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Πολυκριτηριακή Ανάλυση Ενεργειακής Ανεξαρτητοποίησης από ΑΠΕ.
Περιπτωσιολογική Μελέτη.

Διπλωματική Εργασία

Ιωάννης Βαρδόπουλος

Αθήνα, 2017

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Τριμελής Εξεταστική Επιτροπή

Ελένη Θεοδωροπούλου (Επιβλέπουσα)
Καθηγήτρια, Τμήμα Οικιακής Οικονομίας και Οικολογίας, Χαροκόπειο Πανεπιστήμιο

Ρόιδο Μητούλα
Καθηγήτρια, Τμήμα Οικιακής Οικονομίας και Οικολογίας, Χαροκόπειο Πανεπιστήμιο

Ελένη Σαρδιανού
Επίκουρη Καθηγήτρια, Τμήμα Οικιακής Οικονομίας και Οικολογίας, Χαροκόπειο Πανεπιστήμιο

Ο Ιωάννης Βαρδόπουλος

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HAROKOPIO UNIVERSITY

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SUSTAINABLE DEVELOPMENT POSTGRADUATE PROGRAMME

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Determination of the Optimal Renewable Energy Source for the Sustainable Energy Independence by Using Multi-criteria Optimization Analysis. Case Study.

Thesis

Ioannis Vardopoulos

Tripartite Jury

Helen Theodoropoulou (Advisor)
Professor, Department of Home Economics and Ecology, Harokopio University

Roido Mitoula
Professor, Department of Home Economics and Ecology, Harokopio University

Eleni Sardianou
Assistant Professor, Department of Home Economics and Ecology, Harokopio University

Athens, 2017

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Περίληψη στα Ελληνικά

Η παρούσα μελέτη διαπραγματεύεται την βιώσιμη εφαρμογή ανανεώσιμων πηγών ενέργειας στην υπό μελέτη περιοχή, την Ζάκυνθο. Προκειμένου να προσδιοριστεί η βέλτιστη ανανεώσιμη πηγή ενέργειας ακολουθείται ανάλυση πολλαπλών κριτηρίων. Οι τρείς κύριοι πυλώνες της αειφορίας χρησιμοποιούνται ως βασικά κριτήρια στο πλαίσιο του στόχου. Ταυτόχρονα, αποτελούν και αντικείμενο εφαρμογής του DPSIR μοντέλου δεικτών. Αρκετά σε αριθμό οικονομικά, περιβαλλοντικά και κοινωνικά υπό-κριτήρια αναπτύσσονται και υποβάλλονται σε αξιολόγηση σημαντικότητας τόσο μέσο συγκριτικής ανά ζεύγος όσο και από τα αποτελέσματα ποιοτικής έρευνας (συνεντεύξεις) με τη χρήση τυπικής γραμμικής κλίμακας αξιολόγησης. Τα αποτελέσματα, σε συνάρτηση με τους περιορισμούς που καθορίζουν το πεδίο εφαρμογής της παρούσης, καταδεικνύουν ότι τα συστήματα ηλιακής ενέργειας αποτελούν την βέλτιστη εναλλακτική λύση.

Λέξεις κλειδιά: Βιωσιμότητα, Δείκτες, Ανανεώσιμες Πηγές Ενέργειας, Ανάλυση Πολλαπλών Κριτηρίων

Abstract

The current study deals with sustainable development with regard to renewable energy sources in the case under study; Zakynthos Island, Greece. In order to determine the optimal renewable energy source, a multi-criteria optimization is followed. The environment, the economy and the society, as the three pillars of sustainability are used as primary criteria in the context of the under determination goal. Primary criteria were also subject to a DPSIR model of indicators. A number of economic, environmental and social sub-criteria were subject to weight evaluation using both pairwise comparison and qualitative research survey (structured interviews) evaluation results through a developed typical linear scale. Results, with regard to the delimitations set for the scope of the current study, indicate that solar energy source is the optimal sustainable alternative.

Keywords: sustainability, indicators, renewable energy sources, multi-criteria analysis

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INTRODUCTION

In our days, energy demand is considered a notable problem in the world with serious consequences on the environment, the economy and therefore the development. Recent utilization of renewable energy sources, aimed not only towards oil independence, financially speaking, but also protecting the environment from the unrestrained human usage. Renewable energy sources should at some point overcome the environmental, social, economic, technical and institutional raised obstacles. However, the environmental impact of renewable energy sources has more or less been identified, including the extensive use of land and natural resources, the alteration of the landscape, the visual impact, and so on so forth. The intricate renewable energy sources issues make the selection between the different options a multidimensional project (Tsoutsos, Drandaki, Frantzeskaki, Iosifidis & Kiosses, 2009). The purpose of this study is to define, document and finally select an option of only one renewable energy source, as to which is considered the most effective solution from an environmental, social and economic point of view, for the energy independence of Zakynthos Island in Greece.

CH.1: STRATEGIES AND POLICIES

1.1. Strategies and Policies of the EU regarding energy targets

Energy plans and designs intend to determine the optimal combination of energy sources in order to satisfy a given energy demand, and so the competent EU bodies have, already since 1996, shown the way towards renewable energy sources issuing the Green Paper. Following that, the context for the impairment of adverse effects and risks was set along with the alignment of the Members States in the new order through the White Paper, focusing in four parameters: a. Institutionalized incentives and facilities for those who choose to utilize renewable energy sources. b. Open up markets to imported renewable energy sources. c. Promote the use of renewable energy especially for public transportation, public lighting and heating and d. Incentivize/motivate energy proofing of buildings and infrastructure (European Commission, 2016). Thus, EU willing to apply policies towards “green” direction and align with the above mentioned contexts, has raised -non legislative- a set of objectives, such as the sustainable management of energy with low greenhouse gas emissions against global warming, the creation of a network for the reliable and low level energy supply losses, the operation of 'free market' and competitiveness aiming at affordable prices for the final recipient, etc (European Commission, 2017).

The European Union is mainly based on imported fuels, a fact that affects its economic welfare, given that it costs over 350 billion euros per year (Vasileiadis, 2015). The European Union aims to reduce greenhouse gas emissions by as much as 95% by 2050 -compared to the emissions of 1990- (European Commission, 2011) using certain techniques like the improvement of the internal markets function, the development of solidarity in the event of energy crises, the optimization of the trading emissions mechanism, the increase in carbon capture and storage technologies, the development of safeguards regarding nuclear energy, the raising of the awareness among European Union citizens on energy issues, etc (Ageridis et al., 2011).

On 11 May 1998, the Council of Energy Ministers of the European Union discussed in Brussels resulting the White Paper on renewable energy systems, which constitutes a guide for the necessary measures in order for the European Member States to develop and use renewable energy systems in the European area (Koronaios, 2012). With a view to the next 20-30 years, the Green Paper drew attention to the structural weaknesses and the geopolitical, social and environmental disadvantages of the European Union's energy supply in 2000, particularly with regard to the commitments made by Europe's stakeholders under the Kyoto Protocol (European Commission, 2011). More specifically the main objectives were: a. Climate change mitigation, b. Restriction of the dependence on imported hydrocarbons, c. Sustainable growth development, innovation and employment (European Commission, 2007) and d. in an effort to achieve the set sustainability goals through energy supply safety, the implementation of the 20/20/20 project, which aims to reduce gas emissions by 20% compared with the emissions back in 1990 while saving energy and improving energy efficiency 20% (European Commission, 2008).

A long-term and ambitious European energy policy should, after all, be based on the following axis: sustainability, supply safety, competitiveness (European Commission, 2007).

1.2. Strategies and Policies of the EU regarding energy systems

According to the European Directives, such as the 2009/28/EC Directive, some quantitative objectives -non binding- have been set towards 2020, which among others mainly include 20% reduction in greenhouse gas emissions -in relation to the preindustrial period values-, measures towards 20% energy coming from renewable sources and finally 20% energy efficiency (European Commission, 2017). Accordingly, EU recognizing that these objectives are not enough for the overall sustainable balance of the already strained environment, has set even higher objectives towards 2030 which include among others 20% (40% overall) greenhouse gas emissions reduction, 7% further (20% total) energy efficiency using renewable energy sources, 10% (30% in total) in energy efficiency improvement, and reach a point where able to deliver 15% of the total produced energy (thus including the 40% energy coming from renewable energy sources) to other countries within or outside Europe.

Respectively, even more ambitious are the objectives set towards 2050, been aware with the intense issue of climate change, aiming 50% greenhouse gas emissions reduction (European Commission, 2017).

For the above mentioned guidelines, some binding and some other non-binding content has been compiled to Member States. Some of them are: a) 2001/77/EC Directive regarding the national objectives for each Member State towards 2020, b) 2003/30/EC Directive concerning promoting biofuels towards replacing oil -at least for public transportation- c) 2004/8/EC Directive concerning the encouragement towards multifaceted energy production using conventional and renewable energy sources, etc (European Commission, 2017).

European Union's energy system should ensure a sustainable, safe and competitive environment. Todays' energy system has to transform according to the following five parameters in order to achieve its goals:

1. Energy supply safety. The European Union should accomplish to be less vulnerable from the energy crises coming from its energy suppliers. This will be achieved

through the diversification of the energy suppliers, the use of new technologies and the use of indigenous resources.
2. Support of the internal energy market through reinforced regulations regarding the cross-border energy trade and promotion and abetment of the renewable energy producers to further integrate into the energy market.
3. Improvement of the energy performance of buildings, particularly with regard to heating and cooling systems, through grant programs.
4. Decarbonisation through advanced low emissions technologies.
5. Smart technologies promotion

1.3. Strategies and Policies in Greece

The first essential legislative samples of the Greek state, were the enactment for the No 2773 Greek Law in 1999 and No 3468 Greek Law later in 2006, with which some national objectives were set, such as manage 20% of energy production -of domestic consumption- out of renewable energy sources until 2010 and 30% until 2020, the institutionalization of licensing, the authorization for hybrid energy production solutions on islands -not connected to the main network-, the pricing rank set dependent on the source of electricity, and more (Greek Ministry of Environment and Energy, 2017). No 3851 Greek Law in 2010 regarding further development of renewable energy sources in order to address climate change, along with similar provisions under the auspices of the Greek Ministry, actually incorporate 2009/28/EC Directive into the national legislation and together with the earlier No 3734 Greek Law in 2009 set the following objectives towards 2020: a) 40% penetration of renewable energy in gross electricity consumption b) 20% share of renewable energy sources in gross electricity consumption for heating and cooling and c) 10% share of renewable energy sources in transport sector. It also includes issues related to simplifying licensing procedures for renewable energy sources installations and the creation of a renewable energy agency for d) the exploitation of natural resources in Greece, for renewable energy production, e) drawing green growth strategies and plans, etc (Greek Ministry of Environment and Energy, 2017).

The national 2020 targets regarding renewable energy production were set to meet 13.3 GW energy production from renewable energy systems and more specifically 7.5GW out of wind power systems, 2.5GW out of solar power systems and 3GW hydroelectric systems. This target, according to recent ministerial estimations, will not be achieved unless an extensive orientation on wind power systems is not applied, particularly on the Aegean Islands, wherein the greatest potential actually exists.

Energy production in Greece comes mainly from thermoelectric power station located in the Northern part of the county mainly due to domestic lignite deposits. The 2016 energy balance shows that 60% of the total produced energy is out of lignite, which is considered a highly pollution fuel.

Environmental protection, as a high priority objective of the Greek State along with the strategy towards resolving the country's energy needs is achieved through the legislative initiatives following certain simple guidelines:

- The use of various energy sources
- Oil and gas transportation pipelines construction using international networks
- Efficient domestic energy sources consumption
- Dependence on high risk imported energy sources
- Renewable energy systems development
- Clean energy technologies development
- Liberalization of the energy market
- Private investments on energy systems promotion
- Energy efficiency systems

CH.2. CASE STUDY: ZAKYNTHOS ISLAND

In an attempt to plan and implement a sustainability proposal in a place, what should one researcher look for? What special characteristics should one measure and take under consideration? Do only economic data, or environmental needs and sociopolitical circumstances matter? This is an important aspect that researchers are constantly facing in their attempt to offer in the academic community and the society solutions in the major issues that cause global concern.

In this context, this research approaches a place, as a case study with respect to those characteristics that constitute its physiognomy (Mitoula, Theodoropoulou, Karnabos & Apostolopoulos, 2012). Certain characteristics that are included in fields from all three pillars of sustainability, namely society, economy and environment are recorded, analyzed and investigated (Mitoula, 2007).

The area under study, Zakynthos Island of Greece, is internationally known due to the specific natural and cultural characteristics some of which include among others the under protection nature areas and the rich natural resources. The area of the Island reaches 410 square kilometers and the population is 40,564 inhabitants according to the latest census (Hellenic Statistical Authority, 2017). The Municipality of Zakynthos of the Ionian Islands Region, includes Zakynthos, the nearby islets and Strofades. The current municipality was created under No3852 Law of 2010, commonly known as "Kallikratis Law", combining several pre-existing municipalities on the Island. Headquarters of the current municipality are located in the city center of Zakynthos. Zakynthos area is notably large and is sorted in the eleventh position in land terms to all the other Greek Islands. Regarding the Ionian Islands, Zakynthos is the third largest (after Kefalonia and Corfu) and the second in population. As shown from the Hellenic Statistical Authority, half of the total area of the island is farmland and 10% pastures, while -despite the frequent and extensive fires 35% is forests (Hellenic Statistical Authority, 2017). Regarding the infrastructure of the island, a road network of nearly 95 kilometers (major roads) exist, two main ports that connect the island with central Greece and Italy operate, as well as many other smaller harbors and marinas. In the island a national airport exists which hosts flights mainly of medium-sized aircrafts. Also notable is that the island records cultural heritage with a number of archaeological sites and monuments. According to recent studies of possible sitting renewable energy systems, which implement criteria set by Law and gradually remove (buffer tool) the conflicting areas of infrastructure, housing, production, cultural sites and environment protected, it appears that approximately 100 areas are suitable, of a total 60 square kilometers surface (Giannakopoulos, 2015).

According to the Hellenic Independent Power Transmission Operator (Hellenic Independent Power Transmission Operator, 2017), for the energy needs of Zakynthos Island underwater electricity transmission lines are connected (150kV high voltage cables) with the neighboring Cephalonia Island and with the national interconnected system in the Prefecture of Ilia. A 150kV single-circuit transmission network runs through the island, which effectively connects the underwater electricity transmission lines with the electricity substation located in the city if the island (Hellenic Statistical Authority, 2017). Also in the city of the island a power station with installed capacity of 27MW operates (Public Power Corporation S.A. - Hellas, 2017). The island's energy need as reported from the Hellenic Statistical Authority (Hellenic Statistical Authority, 2017) deriving from the energy consumption is about 185.000kWh. At least half of the abovemention recorded consumption is of commercial use, about one third of domestic use while public and municipal infrastructure uses about 2%, agriculture about 1% and industrial about 6% (Hellenic Statistical Authority, 2017).

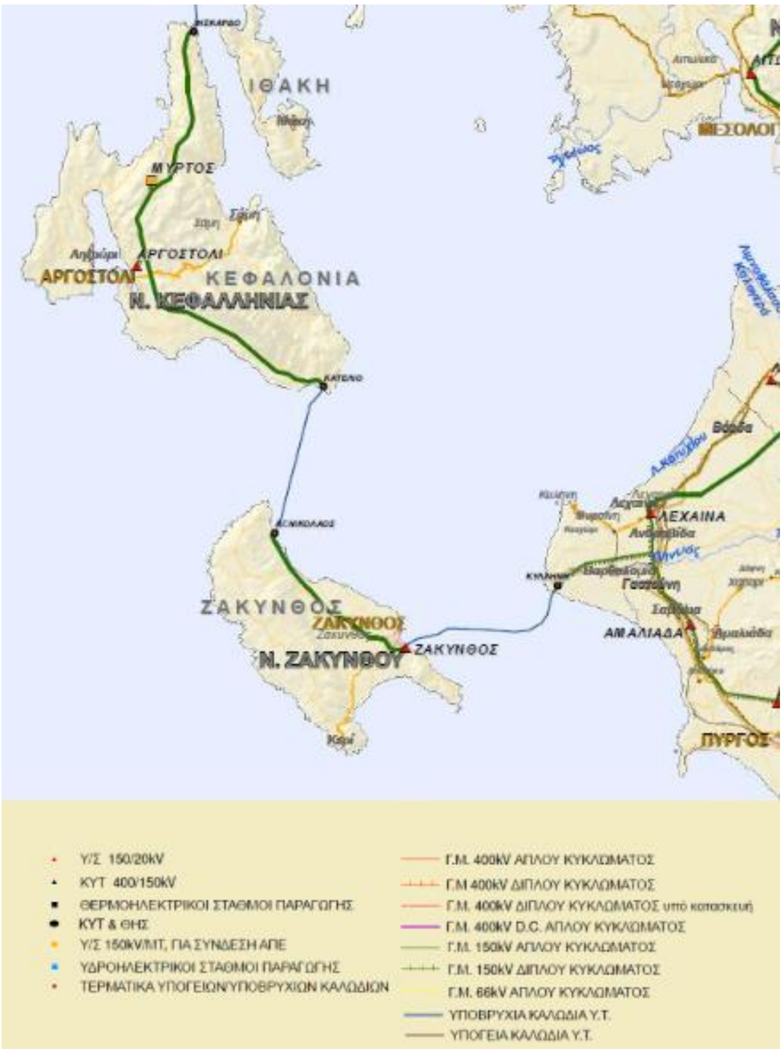


Figure 1 Zakynthos Electricity Transmission Network (Greek Ministry of Environment and Energy, 2017)

2.1. Geography

Zakynthos lies in the eastern part of the Ionian Sea, around 9.5 miles northwest of the Greek mainland. The neighboring Island Kefallinia lies 8.5 miles on the north. Zakynthos Island is the southernmost of the main group of the Ionian Islands (not considering Kithira). The island is approximately 25 miles long and 12 miles wide. The coast line is about 76 miles long. Countless are the beaches in the Island, to the west, the icy water coast where the sea bottom is lost in the abyss of the Ionian rift. From Laganas village to Kalamaki village, with the endless sand beaches to Porto Limiona, the Korfadakia and the Ampelia with the rocky beaches. Planos-Tsilibi beach, located in the northeast of the island also stands out, while a bit northern in Tragaki village, Gerakari village one can overlook the scenery of sandy shores. Finally, on the southeast side, Gerakas beach, Porto Roma, Saint Nicholas, Porto Zoro etc, with the under Law protected Caretta-Caretta nesting beaches (Vardopoulos, 2015).

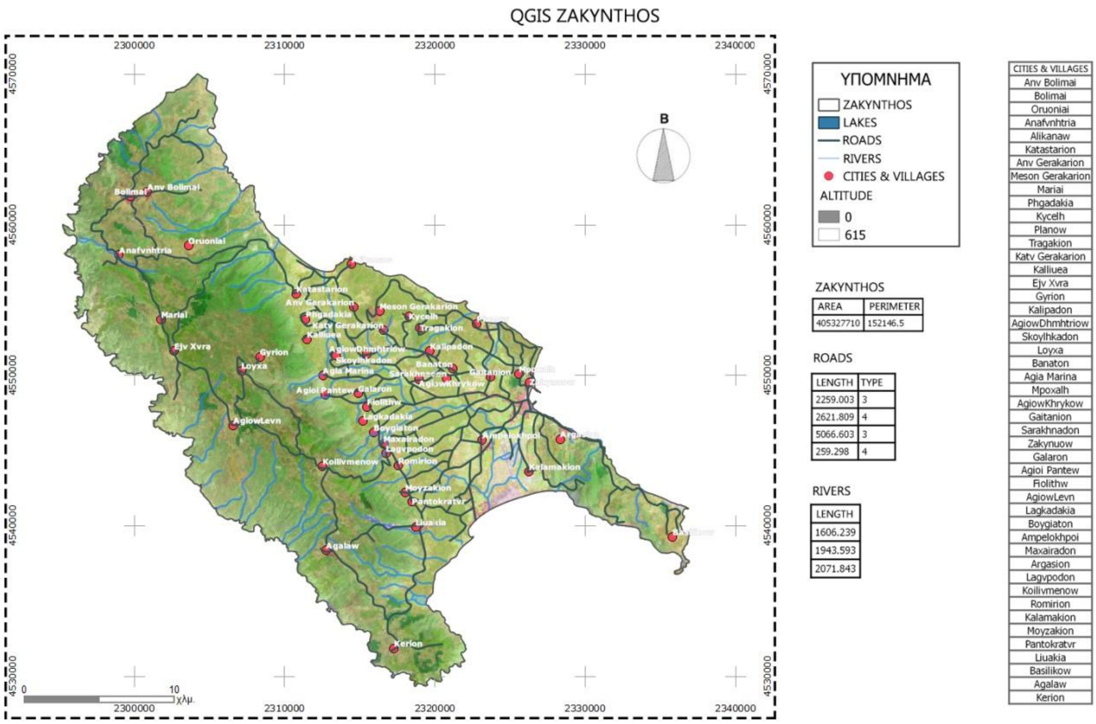


Figure 2 Quantum Geographic Information System Map of Zakynthos (Vardopoulos, 2016)

2.2. Geology

Zakynthos is located exactly in-between two geotectonic zones of the Ionian, that is considered to be overthrusted to the Paxos zone, and the Pre-Apulia (Greece's mainland side) (Aubouin and Dercourt, 1962) making the island tectonically speaking quite active, with numerous of either mild or intense earthquakes. Mountainous Zakynthos is composed of upper Cretaceous limestones (National Agricultural Research Foundation, 2017) that are overlain by Eocene limestones (Kati, 1999). Those rocks are solid with significant erosion which is responsible for the creation of various karst phenomena (caves, limestone sinks, etc). Rainwater is lost in the gaps, making the region notably barren. The fruitful territory is mostly observed near closed basins. The rocks of the southeast side are Miocene and Pliocene ones, mainly composed of clay, gypsum, marl, limestone, sand and sandstone layers (Underhill, 1988). Their existence makes the soil fruitful while rainwater is prevented from penetrating to the lower layers by the impervious clay, which explains the existence of numerous wells in the area. The other part, commonly known under the name Skopos, is similarly composed with the latter but mainly of gypsum which under the tectonic pressure, swelled and came to surface. West Zakynthos ends with the commonly known steep cliffs, which are result of the recent tectonic fractures and transitions, prior to 1 mil. years ago at the beginning of the Quatemary.

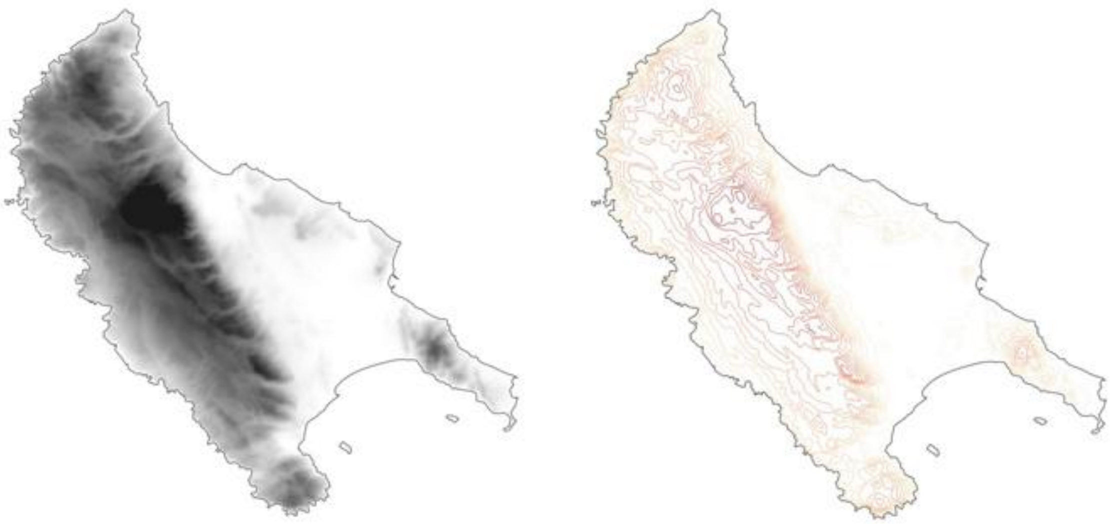


Figure 3 Left:Zakynthos Terain Digital Model. Altitude values from 0m. (white) to 615m. (black). Right: Zakynthow Contour Lines (Vardopoulos, 2016)

A geological map of Zakynthos based on the original from the Institution of Geological and Mineral Exploration in Greece (IGME) (Diamantopoulou & Voudouris, 2007) and Professor's Megalovasilis's simplified and modified version (Megalovasilis, 2014) is shown in Figure 3.

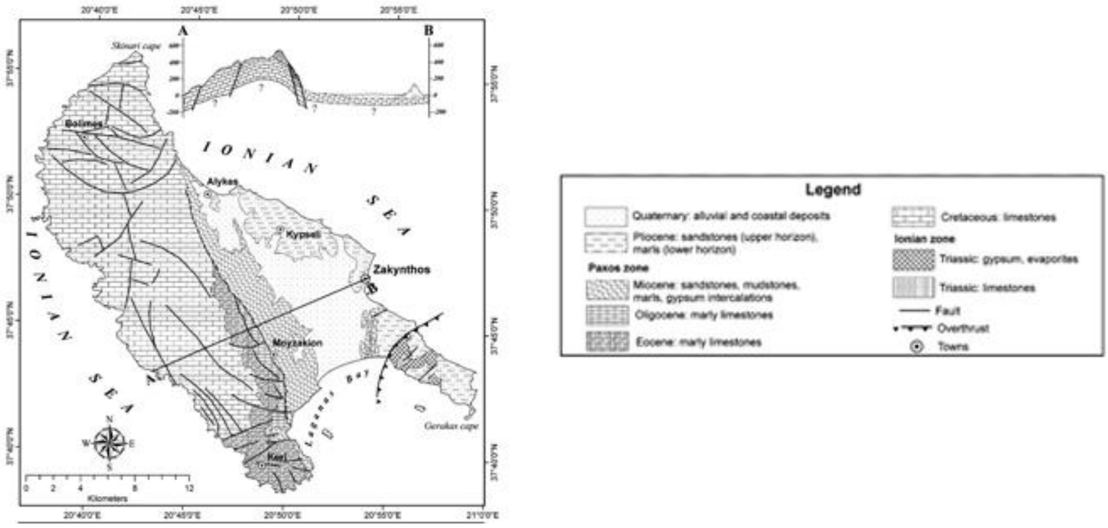


Figure 4 Geological Map of Zakynthos (Megalovasillis, 2014)

2.3. Flora

According to the Greek Ministry of Agriculture orthophoto maps (Greek Ministry of Agriculture, n.d.), the mountainous Zakynthos flora has the structure of a degraded Mediterranean Forest. Low shrubs and bushes, high evergreen broadleaf (maquis) and pine forests compose the scenery. The island is situated in the thermo-Mediterranean Bioclimatic Zone, which represents hot and dry climate. At this point three phytosociological formations can be distinguished: a) Low phrygana and bushed flora, which are considered suitable for extreme soil conditions and fire. Having two kinds of leafs, the summer ones, which are small and fleshy in order to be fire resistant with minor moisture losses, and the winter ones. Cistus is also pyrophyt and its seed are germinated with the help of fire. Aleppo Pine is “reborn through fire”. Anthylis Hermanniae is a phrygana kind which is also found in Zakynthos, where, in some cases, intense regeneration of Pinus Halepensis with 30 to 60 cm plant height has been witnessed. b) The shrubby maquis, degraded flora with 1 to 2 meters plant height and soil cover of 100%. In Zakynthos, kinds of Cedar, Strawberry, Cypress and Pinus Halepensis prevail with maquis flora typical height. The maquis mostly prevails in inland hilly slopes with gently or steep slope while near streams appears dense and rich (streams leading to the Celery bay, beneath Agalas village). c) Pine forests appear less, especially the last 30 years have been limited because of the recurrent fires (Spanou, Verroios, Dimitrellos, Tiniakou & Georgiadis, 2006). Forests appear degraded and aged between 50 and 60 years old, of about 8 meters height, with bushy surrounding subsoil. Solid forests of Aleppo Pine are found in Volimes village around the monastery of Saint George, in Agios Leontas village, in Agios Nikolaos village and in Porto Vromi peninsula, while disseminated are found in Kampi village all the way to Exochora and Keri villages (Valli & Iatroy, 2013). Transient formation of pine forest in maquis scrubland flora or phrygana, wherein pine regeneration is intense and degraded maquis with strong presence of phryganic species, is also witnessed (Tsirika & Haritonidis, 2005). Frequent fires degrade the high flora with phrygana invasion (Keri village, Schinari village, etc), and in some cases maquis with pine regeneration (Anafonitria village). Brushwood, maquis and scattered pines that made it through fire, occur in western cliffs (Shiza area), which are considered unique habitat, with a significant number of rare species (Valli and Iatroy, 2013). The few crops cultivated in the upland area are mainly raisings, grapes and wheat. The last 30 years, a reduction of pasture in favor to crops is observed. In forests, overgrazing does not occur, although studies regarding the grazing capacity where not found. No logging occurs. The principal agricultural products are olive oil, grapes, currants and citrus fruits. In conclusion, the Island's flora belongs to the Mediterranean ecosystems degraded due to extended fires, with clear human induced affects (Tsirika, Skoufas & Haritonidis, 2007). For more and specialized information the use of geographical information systems is necessary.

2.4. Fauna

In Zakynthos Island inhabit all kind of pets, rabbits, ferrets and the grey squirrels. Numerous species of insects exist, such as bees, that provide a fine "gold" Zakynthian honey, butterflies, which stand out in relation to the rest of Greece due to their lack of vivid colors. Birds that inhabit the island are distinguished depending on where theirs nest is made. In that order, birds that inhabit in the rocks are Kestrels and/or Falcons. In the other hand, birds that inhabit in the fields are Hawfinches, Collared Doves, Yellowbirds, Swallows and/or Eurasian Scopes. Finally, birds that inhabit in the forests are Finches, Common Buzzards and/or Long-Earned Owls. In the surrounding isles, Strofades, Arpia and Stamfani, during the spring more than 1200 species of migratory birds rest. Furthermore, in the above mentioned isles, Seabirds, Sperm Whales, Civier's beaked Whales and a number of the Dolphin's family species inhabit (Hellenic Statistical Authority, 2017). Zakynthos owns two very important inhabitants of rare marine species protected by international conventions and domestic Law's. The first habitat is associated with the reproduction of the sea turtle

Caretta Caretta, located in Laganas bay. The second habitat concerns the reproduction of the Mediterranean Mock Seal Monachus Monachus and is situated in the western and northern coastal cliffs of the island. Both areas are pole of attraction for tourists. The national Marine Park of Zakynthos, an 135.000 ha area, was established by Law in 1999, the first of its kind in Greece and an example for other regions in Greece that require integrated management of the environment. In Zakynthos have been recorded three wildlife sanctuaries, an Area of Conservation (SAC), and a zone protected by the Special Protected Areas (SPA) Law (Greek Official Gazette 906/D/22.12.1999). Laganas Bay has been characterized as a 'Biogenetic Reserve' (Council of Europe). Furthermore, two more special areas of conservation of about 65,000 ha, two more special protection areas of about 215.000 ha have been identified. Finally, aligning with the European Directive 92/43/EC regarding the conservation of nature habitats and wild flora and fauna, Zakynthos state has legislated networks of protected areas of Natura 2000 project (National Marine Park of Zakynthos, 2017)

2.5. Climate

The climate of the mountainous part of Zakynthos is Mediterranean, mild, without extreme values of temperature. Conditions of still air appear 36% of the time of a year and maximum wind speed can reach up to 8 Beaufort. The prevalent winds are northern and south. Winds are stronger from November to February. Temperature rarely drops below 1° or 2° Celsius degrees. Moisture in November reaches 78% while in July reaches up to 56%. (Kalimeris, Founda, Giannakopoulos & Pierros, 2011).

Table 1 Zakynthos Temperature Data (1997-2010) (Hellenic National Meteorological Service, 2017)

1o Semester	Jan	Feb	Mar	Apr	May	Jun
Min Monthly Temp	5.1	5.7	6.8	9.2	12.9	16.4
Average Monthly Temp	9.7	10.3	12.0	14.9	19.6	23.9
Max Monthly Temp	13.9	14.2	16.0	19.0	23.8	28
2o Semester	Jul	Aug	Sep	Oct	Nov	Dec
Min Monthly Temp	18.4	18.8	16.5	13.4	9.9	6.8
Average Monthly Temp	26.4	26.3	22.7	18.4	14.3	11.1
Max Monthly Temp	30.9	31.3	27.6	23.2	18.7	15.3

According to rainfall stations in Zakynthos, rain reaches an average concentration of 830mm, considering the annual distribution quite satisfactory. Lastly, according to the bioclimatic map of Greece, the climate in lowland Zakynthos is weak thermo-Mediterranean. More detailed studies of rainfall in Zakynthos (Megalovasilis, Kalimeris, Founda & Giannakopoulos, 2011) have come to realize a significant loss of about 22% of available water in 4 decades.

Table 2 Zakynthos Humidity Data (1997-2010) (Hellenic National Meteorological Service, 2017)

1o Semester	Jan	Feb	Mar	Apr	May	Jun
Average Monthly Humidity	75.4	74.3	73.4	72.8	69.5	63.4
2o Semester	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly Humidity	60.0	62.2	70.4	74.6	77.5	77.2

Table 3 Zakynthos Rainfall Data (1997-2010) (Hellenic National Meteorological Service, 2017)

1^{o} Semester	Jan	Feb	Mar	Apr	May	Jun
Average Monthly Rainfall	136.6	124.6	98.1	66.7	37.0	14.1
Rain Days	16.1	14.6	14.5	12.9	8.0	4.9
2^{o} Semester	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly Rainfall	9.2	19.0	81.3	137.7	187.4	185.6
Rain Days	2.3	3.4	7.0	11.8	15.7	17.5

Table 4 Zakynthos Wind Intensity Data (1997-2010) (Hellenic National Meteorological Service, 2017)

1^{o} Semester	Jan	Feb	Mar	Apr	May	Jun
Average Monthly Wind Direction	SE	SE	SE	SE	SE	NW
Mean Monthly Wind Speed	4.9	5.5	5.0	4.3	3.5	3.7
2^{o} Semester	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly Wind Direction	NW	NW	SE	SE	SE	SE
Mean Monthly Wind Speed	3.5	3.5	3.3	4.0	5.1	5.2

2.6. Aquifer

The limestone formations of Cretaceous, Eocene, Oligocene are considered the most important water recipients in Zakynthos. But the water in many cases near the coasts, suffers from salinization due to the low levels of the aquifer (2-3 meters for the sea level). Into the geological formations in Zakynthos three major aquifers are developed. a) In the east, the restricted aquifer in Neogene deposits of Kypseli Unit, b) the unique karstic source of carbonate formations located west in Keri Lake and c) in the central-east the unconfined alluvial aquifer (Megalovasilis, Kalimeris, Founda & Giannakopoulos, 2011; Megalovasilis, 2014).

Figure 5 Left: Zakynthos Hydrographic Network Map (Vardopoulos, 2016). Right: Drill Hole Location Map (Megalovasilis, 2014)

2.7. History

The island of Zakynthos brings some more internationally recognizable names. It is reported that by the time the island was under Venetians jurisdiction, was known by the name "Zante" or "Fioro di Levante" (meaning Flower of the East). Regarding mythology, Zakynthos is linked with the Artemis, the hunting goddess, who used to wander around the Zakynthos forests. Her brother, Apollo, was playing his lyre beneath the laurel trees in order to praise the beauty of the island. The worship and devotion to Artemis and Apollo, in ancient times, prompted the inhabitants to spectacles and games. According to Homer, founder of the Island was Zakynthos, son of Dardanus, King of Troy, who travelling with his fleet from Phsophis, arrived on the Island and established the acropolis. Zakynthos, as founder of the Island, was faced in many coins and many symbols used representing the Island. In the latter mentioned symbol, Zakynthos holds a snake with this bare hand, according to some legends, wanting him to have freed from flooded snakes the island. The foundations for the development of the island, through economic and administrative organization, were set in 1357 by the De Toli Dynasty. However, that growth was interrupted when the Turks seized the island. The Turks held their jurisdiction for five years, during which many residents left heading to Peloponnese. In 1485, the Venetians took over the island expelling the Turks and calling back the inhabitants to their homes and properties. During the Venetian jurisdiction, the island enjoyed great development and the Central City acquired particular architectural style. The population was separated in "nobili" (noble), "civili" (bourgeoisie) and "popolari" (folks) (Moutsioulis, 2000). The aforementioned class distinction created inequalities, which eventually lead popolari rise up against nobili. That revolution is widely known as "The Rebellion of the Popolari" (Tzivara, 2009). Later on, the French Revolution of 1789, as expected, also affected Zakynthos. The values and ideas of the French Revolution, such as social equality and justice, expressed the inhabitants as their former revolution proves. During that period, and particularly in July 1797, France takes over the island and abolishes the social discrimination. However, quickly the Turks took over the island once again, in October 1798 (Solman and Cox, 1991). Two years later, the foundations for the establishment of the Greek State of the Seven Ionian Islands were set, product of agreement between Russia and Turkey, and was implemented for seven years. The newly established state of the Seven Ionian Islands was conquered in 1809 by the British. In the following years, and while the rest of Greece was under the Ottoman rule, Zakynthos remained under British jurisdiction. Important historical fact is considered that in Zakynthos was first given the oath of initiation into the Society of Friends, a secret organization of member who initiated the Greek War of Independence in the spring of 1821 (Whittaker, 2002) However, despite the fact that Greece manages and acquires independence in 1830, Zakynthos was kept by the British until 1864. Like the rest of Greece, Zakynthos also was under Italy and Germany during the Second World War. After the war, in 1953, the island suffered another terrible setback; an earthquake that knocked down the whole city structures. Many important proofs, with respect to history and culture, of the various dominations that succeeded one another the Island were suddenly lost forever.

2.8. Culture

Zakynthos's culture is rich and long-lasting. Art and literature, beginning from the Venetian colonialism in the 15th Century testifies the flourish past.

Specifically literature, dated back to 1400's, when poets became quite known for their poems, prosaism, and ancient Greek texts translations. In the next century, Zakynthos contribution to the Greek Literature and art was significant with the foundation of the first Greek Academy. The contribution was beyond the literature and the art it self, since many, like Dionysios Solomos, wrote poems to sustain the population during the revolution against the Turks (Sammon & Hirst, 2014)

In painting, the first affects were direct to the Byzantine art, with religious themes. It was later in the 17^{th} century when portraits (Tsakos) became themes and perspective drawings with different painting techniques emerged (Doxaras). As literature took a nationalistic perspective, during the war against the Turkish domination in Greece, so did painting (Koundouris). Finally, it was around 19^{th} century that painting art took the form of art for everyone, contrary to the until then known holy form of art to be exposed in churches or public use buildings. (Pelekasis) (De-Viazi, Konomos & Tsourakis, 1968). Regarding sculpture, the art of silver engraving and of wooden sculpture was significantly developed and mainly used for church decoration (Bafas, Vlachos), but notable is also the mosaic art technique that flourished in the Island (Xenopoulos) (Petris, 1978). Music in Zakynthos is a very characteristic feature. Started by accompanying the military parades, made its way through centuries accompanying with ballads folk feasts. Decides the Venetian overcome (Zakynthian Seranade) or the Cretan influences (Arekia), Zakynthians managed to develop their own form of music, which is historically testified by the establishment in 1815 of the School of Music of Zakynthos, the choirs and the music clubs, the following years. Music in Zakynthos can be seen both ecclesiastical and folk (Zervanos, 2015) Since 2009, Zakynthos has its own Jazz Festival. Theater was also an important form of art in the island. Started been held in the nobles parlors, considered to be addressed only for the wellbeing classes (bourgeois). Opera, operetta and the so called Omelies (folk representations denouncing the social injustices) were particularly developed.

The main museums located in the city center are the Byzantine Museum of Zakynthos, hosting Byzantine style Orthodox Church Saint's Portraits, renaissance painting, etc., (Mylona, 1998) and the Museum of Solomos, Kalvos and Eminent People of Zakynthos, featuring the tombs of Dionysios Solomos and Andreas Kalvos, along with testimonies and donafide works of the most notable Zakynthians. Also in the city center is located the Town

Hall Library keeping unique papers and books of significant historians, scientists, writers and poets along with copies of old newspapers, pictures (photographs) concerning the second world war and the pre-earthquake-damaged scenery of the island. Some other notable cultural centers are namely the Exhibition Center of the National Marine Park, the Helmi's Natural History Museum, the Naval Museum and the Cultural and Agricultural Museum.

The major festival (folk feasts) nowadays in Zakynthos is about the religious Orthodox Church celebration of the Saint Patron of Zakynthos, Agios Dionysios (Aygust 24), whose imperishable corpse is kept in the namesake church. Orthodox Church Easter in Zakynthos is also one great example, a quite spiritual one. Notable, is also considered the Zakynthian Carnival, directly Venetian influenced, with masked balls, feast calls, and the mask funeral, a ritual from the past.

Nowadays, regarding culture, the islanders and the state authorities, do keep high standards, well organizing all the traditional folk feasts, continuing the tradition of choirs, well preserve the museums and all the cultural history testimonies, and keep constantly organizing several cultural events with different themes throughout the whole year. A quite notable example is the journal of culture the city state publishes quarterly.

2.9. Architecture

The architectural style of most buildings is generally named "Eptanisian", but a closer observation will highlight particularities and differences from the rest of the Ionian Islands. Architecture in Zakynthos has been evolving during the last centuries, adopting elements from various architectural trends during the island's rich history.

An important period of its architectural history is in the middle of 19th century, when, a number of buildings, namely public buildings, big mansions and churches, were built in an eclectic (due to the Venetian colonialism) Neo-Classical style, with influences from Renaissance and Baroque, best expressed in their exquisite details and decoration. A great sample of this architecture, still standing today, is the Municipal Theater, built in 1875 by Ernst Ziller.

The five types that could be distinguished were a) the city mansions, reflecting on the cosmopolitan histories, which were mainly triplexes with firebrick facades, b) the country side mansions, larger and more complicated, c) the city houses, with their characteristic extrusions of the upper floors above the street, d) the public buildings, forming the characteristic arcades, and e) the churches.

The special characteristic of the churches is their elaborate belfries, built next to the churches in the form of small towers with elegant carvings and decoration (Zivas, 1984). A great number of churches that still survive today followed the three-aisled Basilica rhythm. The Cathedral of Zakynthos, Agios Dionysios, is considered the most important and finest example of the Venetian architecture in the Island. The Byzantine rhythm and art is followed only by a few monasteries, which managed to remain almost unaffected from the European conquerors (Konomos, 1964).

However, a key factor in the formation of the current architecture and urban design in Zakynthos was the 1953 earthquake. The catastrophic earthquake and the fire that followed destroyed almost the total of its historic buildings. The restoration of those buildings was very difficult, due to the scale of the destruction.

Regarding the urban planning of the city of Zakynthos before the 1953 earthquake, the following could be noted. The older settlement was located higher with respect to the Castle hill, to secure it from the pirates. With reference to Coronelli plans (Coronelli, 1950), the settlement was typically medieval, with irregular form, with narrow streets and few free spaces. In the narrow strip of land between the castle and the sea, a small settlement existed. The Venetian authorities were situated inside the Castle where a Catholic Cathedral and nobles' mansions were also located. However, this site was considered disadvantageous and with no possibilities of extension by the Venetians. Therefore, the old city kept the administrative and religious role while the rest of the activities and housing gradually began to formulate the new settlement near the coastline. The continuously augmented needs of the new settlement were pushing towards continuous embankments towards the sea. The last big embankment was in 1953 were all the ruins of the destroyed city were used, in order to extent and flatten the area.

Since 1953, Zakynthos follows the strictly antiseismic construction regional Law of the Greek State, according to which, the restriction of a maximum height of three stories is applied for all buildings. Apart from that, a reference in natural and cultural heritage protection is always made with the aid of an official Committee.

Regarding spatial planning and land cover, in Zakynthos a master plan has been completed and approved for the settlement of the city center and the Bohali district (Greek Ministerial Decision 32891/1221/04.23.1986, Greek Official Gazette 677/A/21.8.1986). Furthermore by Presidential Decree in June 16, 1990 Urban Control Zone threshold for segmentation and construction restriction has be determined on the outside the approved urban plan area and on the outside the boundaries of districts existing prior to 1923, namely Vasilikos, Lithakia and Pantokratora districts. Today, the legislative tool by which the construction restriction and rules and by which the build environment is actually formed, is the relative Law. The latter, recently re-legislated (Greek Official Gazette 79/A/9.4.2012) fully replaced the previous one.

Quite notable and useful is consider the development of a mobile augmented reality application, design to represent and experience the historical center of Zakynthos before the earthquake incident (Chalvatzaras, Yiannoutsou, Sintoris & Avouris, 2014).

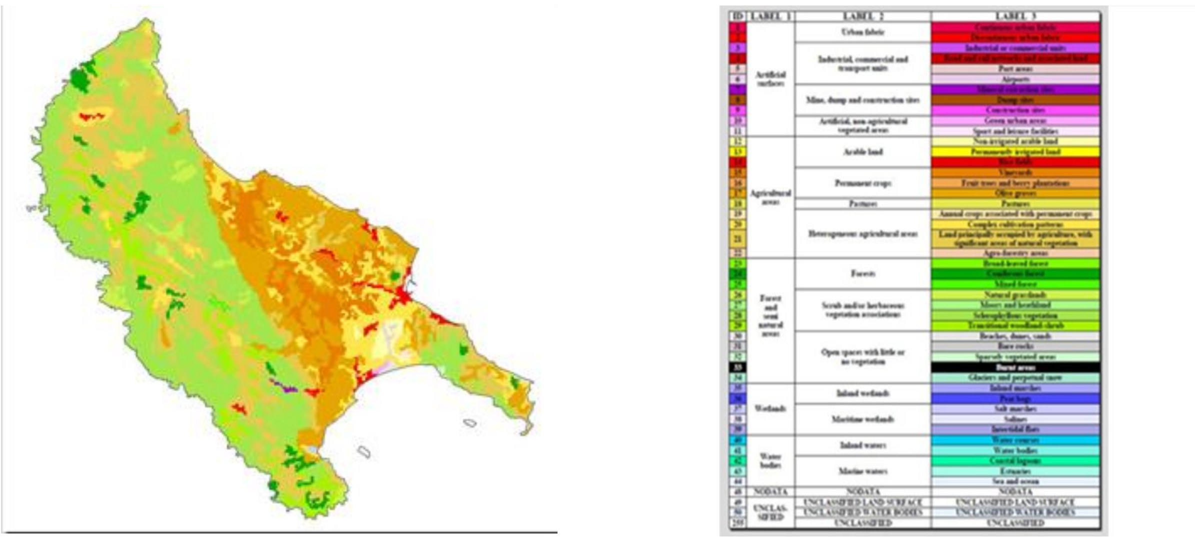


Figure 6 Zakynthos CORINE Land Cover (Vardopoulos, 2016).

2.10. Legally binding protection framework

As previously mentioned Laganas bay Due to the connection with the sea turtles, is under Law protection since 1984 and among others this framework includes; development regulation in a broader zone, safeguarding of the nesting sites, signs informing the public of relative restrictions, maritime traffic regulations, off limit access to the public after sunset and before sunrise, beach furniture restriction, prohibited vehicles, no lights are allowed to shine the nesting beaches, night flights to and from the airport banned, nearby private land acquired be WWF Greece, etc (Charalambides & Katsoupas, 1993; Mylonopoulos, Moira & Parthenis, 2011).

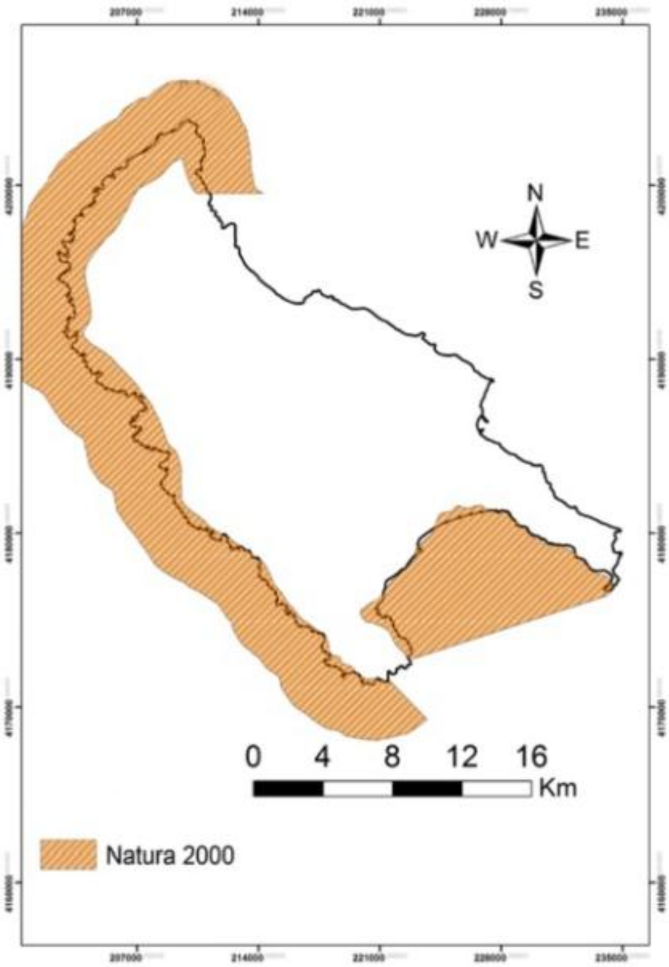


Figure 7 Zakynthos Natura 2000 under Legal Protection Areas Map (Chatzipanagiotou, Oikonomidis & Voudouris, 2015)

The responsibilities of the 20th Byzantine and Ancient Ephorate is on all matters related to scientific, research, disclosure, revelation, retention, preservation, protection, promotion, presentations and storage of antiquities, their exhibition to museums if possible and the participation in domestic and abroad exhibitions. Museums, their collections, operation, exhibits, and their participation in exhibitions in Greece and abroad is also subject of the Ephorate. Furthermore, the responsibilities of the Ephorate lie on the design, plan, manage and implement any archaeological maintenance work, repair project, rehabilitation, restoration, enhancement and (re-)shape of monuments and archaeological sites and their immediate natural of not environment. Also, the Ephorate within the responsibilities has to ensure the scientific study and publication of antiquities for the management of monuments, archaeological sites, museums and collections, has to organize and participate in meetings, conferences, seminars and training activities on relative issues for the production of conventional or digital publications and training materials and for drawing up proposal for the under study subjects. The Ephorate besides the other regional Ephorates directly cooperates with the Ministry of Culture and the General Directorate of Antiquities and Heritage in order to achieve the abovementioned objectives and actions. The main legal framework under which the bureau is operating is the Law No 3028/2002 for the protection of antiquities and the cultural heritage and the Presidential Decree No 99/1992 for the design and implementation of archaeological projects (Greek Ministry of Culture, 2017).

Greece, and therefore Zakynthos, as already mentioned, is under legally binding international and domestic agreements and laws, regarding culture protection of both natural and human environment. Table 9 includes all declared preserved sites and monuments.

2.11. Economy

Zakynthos economy relies mainly on tourism and the primary sector, and constitutes the 0.3% of GDP (Hellenic Statistical Authority, 2016). Zakynthos owns rich vegetation, resulting a significant agricultural production, mainly based on cultivating olive, citrus fruits, raisins, vegetables and grains along with floriculture and wine. However, the agricultural sector contributes 12% to the income of residents (Hellenic Statistical Authority, 2017). Important is still considered the stockbreeding sector, with signs of growth along with the beekeeping. The secondary economic sector includes the production of the Zakynthian Nougat, Sesame Seed Candy, Soap and the standardization and processing of the agricultural and stockbreeding products (wineries, cheese industries, etc.). Although in recent years productivity sectors are facing difficulties due to the economic crisis, also important is the production of construction materials (gravel, concrete, etc.) and the cutting and processing of stone, marble, wood (furniture), steel, etc. The services sector of the economy contributes by almost 68% in local income, including tourism, local services, banks, insurance market, retail and wholesale shops (Hellenic Statistical Authority, 2016). The significant business activity and development focusing in the tourism sector, which besides the fact that sometimes becomes enlarged, is assisted by the globally well known history, beauties, food, tradition, weather this land offers combined with the local national airport and the numerous hotels and accommodation infrastructure. (Ithakisios, 1988; Kütting, 2010; Zarkadi, 2009).

Table 5 Economically Active Population (resident's number) in Zakynthos vs Ionian Islands Region (Hellenic Statistical Authority, 2017)

Region	Economically Active				
	Total	Employed			
		Total	Primary Sector	Secondary Sector	Tertiary Sector
Ionian Islands	88.693	73.350	6.898	9.852	56.392
Zakynthos	18.271	15.206	2.158	1.756	10.992

Consistent with the wider literature (see above), finding from this study suggest widespread knowledge and concern about Zakynthos cultural heritage. However, this does not translate into personal engagement namely in terms of cognition, affect and behaviour. Indeed, Zakynthos is a unique Island regarding its history and environment, thus sustainability approaches are the often an issue. Our observations in the aforementioned findings indicate that although sustainability approaches, with respect to science, are much likely to be proposed and implemented, with respect to Zakynthos physiognomy are much likely to fail. For example, although is proven from the literature review that Zakynthos Island is ideal for tourism investments, respondents of the survey tend to consider tourism as a negative feature of the island, thus such an investment could potentially not have the expected outcome. Also, authorities might consider that Solomos Square Bioclimatic Upgrade is a suitable way to invest EU community support funds, but respondents consider way far better investment the Medical Equipment. Even, using all technology and research means in order to indentify those certain areas in the island that are most suitable for renewable energy systems installation, buffering all conflicting areas, the result may not be quite suitable with regard to history, culture, tradition and habits of the nearby residents. As follows, a multidimensional issue requires a multidisciplinary approach.

CH.3. RENEWABLE ENERGY SYSTEMS

Renewable energy sources are generally speaking considered those sources use natural resources which can be replaced in human time scale, such as sunlight, wind, rain, tides, waves and geothermal energy (Sanz-Bobi, 2014). Renewable energy sources often provide energy on four key sectors, the electricity production services, cooling and heating systems, the transport sector and the rural services (Ellabban, Abu-Rub & Blaadjerg, 2014) (Papaefthymiou & Dragoon, 2016) (Sørensen, 2004). A brief description of the alternatives offered in this case study follow.

3.1. Wind Power

The wind may be used for operating wind turbines. Modern wind turbines range from about 600kW to 5kW of the nominal total power, with the most common being the turbines with rated output of 1.5 up to 3 MW. The electricity coming from wind is a formula of the wind speed, were as the wind speed escalades the power generated increases (European Wind Energy Association, 2009). Preferred areas are considered those where the winds are strong and stable, such as the coastal and high altitude areas (Sanchez-Lozano, Garcia-Cascales & Lamata, 2014).

Usually, the full-load hours range between 16% and 60% annually (Badr, Atallah & Bayoumi, 2016). Worldwide, the long-term technical potential of wind power is believed to be many times of the total current global energy production (Wiser et al., 2016). Wind power is nowadays extensively used and especially in Europe, China and the USA. Within a decade (2004-2014), wind power has a more than seven fold increase from 47GW to 370GW (Global Wind Energy Council, 2017).

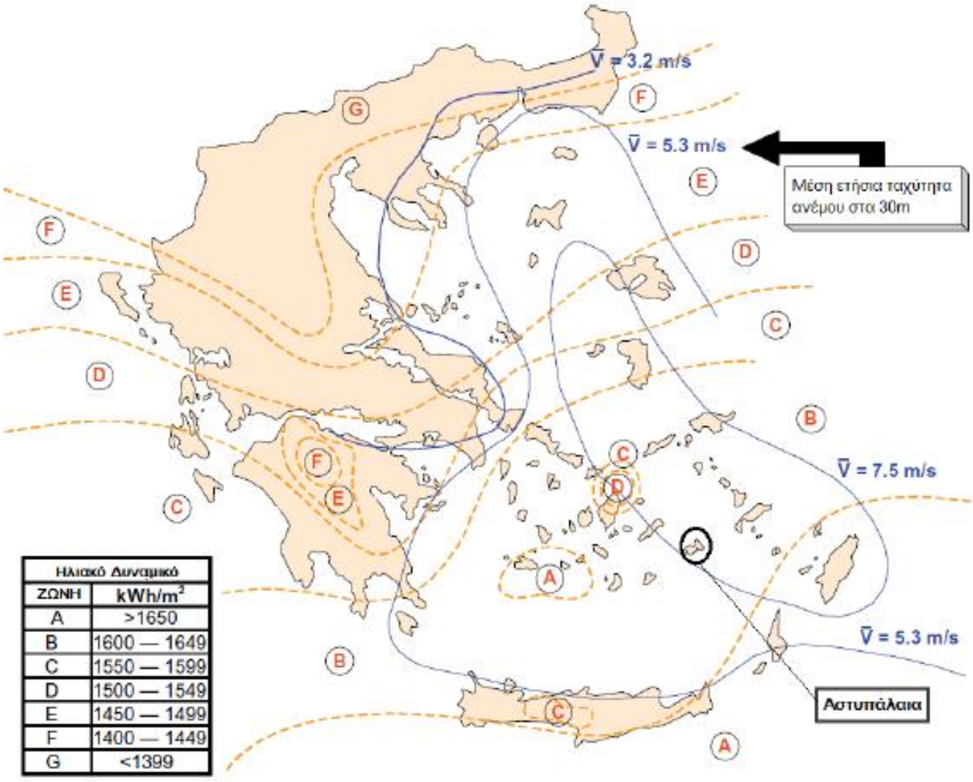
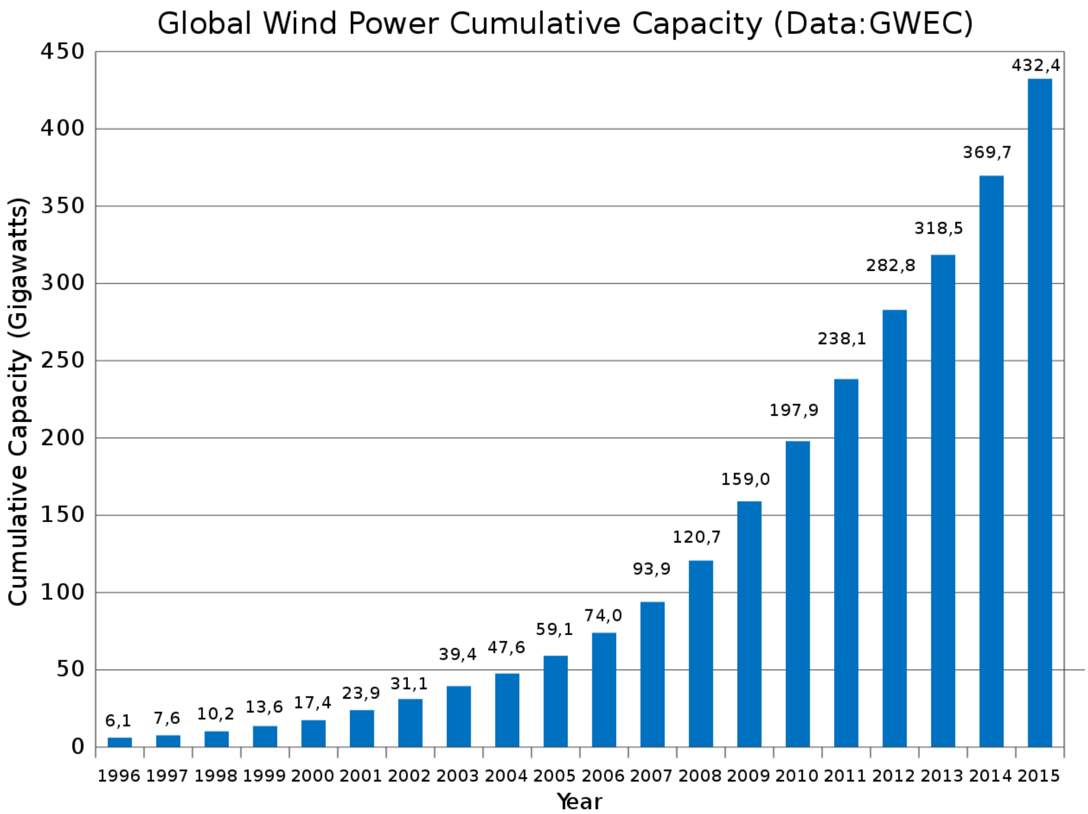


Figure 8 The wind and solar potential zones in Greece. (Kaldellis, Zafirakis & Kondili, 2010)

Apart from the environmental benefits deriving from using wind energy systems, it is particularly important that this type of energy source can be produced in any location, such as remote villages and islands and contributes towards their energy autonomy. Indicatively, the operation of a 10MW wind farm offers the annual electricity needed by 7.250 households and contributes towards saving about 7.500 tonnes of conventional fuels, thus approximately 900 tonnes of CO2 are not emitted and 140 job opportunities are created. Due to the existing infrastructure constrains (road conduction, port size, etc) the most prevalent types of wind turbines for the most islands in Greece are machines with nominal power of up to 500KW (Kaldellis, 2005).

According to the recent international academic literature, depending on the installation site and the investment, the initial cost for installing a wind farm ranges from 700€/kW to 1.200€/kW, while to cost for maintenance and operation is annually 25% of the initial installation cost, thus it ranges from 125€ to 300€ (Türkay & Telli, 2011).



Graph 1 Global wind capacity growth (1996-2014) (Global Wind Energy Council, 2017)

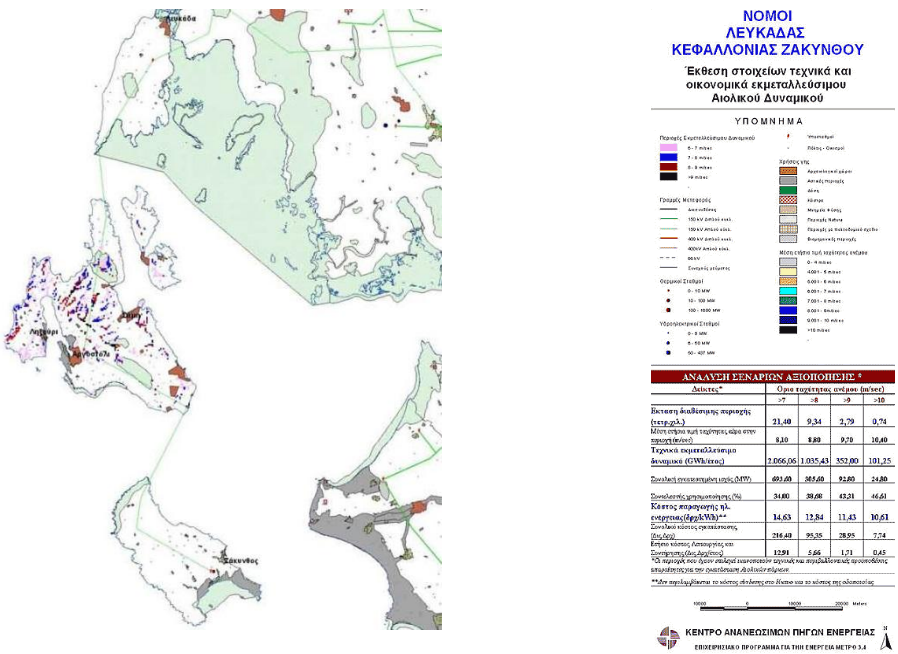


Figure 9 Technically and economically exploitable wind potential in Zakynthos (Hellenic Centre for Renewable Energy Sources and Saving, 2017)

3.2. Solar Power

Solar energy is energy that is transferred to the earth from the sun. This is primordial, mild and renewable energy source. The energy of the sun comes from the nuclear fusion reactions on its mass, by converting hydrogen into helium at a rate of 4 billion tones per second. Earth surface receives directly and indirectly radiation, which in Europe stands for 50% of the total (Wang, O'Donnell & Brandt, 2017). Photovoltaic elements directly convert solar energy into electricity. Photovoltaic systems are very flexible and can cover both low and great electricity needs. The obstacles for spreading the photovoltaic systems use is mainly located in a) their relatively high cost (4-9K €/kWp), b) the fact that the produced energy(/electricity) is significantly more expensive than the one produced using other renewable energy sources, and c) the huge land exploitation -at least for large power systems- (Diakoulaki & Karangelis, 2007).

According to the Hellenic Energy Regulatory Authority, Greece is ranked in the areas of the planet that are considered favored with regard to solar radiation. Greece notes sunshine duration of more than 2.700 hours per year (Šúri, Huld, Dunlop & Ossenbrink, 2007).

The initial cost for installing a photovoltaic park varies between 4.000€ and 9.000€ (Türkay & Telli, 2011), while maintenance and operation costs are considered much less, with numbers ranging up to 0.5% of the initial installation cost (Giatrakos, Tsoutsos, Mouchtaropoulos, Naxakis & Stavrakakis, 2009). For Greece, following the relative social and economic parameters, the purchase and installation price of a photovoltaic park is approximately 7.000€/kW and the annual maintenance and operation cost at approximately 22€/kW (Georganteas, 2011).

The photovoltaic systems produce unstable energy, automatically generating needs for setting, controlling, storing and eventually use of the power. Inverters convert the direct current into alternating current which is suitable for powering the mains and provide the possibility of incorporating protective devices that automatically disconnect the system if there are anomalies on the grid or the generator. At the same time, it is necessary to install electric accumulators to store excess production and use it when the production fails to meet the demand. The amount of electricity that needs to be stored in batteries, determining to some extent their size, is influenced be factors such as local conditions, energy requirements, consumption peaks, reliability degree of the power system, but above all the maximum sunshine days number (Koronaios, 2012). The excess energy (the one over the hourly average demand), if any, charges the batteries till the point they are fully charged.

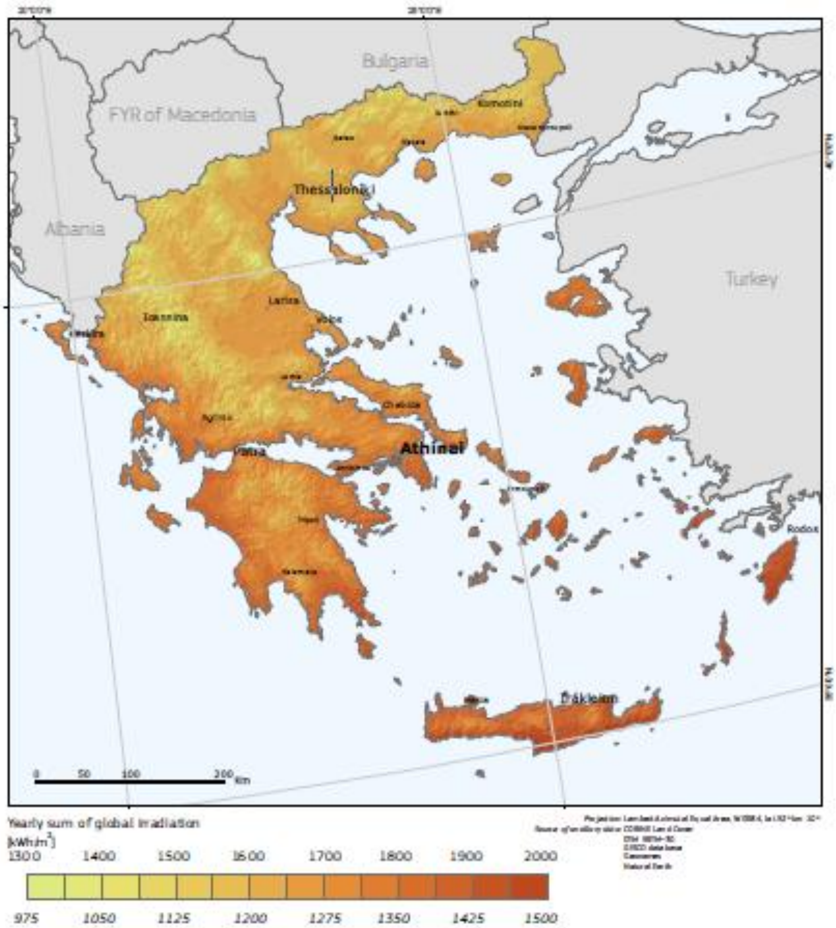
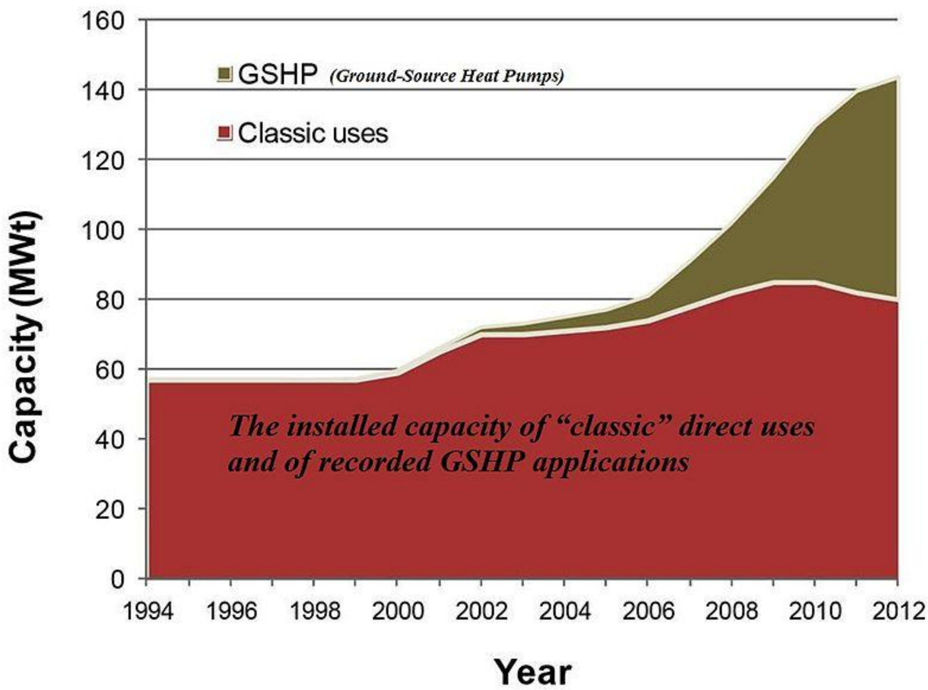


Figure 10 Solar power potential. Horizontally positioned photovoltaic elements - Map of Greece (Šúri, Huld, Dunlop & Ossenbrink, 2007)

3.3. Geothermal Power

Geothermal energy is a part of the earth's heat that is stored in the form of hot water or steam in favorable geological conditions. Is limited to the first 3 kilometers from the earth's surface and can relatively easy be exploited. It is relatively mild, alternative and may can cover a significant part of the energy needs (Gando et al., 2011). The greenhouse gas emissions generated from geothermal electric stations are on average 50gs CO2/kW-h, or approximately 5% less than the conventional coal based energy production stations

(Moomaw, 2011). Impact of geothermal source mainly concern a) air pollution which occurs primarily from geothermal systems of high enthalpy, b) the water and thermal pollution from the discharge of geothermal water containing dissolved salts from which heat is extract, c) the risk for (minor) seismic activity and subsidence, d) the leaks that occur mainly in the early stages of exploitation and e) the noise. It is known that the geothermal energy has many advantages compared to the solar energy systems (Li, Bian, Liu, Zhang & Yang, 2015). These advantages include: a) not affected by weather conditions, b) it is considered energy of base load c) is energy of constant flow with low capacity factor (over 90% in many cases) d) requires less land surface and has less ecological impact. The total installed capacity of geothermal systems, however, is much less than the solar ones (Pohekar & Ramachandran, 2004).



Graph 2 The installed capacity of "classic" direct uses and of recorded GSHP applications since 1994 (Andritsos et al., 2013)

Internationally the average annual rate of the markets growth for the last five years is estimated at 5% while by 2020 the total power capacity is expected to reach up to approximately 20GW (Romitti, 2015).

Geothermal generated electricity does not depends upon fuel, thus is whole investment is not affected by fuel cost fluctuations. Nevertheless, capital amounts are considered high with drilling standing for almost the half of the total investement and deep resources exploration involving serious risks. An ordinary well doublet in the USA supporting approximately 5MW can cost to drill nearly 10 million €, with a 15% failure rate. The total construction of the station can cost about 4 million € per MW capacity, with the levelised energy costs being at about 7€/kW-h. Note that enhanced geothermal installations may cost well above the previously mentioned estimations (Sanyal, Morrow, Butler & Robertson-Tait, 2007).

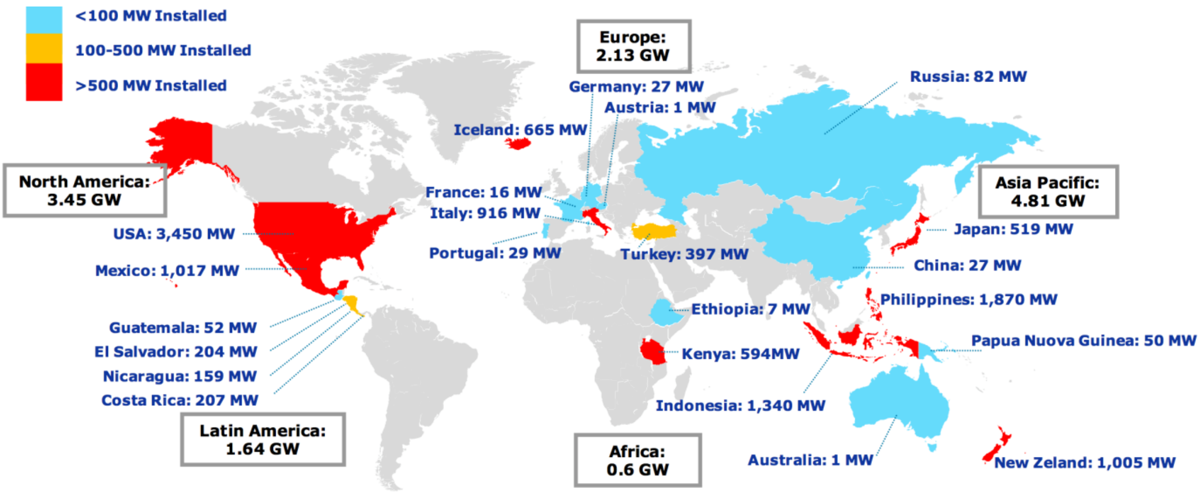


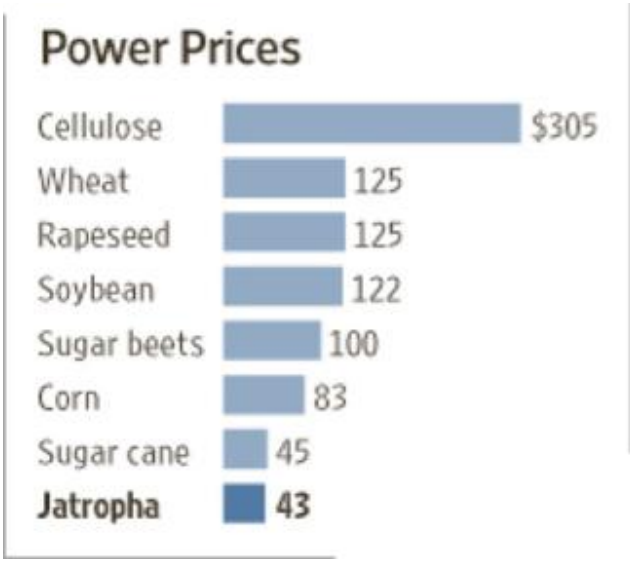
Figure 11 Installed capacity in 2015 worldwide (Bertani, 2015).

3.4. Biofuels Power

Biomass is biological material originating from living or recently living organisms. As an energy source, biomass can be used either directly through combustion to produce heat, or indirectly after the transformation into a number of biofuel types believed to be inherently environmentally friendly (Acheampong, Gyasi, Darko, Apau & Addai-Arhin, 2016). Biomass is produced every day by human economic activity in the world and it has be estimated to reach 105 petagrams carbon annually, equally apportioned in land and sea (Field, 1998). The conversion of biomass into biofuel may be accomplished using different methods, which are sorted into thermal, chemical and biochemical (Demirbas, 2009).

The biological sources used to produce biomass, hence biofuels, vary depending the region. In the USA for example the forest by-products (I.e. wood residues) are quite popular, while in the UK the animal husbandry residues (i.e. poultry litter) are quite commonly used, when at the same time agricultural waste are widespread used in Southeast Asia (I.e. sugar cane residues, rice husks) (Urban & Mitchell, 2011).

The biofuel production issue has already been addressed by academic communities and scientific journals regarding the numerous technical, economic, social and environmental issues that arise during their production and use. Some of those issues regard the direct influence on the oil prices reduction and the food market prices, the controversy between “food” and “fuel”, the potentiality regarding poverty reduction, the energy (/electricity) ratio, requirements, balance, efficiency and sustainability, the CO2 emissions, the water resourced impacts, etc. (Cotton et al., 2015).



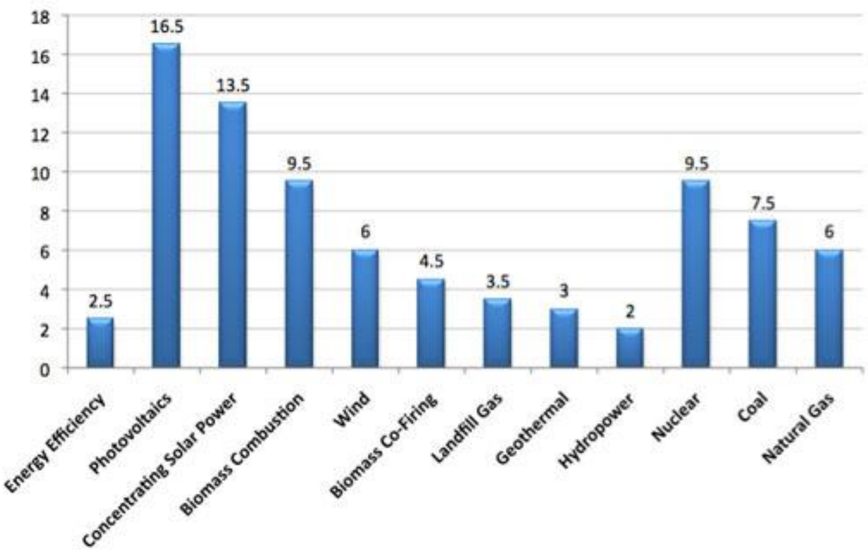
Graph 3 Power Prices: Estimated cost per barrel of fuel produced by biofuels (The Goldman Sachs Group, Inc., 2017)

The international Resource Panel (Bringezu et al., 2009) in a publucation regarding biofuels, abstracted the extended and correlative determinants needed to be considered in a decision making procedure regarding the comparative advantages of one biofuel over another, noting that different types of biofuels have different impacts on ecosystem, climate and offer different energy supply safety, thus it recommended that social and environmental impacts need to assessed during the entire life cycle.

3.5. Hydropower

Hydroelectric power is one of the oldest methods of producing power (Murthy & Hegde, 2015). Hydroelectricity is the term commonly used for large scale hydroelectric dams. Such power installations typically produce up to 100kW power. Hydropower is currently produced in 150 countries (Apergis, Chang, Gupta & Ziramba, 2016), and represents about 16% (International Energy Agency, 2016) of the total electricity production, while it is estimated that 2/3 of the economically feasible potential remain to be developed (Santos, Vieira, Tiago Filho, Barros & Souza, 2016).

Hydropower is mainly connected with the energy deriving from falling water. The operation of such hydroelectric stations is based on the water moving due to a height difference between the entry and exit point. When the water falls it moves a turbine, which turns the generator on. For that reason a water reservoir is usually constructed. The amount of energy produced by the generator is usually determined by the volume of the water falling. That kind of hydroelectric projects are classified as large scale project units with significant environmental impacts. For example, the construction of reservoirs (dams) restricts the natural fishery movement affecting the entire surrounding ecosystem, radically changing its morphology.



Graph 4 Levelized cost of electricity for various power and energy efficiency options ($/KWh) (U.S. National Hydropower Association, 2017)

Advantages of the hydropower falling water stations besides being a clean and renewable energy source, is that they can be put into operation at will, providing an energy supply safety, while through the water reservoirs certain needs can also be satisfied, such as water supply. On the other hand, the huge construction and operation costs, the lengthy construction time and the intense environmental degradation of the surrounding area are certainly considered notable disadvantages of that kind of projects (Kelly-Richards, Silber-Coats, Crootof, Tecklin & Bauer, 2017).

However, other types of hydropower are emerging the last five years; tidal power and wave power. Those technologies although not currently a widely employed alternative, has proofs of being a giant power reservoir whose potential could reach 120K TWh annual output (Clément et al., 2002), and hence should be widely be considered.

CH.4. METHODOLOGY

This research attempts to address the energy needs of Zakynthos Island using exclusively one renewable energy system. For the aim of the current research, we examine through multi-criteria decision analysis the following applicable renewable energy source alternatives; Biofuels Production Station, Geothermal Power Station, Hydroelectric Power Station, Solar Power Station and Wind Power Station.

First following the DPSIR causal framework, we develop indicators in order to describe the interaction between the three pillars of sustainability, namely environment, society and economy. In addition, we develop sub-criteria under the three pillars in the context of the scope of the current research (Figure 12).

The multi-criteria analysis follows two steps. At first, we proceed in weighting the criteria and sub-criteria using Saaty's pairwise comparison method (Saaty, 1987), within the framework of the multi-criteria decision making method of Analytical Hierarchy Process, which provides the ability to control the consistency in the determination of criterion weight (Cristobal, 2014). Then, we develop a typical linear scale (see Table 7) in order to evaluate all developed criteria and sub-criteria. The scores are then combined with the weighting of the criteria and sub-criteria to create an overall score for each given alternative.

For the scope of the current research the criteria and sub-criteria weighting using Saaty's pairwise comparison method was subject to the author's point of view. However and in order to address this multidimensional and multidisciplinary issue, for the evaluation using the developed linear scale, qualitative research survey (structured interviews) was considered the most suitable approach, as one reflecting personal experiences, perception and beliefs of the evaluators which can be regarded as experts by experience and expertise. Thus, a group of experts[1] in the relative field and a group of decision makers[2] where interviewed (N=10+1). The first group given was given full evaluation strength, while the second group, the decision makers, was given half evaluation strength, considering that political perceptions could determine their judgment. The sampling process did not aim to achieve a representative sample, but was used as a strategy in order to provide more accurate and acceptable results. This we achieved through the purposive sampling technique (Guarte and Barrios, 2006) which concerns selecting individuals taking active part in renewable energy research and implementation procedures and who are likely to contain the most information on the under study issue. The interviewees were asked to evaluate the twenty seven criteria for each of the five given alternatives.

To get the overall score for each alternative we summed up the evaluation resulting from the qualitative survey to get an individual score for each sub-criterion. We multiplied each

[1] **George Xydis**: Associate Professor, Aarhus University, School of Business and Social Sciences, Department of Business Development and Technology
Costas Velis: Lecturer, University of Leeds, School of Civil Engineering
Antonis Zorpas: Lecturer, Open University of Cyprus, Faculty of Pure and Applied Sciences, Environmental Conservation and Management
Zoi Konstantinou: Research Consultant, Aristotle University of Thessaloniki
Daniel Oto: Scientific Assistant, FernUniversitat in Hagen
Constantine Karytsas: Assistant Director, Centre for Renewable Energy Sources and Saving
Spyros Karytsas: Centre for Renewable Energy Sources and Saving, RES Division, Geothermal Energy Department

[2] **Panos Skourletis**: Member of the Hellenic Parliament and Minister of the Interior and Administrative Reconstruction of the Hellenic Republic, former Minister of Environment and Energy of the Hellenic Republic
Stavros Kontonis: Member of the Hellenic Parliament for Zakynthos and Minister of Justice, Transparency and Human Rights, former Deputy Minister for Sports.
Dionysions Gasparos: former Member of the Hellenic Parliament for Zakynthos, former prefect of Zakynthos

sub-criterion weight resulting from the pairwise comparison with the individual score for each sub-criterion separately and then added them all together.

In order to address this multi-criteria decision analysis case, we use the online tool TransparentChoise. The aforementioned online tool is a decision making set of tools based on Analytical Hierarchy Process (AHP) aiming to help decision makers to conclude to a rational and transparent choice (TransparentChoice, 2017).

Sub-criteria were developed aiming the maximum contribution of each renewable energy source in the energy mix and follow the below requirement:

- Compliance with the environmental and ecological constraints, as expressed from the Islands' characteristics.
- Compatibility with the current economic, legislative and political conditions
- Compliance with the technical and technological circumstances of the area concerned and the technical specifications of the proposed alternatives.

CH.5. RESULTS

5.1. Sustainability Indicators

Indicators are computational sets helpful for simplifying, quantifying and transmitting information (Girardin, Bockstaller & Werf, 1999). In other words, an indicators system for environment and sustainability looks forward to counterbalancing the proven perpetual need for evaluation and comparison of each alternative to the other. Thus it is a platform for recording trends concerning the environment (Loken, 2007).

Indicators present the existing status of an area by quantifying the available selected data in measurable terms. Sustainability indicators could determine the level of development of a region; the current development, the expected and their differences (Robert, Parris & Leiserowitz, 2005). Indicators are based on the relation between the environment and human, namely the economic and social development, causing Pressures, and therefore Impacts on ecosystems, natural resources (seen as raw materials) and human health, which could affect a social Response leading back to Driving Forces, or States of even back to Responces (DPSIR Model) (Tscherning, Helming, Krippner, Sieber & Paloma, 2012). The sustainability indicators which are developed for the scope of the current research are a set of two factors for each one of the three pillars and are presented in Table 6.

Table 6 Environmental Sustainability Indicators

		Biofuels Production Station	Geothermal Power Station	Hydroelectric Power Station	Solar Power Station	Wind Power Station
	Indicator					
Environment	Greenhouse Gas Emissions	80[2]	170[4]	41[4]	90[4]	25[4]
Economy	Cost	[1]0.14	[4]0.07	[4]0.05	[4]0.24	[4]0.07
Society	Social Impact & Acceptance	[3]Odors: Minor [3]Employment: Major	[4]Seismic Activity: Minor [4]Odors: Minor [4]Pollution: Major [3]Employment: Major [3]Noise: Minor	[4]Displacement: Major [3]Local Economic Development: Major [3]Noise: Minor	[4]Toxins: Major [4]Visual: Major	[4]Noise: Major [4]Bird Strike: Minor [4]Visual: Minor [3]Employment: Minor

1. [USD/kW-hr] (EIA, 2017)
2. [million tons CO2-equevalant] (German Environment Agency, 2014)
3. (Vezmar, Spajić, Topić, Šljivac & Jozsa, 2014)
4. [g CO2-e/Kw-h] [USD/Kw-h] (Evans, Strezov & Evans, 2009)
5. (Majer et al., 2007)

5.2. Multi-Criteria Analysis

The number of alternatives or possible solutions requires the application of a decision support method (Niemeijer, 2002). Data on economic variables, energy efficiency or environmental impact are currently affected by uncertainty (Howlett & Cuenca, 2016). Hence the importance of multi-criteria analysis arises, to address this high level of complexity and uncertainty (Keseru, Bulckaen & Macharis, 2016), given that, multi-criteria analysis can handle numerous data, variables and alternatives. Thus a valuable assistance in decision making is offered, for each case study, following the evaluation and even the under-evaluation of each criterion, sub criterion and/or indicator separately (Triantaphyllou, 2000). Of course, this method does not replace the decision makers (actors), but rather supports them in all procedure stages, providing useful information (Figueira, Greco & Ehrogott, 2005).

5.2.1. Criteria and sub-criteria determination

The identification and selection of criteria and sub-criteria, aimed to include all possible parameters set for studying the potential alternatives, in an attempt to build a representative structure of specific characteristics and to avoid duplicates and overlaps. Thus, twenty seven total sub-criteria have been developed, which are respectively classified into three criteria groups, in line with the scope of the current research, nine addressing the environmental pillar, eight the economy pillar and ten the society.

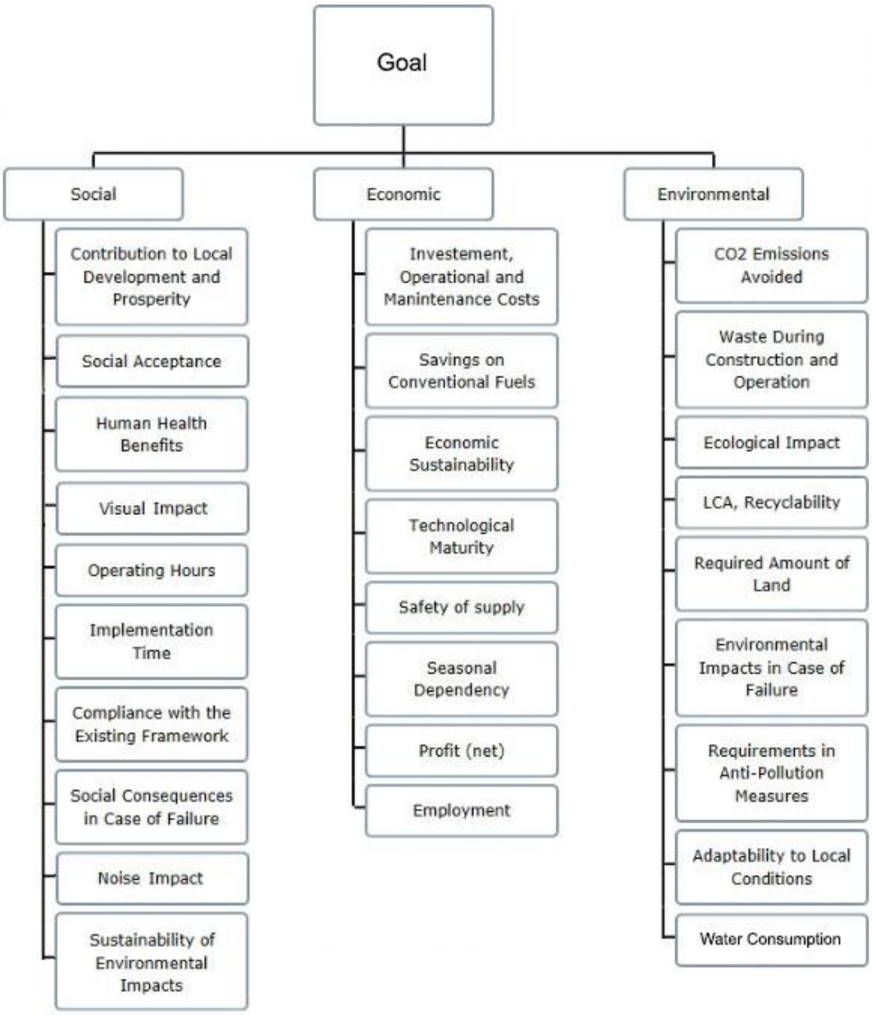


Figure 12 Goal flow chart including criteria and sub-criteria

Criteria:

- Environmental Criterion
  - CO2 emissions avoided

    Renewable energy system exploitation is an essential mean of mitigation of CO_2 emissions. This constitutes several criteria for the reduction of CO_2 emissions because they have a direct impact on human life and an indirect impact on society (tCO_2/y).
  - Waste production during construction and operation

    Construction and operational waste are of the heaviest and most voluminous waste streams generated. Consist of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled (w/y).
  - Ecological impact

    Effects on the living organisms and their non-living (abiotic) environment due to human activity or natural phenomenon.
  - LCA, Recyclability

    Includes upstream (i.e., manufacture, construction, mining), O&M, and downstream (i.e., decommission/disposal) emissions of CO_2, CH_4, N_2O.
  - Required amount of land

    On-site direct operational: land occupied by power plant during operation (include life cycle land use as upper bound). Also, renewable energy production systems require a larger use of land compared to conventional sources. This fact is capable of prompting negative public reactions.
  - Environmental impacts in case of failure

    Continuous changes in technology, environmental regulation, and public safety concerns make the analysis of the safety of energy systems more and more demanding. Reliability of energy systems is the capacity of a device or system to perform as designed and its resistance to failure.
  - Requirements in Anti-Pollution Measures

    Pollution is an example of a negative externality – a cost imposed on a third party. Therefore anti-pollution measures are implemented which can include infrastructure regulations, taxes, pollution permits, etc.

- Adaptability to local conditions

  The need for adaptability in energy emergencies has implications for energy policy during nonemergency times. For example, the ability of an energy system to adapt to acute shortage depends in part on its ability to curtail demand quickly, which, in turn, depends on the pre-existing pattern of local energy use.

- Water Consumption

  The water footprint of the energy mix is significantly important and can have implications for energy policy development.

- Economic Criterion
  - Investment, operational and maintenance costs

    Ratio of sum of the amortized overnight capital costs & O&M costs to annual electricity generation; assumes constant financing cost and project lifetime.

  - Savings in conventional fuels

    This criterion refers to the total quantity of conventional fuels which is replaced by power generation from renewable energy systems.

  - Economic sustainability

    Renewable energy is not just about saving the environment any more. It is now also about stimulating the economy, generating new sources of growth, increasing income and improving trade balances.

  - Technological maturity

    This criterion refers to the reliability degree of the adopted technology and its spread at national and European level.

  - Safety of supply

    This criterion reflects whether the energy supply faces any interruptions. The presence of such interruptions affects the stability of the electricity network.

  - Seasonal dependency

    The renewable power generation aggregated across Europe exhibits strong seasonal behaviors that need to be calculated of counterbalanced.

  - Profit (net)

    Net profit as a measure of the profitability of the venture after accounting all costs.

  - Employment

    Direct, indirect and induced full-time equivalent (FTE) employment during construction and operation stages.

- Social Criterion
  - Contribution to local development and prosperity

    This criterion estimates the total social and economic impact that may become perceptible in the regions that house the sustainable energy systems. Likely results are: new chains of enterprises for energy supply, emerging enterprises in the energy sector, new industrial regions, etc.
  - Social acceptance

    The opinions related to the energy systems of the local population regarding the hypothesized realization of the projects under review. It is extremely important since the opinions of the population and pressure groups may heavily influence the amount of time needed to complete an energy project.
  - Human health benefits

    Renewable electricity projects and energy efficiency measures could have health benefits worth millions of dollars a year. However, the value of such projects varies greatly depending on the type of project.
  - Visual impact

    The installation and operation of renewable energy systems is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc) thus the existed concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology.
  - Operating hours

    To meet its electricity requirements, a renewable energy unit can operate endlessly or not. The operating time is determined for a society since many social and economic factors are at stake.
  - Implementation time

    The time required to complete the installation of a renewable energy unit plays an important role in a local community, and when combined with economic and environmental factors can be deterring factor for the whole project.
  - Compliance with the existing framework

    Those multidisciplinary solutions, being new to humanity, are under hundreds of regulations and frameworks around the world and even more at local sites.

Compliance issues should be taken seriously, investigate each one, and revisit all operational controls, costs, impacts, etc.

- Social consequences in case of failure

  Deaths from accidents involved in power plant manufacture, construction, operation; fuel extraction, processing, storage, transportation; waste treatment, disposal, etc.

- Noise impact

  The installation and operation of renewable energy systemss is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc) thus the existed concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology.

- Sustainability of environmental impacts

  All energy sources have some impact on our environment. Fossil fuels do substantially more harm than renewable energy sources, however, is still important, to understand the environmental impacts associated with producing power from renewable sources. The exact type and intensity of environmental impacts vary depending on the specific technology used.

5.2.2. Criteria and sub-criteria significance scale

In line with the methodology followed for the scope of the current research and in accordance with the multi-criteria decision analysis steps, in order to compare the alternatives, it is necessary to assess and evaluate the weight of each criterion and sub-criterion with regard to the characteristics and the degree of influence it holds in this case. For that reason, a typical linear weight evaluation scale is developed and used (Table 7).

Table 7 Criterion Weight Evaluation Scale

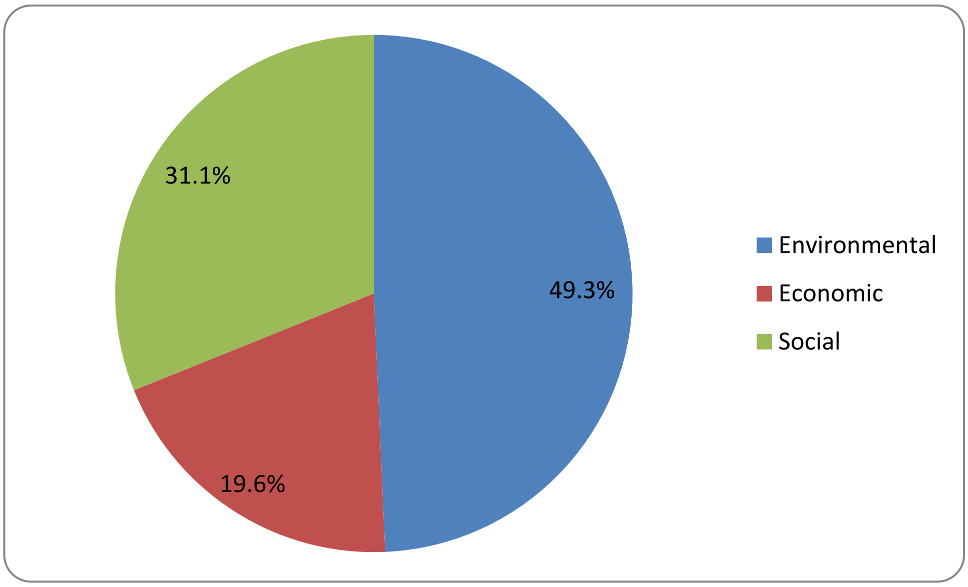
1	None
2	Weak
3	Moderate
4	Strong
5	Very Strong
6	Extreme

5.2.3. Criteria and sub-criteria evaluation results

5.2.3.1. Evaluation in context of: Alternatives

Table 8 Primary criteria pairwise comparison in context of “Goal”

Economic vs Environmental	1:2
Economic vs Social	1:2
Environmental vs Social	2:1



Graph 5 Pairwise comparison primary criteria evaluation

Table 9 Primary criteria weight evaluation in context of “Goal”

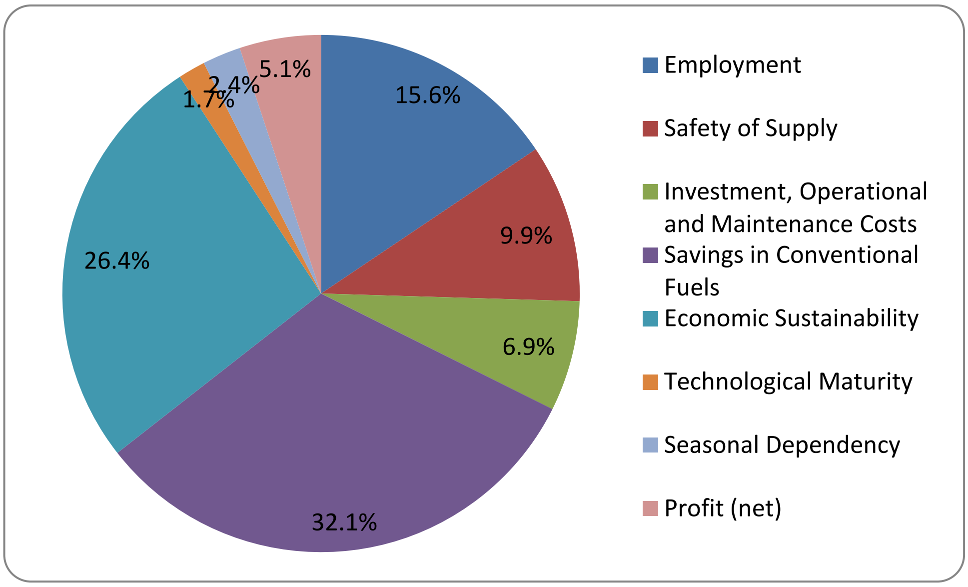
Criterion	Weight [%]
Environmental	49.3
Economic	19.6
Social	31.1

5.2.3.2. Evaluation in context of: Economic

Table 10 Sub-criteria pairwise comparison in context of economic criterion

Economic Sustainability vs Employment	2:1
Economic Sustainability vs Investment, Operational and Maintenance Costs	2:1
Economic Sustainability vs Profit (net)	6:1
Economic Sustainability vs Safety of Supply	4:1
Economic Sustainability vs Savings in Conventional Fuels	2:1
Economic Sustainability vs Seasonal Dependency	7:1
Economic Sustainability vs Technological Maturity	8:1
Employment vs Investment, Operational and Maintenance Costs	4:1
Employment vs Profit (net)	4:1

Employment vs Safety of Supply	3:1
Employment vs Savings in Conventional Fuels	1:4
Employment vs Seasonal Dependency	4:1
Employment vs Technological Maturity	9:1
Investment, Operational and Maintenance Costs vs Profit (net)	2:1
Investment, Operational and Maintenance Costs vs Safety of Supply	1:2
Investment, Operational and Maintenance Costs vs Savings in Conventional Fuels	1:7
Investment, Operational and Maintenance Costs vs Seasonal Dependency	4:1
Investment, Operational and Maintenance Costs vs Technological Maturity	5:1
Profit (net) vs Safety of Supply	1:4
Profit (net) vs Savings in Conventional Fuels	1:5
Profit (net) vs Seasonal Dependency	4:1
Profit (net) vs Technological Maturity	6:1
Safety of Supply vs Savings in Conventional Fuels	1:7
Safety of Supply vs Seasonal Dependency	6:1
Safety of Supply vs Technological Maturity	8:1
Savings in Conventional Fuels vs Seasonal Dependency	9:1
Savings in Conventional Fuels vs Technological Maturity	9:1
Seasonal Dependency vs Technological Maturity	2:1



Graph 6 Sub-criteria pairwise comparison evaluation in the context of economic criterion

Table 11 Sub-criteria weight evaluation in the context of economic criterion

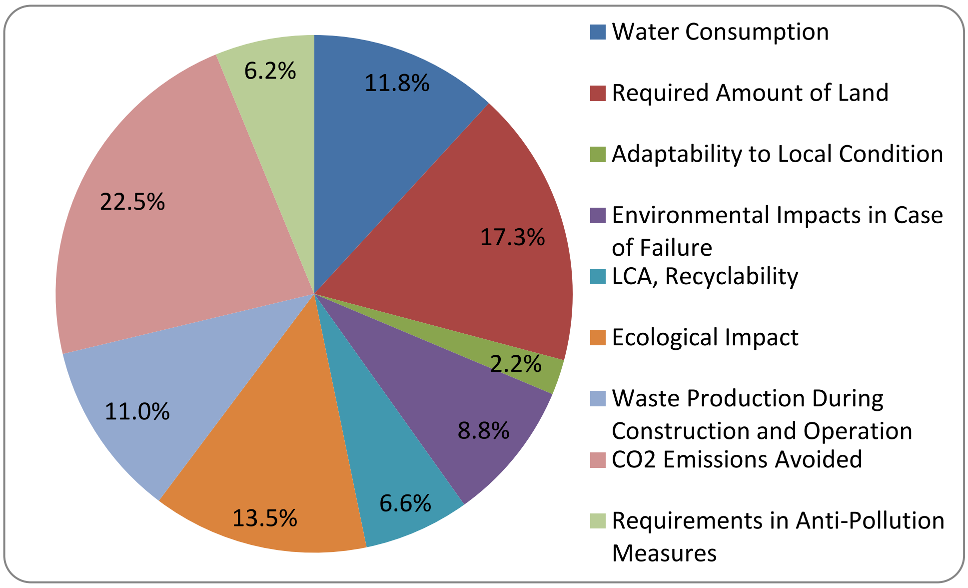
Sub-criterion	Weight [%]
Investment, Operational & Maintenance Costs	6.9
Savings in Conventional Fuels	32.1
Economic Sustainability	26.4
Technological Maturity	1.7
Safety of Supply	9.9
Seasonal Dependency	2.4
Profit (net)	5.1

Employment	15.6

5.2.3.3. Evaluation in context of: Environmental

Table 12 Sub-criteria pairwise comparison in context of environmental criterion

Adaptability to Local Conditions vs CO_2 Emissions Avoided	1:5
Adaptability to Local Condition vs Ecological Impact	1:3
Adaptability to Local Condition vs Environmental Impacts in Case of Failure	1:5
Adaptability to Local Condition vs LCA, Recyclability	1:3
Adaptability to Local Condition vs Required Amount of Land	1:9
Adaptability to Local Condition vs Requirements in Anti-Pollution Measures	1:5
Adaptability to Local Condition vs Waste Production During Construction & Operation	1:7
Adaptability to Local Condition vs Water Consumption	1:9
CO_2 Emissions Avoided vs Ecological Impact	2:1
CO_2 Emissions Avoided vs Environmental Impacts in Case of Failure	2:1
CO_2 Emissions Avoided vs LCA, Recyclability	4:1
CO_2 Emissions Avoided vs Required Amount of Land	2:1
CO_2 Emissions Avoided vs Requirements in Anti-Pollution Measures	3:1
CO_2 Emissions Avoided vs Waste Production During Construction and Operation	3:1
CO_2 Emissions Avoided vs Water Consumption	2:1
Ecological Impact vs Environmental Impacts in Case of Failure	2:1
Ecological Impact vs LCA, Recyclability	2:1
Ecological Impact vs Required Amount of Land	1:2
Ecological Impact vs Requirements in Anti-Pollution Measures	2:1
Ecological Impact vs Waste Production During Construction and Operation	2:1
Ecological Impact vs Water Consumption	2:1
Environmental Impacts in Case of Failure vs LCA, Recyclability	2:1
Environmental Impacts in Case of Failure vs Required Amount of Land	1:2
Environmental Impacts in Case of Failure vs Requirements in Anti-Pollution Measures	2:1
Environmental Impacts in Case of Failure vs Waste Production During Construction & Operation	1:2
Environmental Impacts in Case of Failure vs Water Consumption	1:2
LCA, Recyclability vs Required Amount of Land	1:2
LCA, Recyclability vs Requirements in Anti-Pollution Measures	2:1
LCA, Recyclability vs Waste Production During Construction and Operation	1:2
LCA, Recyclability vs Water Consumption	1:2
Required Amount of Land vs Requirements in Anti-Pollution Measures	2:1
Required Amount of Land vs Waste Production During Construction and Operation	2:1
Required Amount of Land vs Water Consumption	2:1
Requirements in Anti-Pollution Measures vs Waste Production During Construction & Operation	1:2
Requirements in Anti-Pollution Measures vs Water Consumption	1:2
Waste Production During Construction and Operation vs Water Consumption	1:1



Graph 7 Sub-criteria pairwise comparison evaluation in the context of environmental criterion

Table 13 Sub-criteria weight evaluation in the context of environmental criterion

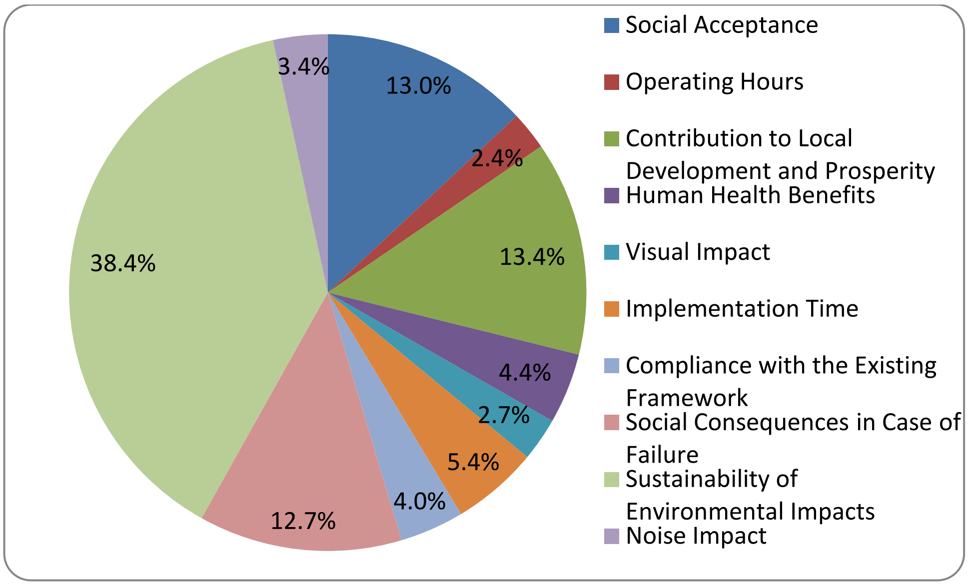
Sub-criterion	Weight [%]
CO_2 Emissions Avoided	22.5
Waste Production During Construction & Operation	11.0
Ecological Impact	13.5
LCA, Recyclability	6.6
Required Amount of Land	17.3
Environmental Impacts in Case of Failure	8.8
Requirements in Anti-Pollution Measures	6.2
Adaptability to Local Condition	2.2
Water Consumption	11.8

5.2.3.4. Evaluation in context of: Social

Table 14 Sub-criteria pairwise comparison in context of social criterion

Compliance with the existing framework vs Contribution to local development & prosperity	1:7
Compliance with the existing framework vs Human health benefits	2:1
Compliance with the existing framework vs Implementation time	1:3
Compliance with the existing framework vs Noise impact	2:1
Compliance with the existing framework vs Operating hours	2:1
Compliance with the existing framework vs Social acceptance	1:3
Compliance with the existing framework vs Social consequences in case of failure	1:5
Compliance with the existing framework vs Sustainability of Environmental impacts	1:9
Compliance with the existing framework vs Visual impact	2:1
Contribution to local development & prosperity vs Human health benefits	2:1
Contribution to local development & prosperity vs Implementation time	2:1
Contribution to local development & prosperity vs Noise impact	2:1
Contribution to local development & prosperity vs Operating hours	3:1
Contribution to local development & prosperity vs Social acceptance	2:1

Contribution to local development & prosperity vs Social consequences in case of failure	2:1
Contribution to local development & prosperity vs Sustainability of Environmental impacts	1:2
Contribution to local development & prosperity vs Visual impact	2:1
Human health benefits vs Implementation time	1:2
Human health benefits vs Noise impact	2:1
Human health benefits vs Operating hours	2:1
Human health benefits vs Social acceptance	1:2
Human health benefits vs Social consequences in case of failure	1:3
Human health benefits vs Sustainability of Environmental impacts	1:6
Human health benefits vs Visual impact	2:1
Implementation time vs Noise impact	2:1
Implementation time vs Operating hours	3:1
Implementation time vs Social acceptance	1:5
Implementation time vs Social consequences in case of failure	1:7
Implementation time vs sustainability of Environmental impacts	1:9
Implementation time vs Visual impact	2:1
Noise impact vs Operating hours	2:1
Noise impact vs Social acceptance	1:3
Noise impact vs Social consequences in case of failure	1:5
Noise impact vs Sustainability of Environmental impacts	1:9
Noise impact vs Visual impact	2:1
Operating hours vs Social acceptance	1:9
Operating hours vs Social consequences in case of failure	1:7
Operating hours vs Sustainability of environmental impacts	1:9
Operating hours vs Visual impact	2:1
Social acceptance vs Social consequences in case of failure	2:1
Social acceptance vs Sustainability of environmental impacts	1:5
Social acceptance vs Visual impact	5:1
Social consequences in case of failure vs Sustainability of environmental impacts	1:9
Social consequences in case of failure vs Visual impact	3:1
Sustainability of environmental impacts vs Visual impact	9:1



Graph 8 Sub-criteria pairwise comparison evaluation in the context of social criterion

Table 15 Sub-criteria weight evaluation in the context of social criterion

Sub-criterion	Weight [%]
Contribution to Local Development & Prosperity	13.4
Social Acceptance	13.0
Human Health Benefits	4.4
Visual Impact	2.7
Operating Hours	2.4
Implementation Time	5.4
Compliance with the Existing Framework	4.0
Social Consequences in Case of Failure	12.7
Noise Impact	3.4
Sustainability of Environmental Impacts	38.4

Thus, the most contributing indicators, resulting from the pairwise comparison, are the “Sustainability of environmental impacts” with 11.9% global weight[3] significance followed by “CO_2 emissions avoided” with 11.1% weight significance. “Required amount of land” comes third with 8.5% weight significance while fourth is the “Savings in conventional fuels” with 6.3% weight significance.

5.2.4. Qualitative Survey Results

Table 16 Environmental sub-criteria evaluation survey results

Environmental Criterion	B	G	H	S	W
CO_2 Emissions Avoided	3.74	4.42	4.32	4.84↑	4.63
Waste Production During Construction & Operation	3.37	3.47	3.32	4.16↑	3.11
Ecological Impact	3.53↑	3.42	2.95	3.47	3.47
LCA, Recyclability	4.11↑	3.26	3.16	3.63	3.53
Required Amount of Land	3.42	3.58	3.58	3.68↑	3.68
Environmental Impacts in Case of Failure	4	3.37	4.11	4.84↑	3.53
Requirements in Anti-Pollution Measures	3.47	3.11	3.79	4.47↑	3.58
Adaptability to Local Condition	3.95↑	3.79	3.84	3.47	3.53
Water Consumption	3.63	3.89	4.79↑	4.95	3.84

Table 17 Economic sub-criteria evaluation survey results

Economic Criterion	B	G	H	S	W
Investment, Operational & Maintenance Costs	3.26	3.16	3.47	4.11↑	3.79
Savings in Conventional Fuels	3.84	4.53	4.42	4.53↑	4.53

[3] Global Weight: the contribution that each criterion makes to the overall score, not the weight of each criterion within its own category in the hierarchy. It is calculated as the product of weight up the hierarchy. For example the criterion “Sustainability of environmental impacts” is calculated as: 38.4% (S-Cr local weight - See Table 15) x 31.1% (the local weight of the parent of the sub-criterion, social criterion - see Table 9) = 11.9%.

Economic Sustainability	3.79	3.79	3.53	4.05↑	4
Technological Maturity	4.11	4.37	4.79↑	4.37	4.68
Safety of Supply	3.53	4.42	4.47↑	3.89	3.63
Seasonal Dependency	3.47	2.95	3.26	4.16	4.26↑
Profit (net)	3.42	3.53	3.84	3.79	3.89↑
Employment	4↑	3.74	3.26	3.16	3.05

Table 18 Social sub-criteria evaluation survey results

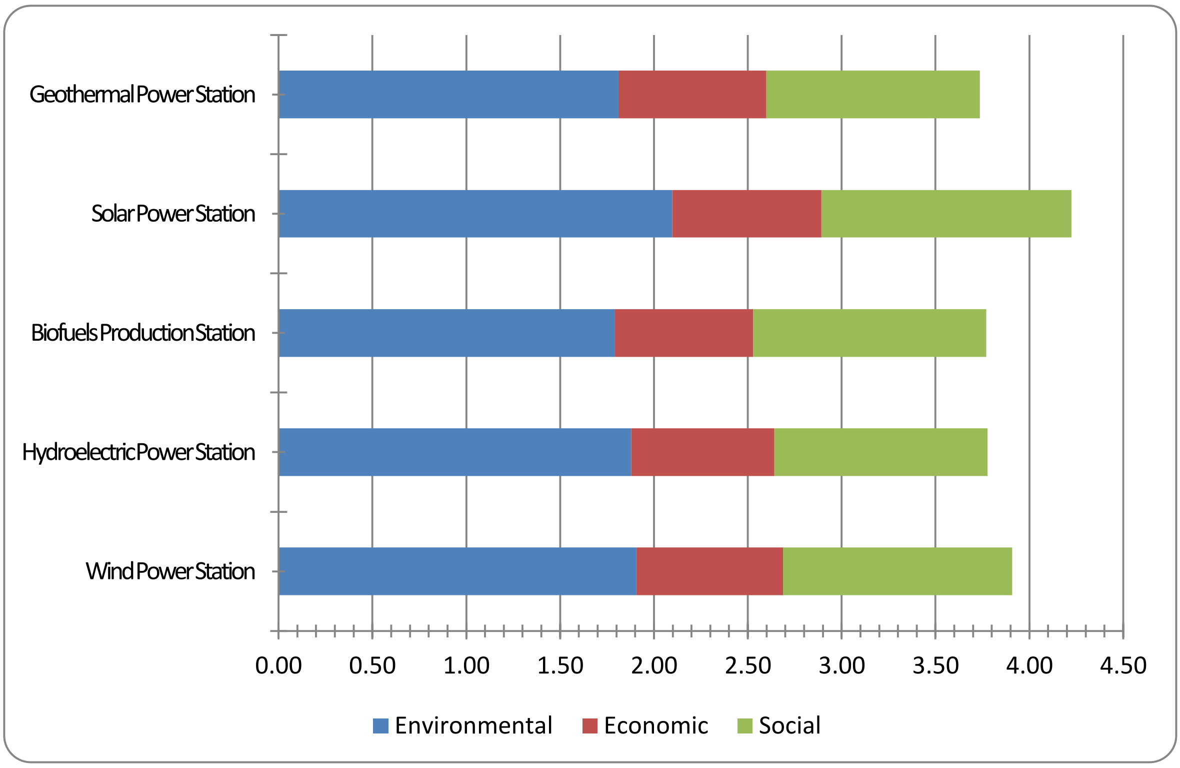
Social Criterion	B	G	H	S	W
Contribution to Local Development & Prosperity	3.79	3.63	3.84	3.84	4.05↑
Social Acceptance	3.74	3.21	3.58	4↑	3.68
Human Health Benefits	3.95	4.05	3.74	4.21↑	3.89
Visual Impact	4↑	3.32	3.95	3.68	3.89
Operating Hours	3.32	3.63	3.63	4.05↑	3.63
Implementation Time	3.63	3.37	3.63	3.84↑	3.58
Compliance with the Existing Framework	4.42	4.42	4.16	4.89↑	4.63
Social Consequences in Case of Failure	3.95	3.63	3.74	4.26↑	3.74
Noise Impact	3.63	3.58	3.47	5.26↑	3.79
Sustainability of Environmental Impacts	4.26↑	3.79	3.53	4.11	4.05

5.3. Alternatives ranking

Table 19 Alternatives final ranking

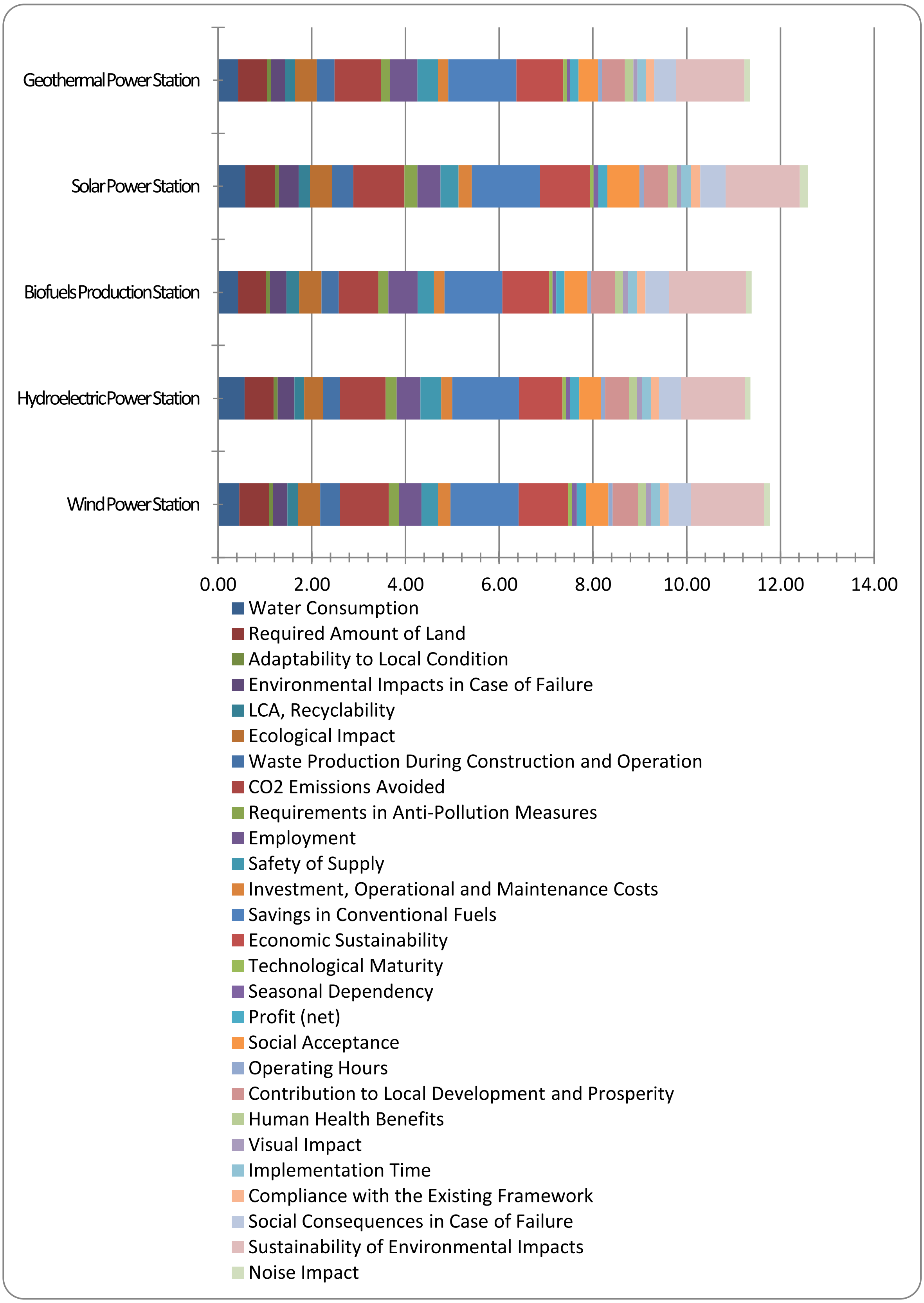
Alternatives	Environmental	Economic	Social	Total
Wind Power Station	1.91	0.78	1.22	3.91
Hydroelectric Power Station	1.88	0.76	1.14	3.78
Biofuels Production Station	1.79	0.74	1.24	3.77
Solar Power Station	2.10	0.79	1.33	4.22↑
Geothermal Power Station	1.81	0.79	1.14	3.74

the final ranking of the alternatives is given in the form of a bar chart (Graph 9) following Table 19, which lists the renewable energy alternatives under evaluation (axis-y) in conjunction with the overall alternative utility of each renewable energy scenario (axis-x). Total utility represents the total score that occupies each alternative with respect to criteria and sub-criteria satisfaction. The alternative with the highest total utility is considered the optimal one.



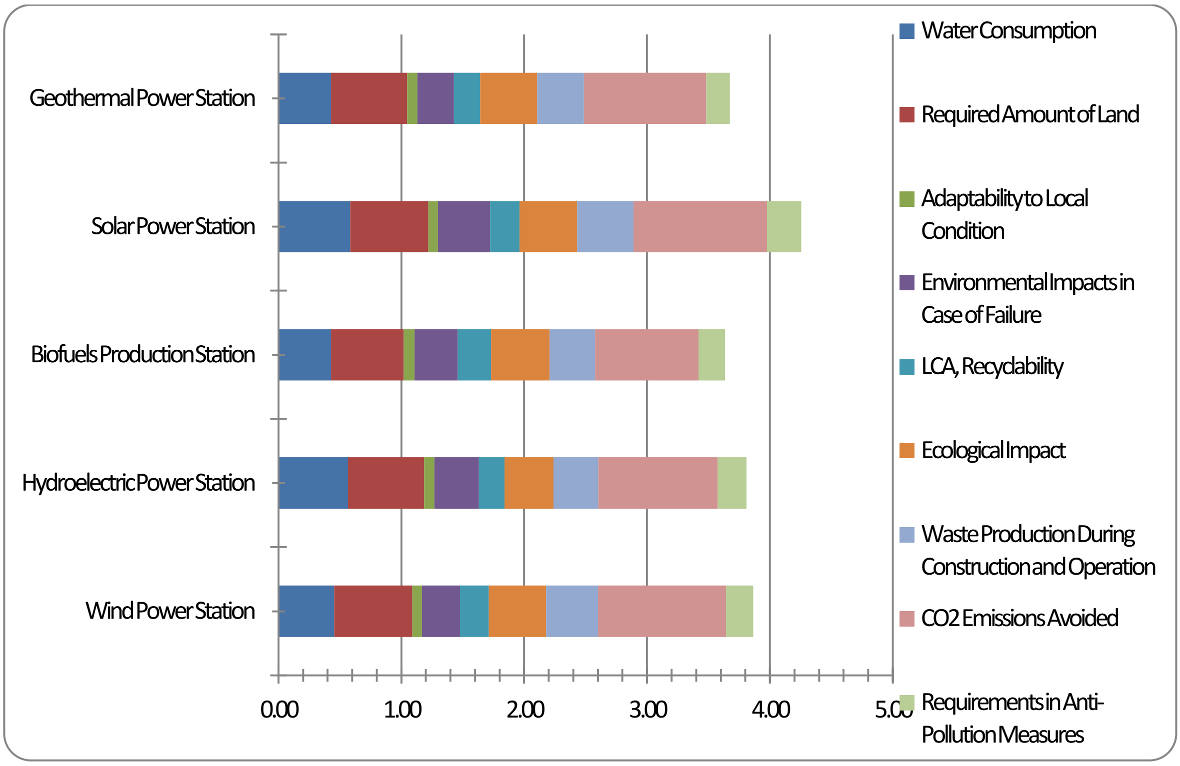
Graph 9 Alternatives Final Ranking

From the final ranking of the alternatives, we observe as mentioned a slight predominance and certain variations contrary to the final outcome, especially in Graph 10 were all criteria and sub-criteria are bottom-up displayed, thus a more detailed breakdown in each sustainability criterion and sub-criteria is necessary.



Graph 10 Alternatives final ranking (Bottom-Up Display)

5.3.1. Ranking in context of: environmental criterion

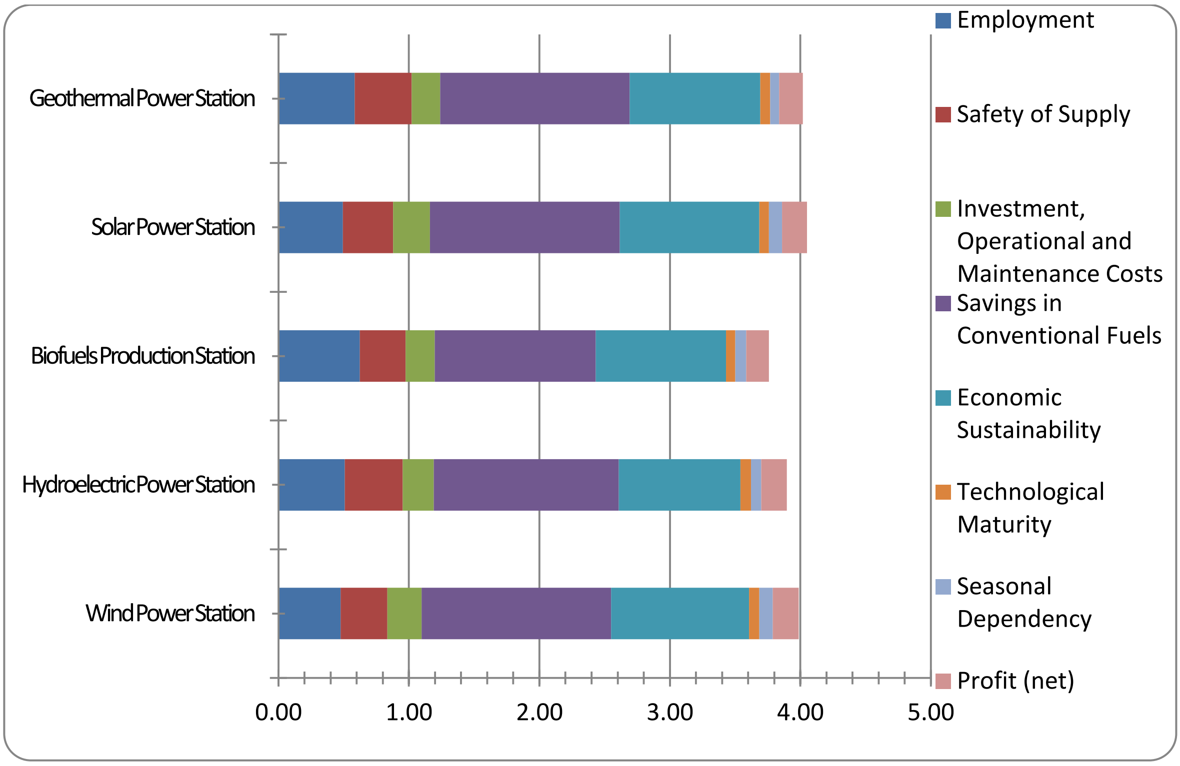


Graph 11 Final ranking of the renewable energy alternatives under the sub-criteria of the environmental criterion

Table 20 Alternatives final ranking in context of: environmental criterion

Environmental Criterion	B	G	H	S	W
CO_2 Emissions Avoided	0.84	0.99	0.97	1.09	1.04
Waste Production During Construction & Operation	0.37	0.38	0.37	0.46	0.42
Ecological Impact	0.48	0.46	0.40	0.47	0.47
LCA, Recyclability	0.27	0.22	0.21	0.24	0.23
Required Amount of Land	0.59	0.62	0.62	0.64	0.64
Environmental Impacts in Case of Failure	0.35	0.30	0.36	0.43	0.31
Requirements in Anti-Pollution Measures	0.22	0.19	0.23	0.28	0.22
Adaptability to Local Condition	0.09	0.08	0.08	0.08	0.08
Water Consumption	0.43	0.43	0.57	0.58	0.45
Total	3.63	3.67	3.81	4.25 ↑	3.87

5.3.2. Ranking in context of: economic criterion

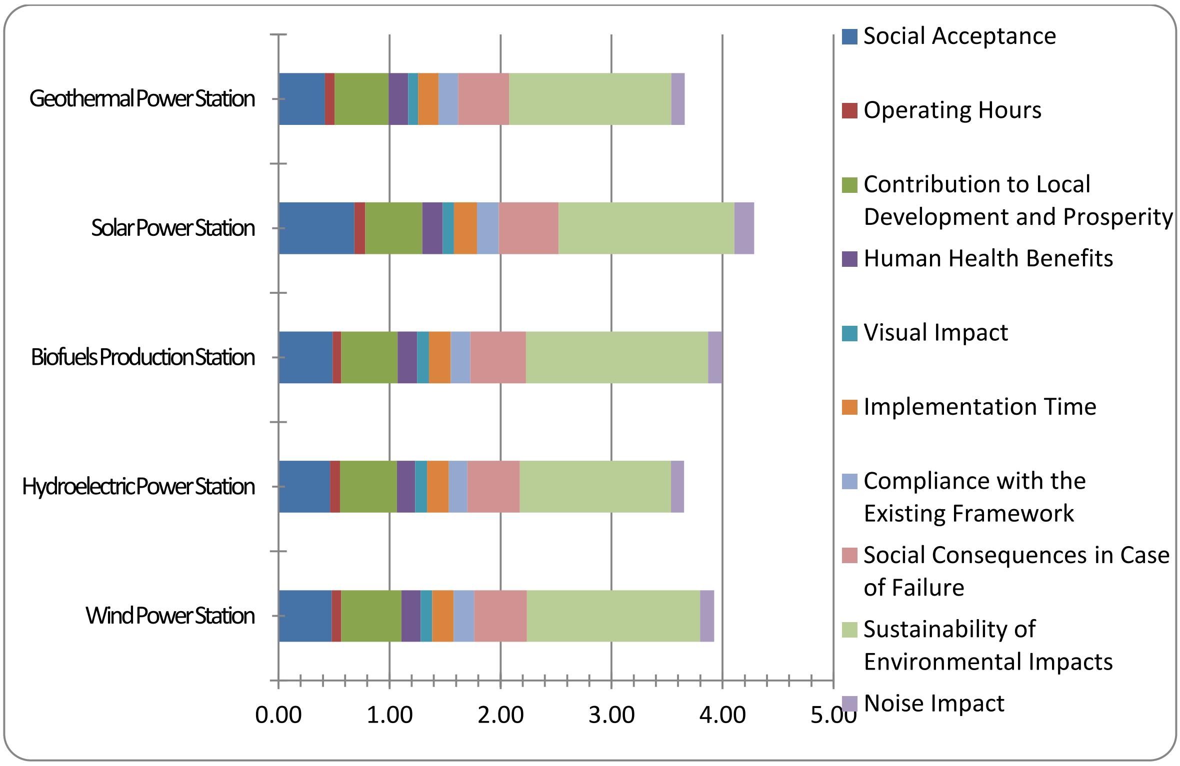


Graph 12 Final ranking of the renewable energy alternatives under the sub-criteria of the economic criterion

Table 21 Alternatives final ranking in context of: economic criterion

Economic Criterion	B	G	H	S	W
Investment, Operational & Maintenance Costs	0.22	0.22	0.24	0.28	0.26
Savings in Conventional Fuels	1.23	1.45	1.42	1.45	1.45
Economic Sustainability	1.00	1.00	0.93	1.07	1.06
Technological Maturity	0.07	0.07	0.08	0.07	0.08
Safety of Supply	0.35	0.44	0.44	0.39	0.36
Seasonal Dependency	0.08	0.07	0.08	0.10	0.10
Profit (net)	0.17	0.18	0.20	0.19	0.20
Employment	0.62	0.58	0.51	0.49	0.48
Total	3.76	4.02	3.90	4.05 ▲	3.99

5.3.3. Ranking in context of: social criterion



Graph 13 Final ranking of the renewable energy alternatives under the sub-criteria of the social criterion

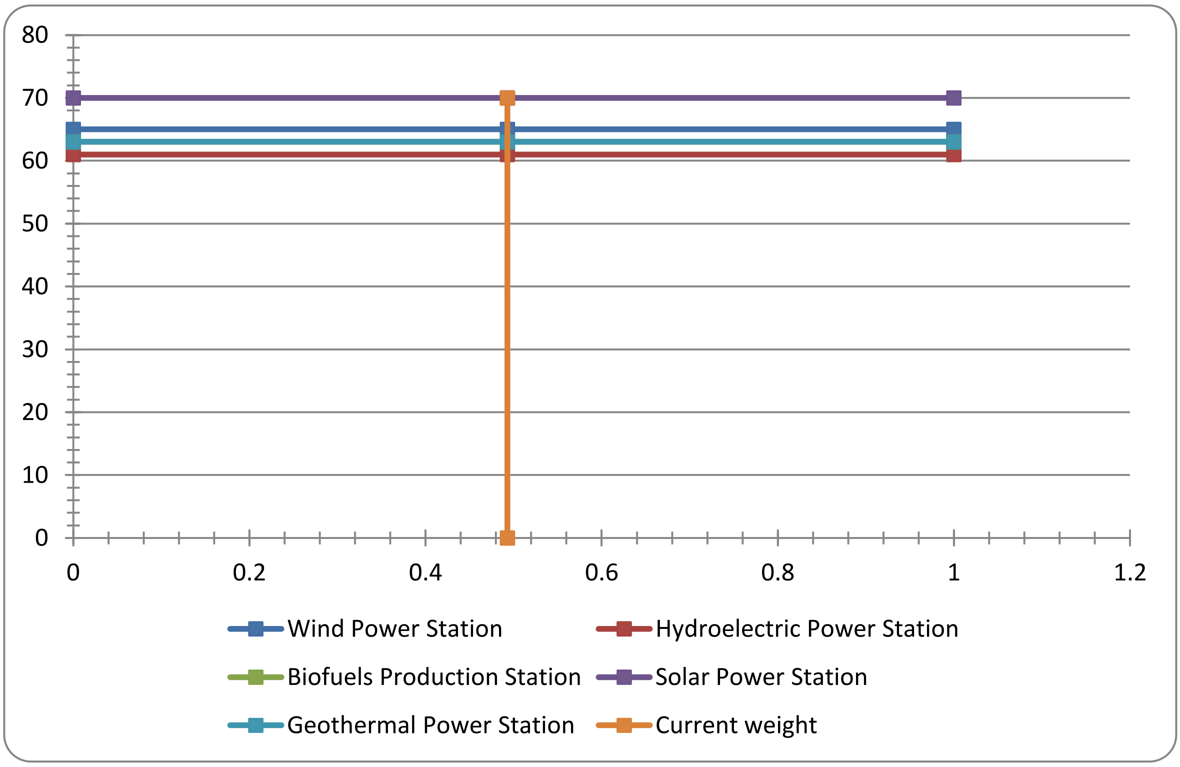
Table 22 Alternatives final ranking in context of: social criterion

Social Criterion	B	G	H	S	W
Contribution to Local Development & Prosperity	0.51	0.49	0.51	0.51	0.54
Social Acceptance	0.49	0.42	0.47	0.68	0.48
Human Health Benefits	0.17	0.18	0.16	0.19	0.17
Visual Impact	0.11	0.09	0.11	0.10	0.11
Operating Hours	0.08	0.09	0.09	0.10	0.09
Implementation Time	0.20	0.18	0.20	0.21	0.19
Compliance with the Existing Framework	0.18	0.18	0.17	0.20	0.18
Social Consequences in Case of Failure	0.50	0.46	0.47	0.54	0.47
Noise Impact	0.12	0.12	0.12	0.18	0.13
Sustainability of Environmental Impacts	1.64	1.46	1.36	1.58	1.56
Total	3.99	3.66	3.65	4.29 ↑	3.93

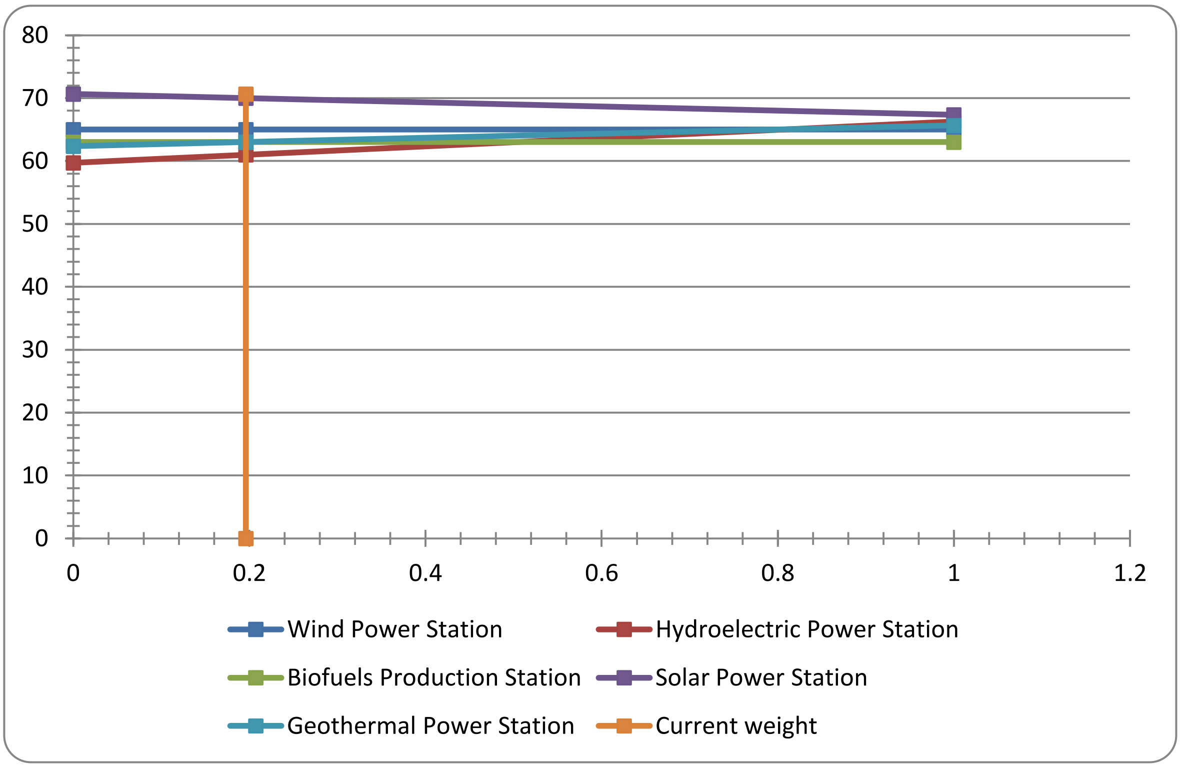
5.4. Sensitivity analysis

Sensitivity analysis gives insight into how robust the result is to changes in criteria weighting. Each horizontal line shows how the score for each alternative varies as weighting of the criterion changes. The vertical line shows the current weighting of the criterion. Crossing lines show where the "best" alternative changes.

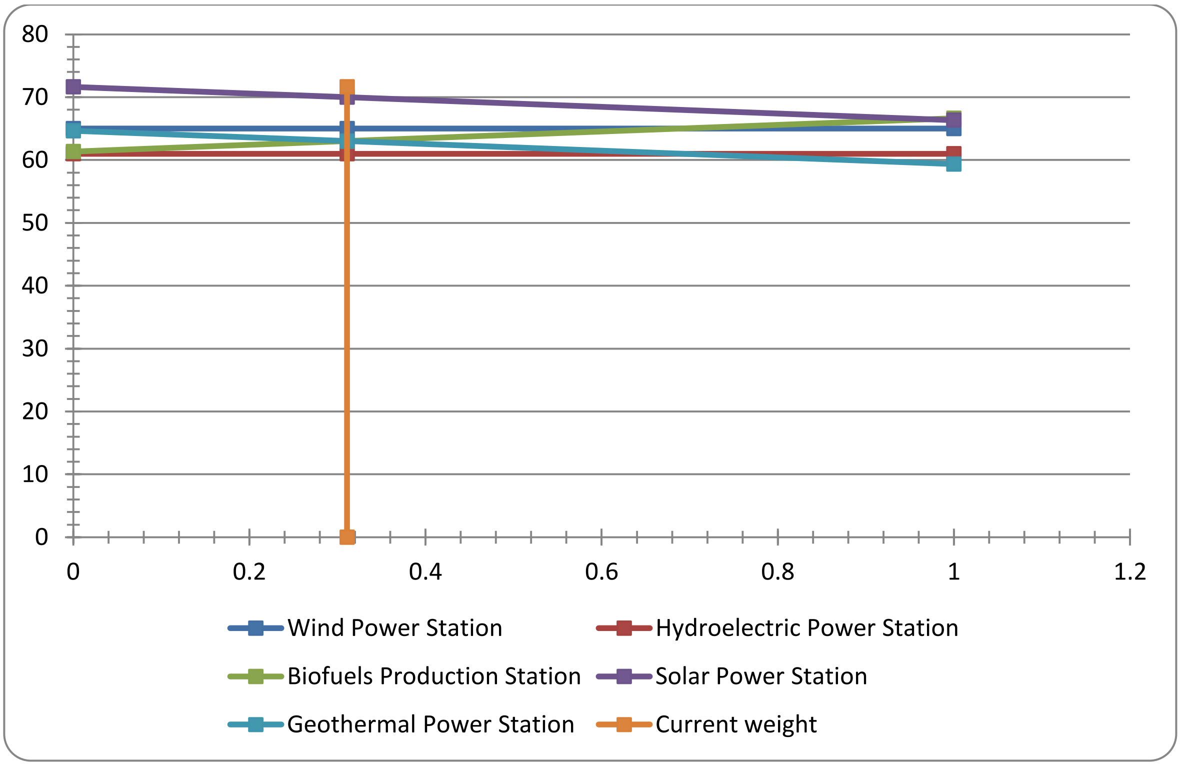
Although sensitivity analysis is not recommended in the upper criteria of the hierarchy we attempt a presentation as follows in Graphs 14-16.



Graph 14 Sensitivity analysis in the context of: environmental criterion (normalized alternative score values)

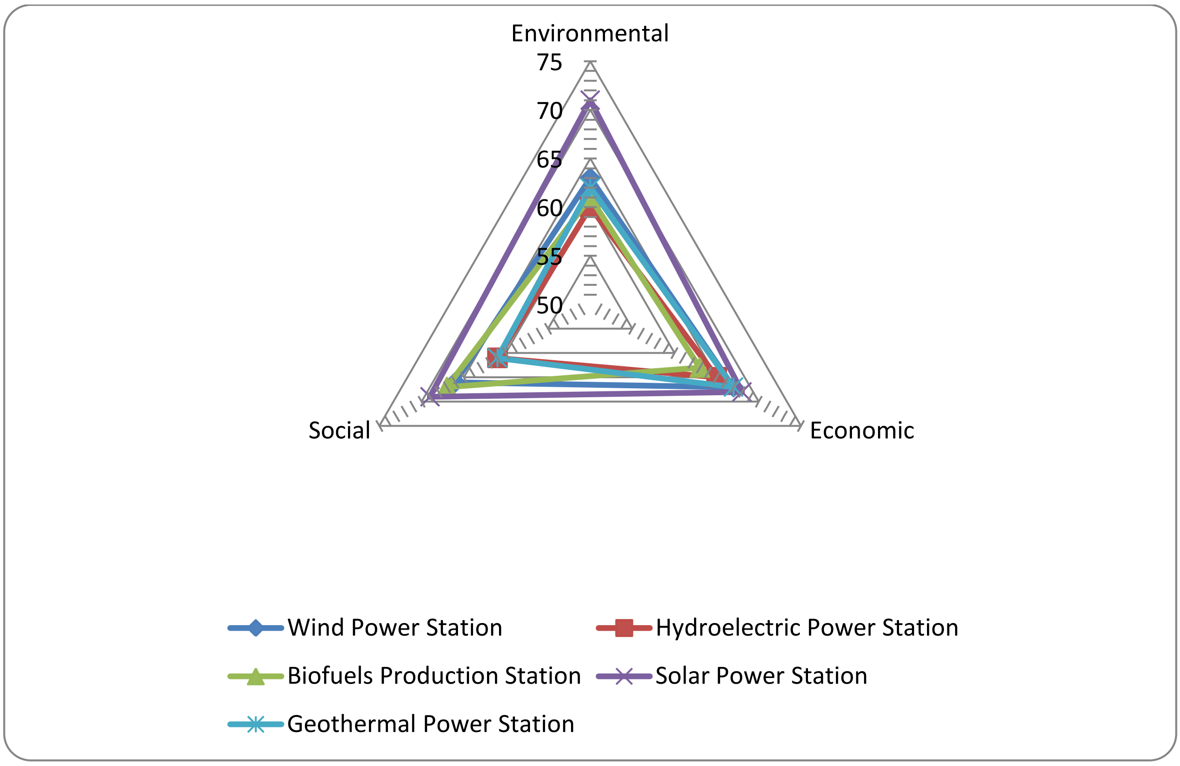


Graph 15 Sensitivity analysis in the context of: economic criterion (normalized alternative score values)

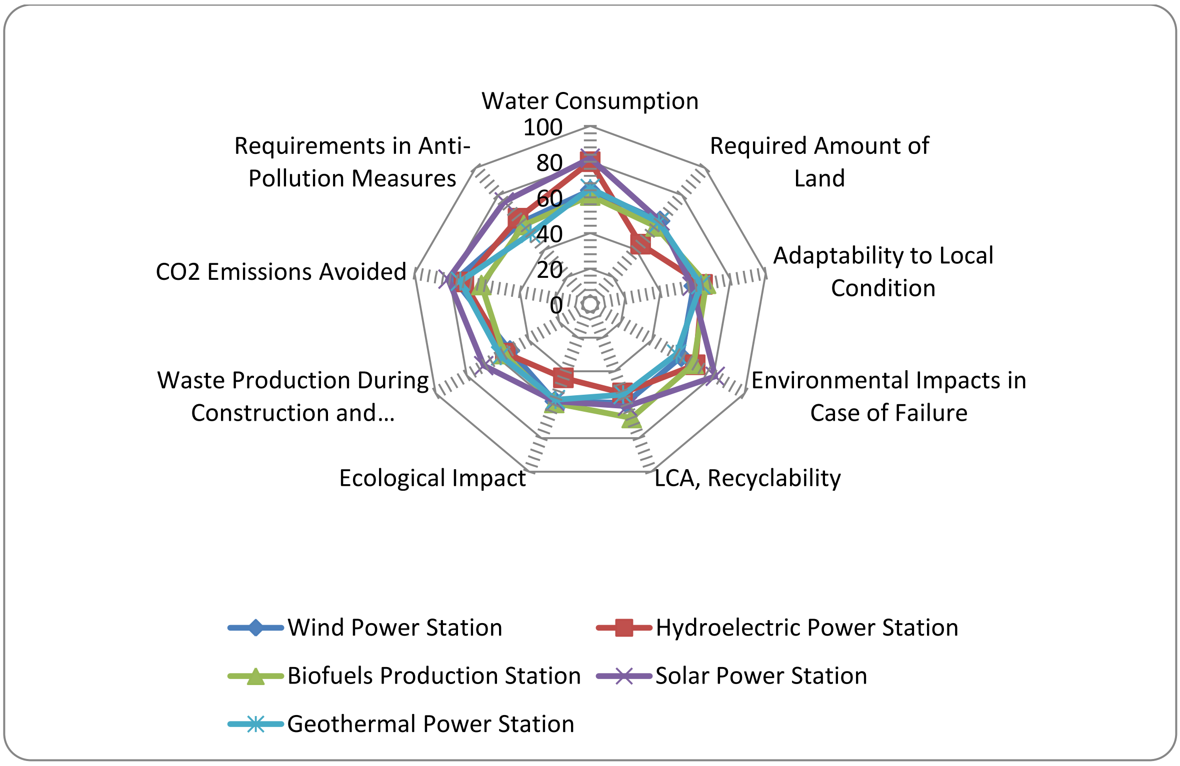


Graph 16 Sensitivity analysis in the context of: social criterion (normalized alternative score values)

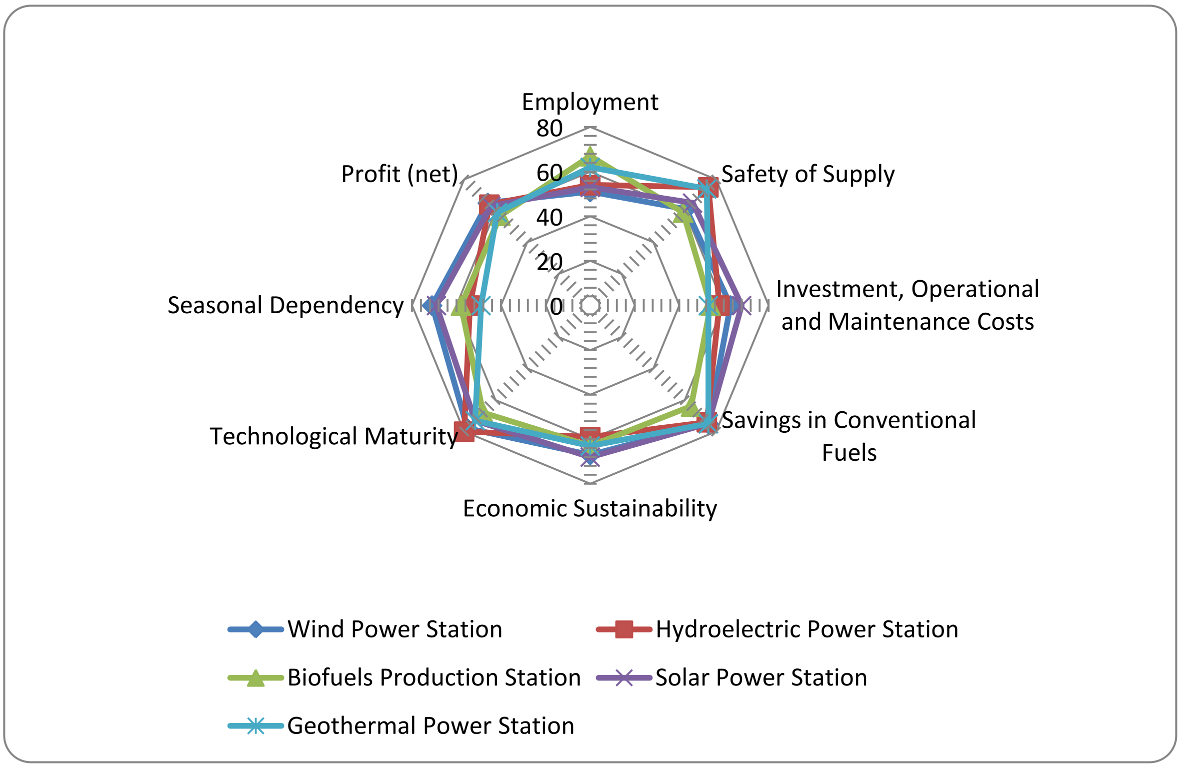
5.5. Alternatives comparison



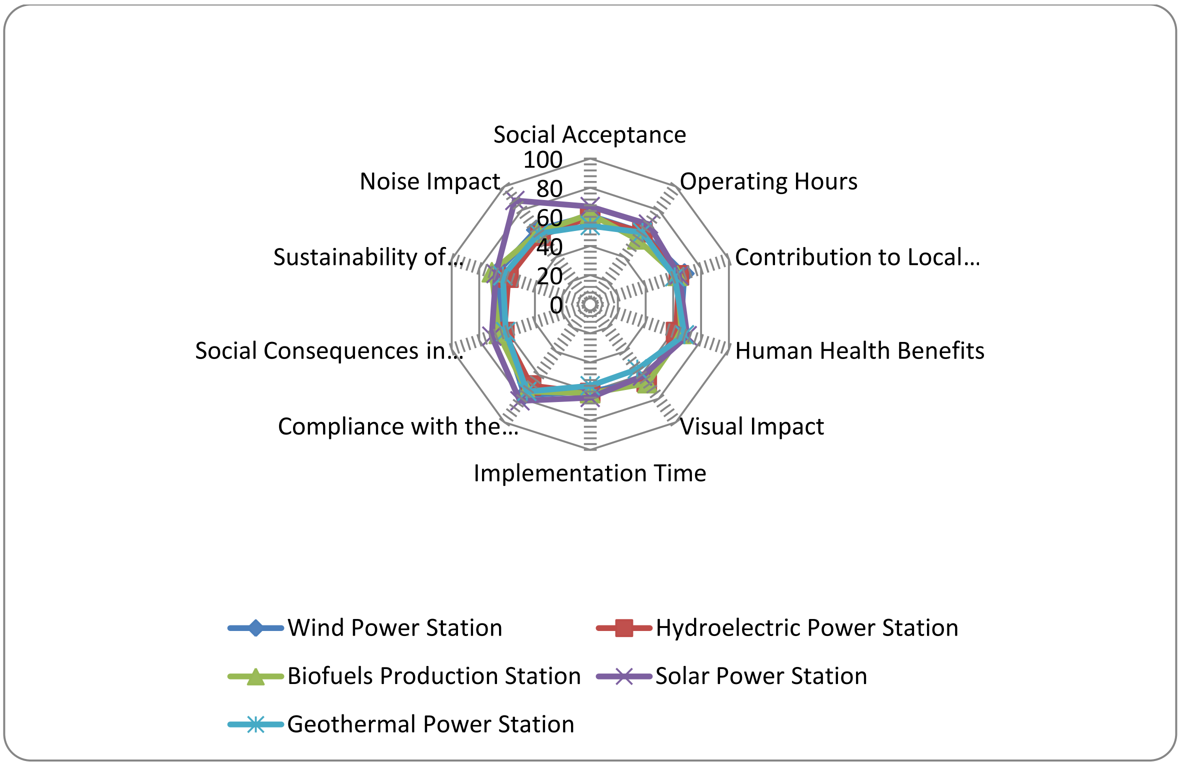
Graph 17 Alternatives comparison (normalized alternative score values)



Graph 18 Comparison in the context of: environmental criterion (normalized alternative score values)



Graph 19 Comparison in the context of: economic criterion (normalized alternative score values)



Graph 20 Comparison in the context of: social criterion (normalized alternative score values)

CH.6. CONCLUSIONS

To decide the most suitable and sustainable alternative for energy independence using renewable energy systems remains a considerably complicated process taking into account the delimitations of the physiognomy of the place sets, in our case Zakynthos island. The geography, the geology, the climate, the economy, the architecture, the history etc., are certain factors that must be taken under consideration in order to set a number of criteria.

In addition, those previously mentioned criteria must be evaluated in order to extract a final outcome/decision. As demonstrated, a multi-criteria analysis can clearly help towards this direction.

With regard to the delimitations set for the scope of the scope of the current research, results obtained, aiming at improving the quality of sustainable decisions through clear, reasonable, rational and transparent test results, indicate that the installation of solar power station is the preferable option, as best compromised and well balanced.

Although the outcome is considered consistent with our findings obtained in our first limited attempt (Vardopoulos, 2017), given the fact that the methodology exceeds certain initial delimitations and most importantly includes all possible applicable alternatives, the result deriving from the current research should be regarded as of primary consideration. Current study's main limitations are a. none hybrid renewable energy system was considered as alternative, b. criteria and sub-criteria pairwise comparison weight evaluation was subject to the authors point of view c. the interview's structured questionnaire was extremely extended (see Appendix). However, despite the fact that this work has some limitations, we believe our work could be a springboard for setting a sustainable methodology towards addressing such multidimensional and multidisciplinary issues.

Without doubt, in order to suggest the installation of solar power systems in the under study as the most feasible alternative to cover the island's energy needs, further research, actions, application and plans are in need. Apart from the extensive research and study regarding the alternative scenarios technology, installation, function and combination (hybrid energy systems), considerations in order to achieve full energy independence should be taken upon:

- Maintenance and upgrade of the existing energy transmission network
- Enforcement of limitations regarding building’s energy proofing
- Incentives regarding additional solution utilizing renewable energy systems at local level (or activities, ex. Agriculture)

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Appendix

Table 23 Pairwise comparison questionnaire

Choose one number below using Saaty's scale 1=Equal, 3=Moderate, 5=Strong, 7=Very Strong, 9=Extreme 2,4,6,8- Intermediate values																			
Compare the relative importance with respect to the five RES alternatives																			
1	Economic	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental
2	Economic	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social
3	Environmental	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social
Compare the relative importance with respect to the economic criterion																			
4	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Employment
5	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Investment, Operational & Maintenance Costs
6	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Profit (net)
7	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Safety of Supply
8	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Savings in Conventional Fuels
9	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
10	Economic Sustainability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
11	Employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Investment, Operational & Maintenance Costs
12	Employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Profit (net)
13	Employment																		Safety of Supply
14	Employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Savings in Conventional Fuels
15	Employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
16	Employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
17	Investment, Operational & Maintenance Costs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Profit (net)
18	Investment, Operational & Maintenance Costs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Safety of Supply
19	Investment, Operational & Maintenance Costs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Savings in Conventional Fuels
20	Investment, Operational & Maintenance Costs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
21	Investment, Operational & Maintenance Costs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
22	Profit (net)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Safety of Supply
23	Profit (net)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Savings in Conventional Fuels
24	Profit (net)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
25	Profit (net)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
26	Safety of Supply	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Savings in Conventional Fuels
27	Safety of Supply	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
28	Safety of Supply	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
29	Savings in Conventional Fuels	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seasonal Dependency
30	Savings in Conventional Fuels	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity
31	Seasonal Dependency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technological Maturity

Compare the relative importance with respect to the environmental criterion																		
32	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CO_2 Emissions Avoided
33	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological Impact
34	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental Impacts in Case of Failure
35	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LCA, Recyclability
36	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Required Amount of Land
37	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-Pollution Measures
38	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
39	Adaptability to Local Condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
40	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological Impact
41	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental Impacts in Case of Failure
42	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LCA, Recyclability
43	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Required Amount of Land
44	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-Pollution Measures
45	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
46	CO_2 Emissions Avoided	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
47	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental Impacts in Case of Failure
48	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LCA, Recyclability
49	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Required Amount of Land
50	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-Pollution Measures
51	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
52	Ecological Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
53	Environmental Impacts in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LCA, Recyclability
54	Environmental Impacts in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Required Amount of Land
55	Environmental Impacts in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-Pollution Measures
56	Environmental Impacts in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
57	Environmental Impacts in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
58	LCA, Recyclability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Required Amount of Land
59	LCA, Recyclability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-Pollution Measures
60	LCA, Recyclability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
61	LCA, Recyclability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
62	Required Amount of Land	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Requirements in Anti-

																			Pollution Measures
63	Required Amount of Land	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
64	Required Amount of Land	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
65	Requirements in Anti-Pollution Measures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste Production During Construction & Operation
66	Requirements in Anti-Pollution Measures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
67	Waste Production During Construction & Operation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water Consumption
Compare the relative importance with respect to the social criterion																			
68	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Contribution to Local Development & Prosperity
69	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Human Health Benefits
70	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Implementation Time
71	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Noise Impact
72	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Hours
72	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
74	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
75	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
76	Compliance with the Existing Framework	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
77	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Human Health Benefits
78	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Implementation Time
79	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Noise Impact
80	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Hours
81	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
82	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
83	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
84	Contribution to Local Development & Prosperity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
85	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Implementation Time
86	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Noise Impact
87	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Hours
88	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
89	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
90	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts

91	Human Health Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
92	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Noise Impact
93	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Hours
94	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
95	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
96	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
97	Implementation Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
98	Noise Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Hours
99	Noise Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
100	Noise Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
101	Noise Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
102	Noise Impact	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
103	Operating Hours	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Acceptance
104	Operating Hours	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
105	Operating Hours	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
106	Operating Hours	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
107	Social Acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social Consequences in Case of Failure
108	Social Acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
109	Social Acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
110	Social Consequences in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sustainability of Environmental Impacts
111	Social Consequences in Case of Failure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact
112	Sustainability of Environmental Impacts	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Impact

Table 24 Sub-criteria weight evaluation structured questionnaire

Choose one number below using the scale: 1=None, 2=Weak, 3=Moderate, 4=Strong, 5=Very Strong, 6=Extreme In the context of Waste Production During Construction and Operation please rate:							
Info:	Construction and operational waste are of the heaviest and most voluminous waste streams generated. Consist of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled (w/y). Rate with 6 if the produced waste of the under question alternative are considered extremely few (w/y) or with 1 if not.						
1	Biofuels Production Station	1	2	3	4	5	6
2	Geothermal Power Station	1	2	3	4	5	6
3	Hydroelectric Power Station	1	2	3	4	5	6
4	Solar Power Station	1	2	3	4	5	6
5	Wind Power Station	1	2	3	4	5	6
In the context of Water Consumption please rate:							
Info:	The water footprint of the energy mix is significantly important and can have implications for						

	energy policy development. Rate with 6 if the water required by the under question RES alternative for energy production is extremely decreasing with regard to the water needed from conventional sources to produce energy or with 1 if it is increasing, requiring extensive improvements in water use efficiency.						
6	Biofuels Production Station	1	2	3	4	5	6
7	Geothermal Power Station	1	2	3	4	5	6
8	Hydroelectric Power Station	1	2	3	4	5	6
9	Solar Power Station	1	2	3	4	5	6
10	Wind Power Station	1	2	3	4	5	6
In the context of Compliance with the Existing Framework please rate:							
Info:	Those multidisciplinary solutions, being new to humanity, are under hundreds of regulations and frameworks around the world and even more at local sites. Compliance issues should be taken seriously, investigate each one, and revisit all operational controls, costs, impacts, etc. Rate with 6 if compliance with the existing framework is extremely clear and easy for the under question alternative or with 1 if it is not.						
11	Biofuels Production Station	1	2	3	4	5	6
12	Geothermal Power Station	1	2	3	4	5	6
13	Hydroelectric Power Station	1	2	3	4	5	6
14	Solar Power Station	1	2	3	4	5	6
15	Wind Power Station	1	2	3	4	5	6
In the context of Contribution to Local Development and Prosperity please rate:							
Info:	This criterion estimates the total social and economic impact that may become perceptible in the regions that house the sustainable energy systems. Likely results are: new chains of enterprises for energy supply, emerging enterprises in the energy sector, new industrial regions, etc. Rate with 6 if the contribution to local development and prosperity deriving from the under question alternative is considered extreme or with 1 if you consider that there is none contribution.						
16	Biofuels Production Station	1	2	3	4	5	6
17	Geothermal Power Station	1	2	3	4	5	6
18	Hydroelectric Power Station	1	2	3	4	5	6
19	Solar Power Station	1	2	3	4	5	6
20	Wind Power Station	1	2	3	4	5	6
In the context of Human Health Benefits please rate:							
Info:	Renewable electricity projects and energy efficiency measures could have health benefits worth millions of dollars a year. However, the value of such projects varies greatly depending on the type of project. Rate with 6 if the benefits deriving from the under question alternative are considered extreme or with 1 if you consider that there are no benefits at all.						
21	Biofuels Production Station	1	2	3	4	5	6
22	Geothermal Power Station	1	2	3	4	5	6
23	Hydroelectric Power Station	1	2	3	4	5	6
24	Solar Power Station	1	2	3	4	5	6
25	Wind Power Station	1	2	3	4	5	6
In the context of Implementation Time please rate:							
Info:	The time required to complete the installation of a renewable energy unit plays an important role in a local community, and when combined with economic and environmental factors can be deterring factor for the whole project. Rate with 6 if the implementation time is extremely quick for the under question alternative or with 1 if the time needed (years) is great.						
26	Biofuels Production Station	1	2	3	4	5	6
27	Geothermal Power Station	1	2	3	4	5	6
28	Hydroelectric Power Station	1	2	3	4	5	6
29	Solar Power Station	1	2	3	4	5	6
30	Wind Power Station	1	2	3	4	5	6

In the context of Noise Impact please rate:							
Info:	The installation and operation of RESs is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc) thus the existed concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology. Rate with 6 if the noise impact of the under question alternative is extremely poor or with 1 if it is not.						
31	Biofuels Production Station	1	2	3	4	5	6
32	Geothermal Power Station	1	2	3	4	5	6
33	Hydroelectric Power Station	1	2	3	4	5	6
34	Solar Power Station	1	2	3	4	5	6
35	Wind Power Station	1	2	3	4	5	6
In the context of Operating Hours please rate:							
Info:	To meet its electricity requirements, a renewable energy unit can operate endlessly or not. The operating time is determined for a society since many social and economic factors are at stake. Rate with 6 if the operating hours are extremely few for the under question alternative or with 1 if it operates endlessly.						
36	Biofuels Production Station	1	2	3	4	5	6
37	Geothermal Power Station	1	2	3	4	5	6
38	Hydroelectric Power Station	1	2	3	4	5	6
39	Solar Power Station	1	2	3	4	5	6
40	Wind Power Station	1	2	3	4	5	6
In the context of Social Acceptance please rate:							
Info:	The opinions related to the energy systems of the local population regarding the hypothesized realization of the projects under review. It is extremely important since the opinions of the population and pressure groups may heavily influence the amount of time needed to complete an energy project. Rate with 6 if the social acceptance for the under question alternative is considered extreme or with 1 if you consider that the alternative is not socially accepted.						
41	Biofuels Production Station	1	2	3	4	5	6
42	Geothermal Power Station	1	2	3	4	5	6
43	Hydroelectric Power Station	1	2	3	4	5	6
44	Solar Power Station	1	2	3	4	5	6
45	Wind Power Station	1	2	3	4	5	6
In the context of Social Consequences in Case of Failure please rate:							
Info:	Deaths from accidents involved in power plant manufacture, construction, operation; fuel extraction, processing, storage, transportation; waste treatment, disposal, etc. Rate with 6 if the consequences in case of failure of the under question alternative are extremely few or with 1 if the consequences are enormous.						
46	Biofuels Production Station	1	2	3	4	5	6
47	Geothermal Power Station	1	2	3	4	5	6
48	Hydroelectric Power Station	1	2	3	4	5	6
49	Solar Power Station	1	2	3	4	5	6
50	Wind Power Station	1	2	3	4	5	6
In the context of Sustainability of Environmental Impacts please rate:							
Info:	All energy sources have some impact on our environment. Fossil fuels do substantially more harm than renewable energy sources, however, is still important, to understand the environmental impacts associated with producing power from renewable sources. The exact type and intensity of environmental impacts vary depending on the specific technology used. Rate with 6 if the environmental impacts are considered extremely minimum using the under question alternative or with 1 if the impacts are considered large-scaled.						
51	Biofuels Production Station	1	2	3	4	5	6
52	Geothermal Power Station	1	2	3	4	5	6
53	Hydroelectric Power Station	1	2	3	4	5	6

54	Solar Power Station	1	2	3	4	5	6
55	Wind Power Station	1	2	3	4	5	6
In the context of Visual Impact please rate:							
Info:	The installation and operation of RESs is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc) thus the existed concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology. Rate with 6 if the visual impact of the under question alternative is extremely poor or with 1 if it is not.						
56	Biofuels Production Station	1	2	3	4	5	6
57	Geothermal Power Station	1	2	3	4	5	6
58	Hydroelectric Power Station	1	2	3	4	5	6
59	Solar Power Station	1	2	3	4	5	6
60	Wind Power Station	1	2	3	4	5	6
In the context of Requirements in Anti-Pollution Measures please rate:							
Info:	Pollution is an example of a negative externality – a cost imposed on a third party. Therefore anti-pollution measures are implemented which can include infrastructure regulations, taxes, pollution permits, etc. Rate with 6 if the needed anti-pollution measures for the under question alternative are considered extremely limited or with 1 if are needed anti-pollution measures are considered a great deal.						
61	Biofuels Production Station	1	2	3	4	5	6
62	Geothermal Power Station	1	2	3	4	5	6
63	Hydroelectric Power Station	1	2	3	4	5	6
64	Solar Power Station	1	2	3	4	5	6
65	Wind Power Station	1	2	3	4	5	6
In the context of Required Amount of Land please rate:							
Info:	On-site direct operational: land occupied by power plant during operation (include life cycle land use as upper bound). Also, RES production systems require a larger use of land compared to conventional sources. This fact is capable of prompting negative public reactions. Rate with 6 if the required amount of land for the under question alternative is extremely small (m2/MWh) or with 1 if the required amount of land is huge.						
66	Biofuels Production Station	1	2	3	4	5	6
67	Geothermal Power Station	1	2	3	4	5	6
68	Hydroelectric Power Station	1	2	3	4	5	6
69	Solar Power Station	1	2	3	4	5	6
70	Wind Power Station	1	2	3	4	5	6
In the context of LCA, Recyclability please rate:							
Info:	Includes upstream (i.e., manufacture, construction, mining), O&M, and downstream (i.e., decommission/disposal) emissions of CO_2, CH_4, N_2O. Rate with 6 under question alternative is considered extremely "recyclable" or with 1 if not.						
71	Biofuels Production Station	1	2	3	4	5	6
72	Geothermal Power Station	1	2	3	4	5	6
73	Hydroelectric Power Station	1	2	3	4	5	6
74	Solar Power Station	1	2	3	4	5	6
75	Wind Power Station	1	2	3	4	5	6
In the context of Environmental Impacts in Case of Failure please rate:							
Info:	Continuous changes in technology, environmental regulation, and public safety concerns make the analysis of the safety of energy systems more and more demanding. Reliability of energy systems is the capacity of a device or system to perform as designed and its resistance to failure. Rate with 6 if the under question alternative is considered extremely safe for the environment in case of failure or with 1 if it is not.						
76	Biofuels Production Station	1	2	3	4	5	6
77	Geothermal Power Station	1	2	3	4	5	6

78	Hydroelectric Power Station	1	2	3	4	5	6
79	Solar Power Station	1	2	3	4	5	6
80	Wind Power Station	1	2	3	4	5	6
In the context of Ecological Impact please rate:							
Info:	Effect on the living organisms and their non-living (abiotic) environment due to human activity or natural phenomenon. Rate with 6 if the impact for the implementation of the under question alternative is considered extremely small-scaled (w/y) or with 1 if not.						
81	Biofuels Production Station	1	2	3	4	5	6
82	Geothermal Power Station	1	2	3	4	5	6
83	Hydroelectric Power Station	1	2	3	4	5	6
84	Solar Power Station	1	2	3	4	5	6
85	Wind Power Station	1	2	3	4	5	6
In the context of CO_2 Emissions Avoided please rate:							
Info:	RES exploitation is an essential mean of mitigation of CO_2 emissions. This constitutes several criteria for the reduction of CO_2 emissions because they have a direct impact on human life and an indirect impact on society (tCO_2/y). Rate with 6 if the CO_2 emissions avoided using the under question alternative are considered extremely high (tCO_2/y) or with 1 if not.						
86	Biofuels Production Station	1	2	3	4	5	6
87	Geothermal Power Station	1	2	3	4	5	6
88	Hydroelectric Power Station	1	2	3	4	5	6
89	Solar Power Station	1	2	3	4	5	6
90	Wind Power Station	1	2	3	4	5	6
In the context of Adaptability to Local Condition please rate:							
Info:	The need for adaptability in energy emergencies has implications for energy policy during nonemergency times. For example, the ability of an energy system to adapt to acute shortage depends in part on its ability to curtail demand quickly, which, in turn, depends on the pre-existing pattern of local energy use. Rate with 6 if adaptability of the under question RES alternative is considered extreme or with 1 if it is not, thus certain further measures should be considered.						
91	Biofuels Production Station	1	2	3	4	5	6
92	Geothermal Power Station	1	2	3	4	5	6
93	Hydroelectric Power Station	1	2	3	4	5	6
94	Solar Power Station	1	2	3	4	5	6
95	Wind Power Station	1	2	3	4	5	6
In the context of Technological Maturity please rate:							
Info:	This criterion refers to the reliability degree of the adopted technology and its spread at national and European level. Rate with 6 if the under question alternative is considered extremely technologically mature or with 1 if it is not.						
96	Biofuels Production Station	1	2	3	4	5	6
97	Geothermal Power Station	1	2	3	4	5	6
98	Hydroelectric Power Station	1	2	3	4	5	6
99	Solar Power Station	1	2	3	4	5	6
100	Wind Power Station	1	2	3	4	5	6
In the context of Seasonal Dependency please rate:							
Info:	The renewable power generation aggregated across Europe exhibits strong seasonal behaviors that need to be calculated of counterbalanced. Rate with 6 if the under question alternative is considered extremely seasonal independent or with 1 if it is not.						
101	Biofuels Production Station	1	2	3	4	5	6
102	Geothermal Power Station	1	2	3	4	5	6
103	Hydroelectric Power Station	1	2	3	4	5	6
104	Solar Power Station	1	2	3	4	5	6
105	Wind Power Station	1	2	3	4	5	6

In the context of Savings in Conventional Fuels please rate:							
Info:	This criterion refers to the total quantity of conventional fuels which is replaced by power generation from renewable energy systems. Rate with 6 if the conventional fuel quantity replaced using the under question alternative is extremely great (kg/y) or with 1 if it is not.						
106	Biofuels Production Station	1	2	3	4	5	6
107	Geothermal Power Station	1	2	3	4	5	6
108	Hydroelectric Power Station	1	2	3	4	5	6
109	Solar Power Station	1	2	3	4	5	6
110	Wind Power Station	1	2	3	4	5	6
In the context of Safety of Supply please rate:							
Info:	This criterion reflects whether the energy supply faces any interruptions. The presence of such interruptions affects the stability of the electricity network. Rate with 6 if the under question alternative is considered extremely stable or with 1 if it is not.						
111	Biofuels Production Station	1	2	3	4	5	6
112	Geothermal Power Station	1	2	3	4	5	6
113	Hydroelectric Power Station	1	2	3	4	5	6
114	Solar Power Station	1	2	3	4	5	6
115	Wind Power Station	1	2	3	4	5	6
In the context of Profit (net) please rate:							
Info:	Net profit as a measure of the profitability of the venture after accounting for all costs. Rate with 6 if the profit of the under question alternative is considered extremely great (€ /y) or with 1 if it is not.						
116	Biofuels Production Station	1	2	3	4	5	6
117	Geothermal Power Station	1	2	3	4	5	6
118	Hydroelectric Power Station	1	2	3	4	5	6
119	Solar Power Station	1	2	3	4	5	6
120	Wind Power Station	1	2	3	4	5	6
In the context of Investment, Operational and Maintenance Costs please rate:							
Info:	Ratio of sum of the amortized overnight capital costs & O&M costs to annual electricity generation; assumes constant financing cost and project lifetime. Rate with 6 if the cost for the under question alternative is extremely few (€ /kWh) or with 1 if the cost is great.						
121	Biofuels Production Station	1	2	3	4	5	6
122	Geothermal Power Station	1	2	3	4	5	6
123	Hydroelectric Power Station	1	2	3	4	5	6
124	Solar Power Station	1	2	3	4	5	6
125	Wind Power Station	1	2	3	4	5	6
In the context of Employment please rate:							
Info:	Direct, indirect & induced full-time equivalent (FTE) employment during construction and operation stages. Rate with 6 if the employment offered from of the under question alternative is considered extremely high (%) or with 1 if it is not.						
126	Biofuels Production Station	1	2	3	4	5	6
127	Geothermal Power Station	1	2	3	4	5	6
128	Hydroelectric Power Station	1	2	3	4	5	6
129	Solar Power Station	1	2	3	4	5	6
130	Wind Power Station	1	2	3	4	5	6
In the context of Economic Sustainability please rate:							
Info:	Renewable energy is not just about saving the environment any more. It is now also about stimulating the economy, generating new sources of growth, increasing income and improving trade balances. Rate with 6 if the under question alternative extremely contributes towards a sustainable economy or with 1 if it is not.						
131	Biofuels Production Station	1	2	3	4	5	6
132	Geothermal Power Station	1	2	3	4	5	6

133	Hydroelectric Power Station	1	2	3	4	5	6
134	Solar Power Station	1	2	3	4	5	6
135	Wind Power Station	1	2	3	4	5	6