was installed (smart energy network). It combines diesel generators, wind turbines, photovoltaics and batteries. This system can produce up to 2.8 MW in the summer months, managing to meet the needs of the island. In the winter months, where consumption reduced, the grid can supply energy, from renewable sources, for 12 to 13 hours on day [45].

In 2001, the first autonomous micro-electricity network was created in its area Gaidouromandras [46]. It consists of photovoltaic panels, batteries and one backup oil generator as a backup. Energy from photovoltaics supplies one small number of cottages and a farm located in the area. The excess energy is stored in batteries. The monitoring and management of the network is done by the Center for Renewable Sources & Energy Saving (http://www.cres.gr), the national for the promotion and effective management of renewable energy sources.

Smart meters are installed on the island, as part of the project "Smart Networks in 5 Islands" of the Aegean "of the ELENA program of the Central Investment Bank. The program is funded by Horizon 2020, aiming to promote smart grids as a solution to improve the quality of power supply, the introduction renewable energy sources and the conversion of electrical charges into more flexible means of continuous consumption measurements. Thanks to the above, Kythnos is one of the 5 islands that participate in WiseGRID project and will host charging stations for electric cars, they will add electric vehicles in their potential, will install batteries in public buildings, will install equipment to improve the desalination plant as well as will install batteries in the mains to increase the penetration of RES [47].

2.6.3 Islas Baleares

The Balearic Islands, a popular tourist destination for many years, have develop important infrastructure and services for tourists. In 2015, they hosted about 12.5 million visitors, with Mallorca being the most popular destination. Due to the increased traffic, police authorities and hospitals are facing roughly 150 to 200 cases per day, mainly involving children or objects that are ignored as well as minor injuries to cyclists [45].

Aiming at the safety of tourists, the Balearic authorities in cooperation with University of Palma, created the Emergency QR Project. The QR (Quick Response) code is a label that contains information about the object on which is located. It has a square shape consisting of black dots on a white background and can be read by scanners or cameras. It has the ability to store 2045 characters.

This system has been used since 2016 on cruise ship tourists disembark for a short time in Palma. Includes ID, medical information, contacts and location information. They are completely safe as well information is stored locally (in the QR Code), encoded, and can be read only from the appropriate application. However, it is not as widespread as those would like local authorities, which aim to use it mainly the incoming visitors for only a short time and do not have time to get acquainted with the area.

Mallorca is also the European city with the largest WIFI network in Europe. In 2014, the first phase of the development of the wireless network was completed, where 254 hotspots were set up in the Playa de Palma area covering 5.5 km with free internet [45].

Tourists can move around the city without losing it WIFI connectivity, with at least 3 free networks available at each point. Cisco Meraki network equipment was used, which uses traffic techniques shaping, restricting access to applications that require high bandwidth and giving priority in applications based on tourists, such as email, Facebook, WhatsApp and Google Maps. The initial project was undertaken by the company Mallorca WIFI, while other companies began to participate along the way, providing their own
Services [45].

Access to the free network requires the provision of an ID, such as for example login via Facebook account. As long as the free Internet is used, the User behavior is monitored (e.g., places visited), providing suggestions for activities but also giving an idea to the local authorities about traffic per point.

2.6.4 Other European Islands

Smart island projects are not limited just to big-scale transformations. Small-scale projects are also developed and considered to have smart island – features, some of them are presented below in Table 13.

Island (Country)	**Project Name**	**Infrastructure**
Saaremaa (Estonia)	VIRTU/ELVI	Connection of elderly population among themselves and with their families using the internet
Ile d'Yeu (France)	Parc des Iles d'Yeu et de Noirmountier	Marine installation wind farm and Smart network development Grid
Crete (Greece)	Energyn	Replacement traditional lamps with technology bulbs LED
Lesvos (Greece)	N/A	Extension of the pilot heating application with use of geothermal energy tested in 2009 throughout settlement
Favignana (Italy)	Sun and the Starts of the Egadi islands project	Installation photovoltaics on roofs, purchase of electrical and hybrid vehicles, use of LED lamps at the streets, vegetable recycling oil

Table 14 outlines implementation and future projects of others of smart islands in Europe [45] [41].

2.6.5 Trikala City

A city worth mentioning, although not located on an island, is Trikala. The city of Trikala is the first smart city in Greece and has developed a wealth of infrastructure and services which in the years 2009 to 2011 ranked it in the 21 smartest cities in the world [48]. It has a wireless broadband network, offering free internet access to all citizens. Its development began in 2005 with installation of 15 nodes, 5 of which are powered by fiber optics while in 2016, 6 additional nodes were added in the centre of Trikala. THE Access is free and open to all, and there is protection against trafficking copyrighted material as well as pornographic material [48].

2.6.6 Other European Cities

Below we list cities in Europe that have incorporated smart technologies and which could be applied to a smart island. These cities have integrated a large number of implementations in their infrastructure; however, we will refer only to some of them.

Amsterdam: The redevelopment of the city of Amsterdam began in 2009. Since then, smart meters were installed to monitor and save electricity in a large number of houses, as well as smart lighting on the road network, allowing the control of the lighting intensity centrally by the municipalities [49].

Barcelona: Barcelona has already incorporated a number of technologies that can considered as smart. A smart system has been installed in the Center de Poblenou park irrigation, which monitors soil moisture and environmental conditions so that watering is activated whenever required. He has also developed a system telemetry for transport, intelligent waste collection system as well as has install intelligent lighting system in some parts of the road network [50].

Dublin: Smart collection system developed in Dún Laoghaire-Rathdown waste. Conventional waste bins have been replaced by smart, eight-fold capacity bins notifying the competent collection service waste when filled. Dublin is considering supplying 800 extra bins for extending the system to other areas [51].

Madrid: Madrid uses the MiNT platform for centralized management of its infrastructure, part of which is an intelligent system of collection and recycling of waste.

2.7 Conclusions

A careful review of the existing literature can be seen with clear way how the technologies are meant to turn an island or a city into "Smart" have been very busy in recent years with government agencies, companies and the academic community. There is a clear strategy of the European Union, accompanied by funds, aimed at reducing CO_2 emissions from power plants using fossil fuels and petrol / diesel vehicles, through the development of renewable energy sources and use electric vehicles. The islands are considered suitable experimental platforms for application of new technologies. Several projects have already been done in cities and islands all over Europe, many of which can be applied to a large number of islands. Greece in turn participates in these efforts, mainly through actions of the Daphne network. The European Union actions concerning the islands concern the ICT sectors of energy, transport, environment, alternative tourism, fisheries and e-government.

Through this research, we have as base the smart island ideology and we investigate the options for the next island that has the necessary requirements for this kind of transition. It is a fact that more pilot projects need to be developed with higher capacities, using islands that are in need for another energy system and smart technologies. Thus, Greek islands are the best examples and as mentioned are in need for a replacement of their current energy system.

3

Study for development of infrastructure in the NIIs

3.1 NIIs Analysis

3.1.1 Energy Production Units in the Non-Interconnected Islands

The energy production cluster of NIIs is composed by 32 autonomous electrical systems, which provide electricity to 61 islands, which are shown in Table 14, as well as their permanent population, according to the census of the Hellenic Statistical Authority [52]. The production of electricity is based on thermal stations, which operate with heavy oil (mazut) or light oil (diesel). In total, during 2017, the installed capacity was 1808.35 MW [53]. In addition, renewable energy plants are operating in many of the NIIs. The total capacity of RES station in the NIIs was 459.59 MW in the first four months of 2018. Regarding shares in energy consumption, 81.5% of it is covered by thermal stations and 18.5% by RES stations. The RES share is distributed as follows [54]:

- 60.7% wind power

- 34.3% solar power (photovoltaic stations).
- 4.7% solar power (rooftop photovoltaics and net-metering)
- 0.3% from other RES (this is the estimated contribution to RES energy from a small hydro-station with nominal capacity of 0.3 MW and a small biogas unit with nominal capacity 0.5 MW, which are operating in Crete)

It is noted that an important characteristic of the NIIs energy systems is the use of generators (mainly diesel powered) for covering extra, seasonal needs in electricity. The generators are as a rule rented by the energy producers and transported to the islands. This, of course, causes increases in energy production costs and will be further analysed. The management of the energy market in the NIIs is made by the Hellenic Electricity Distribution Network Operator S.A. (HEDNO). A general categorization of the 32 autonomous electrical systems of the NII is the following:

- 19 electrical systems are small-sized, with peak loads less than 10 MW.
- 10 electrical systems are medium-sized, with peak loads between 10 and 100MW.
- 3 electrical systems are big-sized, with peak loads more than 100 MW (the ones of Crete, Rhodes and Kos-Kalymnos).

No.	Autonomous system	Served Islands	Served Population	Capacity of thermal stations (MW)	Thermal stations production (MWh)	Capacity of RES stations (MW)	RES stations production (MWh)
1	Agios Efstratios		270	0.84	92.13	0.02	0.00
2	Agathonissi		185	0.64	58.84	0.00	0.00
3	Amorgos		1973	6.20	793.72	0.29	40.83
4	Anafi		271	1.15	105.33	0.00	0.00
5	Antikythira		68	0.41	21.54	0.00	0.00
6	Arki	Marathi	49	0.41	29.38	0.00	0.00
7	Astypalea		1334	3.83	521.76	0.32	49.12
8	Gavdos		152	0.43	40.33	0.00	0.00
9	Donoussa		167	0.99	70.52	0.00	0.00
10	Erikoussa		496	0.77	66.69	0.00	0.00
11	Thira	Thirasia	15 550	75.09	13 167.48	0.25	84.98
12	Ikaria		8423	15.89	2066.08	1.39	260.04
13	Karpathos	Kassos	7310	16.50	2743.18	2.39	381.94
14	Crete		622 913	796.82	191 659.30	279.38	55 655.12
15	Kythnos	Kalymnos	1456	5.92	761.76	0.91	32.53
		Lispi					
		Leros					
		Telendos					
16	Kos-Kalymnos	Pserimos	59 477	133.66	26 699.95	23.98	3980.96
		Giali					
		Nisiros					
		Tilos					
17	Lesvos	Megalonisi	86 436	94.88	20 597.55	22.79	3986.49
18	Lemnos		16 992	23.60	4342.31	4.93	633.13
19	Megisti		492	1.73	278.55	0.00	0.00
20	Milos	Kimolos	5887	22.98	3636.21	3.27	664.94
21	Mykonos	Delos	10 134	67.49	10 777.76	2.24	381.94
		Rinia					
22	Othoni		392	0.66	52.34	0.66	0.00
23	Paros	Naxos	36 725	93.72	14 660.81	17.07	3346.14
		Antiparos					

		Koufonissi					
		Shinoussa					
		Iraklia					
		Sikinos					
		Folegandros					
		Ios					
24	Patmos		3047	8.93	1278.44	1.35	198.54
25	Rhodes	Chalki	115 968	232.93	56 264.58	66.71	10 647.98
26	Samos	Fourni	34 436	49.63	9178.84	12.75	2329.30
		Thymena					
27	Serifos		1420	6.69	753.72	0.10	18.03
28	Sifnos		2625	11.48	1548.54	0.20	49.18
29	Skyros		2994	8.45	1271.19	0.32	41.72
30	Symi		2590	8.60	1190.19	0.19	22.65
31	Syros		21 507	39.25	7354.03	3.83	611.73
32	Chios	Inousses	52 674	77.78	14 857.64	14.25	2336.94
		Psara					

Table 15 Energy systems of NII and population served by them and Average, monthly electrical energy consumption from thermal and RES station in the NII. [52] [54] [55]

* Must be noted that the islands of Mykonos (including Delos, Rinia), Paros (including Naxos, Antiparos, Koufonissi, Shinousa, Iraklia, Sikinos, Folegandros, Ios) and Syros are connected since 2020 with the mainland grid [56]. Thus this leaves us with 29 autonomous energy systems that have to be replaced.

3.1.2 Electrical Energy Consumption and Production in the NII

According to the data published by HEDNO the electrical energy consumption and production of all the electrical systems of the NII can be summarized as follows [57]:

- Average, annual consumption: 5,672,339 MWh
- Average, annual electricity production from thermal stations: 4,643,288 MWh
- Average, annual electricity production from RES: 1,029,051 MWh

The electricity consumption of the NIIs corresponds to about 10% of the total electricity consumption of Greece [58]. The electricity consumption is maximized during August (692,969 MWh) and minimized during November (356,109 MWh). The maximum monthly consumption is 95% higher than the minimum one. This illustrates one of the most distinctive characteristics among the electrical systems of the NII. The population in many islands increases during the summer due to tourism. So, great fluctuations are observed in the energy consumption. In the case of Mykonos, an island famous worldwide for summer tourism, in August the electricity consumption is 362% higher than in November. Because of the population increase during the summer, in many cases, the installed capacity of power stations is much greater than the capacity needed for the permanent inhabitants of the islands. This is reflected in the installed capacity per capita; in the NII the installed electricity capacity per capita is 21% higher than in mainland Greece, served by the interconnected electricity network. In the case of Mykonos, the installed capacity per capita is 390% higher than the average in mainland Greece. The lowest fluctuation in electricity consumption is noticed in the case of Lesvos (55%), whose economy is not exclusively based on tourism. This value of fluctuation in electricity consumption is similar to the one of the IEG [59].

The thermal station of the autonomous system of Antikythira produces, in average, 21.54 MWh, whereas the mean production of Crete's thermal stations exceeds 190,000 MWh. Such great differences in energy demand imply that there is no a single way for managing and improving the energy systems in the NIIs. On the contrary, specialized strategies, adopted to local differentiations should be developed [60].

3.1.3 Energy Costs in the NII Electrical Systems

Maybe, the most distinctive feature of the autonomous energy systems of the Greek islands is the particularly increased cost of energy production. Besides, this is the reason that causes discussion about the necessity of changing the current situation in the islands. The great energy production cost is attributed, mainly, to two factors:

1) the thermal stations operating as base-load units use oil as fuel that is expensive,
2) the great fluctuations in energy demand that make necessary either the existence of particularly high installed capacity or the transfer of generators, in order to cover peaks of energy demand.

The high energy costs of the NIIs are covered by a special levy that is charged to all electricity consumers, called "Services for common utilities" (SCU). SCU, according to the Law 4067/2012, are intended to cover [61]:

1) the high energy costs of NIIs,
2) the very low electricity charges for families with four or more children, and
3) the low electricity charges of the so called Special Social Tariff that is a special electricity tariff for households with low income.

The rates of SCU are the following for domestic electricity consumers [62]:

- 6.99€/MWh—consumption up to 1600 kWh/4 months.
- 15.70€/MWh—consumption 1601 to 2000 kWh/4 months.
- 39.87€/MWh—consumption 2001 to 3000 kWh/4 months.
- 44.88€/MWh—consumption over 3001 kWh/4 months.

The energy production cost presents differentiations among the NIIs, this is something that was expected because of the great differences between the energy consumption of the various energy systems. The weighted average of the variable cost all the NII electrical systems was 130.519€/MWh, between 2014 and 2017.

The greatest cost is observed in the system of Antikythira (average variable cost 383.863€/MWh), which has the smallest electricity demand and it serves the smallest population among the NII. This autonomous system does not include any RES. The system with the lowest cost is the one of Chios (92.434€/MWh), which is a medium-sized system, with a share of renewables (15.7%), close to the average of the NIIs. In Figure 12, the variable cost in the NIIs is illustrated in descending order. The average marginal price of the interconnected electricity grid of Greece (AMPIG) is also included in Figure 13, to gain a comparative perspective. In the period 2014-2017 the average marginal cost was 51.338€/MWh [59].
The energy production in the system of Chios, with the lowest cost among the NIIs, is 80% more expensive than in the interconnected system. The weighted average marginal cost of the NIIs is 2.5 times higher than the AMPIG, and the variable cost of the Antikythira system is 7.5 higher than the AMPIG. These findings are indicative of the great economic burden of electricity in the NIIs and support the necessity of changing the current situation. The difference between the average variable cost in the NIIs and the AMPIG was 79.181€/MWh.

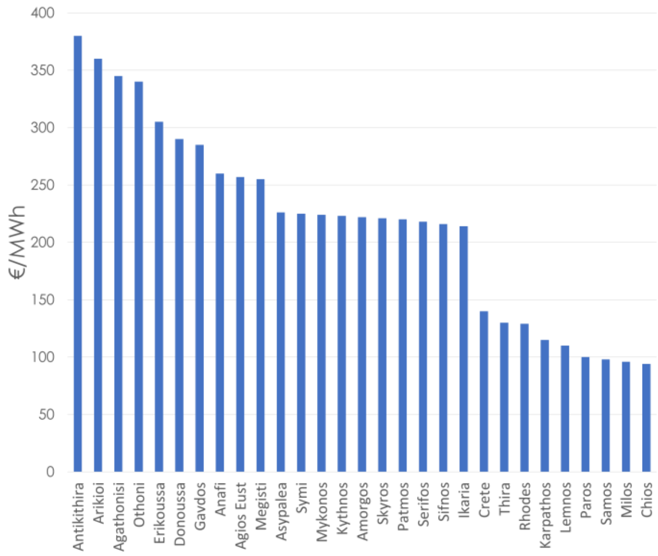

Figure 12 Average variable costs energy costs in the NIIs electrical systems (2014-2017) [60]

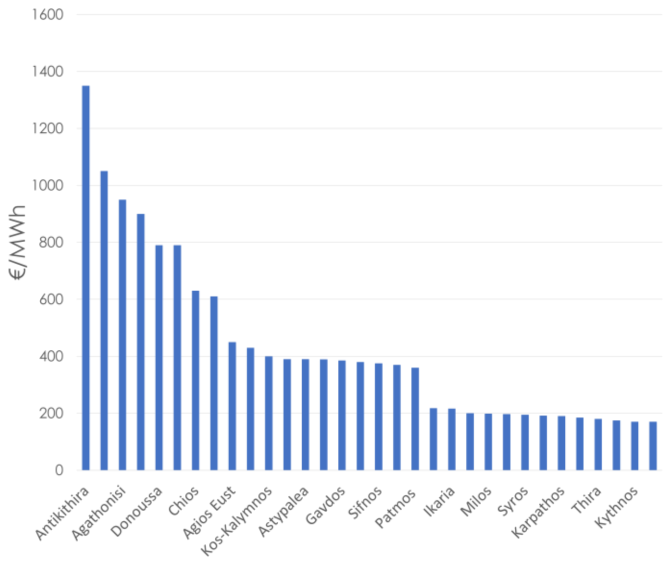

Figure 13 Average total energy costs in the NIIs (2014-2017) [60]

In the previous paragraph the term "variable cost" was used to refer to the energy production cost in the NIIs. According to the official definition, the variable cost of electricity in the NII, in €/MWh, is given by Equation (1) [63]:

$$MMK_{m,s} = \frac{KK_{ms}}{Q_{\Sigma M,m,s}} + K\Lambda_{m,s} + \frac{KP_{m,s}}{Q_{\Sigma M,m,s}} \quad (1)$$

where:
− **KKm,s:** Cost of fuel for electricity production, including the excise duty in €.
− **QΣM,m,s:** The sum of net energy produced and supplied to the grid from all thermal stations of each autonomous system (s) per month (m) in MWh.
− **KΛm,s:** The additional variable operational cost of thermal stations in €/MWh.
− **KPm,s**: The cost of greenhouse gas emissions in €/MWh.

The cost of fuel is determined by Equation (2) [64]:

$$KK_{m,s} = \Pi_{mazut,m,s} \cdot MK_{mazut,m,s} + \Pi_{diesel_{m,s}} \cdot MK_{diesel,m,s} \ (2)$$

where:
– **Π_mazut$_{m,s}$, Π_diesel$_{m,s}$:** The quantities of mazut in tn and diesel in klit which are expected to be consumed in the electric system (s) in the month (m).
– MK_mazut$_{m,s}$, MK_diesel$_{m,s}$: The unit costs of mazut in €/tn and diesel in €/klit.

The variable cost is representative of the actual electricity production costs. The main factor that affects it is the fuel cost. The cost of greenhouse gas emissions is, for the time being, rather low. The relative data are not publicly accessible for every year. Indicatively, for the year 2013, the cost of greenhouse gas emissions is known represented less than 4% of the variable energy cost of the NIIs. According to the available data, between 2012 and 2015, the Public Power Corporation (PPC) which is for the time being the only energy producer in the NIIs—spent nearly 2.5 billion euros for purchasing mazut and diesel oil for the thermal stations of NIIs.

According to the Regulation of NII [65], the conventional power stations receive revenues for:

- The energy they provide to the grids, based on the variable cost of electricity production and the starting cost of the power stations.
- The availability of electrical capacity (also known as cold power reserve).
- The provision of auxiliary services.

However, for the time being, the transitional provisions of the NIIs Regulation are being applied, since there are still pending problems for completing their formation of the energy market of the NIIs. According to these transitional provisions, the energy producers that provide energy to the NIIs are compensated for the total energy production cost, which is defined by Equation (3) [65]:

$$MK\Pi K_{m,s} = \frac{KK_{m,s} + KP_{m,s} + RAV_{m,s} \cdot r + D_{m,s} + O_{m,s} + KEA_{m,s} + E\Delta_{m,s}}{Q_{\Sigma M,m,s}} \ (3)$$

where:
– **RAV$_{m,s}$:** "Regulated asset base", which is the sum of the non-depreciated value of fixed assets plus the working capital.
– **r:** Reasonable return on the value of the regulated asset base (defined each year by RAE).
– **D$_{m,s}$:** Depreciation of fixed assets.
– **O$_{m,s}$:** Operational expenses, namely: payroll costs, costs for maintenance and service of energy units, cost of replacement parts, insurance costs, third-parties remuneration, costs of electricity consumed by the energy units, taxes and levies.
– **KEA$_{m,s}$:** Expenses for renting, transferring and installing electrical generators for covering seasonal energy needs.
– **EΔ$_{m,s}$:** Shared administrative costs.

Year	Average mazut cost (euros/tn)	Average diesel cost (euros/klit)	Annual mazut cost (Meuros)	Annual diesel cost (Meuros)	Total annual oil cost (Meuros)	Excise duty mazut (Meuros)	Excise duty diesel (Meuros)	Total excise duty (Meuros)

2012	548.66	639.30	499.57	146.65	646.22	34.6	75.7	110.3
2013	491.57	599.67	413.89	130.03	543.92	31.99	71.56	103.55
2014	459.94	556.52	395.08	130.87	525.95	32.64	77.6	110.24
2015	272.76	395.60	233.43	99.48	332.91	32.53	82.99	115.52
2016	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2017	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2018	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2019	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2020	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total costs		1541.97	507.03	2049	131.76	307.85	439.61

Table 16 Costs and spending on mazut and diesel oil for the thermal stations of the electrical systems of the NII [60]

The total energy production cost is, as expected, higher than the variable cost. There are cases of autonomous island systems is particularly high, mainly, due to the $KEA_{m,s}$ factor, related to seasonal needs and costs of extra electrical generators. Unfortunately, precise data regarding KEAm,s are not publicly available. However, fragmentary data and publications support the claim about the high values of KEAm,s. For instance, in summer 2017, RAE approved the rental of generators with a total capacity of 37 MW for covering seasonal loads in the NIIs [66]. This is certainly a big value of extra electrical capacity.

In the case of Antikithyra it reached the excessive price of 1328.03 €/MWh. Due to the low energy loads of such islands, the cost of electricity in the NII is not increased much due to the energy cost of very small islands. However, these cases are indicative of the difficulties and the high expenses for providing energy to particularly remote areas. But even in the case of Lesvos, which has the lowest total electricity production cost among the NIIs, the revenue of energy producers (148.967€/MWh) is almost three times higher than the revenue provided to energy producers in the interconnected energy grid of Greece. In the period 2014-2017, the weighted, average total energy cost of the NII was 186.547€/MWh. In other words, it was 3.6 times higher than the AMPIG during the same time period [60].

3.2 Conclusions

According to the information provided, it is necessary for Greece to take seriously the financial damage that the current electricity supply systems cause to the nation. The necessity for transitioning to more eco-friendly solutions is clear. Greece should take in consideration the RES sources potential and take advantage on the current investments and funding provided from Europe. A good start are the initiatives that focus on the Greek Non-Interconnected Islands – hence the focus of this research.

Analysing the aforementioned information, it is important for this study to select an island that presents the characteristics needed to develop a microgrid system and is classified as an island that is unable to have a mainland electricity supply interconnection.

For the purposes of this research the island of Astypalea will be examined as it covers all the main characteristics and it is one of the first islands that are to be transformed under the smart island initiative. In the following sections, the research dives in the background of Astypalea island and with the inputs of some other similar researches it will outline the current needs, possible solutions and energy systems that can replace the existing one.

4

The Island of Astypalea

4.1 General Information

Greece is a peninsular and mountainous country located in Southern-Eastern Europe. A characteristic of Greece is the vast coastline of 13.676 km which is the largest in Europe. This record is because of the abundant Greek islands which reach 2.000 in numbers while only 168 of them are populated. The Greek islands are divided according to their geographical location and the sea water area to: Crete, Cyclades, Dodecanese, Ionian, Sporades, Saronic and Eastern Aegean islands [67]. The Dodecanese island complex is in south-eastern Aegean Sea between the Cyclades island complex, Crete island and the coastline of Minor Asia (Turkey). It comprises of 18 larger and smaller islands and numerous islets. An island which belongs to the Dodecanese island complex is Astypalea. The location of Astypalea island is illustrated in figure 14.

Figure 14 Astypalea Map [68]

Astypalea island is characterised by rough and rocky coastlines and mountains which are not significantly high. The highest peak is Vardia mountain at an altitude of 482m. The soil morphology of Astypalea, as in the majority of the Dodecanese islands, is sterile and rocky. The are no rivers in the Dodecanese region but only a number of areas with streams.

The population of the island according to the last census realized in 2011 equals to 1334 residents. The municipality of Astypalea has an area of 114077 km per square. A small area of land of approximately 126 metres wide almost divides the island in two sections. There are 4 villages on the island which are the villages of 'Astypalea' or 'Chora', 'Livadi', 'Analipsi' or 'Maltezana' and 'Vathi'. The village of 'Chora' has the largest amount of people and most of the island's life is concentrated there. [68]

4.2 Indigenous Resources and Local Potential

The indigenous resources and the local potential in the island of Astypalea include the wind dynamic and the solar irradiance. These two elements are described below and the purpose is to argue about the selection of RES that are implemented in the alternative SES scenarios. Furthermore, the geography and soil morphology (highest elevation point etc.) in of the Greek island of Astypalea have been already examined in section. This could play an important role in the identification and employment of the most relevant and practically feasible storage solutions (hydro pump storage). In the following, a description of the strengths, the indigenous resources and the local dynamics in Greece and in Astypalea are described. As can be seen from the figure 15, in Astypalea the average annual sum of PV output is in the range of 1600 to 1700 kWh/kWp. It is observed that there is a high potential for implementing PV technologies, as the solar irradiance is significantly high and for most of the Greek islands. Hence, RES technologies which harness the solar irradiance should be considered in the design of the alternative scenarios [69].

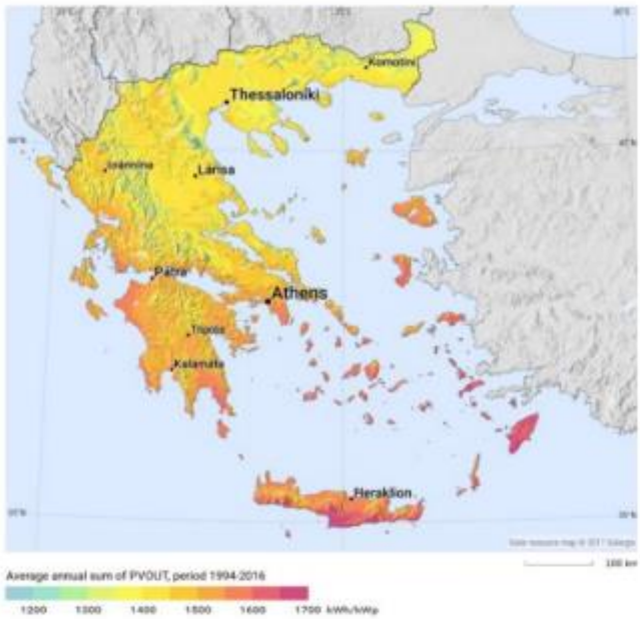

Figure 15 Average Annual Sum of PV output 1994-2016 [70]

As illustrated, in general the majority of the Greek island and with specific focus in Astypalea, there are encountered the highest values of average annual wind speed. Astypalea is in the range between 8 to 9 m/s. This range is placed between the highest values of average annual wind speed. This is and indicator for this research to also consider this fact in the process of choosing RES technologies for the alternative scenarios.

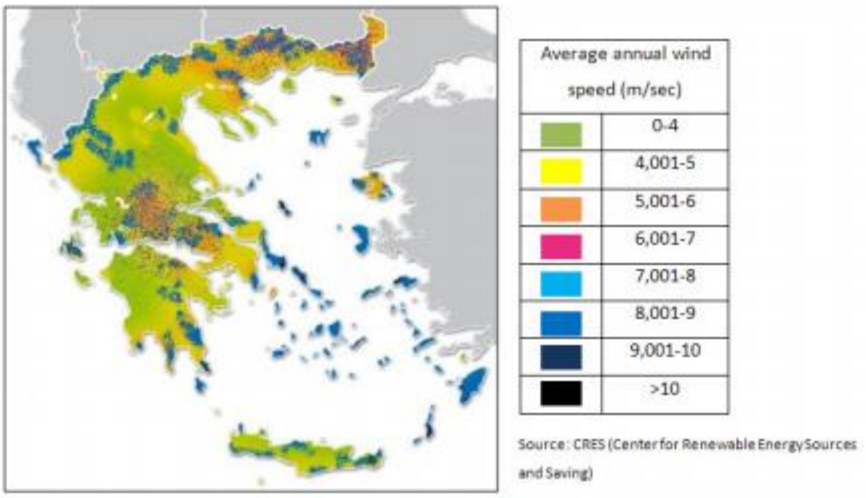

Figure 16 Average annual wind speed in Greece [71]

4.3 Electrification System

4.3.1 Investigation of Improvement Options for the Autonomous System of Astypalea

Astypalea is an ideal and representative case study for investigating future perspectives of small, autonomous electrical systems in the Greek islands. It lies in the middle of the Aegean Sea, as reflected by the distance between the island and other greater islands, as well as the mainland [69]:

- Astypalea—Kos: 55 km
- Astypalea—Naxos: 90 km
- Astypalea—Crete: 140 km
- Astypalea—Rhodes: 170 km
- Astypalea—Lavrio: 240 km
- Astypalea—Athens: 280 km

Hence, practically, the operation of an autonomous electrical system in Astypalea is compulsory, because its connection to other, greater electrical systems (or to the interconnected electricity grid of the mainland) is rather difficult.

The permanent population of the island, according to the last census, is 1334 inhabitants. The area of the island is 96.9 km^2. Astypalea is a rather popular tourist destination, especially for alternative summer tourism and so, its population (and consequently the energy demand) rises during the summer.

The energy system of Astypalea is based on thermal plants that use diesel oil for electricity production. The type and the power of the islands' generators are shown in Table 15. In 2015, the fuel consumption for electrifying the island was 2,262,347 lit of diesel oil; this is a high quantity of oil and its reduction will have positive results both from an economic and an environmental point of view. Moreover, there is an energy unit based on solar power in Astypalea that includes a photovoltaic array with peak power 320 kW. The share of solar energy in the electricity consumption ranged between 8% and 9%, in the period 2014-2017. Regarding the electricity consumption in Astypalea, for the period 2014-2017, the average values per month are shown in Figure 17. The maximum consumption (August) is almost 2.5 times higher than the minimum consumption (November). This is a typical situation for an island, whose main economic activity is summer tourism, as already discussed. The electrical load was possible to be retrieved by HEDNO, at an hourly base for the years 2014 and 2015. The hourly load is a prerequisite for conducting realistic simulations and optimizations. The peak load of the island was 2.25 MW. A view of the hourly load in Astypalea is given in Figure 18 [60].

The average costs in Astypalea for the period 2014-2017 have as follows:

- Variable electricity production cost: 228.81€/MWh
- Total electricity production cost: 379.27€/MWh

So, Astypalea is ranked 11th among the 32 autonomous systems regarding the variable cost of electricity production and 13th regarding the total cost. It is reasonable that the reduction in the island's electrification cost is utterly necessary. For improving the current situation, by considering the findings in the previous sections, the two main choices are [60]:

1) connecting the island to the IEG and,
2) changing the current structure of Astypalea's system and increasing the use of renewable energy sources.

Type of generator	Fuel	Nominal Capacity(kW)	Power Output(kW)
STORK ABR-216S	Diesel	208	150
STORK ABR-216S	Diesel	208	150
STORK ABR-216S	Diesel	208	150
STORK ABR-216S	Diesel	208	150
MITSUBISHI S16R-PTA	Diesel	1275	1100
MITSUBISHI S16R-PTA	Diesel	1275	1100
MITSUBISHI S16R-PTA	Diesel	1275	1100

Table 17 Type, fuel and capacity of the electricity generators used in the electrical system of Astypalea [72]

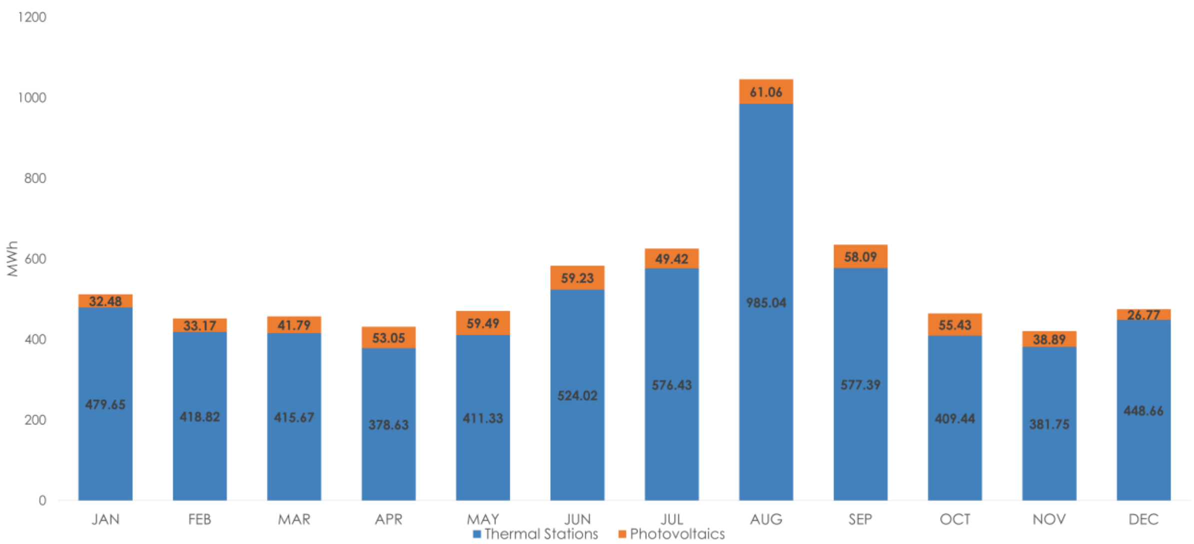

Figure 17 Average Monthly electricity consumption in the system of Astypalea (2014-2017) [60]

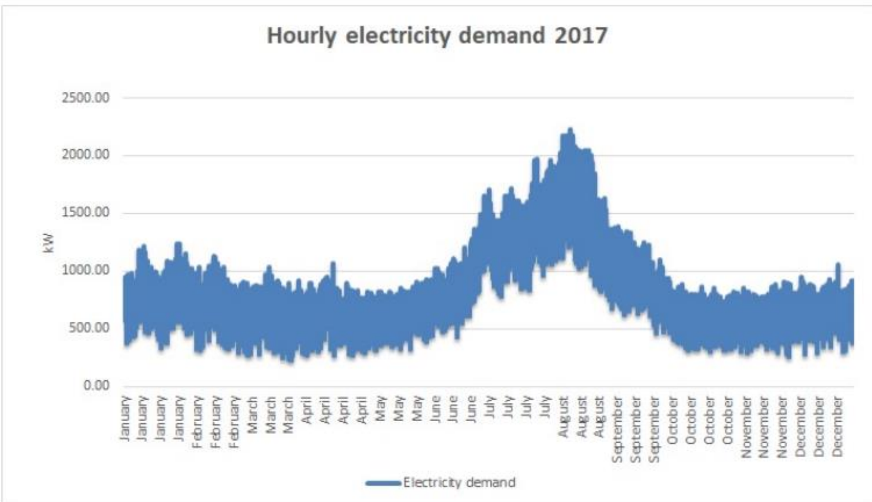

Figure 18 Hourly electricity demand 2017 of Astypalea island [60]

According to HEDNO information this table of details can be extracted concerning electricity demand:

Total annual electricity demand	6.56 GWh
Hourly maximum demand value	2224 kW
Hourly minimum value	241 kW
Annual average load value	748.90 kW

Table 18 Info concerning Astypalea electricity demands and loads [72]

In order to assess and design the system in Astypalea, an investigation on each sector is conducted separately so we obtain more realistic and accurate results for the design.

4.3.2 Analysis of residential sector

A typical residence in Astypalea is considered as a two-floor building of a total area ranging from 50-60 square meters. A typical traditional house can be divided in 2 communication levels. Level 1 includes a kitchen with a refrigerator and a cooking stove, a living room/dining room and a bathroom. Level 2 includes a large double bedroom in an elevated area, and a single bed in the living room, storage space and access to the balcony. Must be mentioned that these information came from unofficial discussions with local residents.

The total number of inhabitants in Astypalea island is 1334, according to the most recent population census realized in 2011 by the Hellenic Statistical Authority [52]. Since there is no concrete information about the number of persons per household, this research assumes that 3 persons live on average per household. This assumption is done based on the description of a typical residence in Astypalea and the rooms available (one double bedroom, one singe bed). Thus, the total number of residential customers of electricity is approximately 445 residences. This is taken into consideration for the calculations and modelling of the reference scenario.

According to Eurostat, the following percentages describe the share of final energy consumption in Greece in the residential sector:

Space heating	5.7%
Space cooling	11.3%
Domestic hot water	26.4%
Cooking	21.5%
Lighting and appliances	35.1%

Table 19 Greek household energy share [73]

The resulting data for the residential sector is summarised in table 19.

Residential sector		
Total number of inhabitants in Astypalea island	1334	
Total number of residences	455	
Annual electricity consumption per capita in Greece (Eurostat source)	1.6	MWh
Total annual electricity demand (Astypalea residential sector)	2.13	GWh
Total annual electricity demand for heating	0.12	GWh

Total annual electricity demand for cooling	0.24	GWh

Table 20 Data for the residential sector in Astypalea [73]

The data presented in table 16 is considered for the year 2017 while the estimations for the electric heating and cooling demand are based on statistics for Greece and for the year 2016. Since the data for the final energy consumption in relation with the type of end-uses for Astypalea or any other island of a similar context could not be found, the statistics for Greece average residential consumption obtained from Euro-stat are applied for the purposes of this research.

4.3.3 Analysis of commercial sector

Commercial sector as all the non-manufacturing enterprises, including hotels, motels, restaurant, wholesalers and retail stores, health, social and educational institutions.

This research adopts this definition and seeks to identify information about these components of the commercial sector in Astypalea. Hotels and other types of accommodation, dining businesses and food catering services, cafe bars and the schools in Astypalea island are considered in the modelling of the reference scenario.

Hotels and other accommodation services

The tourist infrastructure is developed in all the 4 villages of Astypalea. 'Maltezana' or 'Analipsi' is characterized as the resort with the largest tourist action. In this village the largest number of accommodation services for tourists and visitors are situated (such as hotels, hostels, rooms to let, etc.) and also food and catering services such as restaurants or smaller typical restaurants and taverns, and other shops that serve tourists. [68]

From data obtained and with some estimations the existing infrastructure in Astypalea for visitors and tourists' accommodation is shown in Table 20 [74].

Accommodation type	Units	Rooms	Beds
Hotels	16	235	459
Other accommodation	87	440	990
Total number of services	103	675	1449

Table 21 Existing accommodation infrastructure for tourists and visitors in Astypalea [74]

The total average energy consumption for the hotels and other accommodations is estimated to be 17.59 KWh per night spend.

The hotels and other accommodation services operate during the touristic season (summer months) which is from May to late September (150 days of operation). Hence, the total average energy consumption for the hotels and other accommodation types in Astypalea is calculated to be 10500 kWh/year. It should be mentioned that this number does not reflect the true value of energy consumption in Astypalea and it might deviate from the realistic value.

According to Eurostat, the following percentages describe the share of final energy consumption in Greece in the accommodation sector:

Space Cooling	61%
Domestic hot water	18%

Laundry	5%
Catering	3%
Shared lighting	7%
Electricity for room	2%
Lift	2%
VAC/HVAC	2%

Table 22 Greek hotel electricity share [73]

Hence the resulting data for the hotels and accommodation is summarised in table 22.

Hotels and other accommodation types sector		
Total number of hotels and other accommodation types	103	
Total number of rooms	1350	
Occupancy rate of rooms per day	50%	
Total average consumption per night spend	17.59	KWh
Total days of touristic season	180	days
Total annual electricity demand (Astypalea accommodation sector)	1.8	GWh
Total annual electricity demand for cooling	0.23	GWh
Total annual electricity demand for heating	0.01	GWh

Table 23 Data of the hotels and other accommodation types sector

Dining businesses and other food and catering services

According to the Hellenic Statistical Authority (ELSTAT), on the island of Astypalea are active 64 businesses for dining and food catering services. The majority of dining businesses and food catering services in Astypalea consists of large open areas. It is found that on average that a typical restaurant in Astypalea consists of a total floor area of 120-160 meters squared with indoor and outdoor area to have 40 to 80 and 40 to 100 meters squared respectively [75].

It is found that the fuels in the final energy consumption for a restaurant in Astypalea on average, are electricity and LPG (propane gas). Electricity covers the majority of end-uses and LPG directed for cooking appliances such as the kitchen stoves and grills. As it is acknowledged from the phone-call discussions, the estimated annual consumption of LPG (propane) tanks on average is ranging between 30-40 tanks of 25kg each. 1 kg of LPG (Propane) equals to 49 MJ and 1 MJ equals to 0,278 kWh. Thus, the calculations for the annual LPG (propane) demand for the restaurants and cafe bars can be estimated.

Concerning the heating and cooling of the space, there is no significant demand as the outdoor area is an "open space" are and the restaurants operate at the maximum extent during the summer season. Since the area is outdoor, the majority of restaurants and taverns do not have significant cooling demand and electric cooling demand via air-conditioning units. Nevertheless, in some cases there might be individual fans for ventilation or cool wind flow. For this reason, it is assumed that there is no significant cooling demand to be taken under consideration. The same applies for the space heating as during summer there is no demand and during the winter the restaurants are operating at the lowest extent if not closed.

The following percentages describe the share of final energy consumption in Greece in the dinning businesses and food catering services sector, the data are from assumptions:

Cooking	43%
Domestic hot water	14%
Lighting	14%
Refrigeration	10%
Space Cooling	7%
Cooling	7%
Ventilation	3%
Other	4%

Table 24 Greek dinning businesses and food catering services electricity share

Hence the resulting data for the dinning businesses and food catering services sector is summarised in table 24.

Dinning businesses and food catering services sector		
Total number of dinning businesses and food catering services	64	
Total days of touristic	210	days
Total LPG propane demand (cooking purposes)	0.87	GWh
Total annual electricity demand (Astypalea dinning sector)	1.15	GWh
Total annual electricity demand for cooling	0.10	GWh
Total annual electricity demand for heating	0.16	GWh

Table 25 Data of dinning businesses and food catering services sector in Astypalea

School buildings and education

The school buildings, constructed in stone, consist of four halls, a cabinet manager and teachers and toilets. Nowadays the school, preserved and renovated has six classrooms, IT rooms, integration department, arts room, director's office, teachers' office, multi-purpose room, Infrastructure for people with disabilities. This evidence is capable for providing an overview of the school building floor area, even though the total square meters are unknown. Regarding the energy sources in the final energy consumption, the schools in Astypalea are assumed to fulfil their annual energy demands exclusively by the use of electricity.

The school building is assumed to belong in the category of school building with an estimated total floor area of 1225 square meters. Total annual electricity demand for 2 school buildings of Astypalea island: 471086 kWh or 0.47 GWh.

The following percentages describe the share of final energy consumption in Greece in the school buildings and education sector, the data are from assumptions:

Space heating	45%
Lighting	14%
Space Cooling	10%
Ventilation	9%
Water heating	7%
Other	5%
Computers	4%
Refrigeration	2%
Cooking	1%
Office Equipment	1%

Table 26 Greek school buildings and education sector electricity share

Hence the resulting data for school buildings and education sector is summarised in table 26.

School Buildings and education sector		
Total number of school buildings	2	
Total annual electricity demand	0.47	GWh
Total annual electricity demand for cooling	0.25	GWh
Total annual electricity demand for heating	0.06	GWh

Table 27 Data for School Buildings and education sector in Astypalea

Airport. Other buildings (shops, supermarkets, pharmacies et.) and farming

The facility is located nearby the village Analipsis, and approximately 12 km northeast of the city of Astypalea. The buildings of the airport cover an area of 106,24 m2. Furthermore, Astypalea includes other type of buildings such as museums, churches, shops, pharmacies, car garages, supermarkets, banks etc

Hence the resulting data summarised:

Total number of other buildings		
Airport	1	
Museums	3	
Gas stations	3	
Pharmacies	1	
Supermarkets	7	
Banks	2	
Bakeries	3+	
Other Shops/Businesses	10+	
Farming lands	N/A	
Total annual electricity demand (airport and other buildings)	**0.23**	**GWh**

Table 28 Total number of other buildings in Astypalea island

4.3.5 Analysis of Street Lighting and other public lighting

Currently Astypalea has a developed street light system. The street lighting system mainly consists of a light pole, a lamppost, a street lamp, a light standard, or lamp standard, is a raised origin of light on the edge of a road or path. Street lighting system is an essential part in the island as it prevents accidents and unwanted thefts or robberies. Furthermore, street lighting gives a better aesthetic view of the island and enhance tourism. In general, a street lighting system consumes about 25-30% of the total energy spent in the city. It is assumed that in Astypalea one of these types of street lamps is used.

Lamp Type	Wattage	Lumens	Colour Temp.	Luminous Efficacy	Lamp Life (Hrs)
HPSV	70	6700	2100K	50-150 LM/W	24000
HPMV	125	6200	5000K	35-65 LM/W	8000
FL	100	7650	4200K	100-115 LM/W	12000

Table 29 Current Street Lighting Lamps [76]

Hence the resulting data for the street light and other public lights sector is summarised in table 29.

Street Light and other public lights sector		
Total number of street lights and other public lights	1390	
Total hours of use	9	hours
Total annual electricity demand (street lighting and other lights)	0.54	GWh

Table 30 Data for Street Lighting and other public lights sector

4.3.6 Analysis of Water System

Astypalea water needs are covered through a dam in the centre of the island. The reservoir, saves rainwater and adequately covers the water supply needs of the island. It is one of the most successful construction reservoirs in the Aegean islands with a capacity of 875,000 m^3[77]. However, due to climate change, rain in the area is not quite frequent, thus the region faces some serious issues, especially in the summer period. Apart from the dam there are some ongoing projects for the settlement of Maltezana. These projects are water wells connected with desalination systems with reverse osmosis technology. No further information concerning electricity consumption was found.

Generally yearly water use of a residence with 3 members is 82-175 m^3 [78]. This covers general use of water regarding home, gardening, cooking, etc. An average person consumes 1.10 m^3 drinking annually [79].

Hence the resulting data for the water consumption:

Water sector		
Total number of inhabitants in Astypalea island	1334	
Total number of residences	455	
Total tab water consumption	54600	m^3
Total drinking water consumption	1468	m^3

Table 31 Data for water sector in Astypalea

4.6 Conclusions

The case of Astypalea provides strong evidence regarding the possibility to utilise local RES together with the use of storage systems, in order to improve current situation in small NIIs. The perspectives of the local autonomous system for sustainable improvement are promising

Apparently, the work presented in this paper presents some limitations. The main amongst them are: 1) the focus on one island, namely Astypalea and its energy system and needs, and 2) the fact that thermal energy loads used to determine the energy needs and system size are not 100% accurate and therefor results can differ slightly from reality. These limitations can be addressed by the following steps of future work:

- Collection of hourly electrical load data from all the NIIs of Greece and conduction of simulations like the ones presented for the case of Astypalea.

- Highlight common characteristics regarding loads, consumption and future structures of energy systems among groups of NIIs.
- Introduce precise thermal energy loads and real recorded data in the energy simulation, in order to gain a broad view of the energy future of small, remote islands.

In conclusion, the autonomous electrical systems of Greek islands, although currently are characterised by very high energy costs, they are challenging places for implementing sustainable solutions. Nevertheless the NIIs, particularly the remote ones, are an ideal case for utilising renewables in favours of local societies, at the basis of decentralised applications. The current model of RES development has been based on projects with great installed capacities that provide energy to the IEG, at significantly high prices. In many cases the sustainability of this RES model has been controverted. On the contrary, decentralised RES exploitation in remote islands is a mild, viable way of utilising green energy. Government policies should more actively support this kind of energy future for NIIs.

5

Transformation of Astypalea island into a smart island

5.1 Connecting the Autonomous System of Astypalea to the IEG

As already mentioned, although the connection to the IEG (Interconnected Electricity Grid) is a strategic choice of the Greek Government, Astypalea is far away from the mainland and other bigger energy systems (Rhodes, Kos, Crete, Naxos). The costs for expanding energy grids with underwater cables are quite high. By combining data from relative resources , it is estimated that the necessary cost for expanding the grid towards autonomous island systems amounts to 1,000,000€/km.

A brief simulation, including sensitivity analysis, was conducted with HOMER PRO x64, in order to investigate whether grid expansion towards Astypalea is a viable investment. It was proved that the expansion of the electricity grid cannot exceed 25 km, for keeping the investment financially effective. As already discussed, Astypalea is far away both form the mainland and other, bigger islands; minimum distance 55 km. Therefore, it is not feasible to expand the electricity grid just for electrifying this island.

5.2 Developing Energy Production Units in the Non-Interconnected Islands

According to another research that used HOMER PRO x64, different scenarios of re-structuring the autonomous electrical system of Astypalea are analysed. The main aim of energy optimization in the island is to reduce energy production costs in a sustainable way. Therefore, further use of renewable energy sources is necessary. The scenarios investigated are the following [60]:

- **Scenario A:** Further use of renewable energy without the addition of storage
  - A1: Photovoltaics and small hydropower station.
  - A2: Photovoltaics, wind generators and small hydropower station.

- **Scenario B:** Further use of renewable energy with the addition of energy storage systems (Li-Ion) batteries
  - B1: Photovoltaics and battery array.
  - B2: Photovoltaics, wind generators and battery array.
  - B3: Photovoltaics, wind generators, small hydropower station and battery array.

The cases B1, B2 and B3 have been simulated with different assumptions regarding the costs of the batteries. So, there are additionally three cases, namely B1a, B2a, B3a which have the same structure as the abovementioned (B1, B2, B3), but are simulated with 40% lower costs of batteries, following the relevant tendency in the energy market. The assumptions regarding investment and operation and maintenance costs of the various systems are presented in Table 31.

Type of technology	**Investment cost**	**Replacement cost**	**Operation and maintenance cost**	**Fuel cost**
Photovoltaic panels	100 euros/unit	100 euros/unit	21 euros/kw/year	-
Wind generators (nominal power 25kW)	61,250 euros/pc	55,000 euros/pc	1225 euros/pc/year	-
Small Hydro Turbine (nominal power 80kW)	108,000 euros/pc	90,000 euros/pc	4320 euros/pc/year	-
Batteries Li-Ion (capacity 100kwh)	70,000 euros/pc	30,000 euros/pc	1000 euros/pc/year	-
Batteries Li-Ion low-cost scenario	30,000 euros/pc	10,000 euros/pc	1000 euros/pc/year	-
Converter DC/AC	250 euros/kw	230 euros/kw	-	-
Diesel electro generator	-	1200 euros/kw	0,05/oper.h	0,60 euros/lit diesel

Table 32 Investment, operation and maintenance costs used in the energy simulations. [60]

Regarding energy potential, for solar and wind energy potential the data from the libraries of HOMER were used. As far as hydropower is concerned, the cause for exploiting this source of energy in an island with low rates of precipitation is the fact that there is a water reservoir near the village of Livadi. This reservoir is used for providing potable water. So, a small turbine can be used, in order to utilize the available hydraulic head when transferring water from the reservoir to consumers. According to Daniil (2018), the available hydraulic head is 32 m and, by considering the volume of the reservoir and the precipitation in the island, a small turbine with 80 kW capacity can be installed [72]. The data retrieved by HOMER library regarding solar and wind potential, as well as the assumptions regarding hydropower in Astypalea are summarized in Table 32.

Month	**Clearance Index**	**Daily Radiation (kWh/m3/day)***	**Average Wind Speed (m/sec)***	**Volumetric Water flow (lit/sec)****
JAN	0.497	2.400	6.910	300
FEB	0.529	3.270	7.580	300
MAR	0.578	4.650	6.530	300
APR	0.619	6.100	5.740	200
MAY	0.670	7.420	5.080	200
JUN	0.721	8.340	5.160	150
JUL	0.739	8.350	6.240	150
AUG	0.731	7.520	5.760	150
SEP	0,711	6.150	5.360	100
OCT	0.649	4.360	5.700	200
NOV	0.547	2.800	6.170	300
DEC	0.467	2.060	6.630	300

Table 33 Renewable energy potential in Astypalea [60]

The simulations carried out from another research by using HOMER PRO x64 led to the optimal solutions shown in the Tables below. It is notable that in order to reduce the installed capacity of diesel generators, storage systems are necessary for avoiding power shortages. Even if the optimization results show that the renewable energy capacity and share can increase significantly without using storage systems, it is risky to operate an autonomous small system with low inertia under such conditions.

The use of batteries can ensure power supply, with simultaneous increase in renewable energy use. Under favourable conditions regarding batteries' cost, the renewable energy share in Astypalea can exceed 45% and the unit energy cost can decrease by 42%, in comparison with the current situation. It should also be highlighted that the possibility to utilize hydropower, because of the existing water dam in the island, is particularly important, because of the generally higher load factors of hydro-stations, compared to PVs and wind generators. The operation of a small hydro-plan increases energy supply security and has positive impact on the system's stability.

The investment costs vary between €786,000 and €2,426,000, depending on the renewable and storage capacity installed. Such amounts are much more competitive compared to the electrification of Astypalea through submarine cables. Of course, the present results are a first attempt to optimize Astypalea's system. Apart from a feasibility study, the further use of renewables in the island demands a precise cost benefit analysis, based on extensive data from the energy market.

Scenario	Number of Diesel Generators / Capacity (kW)	Photovoltaics (kW)	Wind Generators (kW)	Hydropower (kW)	Li-Ion Batteries (kWh)
Current Situation	7/3900	320	-	-	-
A1	7/3900	1072	-	80	-
A2	7/3900	550	450	80	-
B1	7/3900	1497	-	-	500
B2	5/3900	835	700	-	500
B3	5/3900	767	650	80	400
B1a	7/3900	1135	-	-	700
B2a	5/3900	880	700	-	600
B3a	5/3900	723	675	80	500

Table 34 Structure of Astypalea's energy system in the current situation and under the various future scenarios [60]

Scenario	Investment cost (euros)	Unit energy cost (euros/MWh)	Annual operating cost (euros)	Annual diesel oil consumption (lit)	Renewable energy share (%)
Current situation	-	230* (2015)	1,428,851*	2,262,347*	8,54*
A1	786,000	151	865,968	1,388,401	25.4
A2	1,896,000	144	735,066	1,119,778	40.6
B1	1,376,000	156	850,623	1,337,461	26.2
B2	2,546,000	143	680,213	995,450	45.0
B3	2,406,000	136	650,781	952,375	47.7
B1a	1,266,000	152	835,679	1,311,072	27.1
B2a	2,426,000	140	669,158	977,368	45.7
B3a	2,306,000	133	639,273	933,276	48.2

Table 35 Investment costs, unit energy costs, annual energy costs, annual diesel oil consumption and renewable energy share for the current situation of Astypalea's energy system and under the various future scenarios. [60]

From the results it seems that the renewable energy options are with a big difference much cheaper than the current system that operates in the island. Due to the rising popularity of the solar power energy and the new developed and improved technologies, in this study we will use B1 scenario. The system is mentioned will consists of PV panels and solar Li-ion battery. The choice of the battery has been made according to the initial analysis and the improved specifications in comparison to other existing technologies.

5.3 Sizing and Design of PV Units for existing power demands

Using all the aforementioned collected data for the island of Astypalea and the design of the solar farms this research finds best to divide the island into two main areas that are distanced between each other to reduce connection and other costs. The two sections are therefor:

- Section A (the west side of the island) and
- Section B (the east side of the island)

	Section A (West)	Section B (East)
Residential sector	1.8491 GWh	0.2809 GWh
Hotels and other accommodation types sector	1.7557 GWh	0.0443 GWh
Dinning businesses and food catering services sector	0.9502 GWh	0.1798 GWh
Public Buildings	0,4700 GWh	0.3000 GWh
Street Light and other public lights sector	0.3820 GWh	0.1660 GWh
Other	0.23 GWh	
Total	**5.64 GWh**	**1 GWh**

Table 36 Data for Section A and Section B Solar Farms

Below a more detailed layout with the help of AutoCAD software has been developed as part of the study that illustrates the island of Astypalea and the possible location of the two Solar Farms in the island.

With the help of google maps and its tools, we have identified all different types of buildings and businesses. Mapping out the number of each type (hotel, restaurant, public buildings, other.) in order to understand and divide the load according to the needs of each section.

The areas that the potential solar farms could be developed have been chosen according these parameters:

- Environmental
  - No obstacles (trees, hills, mountains) that could block irradiation
  - Land to be able to have panels to be facing the sun from sunrise to sunset for maximum solar harvesting
  - Land to be safe from landslide, floods or extreme wind risks
  - Short powerplant distance from coastline (in terms of transporting the equipment)
  - Short powerplant distance from city (in terms of transition lines)
  - Easy access to road

- Social
  - No possible legal restrictions (archaeological sites)
  - Short distance from city (in terms of employees' fast access)

Figure 19 Astypalea Island Satellite map and AutoCad Layout

Autocad Layout for Astypalea Solar-Battery Systems

5.4 Sizing and Design of PV Units for other smart systems

As mentioned in the previous chapters, the aim of this research is not just to replace the current energy system with a more new and eco-friendly system, but to also set up the basis for a Smart Island scale up. In order to do so, this research includes the design of a drinking water system that corresponds to the current demand on total drinking water consumption. Furthermore, an EV charging spot is designed to promote eco-mobility with a hope to support the initiatives of green mobility withing the island and the adoption of EV cars.

5.4.1 Drinking Water System

Currently in the market there are several options and technologies for water pumping and water treatment. In usual cases where there are underground wells and springs, a normal water pump will be sufficient for water pumping and a filtration system will ensure the provision of clean and safe water free from parasites and harmful to human elements. However, this kind of system is not the best solution for water that has high salinity such the type of water we find in the Greek islands, as possible underground soil are affected by the seawater. As a result, in this research we will use a solar powered desalination system that converts sea water to drinking water through the method of reverse osmosis.

According to the data found in previous sections of this research, and the estimation that the total consumption of drinking water per person 1.10 m^3 annually and the average consumption of a full-scale desalination system is around 4.05 KWh, we receive this table.

Drinking Water system - desalination		
Total number of inhabitants in Astypalea island	1334	
Average annual consumption drinking water per person	1.10	m3
Total daily consumption drinking water	4	m3
Total annual drinking water consumption	1468	m3
Total annual electricity consumption (desalination system)	0.0110	GWh

Table 37 Data for drinking water and desalination system in Astypalea

A sample of a desalination system can be seen in the picture below. The system consist of multiple subsystems according to the needs of the treatment and storing the water, some of the sub-systems are:

- Water pumps sub-system - to pump seawater or underground water with high salinity
- Reverse osmosis sub-system – to convert salty water into clean and drinkable
- Disinfection system – to purify more the output water from the reverse osmosis system
- Water tanks sub-system – to store cleaning water
- Solar Panel sub-system – to power the whole system

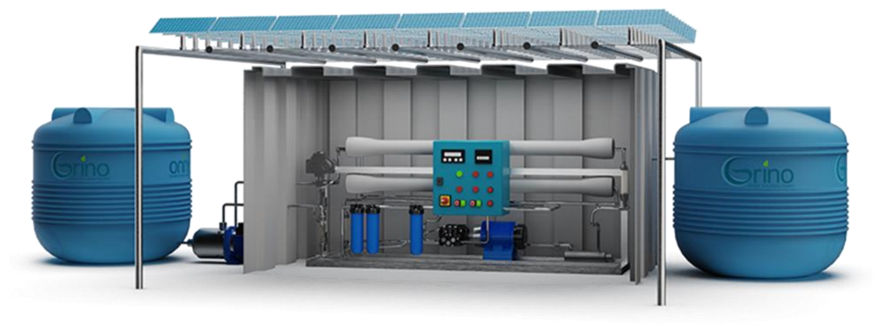

Figure 20 Sample of a desalination system

5.4.2 EV Charging System

In regards to the EV charging system, currently in the market there are 3 types of EV Charging stations [83]:

- AV Level one
- AC Level Two
- DC Fast Charging

Their unique characteristics are presented below in the Table 37.

EV Station Type	Voltage	Amps	Charging Loads	Charge time
AC Level One	120V-1- Phase AC	12-16 Amps	1.4 to 1.9 kW	5-8km of range per hour
AC Level Two	208V or 240V 1-Phase AC	12-80 Amps	2.5 to 19.2 kW	16-32km of range per hour
DC Fast Charge	208V or 480V-3-Phase AC	<125 Amps	<90 kW Average 50-60kW	160 km , 80% charge in 20-30 min

Table 38 Data for EV Station Tupe Categories

Initially it is planned to have one charging station close to the main gas station of Astypalea. It is assumed that it will be mainly used in the touristic season from the rental agencies and tourists. – for the purpose of this research we chose for the development a DC Fast Charge since our energy system can support it. Therefore, the charging load is 90kW.

Hence the resulting data for the EV station:

EV Charging Station		
Total number of inhabitants in Astypalea island	1334	
Total number of cars using the service annually (2%)	10	
Total number of leased cars used during the summer period	30	
Total power consumption for EV charging annually	0.381	GWh

Table 39 Data for EV Charging Station in Astypalea

A sample of how a car is charged through an AC charging plug and a DC Fast Charging station is illustrated below.

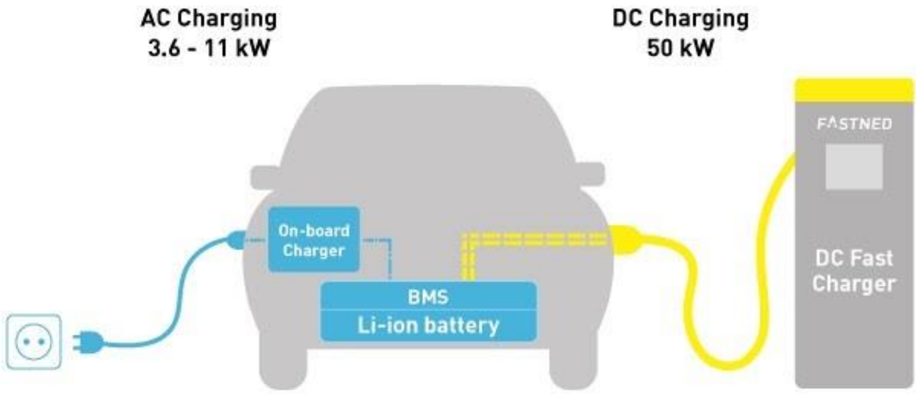

Figure 21 Charging an EV car with AC plug and through a DC charging station

5.5 Total Sizing of PV Units

In total the energy demands with the addition of the 2 subsystems (water system and EV station) do not change, hence the total results following the data of table 35 are extracted in Table 39. For the calculation of the total units of panels and battery capacity, we have assumed that one panel's output average is 455W, and the total irradiation time is 9 hours / day for the summer time. Winter calculations can be skipped as the energy demand is much lower and the reduction of exposure will not affect our system and the energy that needs to be delivered to the end consumer.

	Section A (West)	**Section B (East)**
Total (annual/365 days)	5.64 GWh	1 GWh
Daily	0.015 GWh/day	0.003 GWh/day
9 hours irradiation	1,7 MW	0.3 MW
Battery Capacity	**400 kWh Li-ion**	**100 kWh Li-ion**
455W/panel	**3496 panels**	**617 panels**
Total panels	**4113 panels**	
Total Battery Capacity	**500 kWh Li-ion**	

Table 40 Data for total Sizing of Solar Farms

The final total output is 6.64 GWh that aligns to the initial data we have for the island of Astypalea. The total number of PV units are 4114 and the battery capacity for a 1.7MW system is assumed to be 400kWh and for 0.3MW around 100kWh.

5.6 Communication System

As mentioned in previous chapters, distributed intelligent multi-agent, smart technology is applied to make the power system more reliable, efficient and capable of exploiting and integrating alternative sources of energy. For this case we propose a scalable communication system within frequently agents migration and failure, it will include distribution and parallelisation of message propagation method, a token-ring protocol that considerably improves the performance of, and failure detection mechanisms. For instance, the photovoltaic plant has a rated power and it is equipped with a monitoring system that embraces an acquisition device capable to continuously measure and store required electric variables at both DC and AC side of the five inverters. The measured data is collected and can be transmitted to an external control system and thus the operator can detect any failures and keep a data list to see the different parameters that affect the end performance of the whole system.

Another example are the Battery Modules which are composed of Li-ion battery banks connected to the microgrid through a bidirectional AC/DC converter. Intelligent measuring devices are located at the output of the system for acquiring the information that are required for characterising its operating state. These information are then sent to a local or remote controller and the operators can extract in regards to the energy storage effects, failures and performance.

For each of the individual systems, specifically designed controllers and instruments will be obtained by the manufactures. These controllers as mentioned, gather data during the processes and give real time report about the systems. More specifically the platform will have access and record the data below:

Generators	**PV Modules**	**Battery Modules**	**Desalination system**	**EV Charging Station**
Voltage	Irradiance received	Voltage	Water flow	Voltage
Current	Potential solar energy received	Energy flow	Water tank level	Current
Cos(f)	PV Voltage	Temperature	Water temperature	-
Fuel Flow	PV Current	-	Pumped water flow	-
Fuel Level	-	-	Filtered water flow	-
Fuel consumption	-	-	System voltage & current	-

Figure 22 Sub-systems and data to be recorded from different instruments

This will help recognise any issues and errors that occur in the operation of the systems. In order to ensure a reliable and secure operation of a microgrid, it is crucial to design and implement an efficient communication network. In contrast to what one might think, the design of this system may be more complex since its communication requirements vary significantly according to its nature, size, and scope as well as to the devices enclosed in it.

6

Workplan for the development of Astypalea Smart Island

6.1 Personnel Position Analysis

For this project, a board of professionals and analysts should be put on as below in order to successfully develop and monitor the project. Each position has its own tasks and responsibilities, thus different background of professionals come together to combine their experience and knowledge for this project. In the specific project we distinguish 2 different steering groups, the one is the project management which is responsible to coordinate other groups (engineers) and successfully deliver the project on time and on budget.

Project Management	Units	Description
Project Director	1	Responsible for the successful conclusion of construction of the project. Coordinates with teams to ensure that work is completed on time withing budget.
Steering Committee	5	A group of experienced professionals that provide advice, ensure delivery of the project

		outputs and the achievement of project outcomes.
Project Manager	2	Responsible for planning, overseeing and leading projects from ideation through to completion. Interacts with a range of internal and external stakeholders as well as reports to the steering committee and project director
Site Manager	1	Supervising and overseeing the direction of the project, ensuring that the client's specifications and requirements are met, reviewing progress and liaising with quantity surveyors to monitor costs. Reports to the project manager.
Back Office	5	Administration and support personnel for settlements, clearances, record maintenance, regulatory compliance, accounting, its services
Project Associate	1	Responsible to ensure the client's needs are being met. Inputs on service, sales and operations department
Project Consultant	2	Offers expertise on project in order to help the project management team to achieve their business goals. Inputs are on operational, strategic, and technical nature.
Engineering		
Electrical Engineer	5	Responsible for the design, development and testing of the system. Oversee the technical side of the project
Civil Engineer	2	Design and oversee construction and civil works of the projects.
Environmental Engineer	1	Assess and provide inputs regarding environmental report
Supporting Engineer	1	Provide expertise on the technical part of the project. Helps resolve potential issues
Water Engineer	1	Design and develop water system to please client needs.
EV Engineer	1	Design and develop EV charging station in order to please client needs.

Table 41 Project Management and Positions

In total we have 17 professionals in the project management group and 11 professionals on the engineering group.

6.2 Project Development Phases and Work packages Definition

For this project we identify three main phases and thirteen work packages:

Phase 1 – Local preparation, final engineering and procurement

- WP1 – Final Engineering

- WP2 - Community Management
- WP3 – Procurement
- WP4 – Logistics and Transport

Phase 2 – Construction and Commissioning

- WP5 – Technical Oversight
- WP6 – On- Site Energy system installation
- WP7 – On- Site Civil Construction
- WP8 – Back-office Management
- WP9- Operating Manual Operation
- WP10 – Local Team Training

Phase 3 – Operations and Optimisation

- WP11 – Operations Oversight
- WP12 – Local Operations and Maintenance
- WP13 – Preparation of final Report

A more detailed analysis of the work packages and the deliverables can be seen in the Table 41.

Number		**Description**	**Lead**	**Lead**
PHASE 1 - Local preparation, final engineering and procurement				
WP1	Final engineering	Final system specifications, electrical diagrams, site layout	Engineering support	PM 1
WP2	Community management	Local stakeholder engagement, land contracting	Lead	SE
WP3	Procurement	Supplier negotiations and contracting	Business Lead	BO
WP4	Logistics and transport	Ensuring storge and adequate transport, security and insurance	Technical	BO
PHASE 2 - Construction and commissioning				
WP5	Technical oversight	Coordination of works and subcontractors	Technical Lead	PD
WP6	On-site energy system installation	Electrical works, interconnection and commissioning	Technical	PM2
WP7	On-site civil construction	Installation of water connections, buildings, and road infrastructure	Technical	CE
WP8	Back-office management	Follow-up and coordination of suppliers	Business Lead	BO
WP9	Operating manual preparation	Preparation of operating manual for local team	Engineering support	PM1

WP10	Local team training	Engagement of local team through construction and commissioning	Astypalea Lead	SM
PHASE 3 - Operations and optimisation				
WP11	Operations oversight	Ensure proper operations and optimise system	Technical Lead	PD
WP12	Local operations and maintenance	Evaluate and update operating procedures	Technical	SM
WP13	Preparation of final report	Coordinate and draft project report	Bus Lead	PD

Table 42 Project Phases and Work packages

The work packages are listed below in detail with the works and deliverables.

Project Task	**Work package**
PHASE 1 - Local preparation, final engineering and procurement	
Project kick-off	ALL
Project Steering Committee meetings	ALL
WP1 - Final engineering	
Project plan preparation	WP1
Prepare site plan	WP1
Systems sizing	WP1
Run RFQ process for main suppliers	WP1
Prepare specifications for main components	WP1
Detailed electric design and SLDs	WP1
Detailed civil works	WP1
Select suppliers	WP1
WP2 Community Management	
Prepare surveys and interviews	WP2
Meet local officials and stakeholders	WP2
Preparation of remediation plans (social/env. Impacts)	WP2
Conduct community surveys and interviews	WP2
Finalise land contract	WP2
Organise local involvement for construction	WP2
WP3 - Procurement	
Review supplier offers and terms	WP3
Supplier contracting	WP3
Arrange payment details	WP3
Execute equipment purchases	WP3
Arrange insurance	WP3
WP4 - Logistics and transport	

Coordinate site visits	WP4
Verify custom clearance requirements	WP4
Arrange transport for equipment to site	WP4
Arrange site storage and security	WP4
Arrange on-site accommodation	WP4
Prepare logistics for construction team	WP4
Project Task	**Work package**
PHASE 2 - Construction and commissioning	
Project Steering Committee meetings	ALL
WP5 - Technical oversight	
Prepare plan for time monitoring and detailed milestones	WP5
Address technical issues as they arise	WP5
Monitor milestone completion	WP5
Manage supplier support	WP5
Oversee system commissioning	WP5
Test remote monitoring and operations	WP5
WP6 - On-site energy system installation	
Accept (energy) equipment on site	WP6
First mechanical works	WP6
Install main components (Battery and PV)	WP6
Install sub-systems	WP6
Finalise energy system installation	WP6
Finalized mechanical works	WP6
Test run systems	WP6
WP7 - On-site civil construction	
Prepare site and civil works	WP7
Accept (civil) equipment on site	WP7
Install water system and EV Station	WP7
Construct bases, access and trenches	WP7
Install training centre	WP7
Install rest of buildings	WP7
Integrate water, electrical and monitoring	WP7
Complete final details	WP7
Test run systems	WP7
WP8 - Back-office management	
Monitor delivery schedules	WP8
Review factory acceptance tests	WP8
Follow up and coordination suppliers	WP8
Make payments	WP8
Make final payments	WP8

Obtain equipment warranties	WP8
WP9 - O&M manual	
Outline manual sections	WP9
Contact suppliers for manual input	WP9
Draft initial manual sections	WP9
Finalise and review manual sections	WP9
Prepare print and electronic copies	WP9
WP10 - Local team training	
Prepare training material	WP10
Define hiring criteria	WP10
Hire local operating team	WP10
Prepare training centre	WP10
Train local managers	WP10
Train team	WP10
Update training material	WP10
Project Task	**Work package**
PHASE 3 - Operations and optimisation	
Project Steering Committee meetings	ALL
WP11- Operations oversight	
Define operating metrics	WP11
Monitor energy system	WP11
Monitor water system	WP11
Monitor EV system	WP11
Optimise system parameters	WP11
Prepare upgrade and maintenance plan	WP11
WP12 - Local operations and maintenance	
Support initial operating period	WP12
Review operating procedures	WP12
Propose operating adjustments	WP12
Adjust operations	WP12
Adjust O&M manual	WP12
Perform additional team training	WP12
WP13 - Final report	
Draft report headers	WP13
Coordinate section preparation	WP13
Collect and analyse data	WP13
Draft report sections	WP13
Edit final report	WP13
END OF PROJECT	

Table 43 Details project work packages and deliverables

6.3 Gantt Chart

In order to be more productive, to forecast and enhance communication with the rest of the team we need the best possible execution of a project, and that's where a Gantt chart becomes essential for the development of this project. By definition a Gantt chart, is a type of bar chart that shows the start and end date of several elements in a project such as tasks, activities, resources. The multiple benefits will clearly enable to complete the project the best way. With the help of similar projects workplans, we have included all the work packages and the deliverables in a one full Gantt chart in order estimate the time for successfully completing each action and therefor having a rough estimation of the total development time.

Project Task	Work package	Lead
PHASE 1 - Local preparation, final engineering and procurement		
Project kick-off	ALL	
Project Steering Committee meeting 1	ALL	
Project plan preparation	WP1	
Prepare surverys and interviews	WP2	
Coordinate site visits	WP4	
Prepare site plan	WP1	
System sizing	WP1	
Run RFQ process for main suppliers	WP1	
Review supplier offers and terms	WP3	
Meet local officials and stakeholders	WP2	
Prepare specifications for main components	WP1	
Verify custom clearance requirements	WP4	
Preparation of remediation plans (social/env. Impacts)	WP2	
Arrange transport for equipment to site (1/2)	WP4	
Conduct community surveys and interviews	WP2	
Detailed electric design and SLDs	WP1	
Finalise land contract	WP2	
Project Steering Committee meeting 2	ALL	
Detailed civil works	WP1	
Select suppliers/ EPC	WP1	
Supplier contracting	WP3	
Project Steering Committee meeting 3	ALL	
Arrange payment details	WP3	
Arrange site storage and security	WP4	
Organise local involvement for construction	WP2	
Arrange transport for equipment to site (2/2)	WP4	
Project Steering Committee meeting 4	ALL	
Execute equipment purchases	WP3	
Arrange insurance	WP3	
Arrange on-site accommodation	WP4	
Prepare logistics for construction team	WP4	

Apr 22'	1, 6, 13, 20, 27
May 22'	4, 11, 18, 25
Jun 22'	1, 8, 15, 22, 29
Jul 22'	6, 13, 20, 27
Aug 22'	3, 10, 17, 24, 31
Sep 22'	7, 14, 21, 28
Oct 22'	5, 12, 19, 26
Nov 22'	2, 9, 16, 23, 30
Dec 22'	7, 14, 21, 28
Jan 23'	4, 11, 18, 25
Feb 23'	1, 8, 15, 22
Mar 23'	1, 8, 15, 22, 29
Apr 23'	5, 12, 19, 26
May 23'	3, 10, 17, 24, 31
Jun 23'	7, 14, 21, 28
Jul 23'	5, 12, 19, 26
Aug 23'	2, 9, 16, 23, 30
Sep 23'	6, 13, 20, 27
Oct 23'	4, 11, 18, 25
Nov 23'	1, 8, 15, 22, 29
Dec 23'	6, 13, 20, 27
Jan 24'	3, 10, 17, 24, 31
Feb 24'	7, 14, 21, 28
Mar 24'	7, 14, 21, 28

Table 44 Phase 1 Gantt Chart

Apr 22'	May 22'	Jun 22'	Jul 22'	Aug 22'	Sep 22'	Oct 22'	Nov 22'	Dec 22'	Jan 23'	Feb 23'	Mar 23'	Apr 23'
1, 6, 13, 20, 27	4, 11, 18, 25	1, 8, 15, 22, 29	6, 13, 20, 27	3, 10, 17, 24, 31	7, 14, 21, 28	5, 12, 19, 26	2, 9, 16, 23, 30	7, 14, 21, 28	4, 11, 18, 25	1, 8, 15, 22	1, 8, 15, 22, 29	5, 12, 19, 26

May 23'	Jun 23'	Jul 23'	Aug 23'	Sep 23'	Oct 23'	Nov 23'	Dec 23'	Jan 24'	Feb 24'	Mar 24'
3, 10, 17, 24, 31	7, 14, 21, 28	5, 12, 19, 26	2, 9, 16, 23, 30	6, 13, 20, 27	4, 11, 18, 25	1, 8, 15, 22, 29	6, 13, 20, 27	3, 10, 17, 24, 31	7, 14, 21, 28	7, 14, 21, 28

Project Task	Work package
PHASE 2 - Construction and commissioning	
Project Steering Committee meeting 5	ALL
Outline manual sections	WP9
Prepare plan for time monitoring and detailed milestone	WP5
Address technical issues as they arise	WP5
Make payments (1/2)	WP8
Prepare site and civil works	WP7
Contact suppliers for manual input	WP9
Monitor delivery schedules	WP8
Project Steering Committee meeting 6	ALL
Monitor milestone completion	WP5
Review factory acceptance tests	WP8
Project Steering Committee meeting 7	ALL
Accept (energy) equipment on site	WP6
Accept (civil) equipment on site	WP7
Project Steering Committee meeting 8	ALL
Follow up and coordination suppliers	WP8
Make payments (2/2)	WP8
Project Steering Committee meeting 9	ALL
First mechanical works	WP6
Draft initial manual sections	WP9
Project Steering Committee meeting 10	ALL
Install water system	WP7
Install EV system	WP7
Construct bases, access and trenches	WP7
Prepare training material	WP10
Project Steering Committee meeting 11	ALL
Install training centre	WP7
Define hiring criteria	WP10
Install main components (Battery and PV)	WP6
Project Steering Committee meeting 12	ALL
Hire local operating team	WP10
Install sub-systems	WP6
Install rest of buildings	WP7
Prepare training centre	WP10
Install distribution system	WP6
Project Steering Committee meeting 13	ALL
Manage supplier support	WP5
Train local managers	WP10
Finalise energy system installation	WP6
Project Steering Committee meeting 14	ALL
Integrate water, electrical and monitoring	WP7
Make final payments	WP8
Obtain equipment warranties	WP8
Complete final details	WP7
Oversee system commissioning	WP5
Finalized mechanical works	WP6
Train team	WP10
Finalise and review manual sections	WP9
Project Steering Committee meeting 15	ALL
Project Steering Committee meeting 16	ALL
Test remote monitoring and operations	WP5
Test run systems	WP7
Update training material	WP10
Prepare print and electrionic copies	WP9

Table 45 Phase 2 Gantt Chart

Project Task	Work package
PHASE 3 - Operations and optimisation	
Project Steering Committee meeting 17	ALL
Define operating metrics	WP11
Support initial operating period	WP12
Monitor energy system	WP11
Monitor water and thermal systems	WP11
Project Steering Committee meeting 18	ALL
Draft report headers	WP14
Coordinate section preparation	WP14
Project Steering Committee meeting 19	ALL
Propose operating adjustments	WP12
Collect and analyse data	WP14
Project Steering Committee meeting 20	ALL
Review operating procedures	WP12
Optimise system parameters	WP11
Draft report sections	WP14
Adjust operations	WP12
Project Steering Committee meeting 21	ALL
Adjust operations manual	WP13
Perform additional team training	WP12
Project Steering Committee meeting 22	ALL
Prepare upgrade and maintenance plan	WP11
Project Steering Committee meeting 23	ALL
Edit final report	WP14
Project Steering Committee meeting 24	ALL
END OF PROJECT	

Table 46 Phase 3 Gantt Chart

According to the Gantt chart sections we conclude that the whole project will take 24 months to successfully deliver it assuming beginning month - first week of April 2022 and project finalisation - last week of March 2024. Specifically:

- Phase 1 will occupy the first four months of the timeline (April 2022 – July 2022)
- Phase 2 will occupy month 5 to month 17th of the timeline (August 2022 – July 2023)
- Phase 3 will occupy month 18th to month 24th of the timeline (August 2023 – March 2024)

6.4 Delay Risks and Mitigation measures

In terms of accuracy, the estimated times to complete each task could differ in reality as there are several reasons and risks that could influence them. A brief analysis or risks and possible mitigation measures is outlined below:

The main risk categories that impact the successful pilot implementation and mitigated measures are summarised below:

- **Political and economic risks:** demonstrations, corruption, political risks, instability, economic downturn – mitigated by close monitoring of conditions, protecting physical assets

- **Social/ cultural risks:** labour issues, community resistance to project implementation, public health issues – mitigated by close engagement of the community and relevant local stakeholders and ensuring benefits and opportunities are distributed across community

- **Technology risks:** supplier bankruptcy, integration issues of various components / sub-systems, suitability of technology to conditions – mitigated by selection of established equipment by reputable vendors, close monitoring of industry trends, minimising upfront payments

- **Implementation risks:** personnel issues, skill availability, limited access to site, transport restrictions to site, availability of equipment and tools, robustness of equipment, suitability of equipment to environmental conditions, customs and transport delays, non-delivery of suppliers or contractors – mitigated by due diligence on contractors, accounting for training and development of team, detailed operations manual and close monitoring of project progress

- **Personal risks to key team members** – illness or death of critical team members, rejection of visas / difficulty entering – mitigated by close cooperation so that other team members can fill in roles, proper management of project work and files on shared online database

The project risks and mitigants have to be continuously monitored and updated throughout the implementation of the project. Risks and mitigants have to be broken down by work package with each work package lead assigned to monitor these risks and identify mitigants.

7

Financial Assessment of Astypalea Smart Island

7.1 Budget for Project Development – Detailed CAPEX (Capital Expenditure)

The budget for a project is the combined costs of all activities, tasks, and milestones that the project must fulfil. In short - it's the total amount of money required to finish the project that should be approved by all the stakeholders involved.

There are at least three reasons to explain the importance of having a project budget plan.

- First, it's an essential part of securing project funding. The numbers will tell stakeholders exactly how much money is needed to button up the project and when the money is needed.

- Second, a well-planned budget provides the basis for project cost control. Having an end budget estimate helps measuring the project's actual cost against the approved budget and see how much costs have been burned already. It will give an understanding of how the project is progressing and if any changes need to be made to the plan.

Planning project costs is an essential step in mapping out a project budget. To do so, for this research we will need to create a list of timely line items that are relevant for the project. Hence, we get the table of cost categories below.

	Project cost category		**Details**
1	**General preparation and Project Development**		Costs for licensing, legal support and project kick-start expenses
2	**Personnel**		
2.1		Project Management	Costs for hiring experts for mapping out the development of the project and setting deliverables and deadlines
2.2.		Engineering	Costs for engineering personnel
2.3		Commissioning	Costs for commissioning crew and process
3	**Equipment - Procurement, Installation and Interconnection**		
3.1		Solar PV Plant	Cost for the solar PV Units, spares and cabling
3.2		Battery Energy Storage System	Costs for the battery modules, spares and inverters
3.3		Diesel Generators	Costs for the potential diesel generators for back-up electricity generation
3.4		System Integration	Costs for components like cabling, controllers and other connection materials
3.5		Street Lights and Distribution Network	Costs for street light equipment – consists of lights, poles, cables etc.
4	**EV Station**		Costs for DC Fast Charge Equipment
5	**Water Desalination system**		Costs for pumps, desalination and disinfection system etc.
6	**Installation and Labor**		Costs for labor that has to do with general works on site and additional material
7	**Shipping and Logistics**		Costs for logistics, transport, insurance of materials and equipment
8	**Duties and Custom Clearance**		Duties and custom clearance usually are 10% on average for the imported equipment
9	**Training and Support**		Conferences, workshops, outside contractors
10	**Travelling to Site**		Anyone who travels from one location to another to do project work (including budget for meals and lodging)
11	**Contingency**		Contingency funds to allow for flexibility and reduce risks of budget overruns, usually 5-10% of the budget

Table 47 Project cost categories and details

Following the structure of Table 47, we have created for this research a budget table where all the categories are listed and important data such as Units, No. of Units, Unit Costs have been added. The cost of units is estimated according to trends, average prices and quotation material from other similar projects. In order to be in the budget as many materials and equipment costs could differ from the original estimations, we assume a 10% margin.

Detailed Budget										
Item No	**Description**	**Unit**	**No. of Units**	**Unit Cost**	**Cost**	**Margin**	**Price After**	**% of Total**	**% of Total**	**Grand Total**
				Euros/unit	**Euros**	**%**	**Euros**		**%**	**Euros**
										1,475,844
1	**General preparation and project development**								**42,250**	2.9%
1.1	Project development	months	5	4,000	20,000	10.0%	22,225		47.3%	
1.2	Land contracting & due diligence	activity	1	3,500	3,500	10.0%	3,900		8.3%	
1.3	Legal support	activity	1	8,000	8,000	10.0%	8,900		18.9%	
1.4	Local contracting, licensing and permitting	activity	1	6,500	6,500	10.0%	7,225		15.4%	
2	**Personnel**								**106,225**	7.4%
2.1	**Project management**							**71,100**	66.9%	
2.1.1	Project management (x2)	months	12	3,500	42,000	10.0%	46,675	65.6%		
2.1.2	Site management	months	4	3,000	12,000	10.0%	13,325	18.7%		
2.1.3	Back-office	months	5	2,000	10,000	10.0%	11,100	15.6%		
2.2	**Engineering**							**20,025**	18.9%	
2.2.1	Supporting engineer	months	2	2,000	4,000	10.0%	4,450	22.2%		
2.2.2	Electrical engineer	months	2	4,000	8,000	10.0%	8,900	44.4%		
2.2.3	Civil engineer	months	2	3,000	6,000	10.0%	6,675	33.3%		
2.3	**Commissioning**							**15,100**	14.2%	
2.3.1	Conversion and control	days	8	800	6,400	10.0%	7,100	35.5%		
2.3.2	Battery commissioning	days	5	800	4,000	10.0%	4,450	22.2%		
2.3.3	Diesel commissioning	days	4	800	3,200	10.0%	3,550	17.7%		

3	**Energy Equipment - Procurement, Installation and Interconnection**								**915,175**	63.5%
3.1	**Solar PV plant**							**682,900**	74.6%	
3.1.1	PV panels	kWp	4113	95	390,735	10.0%	434,150	57.2%		
3.1.2	PV spares	kWp	143.955	95	33,110	10.0%	36,800	4.8%		
3.1.3	PV Mounting Structures	kWp	4113	41	168,633	10.0%	187,375	24.7%		
3.1.4	MPPT - 4CH - 250 kW	number	1	17,500	17,500	10.0%	19,450	2.6%		
3.1.5	23 x PV string DC cables (single-core / 2.5 sq. mm.)	meters	4,200	1	3,444	10.0%	3,825	0.5%		
3.1.6	4 x MPPT input DC cables + 1 MPPT output DC cable (single-core / 25 sq. mm.)	meters	100	3	349	10.0%	400	0.1%		
3.1.7	1 x DC combiner to battery bank cable (single-core / 150 sq. mm.)	meters	40	21	820	10.0%	900	0.1%		
						10.0%				
3.2	**Battery Energy Storage System**					10.0%		**196,125**	21.4%	
3.2.1	Power House	number	2	5,000	10,000	10.0%	11,100	5.1%		
3.2.2	Battery modules	kWh	500	262	131,200	10.0%	145,775	66.9%		
3.2.3	Battery spares	kWh	17.5	262	4,592	10.0%	5,100	2.3%		
3.2.4	DSP Based - PIM 150 kVA (Power Inverter)	number	1	30,000	30,000	10.0%	33,325	15.3%		
3.2.5	Extended warranty and support - 5 years	number	1	738	738	10.0%	825	0.4%		
3.3	**Diesel Generation**							**-**	0.0%	
3.3.1	Diesel generator	kVA	0	193	-	10.0%	-	-		
3.3.2	Diesel generator controller	number	0	1,886	-	10.0%	-	-		
3.4	**System Integration**							**35,825**	3.9%	
3.4.1	DCDB Combiner Box	number	2	1,500	3,000	10.0%	3,325	8.4%		
3.4.2	AC Switching Cabinet 100 kW	number	2	6,500	13,000	10.0%	14,450	36.3%		
3.4.3	4 x LVAC 4-core cables (150 sq. mm.)	meters	60.00	21	1,230	10.0%	1,375	3.4%		

3.4.4	Microgrid Station Controller	number	1	6,000	6,000	10.0%	6,675	16.7%		
3.4.5	Set of communication cables for interconnection	number	2	3,000	6,000	10.0%	6,675	16.7%		
3.4.6	Modem and external communication integration	number	1	3,000	3,000	10.0%	3,325	8.4%		
						10.0%				
3.5	**Street Lights and Distribution Network**					10.0%		**325**	0.0%	
3.5.1	Lights	number	0	533	-	10.0%	-	0.0%		
3.5.2	Distribution network cabling	meters	0	5	-	10.0%	-	0.0%		
3.5.3	Pole bases	number	0	41	-	10.0%	-	0.0%		
3.5.4	Installation equipment	number	0	164	-	10.0%	-	0.0%		
3.5.5	Power meters	number	0	205	-	10.0%	-	0.0%		
3.5.6	Aggregator meter	number	1	287	287	10.0%	325	100.0%		
4	**EV Station**								**€ 11,100.00**	
4.1	EV Station system	number	1	10,000	10,000	10.0%	11,100		100.0%	
5	**Water Desalination System**								**€ 22,519.00**	
5.1	Submersible pumps	number	1	820	-	10.0%	902		4%	
5.2	Desalination system	number	1	10,000	-	10.0%	11,000		48.9%	
5.3	Multimedia and Microfiltration skid	number	1	6,105	-	10.0%	6,715		29.8%	
5.4	Disinfection System	number	1	3,245	-	10.0%	3,569		15.7%	
5.5	Utility water filter	number	1	303	-	10.0%	333		1.5%	
6	**Installation and labour**								**31,625**	2.2%
6.1	Labour (non-skilled) (x30 person/day)	person-day	840	29	24,360	10.0%	27,075		77.0%	
6.2	Additional materials	number	1	4,100	4,100	10.0%	4,550		13.0%	
7	**Shipping and logistics**								**66,075**	4.6%
7.1	Logistics (to Astypalea port)	containers	5	2,800	14,000	10.0%	15,550		21.2%	

7.2	Transport to site	containers	5	4,900	24,500	10.0%	27,225		37.1%	
7.3	Storage	containers	5	410	2,050	10.0%	2,275		3.1%	
7.4	Insurance	%	2.0%	946,010	18,920	10.0%	21,025		28.6%	
8	**Duties and customs clearance**								**166,725**	11.6%
8.1	Duties and customs clearance	%	18.0%	833,638	150,055	10.0%	166,725		90%	
9	**Training and support**								**7,000**	0.5%
9.1	As-built drawings	units	1	2,050	2,050	10.0%	2,275		29.3%	
9.2	Signage	units	10	66	656	10.0%	725		9.4%	
9.3	Operation manuals	units	5	82	410	10.0%	450		5.9%	
9.4	Operator Training	days	6	533	3,198	10.0%	3,550		45.7%	
10	**Travel to Site**								**15,100**	1.0%
10.1	Travel to Site - International	pax	3	300	900	10.0%	1,000		6.0%	
10.2	Room and board	days-pax	50	110	5,500	10.0%	6,100		36.4%	
10.3	Travel to Site - Local	pax	6	200	1,200	10.0%	1,325		7.9%	
10.4	Local transport	days-pax	40	150	6,000	10.0%	6,675		39.7%	
11	**Contingency**								**92,050**	6.4%
11.1	General contingency	%	7.0%	1,183,450	82,842	10.0%	92,050		100.0%	

Table 48 Detailed Budget for Project Development - CAPEX

7.2 Budget for Project Operation – Detailed OPEX (Operating Expense)

The budget for operating the project is the combined costs of all activities, tasks, and milestones that the project will continue to have after the development of the project. In short - it's the total amount of money required to keep the project active and same as the CAPEX it should be approved by all the stakeholders involved. Hence, we get a similar table as Table 47 but with the operational cost categories.

	Project cost category	Details
1	Personnel	Costs for on-site personnel for management and operation of system
2	Spare Replacements	Cost for spare units in case of destruction or malfunction of equipment
3	Land Lease	Cost for land lease in case of not owning the lands
4	Asset Management	Costs for basic asset management and back-office paper maintenance
5	Security	Costs for on-site security personnel
6	Admin, insurance and other	Costs for admin, insurance and contingencies

Table 49 Project cost categories and details

Following the structure of Table 49, we have created for this research a budget table where all the categories are listed and important data such as Units, No. of Units, Unit Costs have been added. The cost of units is estimated according to trends, average prices and quotation material from other similar projects. In order to be in the budget as many materials and equipment costs could differ from the original estimations, we assume a 25% margin.

Operating budget									
Item No	**Description**	**Unit**	**No. of Units**	**Unit Cost**	**Cost**	**Margin**	**Price to client**	**% of Total**	**Grand Total**
				Euros/unit	**Euros**	**%**	**Euros**		**Euros**
									183,575.00
1	**Personnel**							**83,075.00**	45.3%
1.1	Technician visits	units/year	2	2,050.00	4,100.00	25.0%	5,475.00	15.4%	
1.2	Local manager	monthly cost	12	2,050.00	24,600.00	25.0%	32,800.00	92.5%	
1.3	Local technician (x3)	monthly cost	36	700.00	25,200.00	25.0%	33,600.00	94.7%	
1.4	Other staff	monthly cost	12	700.00	8,400.00	25.0%	11,200.00	31.6%	

2	**Spare replacements**							**7,500.00**	4.1%
2.1	PV	kW/year	5	262.40	1,312.00	25.0%	1,750.00	23.3%	
2.2	Battery	kWh/year	4.5	278.80	1,254.60	25.0%	1,675.00	22.3%	
2.3	Miscellaneous	**%**	0.5%	84,343.00	421.72	25.0%	550.00	7.3%	
2.4	Building parts	**%**	5.0%	325.00	16.25	25.0%	25.00	0.3%	
2.5	Transport of spares	times	4	656.00	2,624.00	25.0%	3,500.00	46.7%	
3	**Land lease**							**-**	0.0%
3.1	Land lease	euros/month	-	-	-	25.0%	-	-	
4	**Asset management**							**20,800.00**	11.3%
4.1	Asset management	euros/month	12	1,300.00	15,600.00	25.0%	20,800.00	100.0%	
5	**Security**							**28,800.00**	15.7%
5.1	Staff	euros/month	12	1,800.00	21,600.00	25.0%	28,800.00	100.0%	
6	**Admin, insurance and other**							**43,400.00**	23.6%
6.1	Insurance	%	1.5%	1,924,909.50	28,873.64	10.0%	32,075.00	143.5%	
6.2	Contingency	%	0.5%	2,039,175.00	10,195.88	10.0%	11,325.00	50.7%	

Table 50 Detailed Budget for Project Operation - OPEX

According to the data and the estimated costs of each component and headcounts it is estimated that an approach such as this for the development (CAPEX) of the aforementioned systems in Astypalea will cost around €1.5 M and for the operation (OPEX) around €200k yearly. Must be noted that the results of these estimation are aligned with the scenario cost predictions mentioned in the previous chapters. Regarding the accuracy of the results and sensitive factors and uncertainties - they will be discussed in the next chapter.

8

Conclusions

8.1 Final Findings

The research presented in this paper highlighted:

1) the characteristics and problems related to the electrification of Greek islands not connected to the IEG, and
2) provided evidence for planning a better energy future for the small remote island of Astypalea

Some important conclusions that were extracted through this study are that:

- The NII of Greece demand high energy costs for their electrification (in average 2.5 times higher expenses compared to the grid of the mainland). Furthermore, the present structure of the autonomous electrical systems leads to the insecurity of energy supply due to cutouts, sudden fluctuations on demands in the summer touristic periods etc. However, the exploitation of the plentiful solar and wind energy potential is high in the islands making them potential hubs for smart sustainable technologies.

- The use of mazut and diesel for producing more than 80% of the electrical energy needed in the NII does not only have high financial and environmental cost, but it also maintains the country's high energy dependency. Moreover, Greece is obligated to shut down all existing lignite power plants until 2023 and find new sustainable ways to satisfy the country's energy demands.

- The priority of Greece's energy planning for the future of NII with big energy loads (now - Crete, Rhodes, Mykonos, Paros – later other islands) is the expansion of the IEG. This is a reasonable choice for cases with high energy demand and high capacities of installed RES, since the share of renewables in the country will, in general, increase in this way.

- In cases of remote islands with low energy loads, it seems that the improvement of the local autonomous systems is a better choice than the interconnection with the main electricity grid. Such case is the island of Astypalea with peak load of 2.25 MW and average load 0.72 MW—the investment for expanding the grid with submarine cables is not viable for expansion greater than 25 km as it is estimated that it will cost €1 million/km which is not feasible.

- The case of Astypalea provides strong evidence regarding the possibility to utilise local RES together with the use of storage systems, in order to upgrade the current energy system. The perspectives of the local autonomous system for sustainable improvement are promising satisfying most of the energy demands of the island, in addition with smart technologies and systems that will allow the island to become one of the most eco-friendly islands in Greece.

Astypalea as a rich touristic region is described as complex island with huge differences of loads in summer in comparison to the winter period. In this research, we collected different data to map out the different loads and consumptions in the different sectors (hotels and accommodation, dinning, public buildings, residences etc.)

In order to briefly assess different scenarios in regards to the energy system and design one that will comply and satisfy the current demands, results from similar studies have been used as basis. The results of the simulations for each of the scenarios are presented and analysed in chapter 5. With the help of the scenario's data, this research focused on the design of a solar photovoltaic system for energy production and Li-ion Batteries for energy storage.

Hence, the results are summarised in the following table.

Total system capacity of Astypalea	**2 MW**
Section A (West)	1.7 MW
Section B (East)	0.3 MW
Total Battery Capacity	**500 KWh Li-ion**
Section A (West)	400 kWh
Section B (East)	100 KWh

Table 51 Summarised results for system and battery storage capacities

8.2 Sensitive factors and uncertainties in results

The research outlines and categorises two sensitive factors:

i) the uncertainties of estimated data on the demand side and the reference scenario modelling
ii) the uncertainties on the data applied in the modelling of the scenarios

The first category refers to the insufficient data and the estimations made and applied as an input for the reference scenario in Chapter 4. In many cases there has been lack of data specifically the electricity, heating and cooling demand for each one of the sectors examined in this research. In order to handle the imperfect data, estimations have been based on secondary data obtained by other reports and used and adjusted according to the purposes of the research. This means that if the precise and updated data for the island of Astypalea was available, the results and demand profiles, RES capacities and finals costs and financials may have a slight difference.

More specifically the data that were assumed and can be described sensitive for this research are summarised below:

- Residential sector
- Hotels and other accommodation types sector
- Dinning businesses and food catering services sector
- Public Buildings
- Street Light and other public lights sector
- Other

Credible data can be obtained after communicating with local and national entities and organisations that can provide the most updated data or give their advice for the current estimations.

The second category refers to the applied input values for the modelling of the scenarios. The applied costs of the technologies and energy infrastructures concerning the Astypalea smart island and the investment costs, operation and maintenance costs and any other relevant costs applied in the research are dependent on the market evolution and fluctuations. For instance, 2020 has been a favourable year for PV investments since PV costs have dropped down compared to other years and it is forecasted that it will keep dropping down for the following years. Some of the most important data that could affect the end budgeting are listed below:

- **Energy Equipment**
  - Solar PV panels and other
  - Li-ion battery energy storage and other
- **System Integration Equipment**
  - Controllers and Integration equipment
- **EV Station Equipment**
  - Charging Equipment
- **Water Desalination**
  - Submersible pumps
  - Desalination system
  - Multimedia and Microfiltration skid

- Disinfection System

8.3 Main Factor Modifications

In this research the factors that have an important role in the results and conclusions and represent an area of difficulty, adding uncertainty to the results are the following:

- Choice of modelling tool for the initial simulations
- Political context in Greece and potential influence on RES technologies selection

Choice of modelling tool

In this research it is chosen to realise a technical simulation of the energy system in Astypalea, balancing heat and electricity demands and simulations achieved on an hourly basis through other researches data and results. This research has agreed on the modelling scenario as well as the technologies used and taken a step further to verify the financial feasibility as well as creating a workplan and timeline for the development and operation.

In case that this research decided to realise a market economic simulation of the energy system in Astypalea, a different variety of modelling tools could have been investigated. This may have had different results for this research that may deviate from the results presented for this case.

Political environment and potential influence on the RES technologies

In order to empower this research and develop optimised and more concrete results which answer the sub-questions and the principal research question, a policy research and assessment of the institutional settings in Greece could have been made. From the technical point of view and for the modelling and technical simulations for the energy systems these factors are not included. Nevertheless, the political environment, the institutional settings and initiatives for energy transition projects play an important role in the feasibility of this kind if projects.

Although not mentioned at any point in the research, the political environment and the institutional frameworks prevailing in a country are closely linked to the design of an energy system. This fact is particularly apparent in the selection of RES types and the energy infrastructure in general. The political strategies, the institutional settings and the available finance schemes and subsidies for promoting RES and the realization of energy transition projects in islands are pivotal for the feasibility of such projects.

The selected RES capacity combinations, the storage facilities and in general the technology equipment chosen for the SES scenarios and the simulations might have been different. That is due to the fact that if the policy research was conducted, then different indicators regarding the employment of RES technologies and storage systems may have been outlined. This means that the SES scenarios would have been different in this research and subsequently the results and conclusions.

8.4 Press Releases and Project Discussions in Astypalea

World Energy News (www.worldenergynews.gr)

Hybrid systems and actions for electrification are planned by the competent Commission for the interconnected islands as well as those that are to be interconnected as its interconnection will increase the capacity of RES and energy storage is deemed necessary to deal with the volatile production of wind and photovoltaic stability problems they may cause.

In its planning, the Mousourouli Commission takes into account the relevant study proposals of the World Bank . Specifically, the World Bank proposes for the Greek islands [84]:

1. Dramatic reduction of oil use , with high RES penetration, 70% to 90% in the first phase, and lithium battery storage systems , introducing microgrids techniques and ideas, regardless of the evolution of the islands' electrical interconnections with the national system (or in parallel to block blackout).

2. Introduction of digital technology in electrical networks and applications of innovative technologies and techniques, for the most efficient management of RES and consumption.

For the financing of the Program, limited resources will be secured from the Fair Transition Fund , since the majority of them will be directed to the directly lignite-dependent areas of Western Macedonia and Megalopolis and resources from the local Regional Programs of the North and South and South Regions. Discussions in this direction are already underway with the competent bodies [84].

It should be noted the investment interest in installing hybrid systems on the islands is increased and hundreds of applications for licensing have already been submitted . The way for their implementation will be opened with the completion of the institutional framework by June 2021, according to what has been announced by the Ministry of Environment and Energy [84].

Hellenic Republic - Ministry of Foreign Affairs (www.mfa.gr) | Volkswagen Group (www.volkswagenag.com)

On November 2020, the Greek Government and the Volkswagen Group have announced groundbreaking agreement for a pioneering project to transform Astypalea into the first smart, green island in the Mediterranean with energy autonomy [85].

Initially the project aims to replace gradually conventional private and public vehicles to electric ones, promoting an innovative transportation system that where its energy will be supplied through renewable energy sources – hence replacing current use of fossil fuels that leads to a sharp reduction in the island's emissions of greenhouse gases. More specifically the project details include [85]:

- Incentives to replace conventional private vehicles with electric vehicles through a financing program. In total, about 1,000 electric vehicles are to replace about 1,500 vehicles with internal combustion engines.
- Replace public and utility vehicles on the island – police, ambulance and buses – with e-vehicles with the support of the Volkswagen Group.
- Establish the necessary infrastructure for an integrated, electric vehicle charging network.
- Creation of an on-demand public transportation system through the use of digital applications that will allow residents and visitors greater freedom of travel through the use of vehicle sharing, e-moped and e-bicycle services.
- The Greek government will facilitate all necessary processes required to accommodate autonomous driving once this becomes possible.

To conclude – Greece is committed to promote sustainable development, green energy and modern technologies to improve social, economic, and environmental conditions in the country. Therefore, Greece is ready to support local projects and partnerships aimed at helping cities and communities with their local development strategies. The government takes into account the global challenges and opportunities offered by developments in the fields of green energy, electric vehicles, cutting-edge technologies and on-demand travel. This confirms the interest and the potential for transforming Astypalea island into a smart island promising rapid changes in the following years.

8.5 Further research

The results and conclusions made for this research case are based on an arrangement of primary data from reliable sources and from estimated imperfect data based on secondary data obtained from literature and adjusted for the needs of this research. Three basic tasks can be included in future research work with the purpose to optimize the models described in this research.

One task to be completed in further research is to conduct an extensive and detailed analysis in each sector of Astypalea island and combine qualitative and quantitative methods which will provide the realistic and pragmatic data. The qualitative and quantitative methods refer to questionnaires in each sector, focused interviews, documentary evidence and observation and correspondence with the responsible authorities in Greece. The purpose of this would be to scrutinize the input data applied in this research and examine their validity and accuracy. Since this task is completed, an optimization of the reference scenario and the energy balances can be achieved. This will influence the creation and development of the alternative scenarios and eventually will provide more realistic, accurate and vigorous results.

The second task to be completed in further research which could also test the robustness of the results and empower the conclusions of this research, is a sensitivity analysis. Due to limited time and due to the fact that the sensitivity analysis in all of the examined scenarios and for each of the technology combinations would be demanding and needs precision and accuracy, this research chooses to include only a discussion regarding the sensitivity factors. Thus, the next stage and to support the first task of further research described above, would be a detailed sensitivity analysis.

Finally, the third task in further research and to complete the 'umbrella' of validation and robustness of the conclusions and results made in this research, would be a policy research in Greece considering how the existing political frameworks, institutions, financial schemes and other relevant factors could enable or obstruct to the realization of projects which involve the energy transition on the Greek islands. The contribution of this task in this research would have been to outline a specific set of technologies and infrastructures, financial support and funding schemes which could drive the modelling process of the SES (Socioeconomic Status) scenarios and the selected RES technologies.

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