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Planning of renewable energy plants: evaluation of the development potential on the minor Italian islands

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“Change is Inevitable. Growth is Optional”

John C. Maxwell

Abstract

To mitigate the effects of climate change, the transformation of the energy production system is imperative. Among the obstacles encountered in the energy transition from a fossil fuel-based system to one based on the use of renewable energy sources, integration with environmental and landscape constraints plays a fundamental role. According to the literature, one of the biggest technical obstacles in the energy transition is the phenomenon of land consumption, which is typical of photovoltaic and wind power plants that take away a large part of the usable area. For this reason, the technical potential of agro-photovoltaics (APV) has also been investigated, as it can enable the integration of renewable energy source (RES) production and agricultural activities. In this work, a scalable methodology for assessing the technical potential of wind, rooftop and agro-photovoltaic installations is developed, based on a spatial energy planning approach within the open software Quantum GIS (QGIS). To this end, the method analyses the suitability of the areas under consideration in accordance with current legislation and land type classification. Subsequently, the wind and photovoltaic potentials are assessed in terms of installable capacity and annual energy production using, respectively, the Wind Atlas Analysis and Application Program (WAsP) and Urban Multi-scale Environment Predictor (UMEP). This method has been applied to the non-interconnected minor Italian islands, belonging to the following four regions: Sicily, Puglia, Lazio, and Tuscany. Sicily is the region that includes the largest number of islands, for a total of 14 islands: Pantelleria, Ustica, the Eolie Islands (7), the Egadi Islands (3) and the Pelagie Islands (2); Puglia includes the Tremiti Islands archipelago, of which the only inhabited islands are San Domino and San Nicola; the islands belonging to the Lazio region are Ponza and Ventotene and, finally, the Tuscan archipelago includes 6 inhabited islands, some of which represent an exception to the thesis as they are connected to the national grid, and these are: Gorgona, Capraia, Elba, Pianosa, Giglio and Giannutri. The results show that current regulatory restrictions severely limit the installation of RES plants in such vulnerable areas as the minor Italian islands. However, in order to achieve full self-sufficiency for these islands, the regulatory framework needs to be shaped accordingly by relaxing the current restrictions and simplifying and speeding up the authorization procedures to support the energy transition. The application of the methodology in these islands has shown that in most cases the available technical potential can cover more than 100% of the local energy consumption. Self-sufficiency can be achieved mainly thanks to the installation of APV, currently characterized by fewer specific constraints than other RES technologies, whose implementation would be favored by the relative high presence of agricultural land, such as to allow the installation of a total of 2 GW. Photovoltaics on roofs have proved to be the easiest technology to implement today on all the islands considered in accordance with current regulations, for a total of approximately 160 MW that can be installed on roofs, excluding protected buildings. Onshore wind power, on the other hand, is the technology whose implementation is rather limited due to the significant environmental and landscape impacts it entails, so that only 6 MW overall can be installed on some islands in Sicily and Tuscany.

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1. Introduction

The climate crisis has gone over the years from being a topic of which only a few were aware of its extreme potential importance to becoming what is probably one of the issues that is inevitably mentioned when it comes to the current and future conditions of our planet. One of the essential elements that must necessarily be taken into consideration to reduce the causes of climate change is the energy transition, for which traditional fossil fuel systems for the production and use of energy are replaced with greener and more efficient solutions, which guarantee the safeguarding of the health of the planet. In this perspective, the non-interconnected minor islands represent the litmus test of the continent's energy transition, as they currently strictly depend on the import of fossil fuels from the mainland rather than exploiting the enormous potential of local renewable resources.

1.1 Background

Nowadays, one of the greatest challenges that humans have ever had to face is climate change. The main cause of this is the gradual increase in the average temperature of the planet, which, according to the opinion most supported by the scientific community, is due to the increase in the concentration of greenhouse gasses in the atmosphere appears to be responsible for this [1].

The exorbitant exploitation of fossil fuels in the last centuries has brought about a parallel economic-social development thanks to which it has been possible to determine an unprecedented improvement in the quality of human life. However, the combustion process of these, essential for the production of energy and use in industrial processes, is inevitably accompanied by the release of carbon dioxide, which, among the GHGs, is the most widespread in the atmosphere. Currently it is extremely challenging to be able to reduce, if not completely eliminate, the dependence on fossil fuels in the energy mix.

In recent decades, and especially in the most recent years, institutions and governments have taken initiatives to combat the causes of climate change with the aim of changing the energy paradigm and promoting a transition that can allow sustainable development [2], guaranteeing persistence and improvement of the quality of life today without determining the worsening of the ecological dimension.

A first and important global response to the arising threat of the impacts of climate change dates back to 2015, when 195 countries signed the well-known Paris agreement [3], a legally binding international treaty consisting of three main long-term goals the parties committed to reach: Temperature Goal, parties put their efforts to hold the average global temperature well below 2°C above pre industrial level, trying to maintain the temperature below 1.5 C. The Adaptation goal, that aims at adopting measures to face the adverse impact climate change will provoke, putting special attention to the parties most vulnerable, such as insular countries or developing ones.

Last but not least, spurring the financial flows toward more sustainable choices, helping those countries needing economic help and investing in greener technologies.

In response to this agreement, in 2021 the European Union stipulated the EU Green Deal [4] with the aim of reaching a modern, resource-efficient and competitive economy, ensuring no net emissions of greenhouse gases by 2050, an economic growth decoupled from resource use and no person, and no place left behind. Since the production and use of energy account for more than 75% of the EU’s greenhouse gas emissions, decarbonizing the EU’s energy system is therefore critical to reach the 2030 climate objectives (“Fit For 55” Package) and the EU’s long-term strategy of achieving carbon neutrality by 2050.

Moreover, in the perspective of a clean energy transition, the EU Green Deal focuses on three key principles which will help reduce GHG emissions and enhance the quality of life of citizens: ensuring a secure and affordable EU energy supply (highly topical topic in relation to the recent geopolitical imbalances caused by the Russian-Ukrainian conflict); developing a fully integrated, interconnected and digitalized EU energy market; prioritizing energy efficiency, improving the energy performance of buildings and developing a power sector based largely on renewable sources.

As it is known, the COVID-19 pandemic has drastically tested our society from multiple points of view and has had more than considerable effects on the economy, leading to one of the most drastic economic crises in the EU's history. For this reason, on 21 July 2020, EU leaders agreed on a comprehensive package of €750 billion effort, the Next Generation EU, a recovery plan that will help the European Union repair the economic and social damage caused by the coronavirus health emergency and help lay the foundations to make the economies and societies of European countries more sustainable and resilient also considering the EU major policies, particularly the European Green Deal, the digital revolution and resilience.

To access the resources of the Next Generation EU, Member States were called upon to prepare their Recovery and Resilience Plans, giving them the right to receive funds under the Recovery and Resilience Facility (RRF), the centrepiece instrument for providing grants and loans to support reforms and investments. Consequently, on 13 July 2021, the PNRR (Piano Nazionale di Ripresa e Resilienza) was definitely approved with the Council's Implementing Decision, which endorsed the proposal of the European Commission, making Italy the first beneficiary, in absolute value, of the two main instruments of the NGEU (RFF and REACT-EU), accessing resources for 191.5 billion euros, to be used in the period 2021-2026, of which 68.9 billion are non-repayable grants [5].

The PNRR is divided into sixteen components, grouped into 6 missions, each of which reflects reforms and investment priorities in a specific sector or area of intervention, according to the six pillars of the RRF regulation. Within the framework of the measures and resources of Mission 2 (Green Revolution and Ecological Transition), Component 1 (Sustainable Agriculture and Circular Economy), it is possible to identify the area of intervention of the Green Islands, for which 200 million euros are allocated. In the latter, the difficulties that these systems must face are acknowledged, such as the need for greater energy efficiency, in addition to the scarce water supply and the complex waste management process, for which a specific mix of actions for a sustainable development is imperative.

Such actions and interventions will concern, for example, the optimization of separate waste collection, the construction of cycle paths, infrastructures and sustainable mobility services and desalination plants, and, of great interest, the integration of renewable sources in the electric system in order to guarantee the continuity and safety of supplies, accompanied by the inclusion of storage systems, innovative consumption management and monitoring systems and smart grids.

The main topic of discussion of this thesis falls precisely in the latter context described: the technical potential of the wind and solar resource will be evaluated, presenting and describing the scalable methodology adopted in all its parts, with particular attention to the current stringent legislative constraints that slow down the green transition of the minor Italian islands. This thesis will also be accompanied by the development of a WebGis platform in which the main results of the work performed will be added in order to be consulted and accessible by all interested parties. The thesis and the WebGis platform have the ultimate goal of representing an important tool for policy makers in the decision-making process such as to provide information on both legislative constraints and areas with greater exploitation in terms of resources.

1.2 Thesis structure

The thesis in question is articulated starting from the previous introductory Chapter 1 in which the current background scenario is described, with particular attention to the importance of the theme of climate change and its effects, on the International, European and National policies and initiatives established, highlighting the key role that the energy transition of the non-interconnected minor Italian islands play.

The following Chapter 2 focuses on the current state of the Italian minor islands taken into consideration, analyzing, in particular, the main characteristics of the energy system and the policies and actions necessary for the ambitious energy transition towards sustainable development, without forgetting however the main factors hindering this.

Chapter 3 describes the current national legislative framework and its implementation at regional level, considering all the regions including, in their territory, minor islands not interconnected to the national electricity grid, in order to highlight the constraints that influence and impede the installation of RES.

Chapter 4, which represents the core of the thesis, describes the scalable methodology adopted, based primarily on a spatial energy planning approach built on the computerized information system GIS (Geographic Information System), useful for a better identification of suitable areas for the installation of RES according to the regulations in force. This is then followed by the characterization of the methodologies that describe the assessment of wind and solar technical potential. For the latter, in particular, the difference in the methodology used in the case of photovoltaic technical potential in roofs from that used in the case of agro-photovoltaic (AGV) will also be described. In addition to this, the creation of the WebGis platform and the potential benefits as a consultancy tool for policy makers will also be reported.

In Chapter 5, the methodology described in the previous chapter will be applied to the islands under examination and the main results will be elaborated and discussed. This will be followed by Chapter 6, which will contain at the conclusion of the thesis.

2. Current status of minor Italian islands

The main theme of the thesis, as already mentioned, is the energy transition of the minor Italian islands not interconnected with the national electricity system. To better understand how this transition can take place, it is firstly necessary to comprehend the current status of the islands and what are the main criticalities and needs.

First of all, nowadays, there is evidence of how these vulnerable systems are already experiencing the negative impacts caused by the increase in temperatures and by the rise in sea level, which accompany the already known collateral effects of anthropological activities strictly connected to significant tourist pressure concentrated in the summer months [6].

However, unlike what are the continental territories, it is clear how the intervention on the insular realities cannot fail to take into account their intrinsic nature: they, being isolated, host a unique and rare natural environment. From this, inevitably derives the great attention paid to all those works and interventions that can affect their own landscapes and territories.

This attention has been accompanied, over the years, by the implementation of laws and regulations that guarantee their protection from an environmental point of view which, at the same time, represent an important obstacle to the deployment and installation of renewable energy technologies, as will be discussed in detail later.

2.1 Description of the islands

The islands involved in this thesis belong to four Italian regions: Sicily, Puglia, Lazio and Tuscany. In the following table [Table 2.1] the islands under examination have been listed and the main characteristics summarized, such as the region, municipality and archipelago to which they belong, surface area and number of inhabitants [7].

Region	Island	Municipality	Province	Archipelago	Surface $[\mathrm{km}^2]$	Population
Sicily	Pantelleria	Pantelleria	TP	-	83	7327
	Ustica	Ustica	PA	-	8,65	1306
	Alicudi	Lipari	ME	Eolie	5,1	104
	Filicudi				9,3	306
	Lipari				37,6	10700
	Vulcano				21	450
	Panarea				3,4	319
	Stromboli				12,6	497
	Salina	S. Marina Salina - Leni - Malfa			26,2	2522
	Lampedusa	Lampedusa e Linosa	AG	Pelagie	20,2	6032
	Linosa				5,4	430
	Favignana	Favignana	TP	Egadi	19,3	3539
	Marettimo				12,4	819
	Levanzo				5,8	226
Sicily -Total					**269,95**	**34577**
Puglia	San Domino	Isole Tremiti	FG	Tremiti	2,1	236
	San Nicola				0,42	131
Puglia - Total					**2,52**	**367**
Lazio	Ponza	Ponza	LT	Pontino	9,85	3360
	Ventotene	Ventotene			1,89	746
Lazio - Total					**11,74**	**4106**
Tuscany	Gorgona	Livorno	LI	Toscano	2,23	147
	Capraia	Capraia Isola			19,33	378
	Elba	(*)			224	31477
	Pianosa	Campo nell'Elba			10,25	10
	Giglio	Isola del Giglio	GR		23,8	1333
	Giannutri				2,6	13
Tuscany - Total					**282,21**	**33358**
TOTAL					**566,42**	**72408**

(*) Marciana, Marciana Marina, Campo nell'Elba, Capoliveri, Porto Azzurro, Portoferraio, Rio

Table 2.1: Region, municipality, province, archipelago, surface area and demographics

Sicily is the Italian region that includes the largest number of islands in its territory, counting 14 non-interconnected islands. These are grouped into 3 archipelagos (Eolie, Egadi and Pelagie) with the exception of Ustica and Pantelleria. More than one Sicilian island can belong to the same municipality with the exception of the island of Salina which is divided into three municipalities. Eolie islands and Ustica are bathed by the southern tyrrhenian sea while the Egadi are collocated between the channel of Sicily and the lower tyrrhenian. On the other side of Sicily, to the south, there are the Pelagie and Pantelleria islands bathed by the Mediterranean Sea. All the islands are mainly reachable by ship, with the exception of Pantelleria and Lampedusa which have, in addition, their own airport due to their considerable distance from the Sicilian coasts (respectively more than 100 km and 200 km). Overall, there is a population of more than 34,000 inhabitants, equal to about 0.70% of the population of the entire region.

The only two inhabited Apulian islands, bathed by the Adriatic Sea, belong to the same scattered municipality of Isole Tremiti. This belongs to the province of Foggia with a distance of about 10 miles from the Gargano coast. The two islands are sparsely populated and the economy of the is mainly based on fishing and, above all, on summer tourism [8].

The Archipelago of the Pontine Islands is located in the Tyrrhenian Sea, off the coast of the Gulf of Gaeta, with a total population of about 4000 inhabitants, a number that increases in the summer period due to the intense tourist movement. The archipelago includes six major islands, which can be reached by ferry or ship, that are divided into two main geographical groups: the north-west group, administratively belonging to the municipality of Ponza, includes the islands of Ponza, Gavi, Palmarola and Zannone; the southeast group administratively belongs to the municipality of Ventotene and includes the islands of Ventotene and Santo Stefano [9].

To conclude, the Tuscan archipelago is made up of a group of seven major islands. These are located between the Tuscan coast and the island of Corsica and are bathed by four seas: the Ligurian Sea to the north, the Piombino channel to the east, the Tyrrhenian Sea to the south and the Corsica channel to the west. All the islands can be reached by sea and have a helipad or a base for the air ambulance except for Pianosa.

The largest one is the island of Elba, which represents the exception, together with Pianosa, in this thesis being, among all, actually connected to the national electricity grid. Despite this, it was still considered appropriate, for the sake of completeness, to carry out evaluations also on it in order to include the whole Tuscan archipelago.

The smallest one, by population, is the island of Montecristo, which today it is practically uninhabited, and for this reason excluded from the thesis, and only inhabited by some agents of the State Forestry Corps [10].

The island of Pianosa, although it is also almost uninhabited, was however included in the thesis because the "Pianosa Rebirth" project is underway, which aims at the repopulation of the ancient villages, left by civilians after the decommissioning in 1997 of the maximum security prison, and to make the island a model of sustainable development "with zero emissions" [11]. This island, under the administration of the municipality of Campo nell’Elba, is also interconnected with the national electricity grid via a 15kV submarine cable [12]. As mentioned for the island of Elba, it will also be considered in the evaluations of the thesis especially for its favorable topographical characteristics (among the Italian islands it is the one with the least slopes ever and therefore more favorable to the installation of RES systems).

The island of Gorgona can be reached from Livorno only by prison police patrol boat as it currently houses an operating prison [13]. The center of Gorgona is still a village of descendants of ancient fishermen, today sparsely populated by families who live there every year for a few weeks or rarely for a few summer months [14]. Of the 105 inhabitants, in particular, 75 are prisoners, 25 prison officers and 5 civilians [15].

Lastly, the island of Giannutri is administratively part of the municipality of Giglio and is inhabited all year round by only 13 residents, while the population grows exponentially in the summer period [16]. On the island of Giannutri, Terna has redeveloped a landfill by creating a photovoltaic shelter under which waste is deposited, also integrating a storage system. This has allowed the island, which was previously 100% dependent on energy from fossil sources, to immediately reach 30% of energy production from renewables [17].

2.2 Water, Mobility and Waste Management

To better understand the challenges that the islands have to face, Legambiente and the CNR atmospheric institute promote the annual report "Isole Sostenibili" [15], through which it is possible to analyze the most relevant critical issues affecting them, such as water supply and purification, waste management, internal mobility and mobility towards the islands and, last but not least, energy supply.

Starting from the point of view of the water systems in the islands, these represent one of the most delicate issues as water is an indispensable and primary asset necessary for every human activity. Despite the enormous importance of this asset, the minor islands are characterized by a considerable ineffectiveness of the fresh water supply and waste water treatment systems and, therefore, there is a need for indispensable interventions and maintenance works accompanied by the introduction of innovative solutions.
Currently there are three main ways of supplying water:

1. Through tankers, very expensive both from economic point of view and in terms of environmental impact as they are powered by fossil fuels;
2. Desalination plants, insufficient for the island's water needs, highly energy intensive, powered by non-renewable sources and responsible for the discharge of sludge into nearby waters even if the discharge was designed to be destined for the open sea.
3. Submarine pipelines connected to the mainland or to nearby islands. These are part of an insular water network characterized by significant losses (in line with the national one corresponding to 42% of the water introduced into the network [18]).

Reporting some examples of water supply methods [15], the Lipari desalinator is coupled to a photovoltaic system that has never been activated and old distribution pipes that make it not at full capacity while in Ponza and Tremiti Islands, innovative desalination plants are in design stage, capable of satisfying the needs even in the months of greatest tourist turnout.

Wastewater purification systems in general are not sufficient, thus not able to cover the needs of the island, or even non-existent [15]. Nowadays there are insular realities which, thanks to the application of innovative solutions and sometimes unconventional approaches (such as those demonstrated through the HYDROUSA project [19], are able to provide their inhabitants with the necessary freshwater and treat the water wastewater at low cost and, at the same time, not negatively impacting the environment.

Another theme to include is mobility, both within the island and to reach the island itself, whose sustainable development with zero impact cannot fail to take place without, primarily, the green transition of the energy system accompanied by the abandonment of traditional fossil sources. Generally, the road infrastructures of the minor Italian islands are characterized by a great dispersion which makes connections with the remote parts of the island difficult and, moreover, the private vehicle currently remains the main solution to getting around and, in some cases, worryingly motorization rates have been reached (as for Pantelleria and the Pelagie Islands of 0.9 v/inhab [20]). The number of vehicles for local public transport remains modest and the few present are still powered by fossil fuels. An interesting alternative is represented by sharing mobility services, capable of combining economic and environmental sustainability. However, the local administrations themselves admit the difficulties in implementing these due to lack of resources for the management of the services themselves, to be entrusted, preferably, to private operators.

Among the initiatives carried out for the creation of green mobility, in the case of the minor Italian islands, the LIFE SILVER COAST project has designed for the island of Giglio the creation of a sharing service of electric bicycles including charging stations and a electric boat, the development of which however encountered many difficulties due to obtaining permits [21].

Among the challenges that the islands have faced most virtuously in recent years is waste management, which is extremely stressed during the summer tourist periods. Separate waste collection has continued to grow in the last period in almost all the islands (average separate waste collection rate achieved in the islands of 47.33%) with the exception of the only worst case that occurred in the Pelagie Islands (38% to 11%) [22]. Furthermore, waste management represents one of the highest items in the government budget due to the expensive transport of waste to the plants on the mainland and, in addition, in the event of overloads of waste or bad weather which prevents navigation, the waste tends to accumulate, creating problems not only of an environmental nature but also of a health nature.

Consequently, what is imperative is a reduction of waste at source (in line with plastic free initiatives), an improvement in the separate collection activity (strengthening of door-to-door collection or creation of mini ecological islands for less central hamlets) and a recycling on the island of waste fractions such as organic waste through aerobic digestion plants (with the creation of compost and manure) or anaerobic (the product of which is methane gas that can be exploited in heating systems or in the transport sector).

2.3 Energy supply of the minor Italian islands

All the challenges listed above have a common root feature, namely that without the energy supply transition there could be no complete sustainable development and achievement of decarbonization goals. This thesis, as already mentioned, fits precisely into this theme, highlighting what are the main obstacles to the necessary and imperative energetic transition and calculates the technical potentials of three different technologies, explained in more detail later, according to the current legislative environmental and territorial constraints.

The protagonists of the thesis are the minor inhabited Italian islands not interconnected with the national electricity system. Although these, distinguished by the most promising radiation and wind potentials in Italy due to their geographically favorable position, the installation of renewable energy technologies ranks among the lowest at a national level. In fact, in these, the energy supply takes place mainly thanks to diesel thermoelectric plants, dated, highly polluting, with low value of efficiency and with high costs for the supply of fuel, certainly not indifferent to the possible adverse climatic conditions that would prevent its transport to the island [23].

In some of the islands, the production and distribution of electricity is entirely managed by local private companies that hold the monopoly, while the rest are entrusted to the management of the national company Enel Produzione S.p.A.

Table 2.2 summarizes, for each island considered in the thesis, the current installed capacity of renewable sources, the targets of installing power from RES according to the Ministerial Decree of the Minor Islands of 14 February 2017 - Art, 2, paragraph 1, letter b), the installed capacity of the diesel generator, the respective annual electricity production, the electricity company and, finally, the share of RES in the electricity demand [15] [24].

Island	RES installed power [kW]	RES installed power 2020 target [kW]	Annual Electricity Production from Diesel [GWhe/year]	Diesel generator installed power [kW]	Electricity company	Share of RES in electricity demand
Pantelleria	872,3 (+WT)	2720	39	23000	S.MED.E. Pantelleria	3,02%
Ustica	432,6	280	4,87	-	Impresa Elettrica D'Anna e Bonaccorsi	11,99%
Alicudi	508,9	2860	0,4	-	Enel Produzione	1,35%
Filicudi			1,4	-	Enel Produzione	
Lipari			34,8	-	SEL (Società Elettrica Liparese)	
Vulcano			7,28	-	Enel Produzione	
Panarea			3,14	-	Enel Produzione	
Stromboli			3,87	-	Enel Produzione	
Salina	103,5	580	9,16	3900	Enel Produzione	1,53%
Lampedusa	605,12	2310	10,342	10000	S.EL.I.S. Lampedusa SpA	6,22%
Linosa			2,8	-	S.EL.I.S. Linosa SpA	
Favignana	404,1	1060	15,47	20000	SEA (Società Elettrica Favignana)	3,01%
Marettimo			2,04	-	S.EL.I.S. Marettimo SpA	
Levanzo			0,6	1000	SI.C.EL. Srl	
Isole Tremiti (San Domino, San Nicola)	18,4	240	3,87	5000	Germano Industrie Elettriche	0,64%
Ponza	289,3	720	11,5	-	Società Elettrica Ponzese	3,40%
Ventotene	115,4 (+WT)	170	2,7	-	Enel Produzione	5,77%
Gorgona	-	ND		1265	-	-
Capraia	35,52+2391	180	2,76	2400	Enel Produzione	-
Elba	3623,8	-	-	-	Enel Produzione	interconnected
Pianosa	-	-	-	-	Enel Produzione	interconnected
Giglio	34,7	700	10,3	-	S.I.E. Srl	0,45%
Giannutri	60	ND	-	-	S.I.E. Srl	30%

Table 2.2: AEP from RES and from Diesel plant, electricity company, 2020 targets

The values in the first column (counted at 31 December 2021), still definitely low, clearly indicate the failure to achieve the RES installation objectives set at 31 December 2020 in accordance with the D.M. 14 - 02 - 2017, Decree of the Ministry of Economic Development to boost renewable sources in the minor islands . It is important to add that, according to this decree, technological neutrality is in force for the types of plant that contribute to the objective, including, in addition to the new installations of production plants (such as PV or Wind Turbine), also the installation of electric charging columns , plants already in production, upgrading of existing plants, integrated systems in new buildings or in significant renovations and reactivations of existing plants [24].

Overall, photovoltaic is present in all the islands considered: Pantelleria ranks first for the installed photovoltaic capacity with 840 kW and is the only one, together with the island of Ventotene (Pontino Archipelago) to also have micro wind power as another source renewable energy, despite presenting markedly low numbers (respectively of 32 kW and 3.16 kW). Except for a few cases, in general the islands on average do not reach 5% coverage by RES and the island of Giglio and the Tremiti islands prove to be the worst ever, not even reaching 1%.

There are, however, some positive results to consider. In fact, among all, the island of Ustica has been able to meet and even exceed the target set, reaching 432.6 kW of installed photovoltaics. Although the ability to have reached this goal that has to be acknowledged, the coverage of the needs by RES unfortunately still remains far from being able to speak of energy self-sufficiency. Salina, in addition, has demonstrated a great example from the year 2020 to 2021, growing, in this time frame, from a capacity of 22kW to 104kW of PV.

Another peculiarity is represented by the island of Capraia, in the Tuscan archipelago. Despite showing very low installed photovoltaic values (35.5 kW), this is the only one to have achieved 100% independence from fossil fuels for the production of electricity. This was made possible by the use of imported biodiesel deriving from the processing of soybean, sunflower and rapeseed oil [25]. However, since the plant uses imported biomass, it cannot be considered sustainable from an environmental point of view and therefore is not included in the calculation of the coverage of the requirement [15].

To date, the situation from an ecological point of view on the minor islands is sadly very disheartening, as it has been possible to observe from the statistics shown above. There are several barriers and obstacles that stand in the path of the ecological transition of the islands but, at the same time, encouraging are the policies and initiatives that Italy and Europe are putting in place to stimulate and allow change.

2.4 Barriers and Opportunities

The obstacles that have determined and continue to condition the implementation and integration of RES in the minor islands can be of a different nature [26]:

To begin with, one of the characteristics of RES that disadvantages them is the difficulty in matching the demand for electricity due to their variable and intermittent nature, unlike traditional fossil fuel generators whose production follows the demand itself. In order to satisfy the matching between production and demand, whether it is instant-by-instant or seasonal variation (for example during the summer periods in which the number of users increases drastically due to the exponential arrival of tourists), it will be necessary to integrate storage energy systems that could allow an increase in the resilience and stability of the energy system itself.

Another major discriminating factor is the energy density of RES, significantly lower than fossil fuels. In areas such as the minor islands, where the available surfaces are evidently a limited good, the use of land for the production of energy represents a stringent limit on technologies such as photovoltaics (especially Ground-Mounted PV) or wind turbines. In fact, in these cases, increasingly well seen are technologies that allow the production of electricity without any consumption of land on the islands, such as wave energy or off-shore wind turbines.

Finally, the last main barrier to the implementation of the RES is of a regulatory nature. Through the analysis of the regulatory framework on the RES, which chapter 3 entirely will deal with, it is highlighted how too rigid landscape constraints, complex connection requests, intricate and often obsolete authorization procedures, represent non-technological barriers that prevent the much sought-after realization of the energy transition in these territories [15].

The ecological transition, which sees in the energy transition one of the most crucial roles to play by far, is greatly affected by the deficiencies of an entire administrative-political system [15]: absence of a shared vision at national level of interventions on the minor islands; absence of a vision that simultaneously contemplates sustainability and respect for natural assets with the simplification of interventions that facilitate the transition; lack of information, support from public bodies, help in accessing credit; lack of awareness of the fragility of the island contexts and of the importance of energy and water efficiency and the reduction of consumption; lack of technical skills in Local Administrations [27].

Although the overall picture may seem daunting and far from the realization of all the ambitious climate and energy objectives, nowadays all the skills, technologies and resources are available which, if exploited correctly, can dictate and shape that transition ecological now impossible not to include in the path towards a sustainable future.

The minor Italian islands, in the process of transition towards sustainability, are certainly not left on their own. On the contrary, they are part of important and conspicuous financing programs which represent an inevitable opportunity to be seized and exploited to the fullest. To follow, the main initiatives and financing programs involving the island territories are presented.

A first and important recent news is that the minor Italian islands have become part of the "*73rd Internal Ultra Peripheral Area*" in the last year [28]. These areas, identified by the

Internal Areas Committee with the support of ANCIM [29], correspond to the territories of the country most distant from essential services (such as education, health, mobility) and at high risk of depopulation [30]. Approximately 11.4 million euros have been allocated for these and, in addition, the "*Resto al Sud*" incentives have also been extended to the minor islands of the Centre-North [31].

In implementation of article 6 of the DM 14 February 2017 [24], for the Sicilian islands of Favignana, Pantelleria and Vulcano, three projects will be financed in accordance with the initiative "*Innovative integrated projects for the minor non-interconnected islands*" for a value of 10 million euro for the realization of projects that demonstrate the reduction of the production of electricity from the current diesel thermoelectric engines.

The minor islands of the less developed regions (Mezzogiorno) are also beneficiaries of the activity of the MiSE (Ministry of Economic Development) called "*Energy and Territorial Development Program 2014-2020*", a program with a total financial allocation of 120.4 million EUR [32]. The two Actions (4.1.1 and 4.3.1) of thematic objective 4 (Supporting the transition towards a low-carbon economy) see as the main objective, respectively, the "*Promotion of eco-efficiency and reduction of of primary energy in public buildings and structures*" and "*Creation of intelligent energy distribution networks (smart grids) and interventions on transmission networks*". For these two areas, minor islands such as the Tremiti islands, Capri, Pantelleria, Ustica, Lampedusa, Salina and Favignana have seen the approval and, in some cases, the realization of the proposed projects.

For 13 municipalities of the minor islands, 15 projects were admitted becoming beneficiaries of the funding of the call "*Energy efficiency interventions, sustainable mobility and adaptation to the impacts of climate change in the minor islands*" [33], published by the former Ministry of the Environment (now MASE). This loan, with an economic financial endowment of 15 million euros, aims to improve the use of water, energy and for interventions to adapt to climate change.

Other loans specifically intended for the 56 minor Italian islands belong to the conspicuous "*Fund for investments for the minor islands*" managed by the Department for Regional Affairs and Autonomies [34]. This includes projects related to the decarbonisation of the energy sector, building efficiency, improved management of waste, water, mobility, implementation of a greener economy and industry.

In addition to these initiatives specifically aimed at the minor islands, these territories are also among the beneficiaries of loans dedicated to protected areas such as national parks ("*Parks for the Climate*" program for an amount of over 98 million euros [35]) or Marine Protected Areas ("*Marine Protected Areas*" programme, 4.5 million euros [36]). The islands' participation requirement is clearly a function of whether or not they belong to these protected areas. To follow, a further similar initiative of the MiTE not to be excluded is the "*Program of interventions for adaptation to climate change in favor of the Municipalities of UNESCO sites and elements of naturalistic interest and in national parks*" [37], for which an allocation of 75 million euros has been foreseen for the three-year period 2021-2023 and whose islands that can benefit from this are, in particular, Pantelleria, Ponza, the Aeolian Islands and the Islands of the Tuscan Archipelago.

Among all the initiatives and financial supports presented, the most conspicuous is clearly represented by the *Green Islands Program* of the PNRR, already discussed previously in the introduction [5]. The investment 3.1, Mission 2 (Green Revolution and Ecological Transition), Component 1 (Sustainable Agriculture and Circular Economy), makes available 200 million euros aimed at supporting all those projects and initiatives to make the non-interconnected minor Italian islands greener and sustainable. By the past deadline of 22 April 2022, 140 projects were presented covering all areas of intervention envisaged by the programme, such as energy and water efficiency, sustainable mobility, waste cycle management, circular economy, and renewable energy production.

All the islands presented projects also in function of the main problems affecting the islands themselves, such as, among all, the strengthening and improvement of the water system. Wishing to mention the types of projects presented, in the field of mobility these vary from the purchase of electric and hybrid vehicles for public transport (also at sea), incentives for the purchase of green vehicles for individuals and local businesses and charging stations. In the field of waste management: creation of ecological islands, better differentiated collection, construction of composting and waste treatment plants and distribution of domestic composters. As regards the water system: purchase and improvement of desalination systems, maintenance of the water distribution network, supply drinking water dispensers. Finally, concerning the energy sector: the renewal and installation of RES systems are foreseen, especially photovoltaics, the introduction into the energy mix of systems that exploit wave motion and geothermal energy, modernization or replacement of public lighting systems and electrical conduits, energy requalification of buildings starting from public ones.

As has been illustrated, the incentives and funding for the minor Italian islands exist and represent a very important opportunity to be able to radically improve these territories. What is needed, therefore, is the ability to overcome those barriers that impede this process, speeding up the slow bureaucracy in background and simplifying the complex and rigid regulatory system. In the next chapter there will be a detailed study of the legislation framework at multiple levels, both national and regional, examining all the territorial and landscape constraints representing the main hindering elements of the energy transition process and implementation of renewable sources.

3. Legislation Framework

In this chapter, which represents a cornerstone of this thesis, the regulatory framework of renewable energy will be presented and discussed, starting with the main European directives and then going on to analyze the legislation at a national level and subsequently at a regional level for the four regions considered in the thesis.

In the context of the energy transition, the development of a clear, structured and coherent regulatory framework is imperative and performs a double function: not only does it allow, on the one hand, to pursue the obligations to reduce emissions and preserve environmental quality, but on the other on the other hand, it appears to be a necessary precondition to encourage investments by private or public bodies in the installation of renewable technologies [38].

The analysis of the main environmental and territorial constraints will be specified for the technologies of interest in the thesis whose technical potential will be calculated afterwards. It is immediately anticipated that the types of renewable energy technologies protagonists of this thesis are the following: Horizontal Axis Wind Turbines (HAWT), Rooftop Photovoltaic and Agrophotovoltaic (APV). Their characteristics will be described later in Chapter 4 where the methodology used to calculate the technical potential of these technologies will be reported.

3.1 European Legislation

The European Union, especially in recent years, has always been a protagonist in the promotion of sustainable development and in the issue of energy transition, well aware of the high risks that our planet is facing due to the increasingly frequent impacts of climate change. Examining the panorama of the main European regulations governing the renewable energy sector [39], the directive 2009/28/EC (RED I) [40](which abrogates the past directives 2001/77/EC and 2003/30/EC), promoted the development of energy from renewable sources by establishing of the targets to be reached by 2020, such as a 20% reduction in greenhouse gas emissions, a 20% increase in energy from renewable sources and a 20% increase in energy efficiency. In this context, however, each EU country has defined the modalities and roadmap through which to achieve its individual target, which also takes into account the background situation and the overall potential in terms of renewable energy of the country itself.

Since 2009, the energy crisis and the worsening climatic conditions have prompted the EU to make important and urgent changes to the directives on renewable sources:

RED II: In July 2021, as part of the EU Green Deal, the Commission proposed new, more ambitious climate targets, such as increasing the minimum share of energy from renewable sources in the EU's energy mix to 40% by 2030.

RED III: In May 2022, following the Russian aggression against Ukraine, the Commission, as part of the REPowerEU plan, proposed an acceleration of the energy transition process with the gradual elimination of dependence on Russian fossil fuels, promoting the installing heat pumps, increasing solar PV capacity and importing renewable hydrogen and biomethane to raise the 2030 renewable energy target to 45%.

RED IV: Also recently, in November 2022, a new framework to accelerate the deployment of renewable energies was established making renewable energy production plants considered to be in the overriding public interest allowing for faster procedures and permitting.

In this context, the importance that COP 21 had in the global climate-energy field cannot certainly be ignored, which led 195 countries to sign the well-known Paris Agreements (PA) [3]. In accordance with these objectives of the PA, in 2018 the EU established the framework called "Clean Energy for all European Citizens", with the aim of speeding up and producing new legislative instruments in the field of renewable energy and decarbonization [41]. This package includes 8 legislative acts (4 directives and 4 regulations) and two initiatives.

In particular, of great interest for this thesis is the "Clean energy for EU islands initiative", whose main goal is to provide a long-term framework to help islands generate their own sustainable and low-cost energy. To realize that, some achievements will be needed, such as the increased production from renewable energy systems, the construction of energy storage facilities and demand response systems in order to make the islands less reliant on imports enhancing their energy security. All of this will also lead to an improvement of the air quality, lower greenhouse gas emissions and less impact on islands' natural environments, accompanied by benefits from the economic point of view (creation of new jobs and business opportunities, boosting islands' economy) [42].

The plan called "Clean energy for EU islands secretariat" (of which Pantelleria is one of the pilot islands of the project) [42] is closely linked to this initiative. To adhere to this plan, a document must be signed and signed in which one declares the intention to adhere to the initiative and proceeds with the elaboration of a "Clean Energy Transition Agenda", which is divided into four phases [43]: 1) Building a transition team. 2) description of the dynamics of the island. 3) development of a path for transition. 4) monitoring of processes and sharing of results, in such a way as to allow the European islands to exchange knowledge and information that favor the resolution of problems that unite all the islands.

3.2 National Legislation

Over the years Italy has developed legislation in line with the directives and regulations promoted by the EU in the energy-environmental field, adapting them to the particular national context.

About two decades ago, to begin with, Italy implemented the EU Directive 2001/77/EC, the purpose of which was to encourage the promotion of electricity produced from renewable energy sources in the internal electricity market; the implementation of this took place through the legislative decree 29/12/2003 n.387, within which the indicative national objectives and measures for the promotion of renewable sources were defined. In addition to this, specific provisions have been added relating to individual energy sources and rules for the simplification and rationalization of the authorization procedures [44].

The next and important European directive in the field of renewable energies dates back to 2009 (EU Directive 2009/28/EC amending, and subsequently repealing, directives 2001/77/EC and 2003/30/EC). This was implemented in Italy through the legislative decree 03/03/2011 n.28, which defines the tools, mechanisms, incentives, and the institutional, financial and legal framework, necessary for the achievement of the objectives up to 2020 on the matter overall share of energy from renewable sources in gross final energy consumption (17%) and share of energy from renewable sources in transport (10%). Furthermore, within this, the will to favor the development of renewable sources and the achievement of energy objectives was newly expressed among the general principles of the decree. Therefore, the construction and operation of plants for the production of energy from renewable sources has been governed according to special simplified, accelerated, proportionate and adequate administrative procedures, based on the specific characteristics of each individual application [45].

3.2.1 Ministerial Decree 10/09/2010, n.219

The most important document within the broad and complex regulatory framework at national level is certainly Ministerial Decree No. 219 of 10 September 2010 “Guidelines for the authorization of plants powered by renewable sources”, within which the first constraints were identified which will then be considered in the thesis for calculating the technical potential [46]. The definition of national guidelines provides important elements for regional administrative action as well as coordination and supervision action in relation to potentially delegated bodies; moreover, these guidelines can facilitate a reconciliation between the needs of economic and social development and those of environmental protection and conservation of natural and cultural resources in regional planning and administrative activities. It is also highlighted that these guidelines must be updated frequently (cooperatively by the State, regions, and local governments) in light of the results of the monitoring of their implementation in order to increase their effectiveness in terms of speed, procedural simplification, and the reduction of the effects of the plants on the environment.

The administrative modalities and technical requirements of the guidelines not only apply to the processes for the construction and operation of RES-powered electricity production plants on land, but also involve the modifications, upgrades, total or partial renovations, and reactivations as well as the connected works and infrastructures required for their construction and operation.

Going into detail, annex 3 of the decree contains the principles and criteria for the identification of unsuitable areas, on the basis of which each region will carry out this identification taking into account the pertinent environmental, territorial and landscape planning tools. The main criteria are listed below:

a) The identification of unsuitable areas must be based exclusively on objective technical criteria linked to aspects of protection of the environment, the landscape and the artistic-cultural heritage, linked to the intrinsic characteristics of the territory and the site;
b) The identification must be differentiated with specific regard to the different renewable sources and the different plant sizes;
c) zones classified as agricultural by current urban plans cannot generally be considered unsuitable areas and sites;
d) The identification cannot concern significant portions of the territory or buffer zones of dimensions not justified by specific and justified protection needs;

e) The Regions will be able to take into account both high concentrations of energy production plants from RES and interactions with other projects in the same selected area during the process of identifying unsuitable areas;
f) Regions can indicate as unsuitable areas those particularly sensitive and/or vulnerable to territorial or landscape transformations falling within those listed below:

- Sites included in the UNESCO World Heritage List, areas, assets and buildings declared to be of notable public interest (pursuant to Article 136 of Legislative Decree No. 42);
- Areas within visual cones whose image is historicized and of international renown as a tourist attraction;
- Areas located near archaeological parks and in areas of particular cultural, historical and/or religious interest;
- Protected natural areas at national, regional, local level, areas of integral reserve and general oriented reserve and areas included in the Official List of Protected Natural Areas;
- Wetlands of International Importance designated under the Ramsar Convention;
- The areas included in the Natura 2000 network, such as Sites of Community Importance (SCI) and Special Protection Areas (SPA);
- The Important Bird Areas (I.B.A.);
- Areas not included above but which perform crucial functions for the conservation of biodiversity (buffer zones or contiguous areas of protected natural areas);
- The agricultural areas of quality agricultural-food productions (organic productions, D.O.P., I.G.P., S.T.G., D.O.C., D.O.C.G. productions, traditional productions) or of particular value with respect to the landscape-cultural context;
- Areas characterized by situations of hydrogeological instability or risk defined in the Hydrogeological Structure Plans (Piani di Assetto Idrogeologico - P.A.I.);

Attachment 4 of the Ministerial Decree under examination also includes a thorough analysis of wind farms and the factors that contribute to their proper integration into the landscape and territory; in this, the significant contribution that wind farms can guarantee for the achievement of energy and environmental objectives is recognized. However, at the same time, due to their intrinsic characteristics, it is necessary to consider the relevant possible environmental and landscape impacts resulting from their installation and operation and the relative possible mitigation measures to be adopted.

First, concerning the visual impact, this is one of the most significant impacts due to the wind turbines (poles, nacelles, rotors, blades), the transformer substations, the necessary roads to be built and the connecting power line (whether overhead or buried).
For this type of impact, the following mitigation measures have been promoted: Avoid fragmentation or divisions of territorial designs and historical units; Prefer the burial of electric cables (if not in conflict with archaeological areas), degraded or industrial areas of large infrastructures, greater unit power to reduce the number of turbines to be installed for the same total power and adopt a color of the blades that reduce their impact (if not in conflict with aeronautical requirements or with bird perception). Furthermore, among the mitigation measures, the minimum distances between the wind turbines, which correspond to the optimal placement criteria during the micro-siting configuration of wind farms phase [47], are also indicated. According to that, in this thesis, a distance of 10 diameters for the downwind spacing and 5 diameters for the crosswind spacing is assumed.

The impact on flora, fauna and ecosystems refers to the damage and direct elimination of habitats and floristic species due to direct impact (collision of bird species) or indirect impact (modification of habitat and loss of food and reproductive sites). To reduce this, the following mitigation measures have been presented: minimization of habitat changes during construction and operation; containment of construction times and reduction of dust dispersion during construction; reduced use of new roads and blades coloring to increase bird perception (if not in conflict with the visual impact).

Among the mitigation measures in the geomorphological field, the following have been indicated: minimum distance of each wind turbine from habitable housing units and from the inhabited centers identified by the urban planning instruments in force of at least, respectively, 200 m and 6 times the maximum height of the wind generator; avoidance of slopes where erosion phenomena can be triggered (in the case of slopes greater than 20% it will be necessary to demonstrate that the construction of wind farms will not produce further erosion processes and hydrogeological instability phenomena).

Annex 4 continues with the assessment of the possible impacts relating to noise and electromagnetic interference, impacts of an accidental nature, the decommissioning phase and all the related mitigation measures.

Starting from the mitigation measures presented, assumptions were obtained through which it was possible to evaluate the wind technical potential, as will be explained later in paragraph 4.2.

3.2.2 Decree law 03/01/2022, n.17

To conclude the presentation of the regulatory framework at national level, for the sake of completeness, it is necessary to introduce the recent decree law 03/01/2022 n.17, the purpose of which is to propose urgent measures for the containment of energy costs and the relaunch of industrial policies in order to reduce the effects of price increases in the electricity sector [48]. This decree has had important effects in the renewable energy sector, especially regarding the installation of photovoltaic systems. Going directly to the parts that concern the types of systems involved in the thesis, articles 9 and 11 are of relevance.

Article 9 - "Simplifications for the installation of renewable source systems" has determined that the installation of photovoltaic (or thermal) systems on buildings or on above-ground structures and artifacts other than buildings and works functional to the connection to the electricity grid is considered ordinary maintenance and is not subject to the acquisition of permits, authorizations or administrative deeds; however, the areas or buildings defined in art. 136, paragraph 1, letters b) and c), of the Cultural Heritage and Landscape Code, (identified pursuant to articles 138 to 141) and art. 21 and art.157, have been excluded from this simplification.

Article 11 refers to the regulation of photovoltaic development in the Agricultural Area. In particular, as regards ground-mounted photovoltaics (type of plant not contemplated in the thesis), the general prohibition on accessing state incentives for RES for photovoltaic plants with modules placed on the ground has been eliminated, under the following conditions: that they occupy a total area not exceeding 10% of the company's agricultural area; rated power less than 1 MW; located, in the case of land belonging to the same owner, at a distance of not less than 2 km from each other.

3.2.3 National guidelines of APV systems

Since these types of innovative systems for the production of renewable energy are currently little known, it was considered appropriate, in this section of the thesis, to do a brief overview on this topic, in order to better understand the great potential of these systems and the main factors affecting its installation.

Figure 3.1: A pilot plant built by Le Greenhouse [49]

First of all, it is important to start from understanding what an APV plant is and, for this purpose, the art. 11 of the regulation just commented before (decree law 03/01/2022 n.17) is of great relevance as, in this, the definition of Agrophotovoltaic plant (APV) was given: an APV system can be defined as such provided that such systems adopt innovative integrative solutions with assembly of the modules raised above the ground, also providing for the rotation of the modules and in such a way as not to compromise the continuity of the agricultural and pastoral cultivation activities, also allowing the application of digital and precision agriculture tools [48]. Moreover, the access of these plants to state incentives is subject to the simultaneous implementation of monitoring systems to verify the impact on crops, water savings, agricultural productivity and the continuity of farm activities.

Another document relating to APV systems is "Guidelines for the application of Agrophotovoltaics in Italy”, which presents elements that have been essential for the evaluation of the technical potential from APV [50]. Several are the bodies, whether public or private ones, which have participated in the drafting of these guidelines [51]. This document opens by showing the important drawbacks that the installation of ground-mounted photovoltaic systems in productive agricultural land entails, such as, above all, the loss of agricultural income in the portions used for the construction of the plant. From this premise comes the decisive and innovative approach of agrophotovoltaics, based on the integration of the production of energy from renewable sources with agro-zootechnical practices and with the aim of not compromising the essential continuity of agricultural activity.

There are several important benefits determined by the implementation of these types of plants, such as the most basic of dual land use. This integration and coexistence not only do not deprive agriculture of land, on the contrary it allows advantages for both activities:

- Contrasting the abandonment of agricultural land and increasing productivity [52];
- New job opportunities in rural communities [52];
- Stimulation of investments and increased competitiveness of the agricultural company (income increase of over 20%), with digitization and risk diversification [53];
- Reduction of the water footprint of agriculture, with reduction of evapotranspiration [50];
- Increased efficiency of the modules thanks to the lowering of temperatures due to the cooler microclimate (water vapor for evapotranspiration which cools down the rear surface of the modules) [54];
- Promotes higher photosynthetic capacity and generates high quality crop yields [54];
- Protection of crops from extreme weather events, high temperatures, water scarcity and consequent reduction of insurance costs [52].

However, the benefits of APV systems certainly depend on the type of crop, as these can respond differently to the partial increase in shading. The reduction of incident radiation does not always generate a harmful effect on crops which can also adapt to the lower amount of intercepted direct radiation, improving the efficiency of interception [55]. Through the study conducted in Germany on the behavior of different crops subjected to the reduction of light radiation, a classification of crops was carried out based on their tolerance to shading by photovoltaic panels [56] and the results are shown below:

- Unsuitable crops: Wheat, spelled, corn, fruit trees, sunflower, red cabbage, cabbage, millet, squash.
- Little unsuitable crops: cauliflower, sugar beet, red beet;
- Suitable crops: rye, barley, oats, kale, rapeseed, peas, asparagus, carrot, radish, leek, celery, fennel, tobacco.
- Averagely suitable crops: onions, beans, cucumbers, courgettes;
- Very suitable crops: potato, hops, spinach, lettuce, broad beans, citrus fruits.

Another aspect to consider is the environmental impact that these plants may have and therefore evaluate the potential impact of this by classifying and cataloging the different plant, animal and habitat species of the area in order to find solutions to mitigate the impact on biodiversity.

Above all, the elevation of the modules from the ground avoids a typical problem of ground-mounted PV systems such as the inhibition of wildlife movement and the increased risk of predation [57]. The potential effects on birds that these systems can determine are certainly not negligible. However, from observations in the field [50], agro-photovoltaic systems with panels raised above the ground can also represent new habitats suitable for nesting and predation activity necessary for the natural biological cycle of birds. Finally, another consideration is to be made on insects and on the impact due to PLP (Polarized Light Pollution), i.e. an important modification of the polarization pattern of ambient light due to reflection [58]. This phenomenon of disorientation of insects, which can for example exchange the module surface with bodies of water (essential in the reproduction phase), finds as a possible mitigation measure the finishing of the surface of the modules with the creation of a microtexture such as to make the modules almost unattractive to some insect species [59].

As regards the geometries of the system, in the DL n77/2022, although these systems are characterized by an "elevation from the ground", however there is no specification regarding the minimum height that the modules must have and therefore, in order to define this parameter, the Guidelines have investigated the historical legislation relating to the topic: on the one hand, ground-mounted solar systems have modules with a minimum distance from the ground of less than 2 m, as required by Ministerial Decrees 19/02/2007 (art. 2) and 06/08/2010 (art. 20) [60] [61]; on the other hand, the definition of photovoltaic greenhouses provides that they have a minimum height of 2 m and that the modules constitute the construction elements of the roof, according to the Legislative Decrees 05/07/2012 [62]. Therefore, ultimately, according to these guidelines, an APV system can be easily compared to a "modern open greenhouse" for the protection of crops through mobile photovoltaic roofing, without the construction of closed volumes and with raised modules in structures of minimum height of 2 m, so as to allow the continuity of the cultivation activity [50]. Current experiences, however, foresee a height of 3m with a minimum height from the ground of 2.4m (in correspondence with the maximum inclination of the module) [50].

These plants have a support structure in which the main horizontal axes are mounted on which the secondary axes supporting the solar panels are hinged. These systems, as by definition, are characterized by a tracking system and it can have two different configurations, uniaxial and biaxial. Uniaxial solar trackers are the most widespread and capture solar radiation by rotating around their North South axis during the course of the day (simplest system and adopted in this thesis), while biaxial trackers have two rotation axes, perpendicular to each other, which allow you to place the panels constantly pointed in the direction of the sun, as the hours of the day and the seasons vary [50].

In order not to impede the access and advancement of large machinery, sometimes indispensable depending on the type of crop, these guidelines also suggest an average distance between rows of 6 m [50]. However, it should be noted that this spacing is decidedly conservative and, in general, depends on the type of crop, the optimal shading and the use of external machinery.

Due to the limited literature and experience related to these systems, there are no specifications regarding the limitations imposed by the slope of the land. Nevertheless, considering this factor essential for the installation of these systems, the same threshold adopted in the case of ground-mounted PV was imposed, for which the maximum terrain slope that guarantees the technical feasibility is 15° [63].

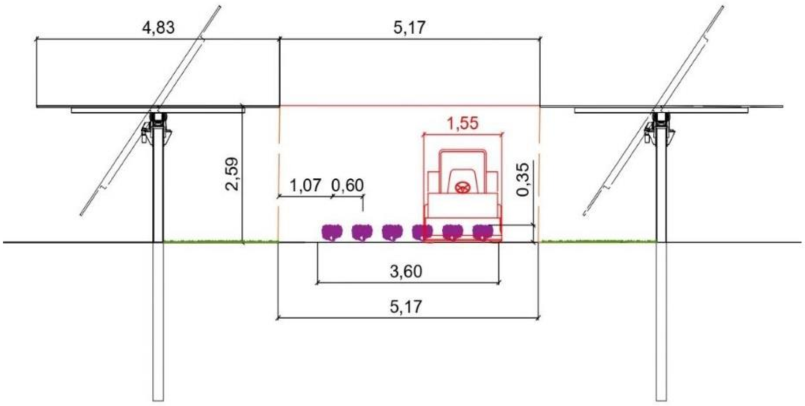


Figure 3.2: Experimental design of an APV system [50]

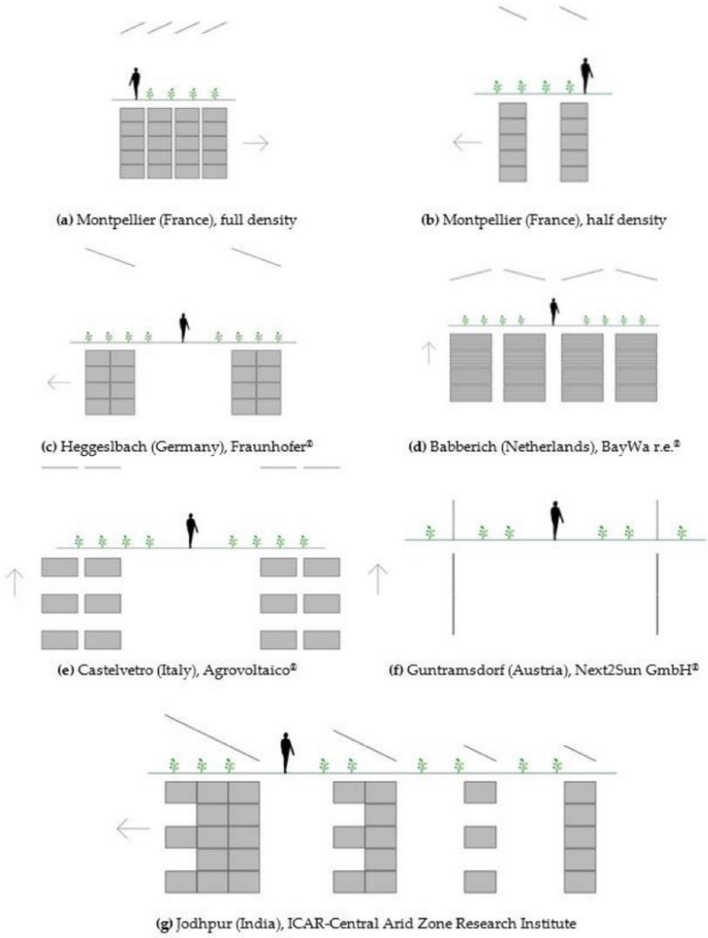


Figure 3.3: Different spatial configuration patterns of APV systems [64]

To conclude, it is anticipated that some of the technical aspects mentioned, such as spacing, tracking system, slope of the terrain, will be essential elements for the evaluation of the technical potential of the APV, as explained later in the methodology (Chapter 4).

3.3 Regional Legislation

In this last paragraph of this chapter, the regulatory framework of the four Italian regions involved will be analyzed. This derives from the fact that the Regions contribute to the elaboration of energy laws and therefore have an important role in the development of the energy sector both in terms of authorizations and as regards the management of the territory and therefore the identification of unsuitable areas to host technologies [65].

3.3.1 Sicily

Analyzing the regulatory framework relating to the autonomous region of Sicily, the presidential decree of 10 October 2017 - "Definizione dei criteri ed individuazione delle aree non idonee alla realizzazione di impianti di produzione di energia elettrica da fonte eolica [...]", is the document which reports the unsuitable areas, identified by the region in accordance with the Ministerial Decree No. 219 of 10 September 2010, for the installation of wind energy production plants, and therefore of essential interest for the thesis [66].

To begin with, the decree distinguishes three different categories of wind turbines according to their nominal power P (based on the PAI classification) as follows:

- EO1 if P ≤ 20 kW
- EO2 if 20 kW < P ≤ 60 kW
- EO3 if P > 60 kW

The decree makes a distinction between “unsuitable areas” and “areas subject to particular attention”, on the basis of which the compatibility of the types of wind turbines is differentiated.

The "Unsuitable Areas" are those characterized by a particular and incisive sensitivity or vulnerability to territorial, environmental and landscape transformations and falling within restricted areas by regulatory deed or measure. In these areas, the installation of wind turbines is generally prohibited. To follow, the areas defined as unsuitable by the region for the three types of wind turbine (EO1, EO2 and EO3):

- Site of Community Importance (SCI);
- Special Protection Area (SPA);
- Special Area of Conservation (SAC);
- Important Bird Area (IBA), including the nesting and transit areas of migratory or protected birds;
- Sicilian Ecological Network;
- Ramsar sites (wetlands) and natural reserves;
- Protection oasis and fauna refuge;
- Geosites;
- Regional and national parks except those that provide for other different measures in force at the time of the enactment of the abovementioned decree;
- Landscape protection zones and archeological areas and parks as in Art. 134, letters (a), (b) and (c) of the Code of cultural heritage and landscape [67]. In these zones, the

construction of individual EO1- and EO2-type wind turbines is allowed to support agricultural activities in areas covered by general regulatory plans under Art. 22 of Regional Law No. 71 of 1978 and subsequent amendments.

While the unsuitable areas specifically for EO2 and EO3 types of system are:

- The ecological corridors that are identified on the basis of the maps drawn up in support of the Management Plans of Natura 2000 sites (SCI, SAC and SPA).
- The areas defined as forests in accordance with art. 142, paragraph 1, lett. g), of the Code of cultural heritage and landscape.
- Areas classified as “very high” (P4) and “high” (P3) risk in the Hydrogeological Structure Plan (PAI).

The "Areas subject to particular attention", due to their sensitivity or vulnerability to territorial transformations, the environment or the landscape, require special precautions or mitigation measures, also according to the power size:

- Areas in which the hydrogeological constraint has been applied pursuant to the royal decree of 30 December 1923, n. 3267, for all three types of turbines;
- The ecological corridors that are identified on the basis of the maps drawn up in support of the Management Plans of Natura 2000 sites (SCI, SAC and SPA), affecting the construction of EO1 type plants.
- The areas identified by the PAI (Piano Assetto Idrogeologico) with medium (P2), moderate (P1) and low (P0) hazard, if accompanied by an adequate geological-geotechnical study that demonstrates the compatibility of the plant to be built with the existing level of hazard for EO1, EO2, and EO3 type systems;
- Areas identified as "very high" (P4) and "high" (P3) danger in the PAI, which is the plan for the defense from the hydrogeological risk of the territory. These areas affect the construction of EO1 type plants.
- Areas indicated in art. 134, paragraph 1, lett. a) and c) and near properties listed in art. 136, paragraph 1, lett. a) and b), of the Cultural Heritage and Landscape Code;
- For EO1, EO2, and EO3-type plants, Areas of agricultural value and beneficiaries of contributions and areas of landscape value as evidence of the agricultural tradition of the Region, listed as follows:
    - Organic productions;
    - *Denominazione di Origine Controllata* (DOC) productions;
    - *Denominazione di Origine Controllata e Garantita* (DOCG) productions;
    - *Denomina*zione di Origine Protetta (DOP) productions;
    - *Indicazione Geografica Protetta* (IGP) productions;
    - Traditional and *Specialità Tradizionale Garantita* (STG) productions.

It should be noted that, in this thesis, the "areas subject to particular attention" will not be considered during the evaluation of the technical potential as they do not bind the construction of the wind farms but rather have the intention of preserving these areas from territorial, environmental and landscape transformations because of their sensitivity or vulnerability;

With regard to photovoltaics, the Presidential Decree 18/07/2012, n.48 [68] governs the authorization provisions of energy production plants powered by renewable sources, in adaptation of the guidelines defined in the ministerial decree 10 September 2010. This explains in detail, precisely in art. 3 - Procedures for administrative simplification, what are the procedures to follow for the realization of renewable plants according to their type, size and area of placement. In the case of photovoltaics therefore, in the regional legislation, there is no precise definition of the areas unsuitable for the construction of photovoltaic systems on the roofs (much less relating to agro-photovoltaic systems).

However, thanks also to the research work published in the paper [69], photovoltaic installation constraints have been identified on the basis of local legislation. In particular, the local urban plan of Pantelleria prohibits any photovoltaic installation within the historic town center and above the local dwellings called *Dammusi*. Moreover, the local zoning and landscape plan of Pelagie Archipelago prescribes measures to mitigate the visibility of PV installations from main roads or certain viewpoints. In addition, the plan prescribes that PV installations must not be located within view of the site, i.e., all parts must exceed parapets. Moreover, the local landscape prescribes a maximum size of 20 kW for wind plant installation.

A common feature of the legislation of the four regions taken into consideration is the almost non-existent regulation relating to agro-photovoltaic systems (APV). In the case of Sicily, there is only a single mention in the PAERS 2030 (Environmental Energy Plan of the Sicily Region), in which it is recognized that, in order to achieve the energy and environmental objectives, specific actions must be evaluated in productive agricultural land to encourage the development of agro-photovoltaics [70].

3.3.2 Puglia

In the case of Puglia, the identification of the constraints for the calculation of the wind and solar technical potential took place starting from the regional regulation of 30 December 2010, n. 24 [71]. This regulation implements the Ministerial Decree of 10 September 2010, establishing the identification of areas and sites unsuitable for the installation of specific types of plants powered by renewable sources in the territory of the Puglia region. Furthermore, as specified in article 1 of the same regulation, this regulation is not meant to represent a hurdle for the energy transition, instead it has the purpose of speeding up and simplifying the authorization procedures for the construction and operation of plants powered by renewable sources and related works.

Within this regulation, annexes 2 and 3 are the essential elements that contain the information for the elaboration of the unsuitable areas of the Puglia region. In particular, annex 2 - "Identification of the types of systems", classifies the different types of systems according to the renewable energy source, power and type of connection, functional to the definition of the unsuitability of the areas. Instead, annex 3 - "Identification of areas and sites unsuitable for the location of certain types of plants" contains the list of areas and sites in which the construction of specific types of plants using renewable energy sources is not permitted, indicated for each area and site.

Table 3.1 shows the different types of renewable source plants included in Annex 2 which, however, are relevant to the technologies considered in the thesis (biomass, ground-mounted PV, geothermal plants are excluded).

Classification of plant types for the purpose of identifying unsuitability.		
Photovoltaic	F.1a	adherent or integrated systems on existing buildings
	F.1b	// with development of external connection works
	F.2a	systems placed on existing buildings
	F.2b	// with development of external connection works
	F.3a	on buildings or on their appurtenances, with methods different from those of F.1 and F.2
	F.3b	// with development of external connection works
Wind turbines n=number of wind turbines h= overall height [m] D= rotor diameter [m]	E.1	Micro wind on the roofs
	E.2a	Mini wind with h<30 m E D<18m in Agricultural Areas and n<=3 P<=20kW ;
	E.2b	// 20kW<P<60kW
	E.2c	// 60kW<P<200kW
	E.4 a), b), c), d)	Wind Farm: a) 60kW < Ptot < 200kW; n<=3; if n>3: E4b b) 200kW < Ptot < 500kW; n<=2; if n>2: E4c c) 500kW <= Ptot <= 1000 kW d) Ptot > 1000kW

Table 3.1: RES plant types classification - Puglia

In addition to attachment 3 described above, another supporting document for identifying the constraints is represented by the PPTR (Regional Territorial Landscape Plan) [72]. Within this are present and very useful for the thesis, in paragraph 4.4, the *Guidelines on the design and location of renewable energy plants*, whose purpose consists in the shared construction of rules for the design of plants from renewable sources. They are therefore addressed to administrators, politicians, entrepreneurs, technical planners, to all those who have to share, both for the planning and for the compatibility assessment, choices of transformation of the territory linked to new forms of energy infrastructure.

Following the examination of the content of annex 3 and the simultaneous consultation of the guidelines, table 3.2 was obtained. This shows the areas and sites that are unsuitable for the construction of renewable energy plants in accordance with their type, size and dimension:

Areas and sites unsuitable for the siting of specific types of plants from renewable sources	
National protected areas (Gargano park)	F.3a;F.3.b; E.2b;E.2c; E.3a; E.3b; E.4a; E.4b;E.4c;E.4d;
Site of Community Importance (SCI)	F.1b; F.2b; F.3a; F.3b; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Special Protection Area (SPA)	F.1b; F.2b; F.3a; F.3b; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Important Bird Area (IBA)	E4.a,b,c,d
Buildings and areas declared to be of notable public interest (Art.136 D.lgs 42/2004)	F.3a; F.3b; E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Historical cultural sites + 100m (part II of Legislative Decree 42/2004)	F.1a; F.1b; F.2a;F.2b; F.3a; F.3b; E.1; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Areas subject to hydrogeological constraints	F.1b; F.2b; F.3b; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Areas of respect for the woods + 100m	F.1b; F.2a;F.2b; F.3a; F.3b; E.1; E.2a;E.2b;E.2c; E3a; E3b;
Shrub formations in natural evolution	F.1b; F.2a;F.2b; F.3a; F.3b; E.1; E.2a;E.2b;E.2c; E3a; E3b;
Coastal territories + 300m	F.3a; F.3b; E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Caves + 100m	F.1b; F.2a;F.2b; F.3a; F.3b; E.1; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;
Slopes	F.1b; F.2b; F.3b; E.2a;E.2b;E.2c; E3a; E3b; E4.a,b,c,d;

Table 3.2: Areas and sites unsuitable for specific type of plants - Puglia

From the previous table it can be seen that there are severe limitations on the installation of wind turbines of any size. As regards the photovoltaic on the roofs, there is a strong distinction between the systems with or without the development of external connection works. The latter refers to the possible need to build power lines and transformation substations for connection to the external electricity grid. It is clear that the adoption or otherwise of these connection works certainly cannot be an examination of the work of this thesis as a feasibility study would be necessary for each specific plant to be built.

In addition to the constraints on photovoltaics presented above, another limitation is added, in accordance with what is reported in the PPTR: all buildings included in the *homogeneous territorial area of type "A"* of the urban planning instruments in force are excluded from the possibility of constructing these plants (DM n. 1444 of 1968) [73]. The latter constraint has imposed further in-depth research work since the delimitation of homogeneous territorial areas is the responsibility of each municipality and usually available in urban regulatory plans as scans of non-digitized and dated worksheets. To conclude, like what was said for the Sicily region, there is not even in this case any specific information about the construction of agro-photovoltaic systems.

3.3.3 Lazio

In the case of the Lazio region, it was possible to examine its legislative framework on the basis of one of the most recent documents among all those used for the other regions, and consequently more suited with the energy emergencies and with the inclusion of more recent technologies and in line with the times.

The document entitled "*Linee guida e di indirizzo regionali di individuazione delle AREE NON IDONEE per la realizzazione di impianti alimentati da fonti energetiche rinnovabili (FER)*" [74], published in May 2022, was drawn up starting from the new Lazio regional landscape plan (PTPR - Piano Territoriale Paesistico Regionale) [75]. The latter, approved with Regional Council Resolution No. 5 of 04/21/2021 [76], is the planning tool through which, in Lazio, the Public Administration implements the protection and enhancement of the landscape by regulating the related actions aimed at the conservation, enhancement, restoration or landscape creation. It contains an organic regulation of the prohibitions and limits relating to the installation of RES plants on the regional territory and, therefore, is one of the main references adopted for the identification of unsuitable areas.

The Guidelines provide indications, throughout the region, of the areas unsuitable for the construction of plants powered by RES, in line with the criteria of the Ministerial Decree of 10 September 2010 and with the provisions of the PTPR. The intent is, therefore, to offer a territorial framework of reference, defined and fully shared with respect to which to plan the development of activities on the regional territory to encourage the development of RES plants. This regulatory framework, inspired by strongly enhancing environmental, social and economic sustainability, has the objective of guiding the transition of the energy system to decarbonization and, at the same time, of reconciling the policies for the protection of the landscape, the environment, soil conservation and agri-food production.

For the purpose of identifying unsuitable areas, the PTPR first of all defined, for each type of RES, its class of compatibility with the landscape system or with the specific area of the territory according to their technical characteristics (visibility, consumption soil, size) and potential negative impacts on the territory. Therefore, three compatibility codes have been defined: Compatible (*C*), Partially Non-Compatible (*PNC*) and Non-Compatible (*NC*). If a type of RES has been defined as PNC, for a particular area or landscape, it means that its realization can take place with limitations, and these are particular to each individual case.

To follow, table 3.3 shows the compatibility of the RES plants in relation to the areas subject to restrictions and to the different landscape systems (as identified in the relevant sections of the PTPR).

RES plant types compatibility	PV P>20kW	PV P<20kW	PV Integrato	Eolico P>60kW	Eolico P<60kW
Ramsar areas (wetlands)	NC	PNC	PNC	NC	NC
Natura 2000 Network Areas (SCI, SPA) and IBA	NC	PNC	PNC	NC	NC
Natural landscape	NC	NC	C	NC	NC
Agricultural natural landscape	NC	NC	C	NC	PNC
Continuous natural landscape	NC	NC	C	PNC	PNC
Agricultural landscape of significant value	NC	PNC	C	PNC	PNC
Valuable agricultural landscape			C	PNC	PNC
Continuous agricultural landscape	PNC	C	C	PNC	PNC
Landscape of urban settlements	PNC	C	C	PNC	PNC
Evolving settlement landscape			C	PNC	PNC
Landscape of historic centers	NC	NC	PNC	NC	NC
Parks, villas and historic gardens			NC	NC	NC
Scattered historic settlement landscape	NC	NC	PNC	NC	NC

Table 3.3: RES plant type compatibility - Lazio

As already anticipated, in some cases the construction of RES plants is permitted only under certain conditions and limitations, and these depend on the type of system and the building or area in which it has to be implemented. In particular, as regards photovoltaics, although it is classified as PNC, this can be achieved if, for example, the following conditions are met: the surface of the system is not greater than that of the roof on which it is built; its implementation is subject to the contextual landscape report containing the specific study of compatibility with the protection of landscape assets and historical and cultural heritage; measures to mitigate the impact on landscape assets are envisaged.

As regards the construction of wind turbines when classified as PNC, these can be built if conditions are met such as: they are built in the areas pertaining to existing buildings if integrated or partially integrated with them in compliance with the building typologies; a prior assessment of landscape compatibility is carried out; adhering to or integrated or partially integrated into agricultural buildings or outbuildings; measures to mitigate the impact on landscape assets are envisaged.

Lazio region has an exceptional importance compared to the other regions under examination. This, in fact, thanks to the creation of a very recent regional landscape plan, was able to include considerations about agro-photovoltaics. In particular, according to the guidelines, its compatibility with the type of area depends on the Land Capability Classification (LCC) of the land. The Land Capability Classification identifies eight main classes based on the type and severity of the limitations. The first four classes indicate soils suitable for agricultural activity, albeit with increasing limitations, while classes V to VII include soils unsuitable for this activity, but where it is still possible to practice forestry and grazing. Class VIII soils can only be used for recreational and conservation purposes. In conclusion, for class I and II LCC, the APV is Non-Compatible (NC). For classes higher than II, it is Compatible (C) subject to punctual verification of the land use capacity class.

3.3.4 Tuscany

At the basis of the analysis of the regulatory framework of the Tuscan region, the PAER (Piano Ambientale ed Energetico Regionale) is a very functional tool containing interventions aimed at protecting and enhancing the environment, but it moves in an ecosystemic context which requires particular attention to renewable energies and to saving and recovering resources [65]. The planning envisaged by the two PAERs published so far (2013 and 2015), not only take into consideration the European directives and the national acts already discussed previously, but also the provisions dictated by the regional law of 21 March 2011, n. 11 [77], as integrated and modified with regional law 4 November 2011, n. 56.

As regards the wind energy sector, the annex of the PAER "Areas not suitable for wind power plants" contains all the information about the constraints to be included and then considered in the assessment of the technical potential of wind energy. This, besides identifying unsuitable areas, indicates the criteria for the inclusion and mitigation of the possible environmental and landscape impacts of the plants and the respective connected structures, in order to improve the architectural and landscape quality of the projects, for the correct construction of the plants, the management methods useful for guaranteeing the correct use of the land and of the plants also in the subsequent phases of operation and decommissioning [78]..

Below, the unsuitable areas are listed. As will be observable, these have exceptions regarding the impacts that can be installed according to their nominal power and geometric characteristics, such as height or diameter of the rotor.

- Buildings and areas of notable public interest (art. 136 of the Code of cultural heritage and landscape);
    - Except: Plants for self-generation with power less than 20 kW; Plants with power lower than 60 kW, overall height lower than 1.5 m and diameter less than 1 m.
- Areas referred to in art. 142 paragraph 1 of the Code lett. a) "coastal territories included in a depth band of 300 meters from the shoreline, even for elevated land above the sea";
    - Except: Plants for self-generation with power less than 20 kW; Plants with power lower than 60 kW, overall height lower than 1.5 m and diameter less than 1 m. Single wind turbine with power lower than 60 kW and overall height lower than 30 m.
- Areas referred to in art. 142 paragraph 1 of the Code lett. e) "glaciers and glacial cirques; lett. i) Wetlands in accordance with the Ramsar Convention;
    - Except: No exception;
- Areas of archaeological interest (art. 142 paragraph 1 of the Code letter m);
    - Except: Plants for self-generation with power less than 20 kW; Plants with power lower than 60 kW, overall height lower than 1.5 m and diameter less than 1 m. Plants with power lower than 60 kW, overall height lower than 30 m

    and with a preliminary study of the archaeological risk in order not to compromise the integrity of the sites.

- National, regional, provincial, interprovincial parks classified as Zones A and B (pursuant to art. 12 of Law 394/1991, pursuant to art. 142 paragraph 1 letter f) of the Code and by Regional Law 49/1995);
    - Except: No exception;
- National, regional, provincial, interprovincial parks classified as Zones C;
    - Except: Plants with power lower than 60 kW and overall height lower than 30m;
- National, regional, provincial, interprovincial parks classified as Zones D;
    - Except: Plants specifically envisaged by the specific planning tool of the protected area.
- Integral natural reserves (national, regional), pursuant to art. 142 paragraph 1 lett. f) of the Code and by Regional Law 49/1995;
    - Except: No exception;
- Animal population reserves pursuant to art. 142 paragraph 1 lett. f) of the Code and by Regional Law 49/1995;
    - Except: Plants with power lower than 60 kW and overall height lower than 30m;
- Special Protection Area (SPA);
    - Plants for self-generation with power less than 20 kW;
- Sites included in the Unesco Heritage list belonging to historic centers and areas intended for residential and/or commercial use;
    - Except: No exception;
- Sites included in the Unesco Heritage list belonging to areas other than those defined in the previous point;
    - Except: Plants for self-generation with power less than 20 kW; Plants with power lower than 60 kW, overall height lower than 1.5 m and diameter less than 1 m;
- Areas identified on the basis of the "Guidelines for the assessment of the environmental impact of wind farms", a regional study on the probable significant impacts of wind farms on naturalistic elements of high value.
    - Except: Plants for self-generation with power less than 20 kW;
- Historic centers as identified by territorial planning tools;
    - Except: No exception;
- Residential areas as identified by territorial planning instruments;
    - Except: Plants with overall height lower than 1.5 m and diameter less than 1m;
- Areas for commercial and/or tertiary use where specifically indicated in the territorial planning instruments;
    - Except: Plants with power lower than 1 MW, overall height lower than 1.5 m and diameter less than 1 m. Plants with power lower than 1 MW and overall height lower than 60 m.
- Areas for industrial use, in port and rear port areas, in freight villages and intermodal centers as identified by territorial planning tools;
    - Except: Plants in which the wind generator closest to a building maintains a minimum distance from the same building at least equal to the overall height of the wind generator.
- Areas of perceptual aesthetic value whose image is historicized falling within visual cones and basins;
    - Except: Plants with overall height lower than 1.5 m and diameter less than 1m;

- The agricultural areas, as identified by the territorial planning tools, in the case of plants with nominal power greater than 200kW;

The Tuscan legislation does not directly identify the areas that are unsuitable for PV on the roofs, but describes in detail the authorization procedures and paths to be followed for the installation of PV plants according to the sizes. Generally, a prior communication to the Municipality is sufficient to install PV plants regardless of the power in the case of plants on a building, with the condition that they fall outside zone A) referred to in the DM public works 2 April 1968, number 1444 and separately authorization of cultural heritage or pursuant to art. 136 lett. B and C [48]. In addition, with regard to agro-photovoltaic, also in this case there is no useful information about the possibility of installing these types of systems.

In conclusion, if on a European or national scale the production of energy from renewable sources is often considered as unilaterally positive, on a regional and local scale, as has been observed by this analysis on the legislative framework at a regional level, the development of renewable energies can produce negative externalities that affect the cultural and natural values of the landscape, with potential repercussions on tourism, agricultural production and the identity and recognizability of places.

4. Methodology

This chapter illustrates the methodology through which it was possible to obtain an estimate of the technical potential of rooftop solar PV, Agro-photovoltaic APV and the technical potential of onshore wind on non-interconnected islands considered in this study. The calculation of the technical potential of renewable energy sources is a first and essential ingredient by which to start the energy transition process and allow the achievement of sustainable development of the area in question. Moreover, this methodology and the results obtained from its implementation can constitute a powerful tool useful to policy makers in the development of new models, scenarios and decarbonization strategies in line with the established energy and environmental objectives [69].

All the information collected in the previous chapter relating to the legislative framework at the various levels (Europe, National and Regional) is necessary to understand the difficulties and constraints affecting the deployment and exploitation of RES in such specific and vulnerable territories as the minor Italian islands are. In this context, the geographic information system (GIS) enables the representation of information about the region under study and collects all the data needed to exploit the RES potential, in fact is a powerful tool that can perform complex spatial queries with georeferenced data [79].

Although several researchers addressed the energy and spatial planning problem using GIS-based multicriteria analysis methods [80], this thesis basically follows the same steps of the methodology defined in [69] and in the master's thesis [81]. These two works, in addition to the definition of the method, have implemented that procedure in the non-interconnected Sicilian minor islands and obtained the technical potential of rooftop solar PV and onshore wind. For the sake of explicitness, the results of these have been included in the thesis and the outputs obtained from the application of this methodology to all the remaining minor Italian islands have been carried out too, according to the particular local and regional legislations. Additionally, the methodology for the APV and the associated results have been added, giving to the future renewable energy mix an important new option.

Before going on to describe in detail the methodology used, it is necessary, first of all, to clarify what is meant by technical potential in the field of renewable energies. According to [82], there are five types of renewable energy potential, as described below:

- Theoretical Potential: the physically usable amount of energy within a given region and time.
- Geographical potential: the area available for energy production, taking into account constraints such as natural protected areas and other land uses such as urban structures and transport routes.
- Technical Potential: the amount of installable capacity under technical constraints within a given region and time.
- Economic Potential: the technical potential that can be realized economically within a given region and time.
- Feasible Potential: the actual achievable economic potential, also taking into account market, organizational and social barriers, which means that the economic potential is not fully realized in practice.

This thesis, as already mentioned, focuses only on the technical potential evaluation and, in order to do that, the theoretical and geographical potentials will be necessarily carried out first. The steps that have been followed for the assessment of the technical potential will be explained in detail later, both for wind turbines and PV plants (whether Rooftop PV and APV systems).

4.1 Spatial Energy Planning, GIS and Web GIS

In view of the evaluation of the technical potential of the renewable energy technologies involved in this thesis, the geographic information system (GIS) represents an essential element in the approach called Spatial Energy Planning (SEP). This kind of approach, which is perfectly suited to the purpose and the particular context of the thesis, is a tool with the potential to provide significant insight into energy planning processes that could prevent barriers to the integration of renewable energy technologies at different scales and levels [83].

As already mentioned, although nowadays many renewable energy technologies are techno-economically viable and essential for the process of sustainable development, their implementation encounters strong slowdowns and contrasts due to their not modest environmental, territorial and social impact. Among the factors that determine this, their low energy density is certainly the one that plays one of the most significant roles. To date, the surface area required for renewable energy systems is about three orders of magnitude greater than that for non-renewable energy systems, worsening the existing environmental policy challenges, from increasing land competition, to visual impacts, especially in peculiar contexts such as the minor islands [84]. For this reason, the SEP approach finds great utility, being a tool based on the land-use planning process, capable of allowing the evaluation of different configurations of the energy supply system and the evaluation of the local renewable energy resources of the area in question, taking into account all the regulatory constraints relating to environmental and territorial safeguard [83].

GIS can be defined as a set of tools for collecting, storing, manipulating, analyzing, and visualizing spatial data, referenced by spatial or geographic coordinates using a projection system [85][86]. Nowadays there are several GIS software, such as, for example ArcGIS or GRASS GIS or others used daily even in non-strictly scientific fields such as Google Map and Google Earth.

In this thesis, the software that has been chosen is QGIS, which is a free and open-source desktop geographic information system application that provides for viewing, editing and analysis of geospatial data [87]. This software, thanks to its features and functionality, allows you to determine, during the energy planning process of a region, the identification of which areas are suitable or unsuitable for the installation of a certain type of renewable energy plant, according to the potential environmental, visual or social impacts that these could have and to the regulatory framework of the territory in question.

Numerous different file types can be handled by QGIS. The most used formats can be grouped into two broad categories: Raster and Vector data. Raster data is a type of continuous spatial data that consists of a matrix of cells organized into rows and columns in which each cell (or pixel) represents specific information (such as temperature, irradiance, wind speed, elevation etc). Whereas vector data is a type of spatial data used for storing data that has discrete boundaries (such as administrative limits, environmental constraints, buffer zones etc.) [88].

The study of the regional regulatory framework, reported in the previous chapter, was accompanied by the research and collection of environmental, landscape and territorial constraints in the form of a layer generally having a vector type extension (for example, a shape file format). Each region that has been included in the thesis has an online geoportal on the regional institutional site, which allows the download of files useful for the thesis itself, such as, for example, hydrogeological risk areas, IBA areas, residential areas etc. This phase, although apparently simple, hides some important difficulties: not all geoportals are updated to the latest regulatory changes; they do not allow an intuitive and immediate download of the files; navigation within a geoportal of one region can be completely different from another; lack of uniformity and conformity between the various geoportals in the display and manipulation of georeferenced data. In some cases, in addition, some constraints, essential for calculating the technical potential, can be found on the regional site in the form of pdf or jpeg files, therefore not georeferenced. In cases like these the precise and time-consuming creation of vector layers on QGIS starting from the cartography image (sometimes even of low quality) was necessary.

In addition, the important study and elaboration of the regional regulatory frameworks that has been carried out makes this thesis capable of providing clear and concise information in the field of the suitability of the areas in which to install RE technologies, extending to four different Italian regions, thus also allowing a comparison between these. For these reasons, in fact, starting from this thesis, a specially designed and structured Web GIS will be developed on the basis of the data collected and the results elaborated from the work of this thesis itself. In particular, a Web GIS is a distributed information system consisting of at least a server and a client, where the server is equipped with the GIS and the client uses a Web browser or any desktop software that can work online [85]. The decision to publish the results and data collected in this thesis in a Web GIS platform is due to the various advantages that this offers, such as the ability of the client and server to work all across the globe allowing, therefore, allowing the possibility of being consulted in real time and freely by all those who need for the purposes, for example, of an evaluation or planning of the territory in terms of installation of RE technologies, simplifying and accelerating the energy transition process [85].

4.2 Assessment of onshore wind energy technical potential

In this paragraph the steps through which the wind technical potential has been calculated are presented, in line with what was done in [69] and [81]. In addition to using QGIS, the implementation of another necessary software, WAsP (Wind Atlas Analysis and Application Program) was necessary in this phase. This software suite, published by the Danish technical university DTU, allows operations such as wind resource assessment, siting and energy yield calculation for wind turbines and wind farms in sites located in all kinds of terrain all over the world [89]. In this thesis, this software has been used to calculate, for each island, the average wind speed, power density and annual energy production.

Figure 4.1 below illustrates the main steps of the methodology for assessing the technical wind potential.

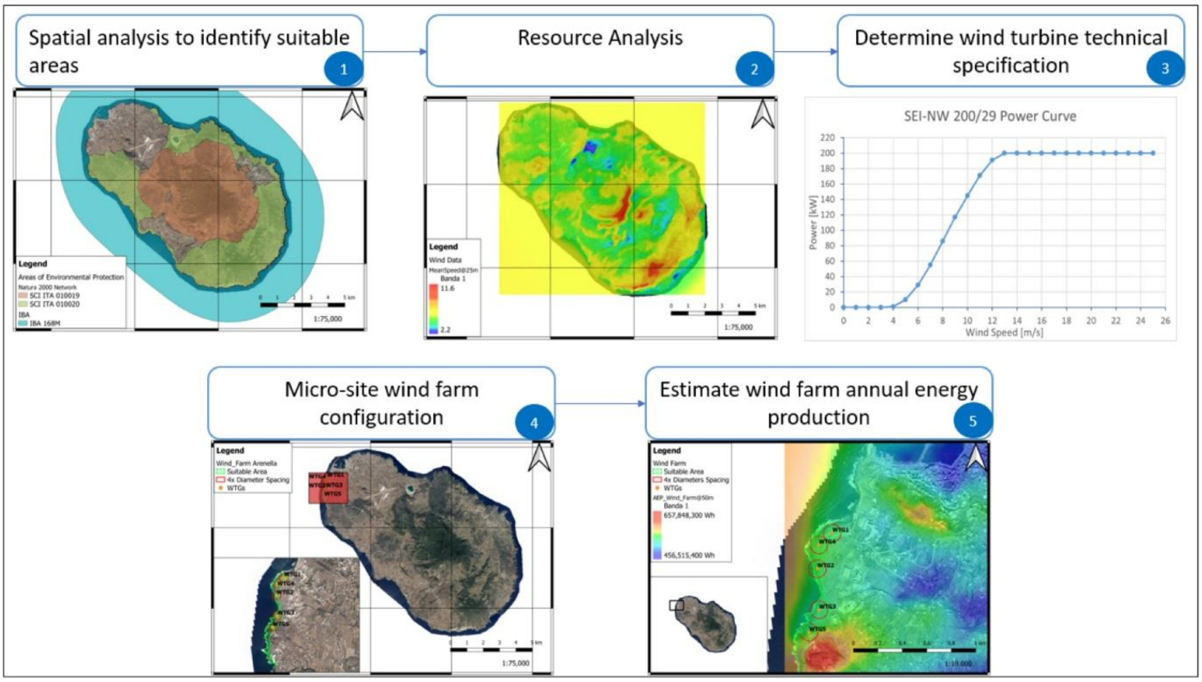


Figure 4.1: Wind technical potential workflow [69]

1. Identification of the area suitable for the installation of wind farms;
2. Wind resource assessment;
3. Wind turbine technical specifications;
4. Micro-site wind farm configuration;
5. Estimation of the AEP (Annual Energy Production) in relation to each type of wind turbine;

4.2.1 Identification of suitable area for WT installation

The first phase is closely related to what is reported in the previous chapter. Through the study of the legislative constraints, it was possible to identify, for each island, which areas are unsuitable for the installation of wind turbines according to their nominal power and size. Through the investigation in the regional geoportals, the georeferenced layers corresponding to the areas characterized by landscape or territorial constraints were downloaded and imported in QGIS. In this, the layers were organized, grouped, and manipulated through the geoprocessing tools offered by QGIS in order to identify, within the island territory, a portion of it that would allow the installation of wind turbines or wind farms in line with the regional and national regulatory framework. Figure 4.2 below shows an example of the overlapping of some layers binding the installation of wind turbines on the island of Ponza (Lazio).

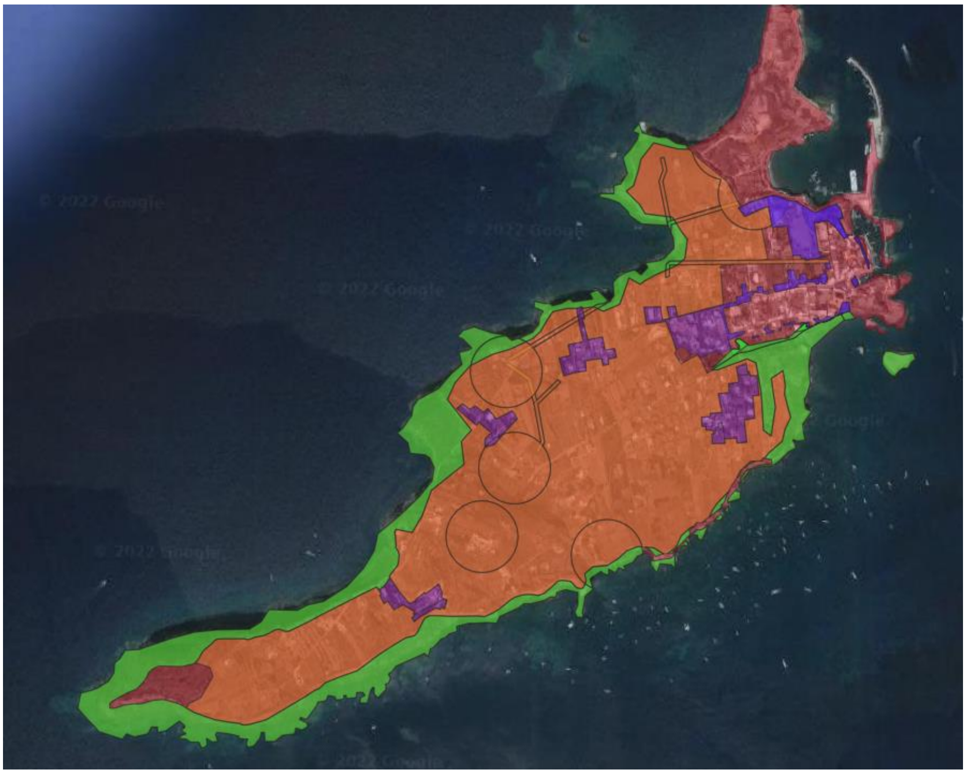


Figure 4.2: Wind turbine unsuitable areas in Ponza Island

In addition to the layers downloaded from the geoportals relating to environmental constraints, it was also necessary to create other essential layers in this phase such as, for example, the areas of distancing from housing units, inhabited centers or helicopter rescue bases. These were obtained from additional georeferenced layers downloaded from geoportals and from the "Buffer" geoprocessing tool. In the figures below a visual demonstration of the buffer zones from inhabited units figure 4.3 and from the helicopter rescue base figure 4.4 are shown.

Figure 4.3: Giannutri buffer zones from inhabited units

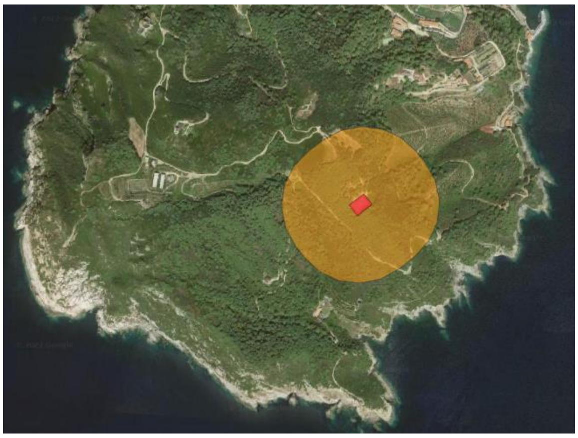


Figure 4.4: Gorgona buffer zone from helicopter rescue base

Another essential factor to consider is related to the topographic characteristics of the land, in fact areas with steep slopes pose several challenges, such as the limited accessibility of cranes and trucks; moreover, such sites are also prone to turbulence, which leads to higher installation and maintenance costs [90]. Therefore, for these reasons, all the portions of the island having a slope greater than 20% have been excluded. The analysis of the slope of an area takes place starting from the Digital Elevation Model (DEM), a raster file defined as an ordered or unordered digital set of ground elevation (spot height) for terrain representation [91]. Once this raster file has been imported into QGIS (easily available online and on regional institutional sites), it becomes an input to the Raster analysis function called "Slope". This tool outputs another raster file containing, in each pixel, the slope (%). Subsequently this must be vectorized, in order to be manipulated and then used with the other vector files relating to the environmental and landscape constraints already described. In the following image, an example of a reticulated vector layer of the slope, showing only the areas where the slope is greater than 20% [figure 4.5].

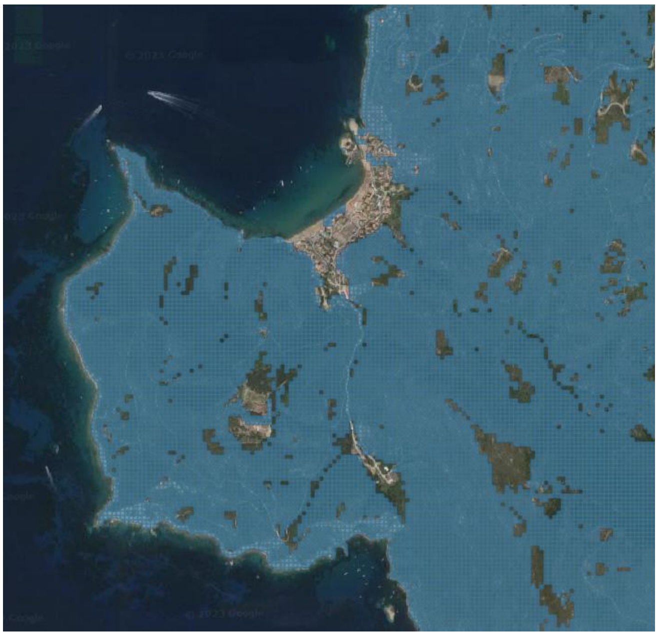


Figure 4.5: Slope areas greater than 20% in Giglio Island

To conclude, the last criterion that has been added concerns more an economic aspect, related to the productivity of the turbines and, thus, with their Capacity Factor.

CF is defined, in general, as the annual generation of a power plant divided by the product of the capacity and the number of hours over a given period. In other words, it measures a power plant's actual generation compared to the maximum amount it could generate in a given period without any interruption [92].

According to a study on the evaluation of wind energy technical potential with a GIS-based approach, areas with capacity factors higher than 20% have been selected as potentially suitable for wind power installations that could be economically viable [93]. As a matter of fact, according to 2021 statistics conducted by Wind Europe [94], the capacity factors for onshore in the EU and UK were 23%, while for new onshore wind farms, the CFs are estimated at between 30-35%. Therefore, it is thought reasonable to place a lower limit on the capacity factor of 20%.

It must be anticipated here that, unfortunately, among the quantities of the resource grid calculated on WAsP (as explained in the following paragraph), the one relating to the capacity factors cannot be exported. However, it has been empirically observed that for wind speed values greater than 4.5 m/s (which can be consulted in the exported resource grid relating to the average wind speed), CF values higher than 20% are obtained. Therefore, to be conservative, a lower threshold of 5 m/s was imposed and added to all the other criteria for identifying the Eligible Area already explained. Although in doing so the area available for installation is reduced, nevertheless, for each turbine, an adequate economic viability is guaranteed.

4.2.2 Resource Analysis

In this second step the theoretical and geographical potentials were calculated. The calculation of the wind resource, in this case corresponding to the average wind speed and power density, was extended to the whole area of the island and not only to the suitable areas identified in the previous step. In this way it is possible to provide more complete information which highlights how, in certain cases and sites, there is an important potential that cannot be exploited due to regulatory limitations. Furthermore, the knowledge of the wind resource is a fundamental element for the subsequent phase of micro-siting as it allows the placement of the wind turbines in the portions of land with a greater resource and therefore determining a better performance of the plant itself.

In order to calculate the wind resource, it is firstly necessary to retrieve the information on the wind climate. The Global Wind Atlas (GWA) is a free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world, and then perform preliminary calculations. It facilitates online queries and provides freely downloadable datasets based on the latest input data and modeling methodologies where users can download high-resolution maps of the wind resource potential [95]. To extract data from the GWA it is sufficient to manually select a point falling within the area of the island in question (alternatively it is also possible to enter the coordinates of the point). Subsequently it is possible to download the Generalized Wind Climate of the area considered as a file whose format is the WAsP lib-file, therefore precisely suitable for use in the WAsP software. The GWC data is derived from the mesoscale grid cell closest to the center of the selected area and it is intended for use in microscale modeling software such as WAsP [95]. A Generalized Wind Climate (GWC) contains the terrain-independent wind climate and it refers to certain standard conditions, i.e. wind roses (sectorial frequency of occurrence) and wind speed distributions (as Weibull probability distribution function) for five standard heights above ground level and five land cover types (roughness classes) in 12 wind direction sectors [95], as shown in the figure below [figure 4.6].

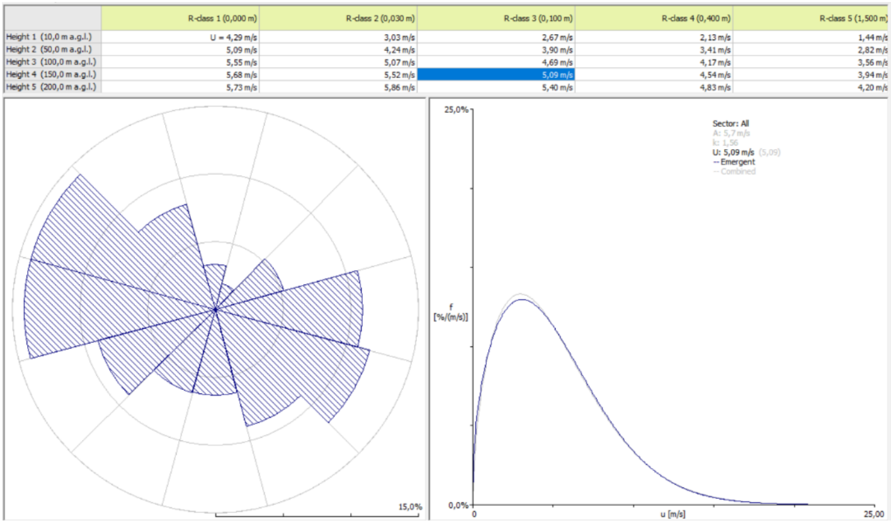


Figure 4.6: Wind rose and wind frequency distribution

At this point the terrain analysis is performed, thanks to which it is possible to create the orography and the roughness vector map. To do this, the tool included in the WAsP software suite, the WAsP Map Editor, allows to directly import the elevation and roughness maps for the selected area from the GWA Web-Database. These two maps are then merged into one vector map and imported into WAsP. Figure 4.7 shows the result of merging: the green and blue lines depict the roughness change vector where the roughness class varies, while the red lines show the contour line along which the elevation is constant.

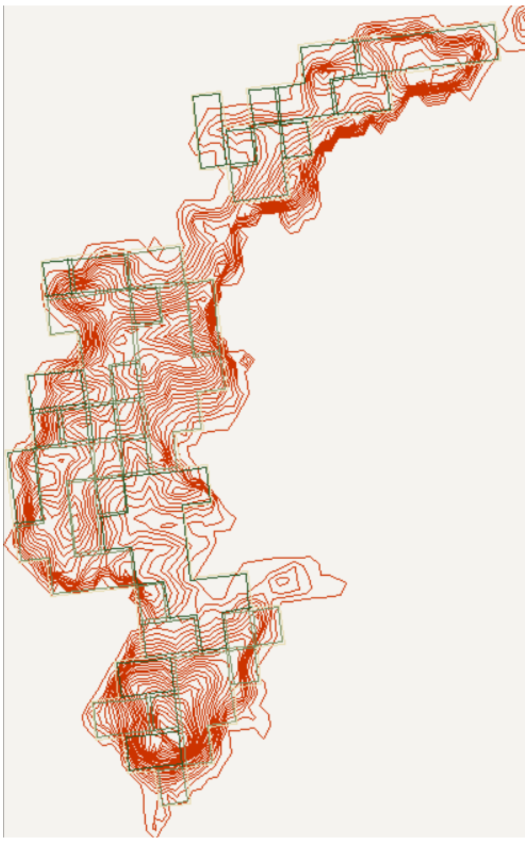


Figure 4.7: Roughness and Orography map in Ponza Island

At this point, knowing the characteristics of both the terrain and the wind climate, the PWC (Predicted Wind Climate) is obtained from the GWC, which takes into account the specificities of the terrain and therefore representative of the actual wind resource in the selected area.

In order to extract the wind resource, it is necessary to calculate the resource grid, i.e. a further map vector containing the results of the analysis performed by WAsP whose calculation inputs are the GWC, the orography and roughness map and a specific hub height at which to calculate the main quantities of interest. As will be observed in the following paragraph, three are types of turbines chosen, which have different heights. Therefore, for each island, three resource grids were calculated for each height in relation to the heights of the three chosen turbines. There are numerous quantities that can be obtained after calculating the resource grid and these are exportable in the form of georeferenced raster files (ASCII format). However, as previously said, only the average wind speed and power density were chosen as representative of the wind resource and therefore these were exported and subsequently imported into QGIS. To have the possibility of being manipulated and better visually displayed, these have been vectorized and therefore modified in the symbology in order to adopt a colored graduated scale that better represents the resource itself, as shown in the following figure [figure 4.8]:

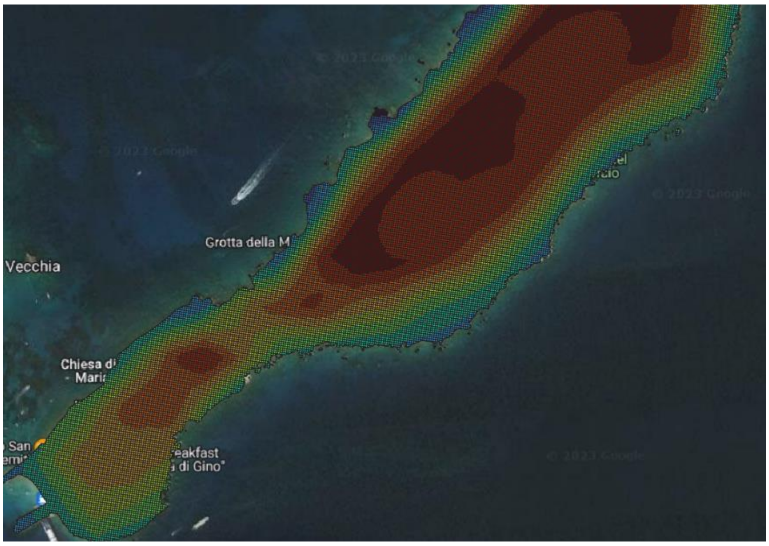


Figure 4.8: Mean speed map in San Nicola Island

4.2.3 Wind Turbine technical specifications

As already mentioned, the Technical Potential is defined, according to [82], as the amount of installable capacity under technical constraints within a given region and time. At this point, once the wind resource is obtained, the technical characteristics of the turbines must be included. In order to have a congruence and concordance with the previous thesis work already mentioned, for this thesis the same three turbine models of the work carried out in the Sicilian islands were selected: these belong to the most common type of wind turbine, namely the horizontal axis wind turbine (HAWT) with 3 blades. In this way, therefore, it is possible to make a meaningful comparison of the results between the four regions. Furthermore, these three types of turbines, with power and dimensions of three different orders of magnitude, allow the possibility of carrying out a more in-depth analysis of the territory and of the respective installation potential since, according to the legislative framework already illustrated previously, the limits to the installation, for each region, are often a function of the nominal power and size of the turbines themselves.

The three turbines and their respective technical characteristics are listed and shown below:

- Ryse Energy E-20 HAWT (20 kW) [96];.

Ryse Energy E-20 HWAT (20 kW)		
Generator	Type	Permanent Magnet
	Maximum Power	20 kW
	Rated Power	18 kW
Rotor	Configuration	Horizontal Axis
	No. of Blades	3
	Blade Material	Glass fibre
	Blade Length	4.5 m
	Rotor Diameter	9.8 m
	Swept Area	75.4 m^2
	Nominal Rotor Speed	120 rpm
	Pitch/Yaw	Downwind active pitch with assisted yaw
Wind	Cut-In Speed	2 m/s
	Rated Wind Speed	11 m/s
	Cut-Out Speed	30 m/s
	Survival Speed	70 m/s
Weights	Nacelle/Rotor	1,000 kg
Towers	Lattice	15 – 36 m
	Monopole	18 – 27 m
	Tilt-Up	18 – 27 m
Design Parameters	Turbine Design Class	IEC 61400-2 Class I
	Temperature Range	-20° to 50°C
	Lifespan & Servicing	20 years, subject to regular maintenance

Table 4.1: Ryse Energy E-20 HWAT technical specification

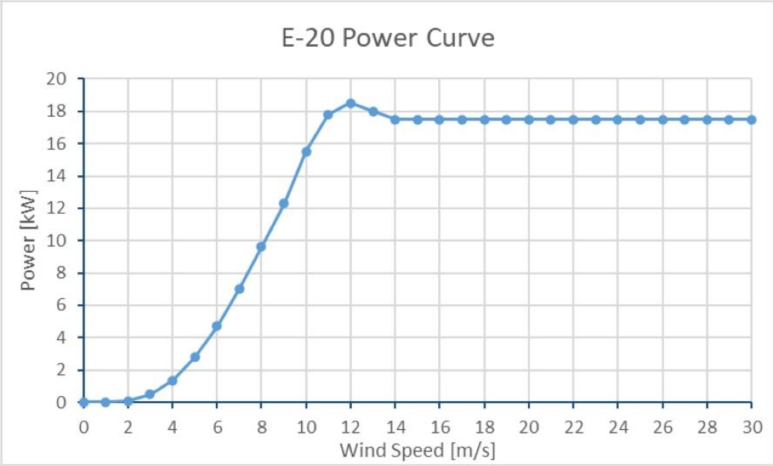


Figure 4.9: Ryse Energy E-20 HWAT power curve

- SEI-NW 200/29 HAWT (200 kW) [97];

SEI-NW 200/29 HAWT (200 kW)		
Generator	Type	Three-phase 4-pole asynchronous
	Maximum Power	225 kW
	Rated Power	200 kW
Rotor	Configuration	Horizontal Axis
	No. of Blades	3
	Blade Material	Glass fibre
	Blade Length	13.4 m
	Rotor Diameter	29 m
	Swept Area	660.5 m^2
	Nominal Rotor Speed	38 rpm
	Pitch/Yaw	Fixed Pitch / Fixed Tilt
Wind	Cut-In Speed	4 m/s
	Rated Wind Speed	13 m/s
	Cut-Out Speed	25 m/s
	Survival Speed	67 m/s
Towers	Galvanized Steel	30 m
Design Parameters	Turbine Design Class	IEC 61400-2 Class 1
	Lifespan & Servicing	20 years, subject to regular maintenance

Table 4.2: SEI-NW 200/29 HAWT technical specification

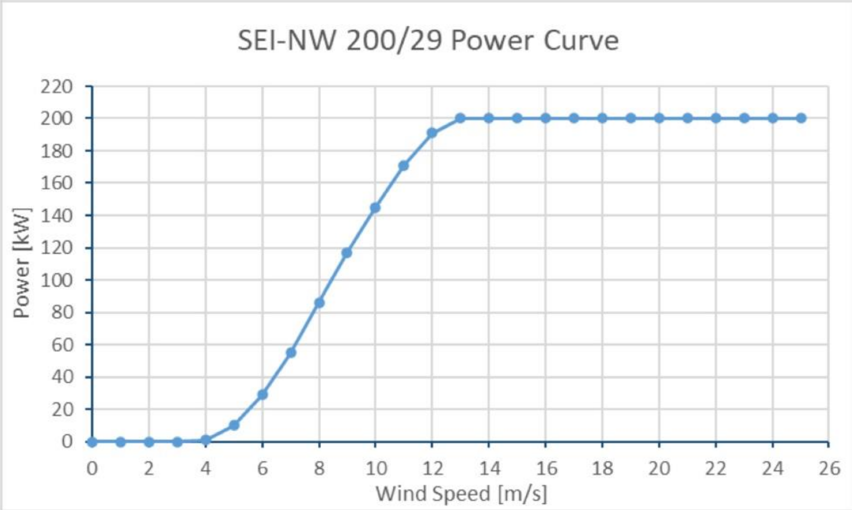


Figure 4.10: SEI-NW 200/29 HAWT power curve

- Vestas V100-2.0 MW GridStreamer (2 MW) [98];

Vestas V100-2.0 MW GridStreamer (2 MW)		
Generator	Type	4-pole (50 Hz) doubly fed generator, slip rings
	Rated Power	2000 kW
Rotor	Configuration	Horizontal Axis
	No. of Blades	3
	Blade Material	Glass fibre
	Blade Length	49 m
	Rotor Diameter	100 m
	Swept Area	7854 m^2
	Nominal Rotor Speed	1550 rpm
	Pitch/Yaw	Pitch regulated with variable speed
Wind	Cut-In Speed	3 m/s
	Rated Wind Speed	12.5 m/s
	Cut-Out Speed	20 m/s
Towers	Tubular Steel Tower	80 m
Design Parameters	Turbine Design Class	IEC IIB
	Temperature Range	-20° to 40°C

Table 4.3: Vestas V100-2.0 MW GridStreamer technical specification

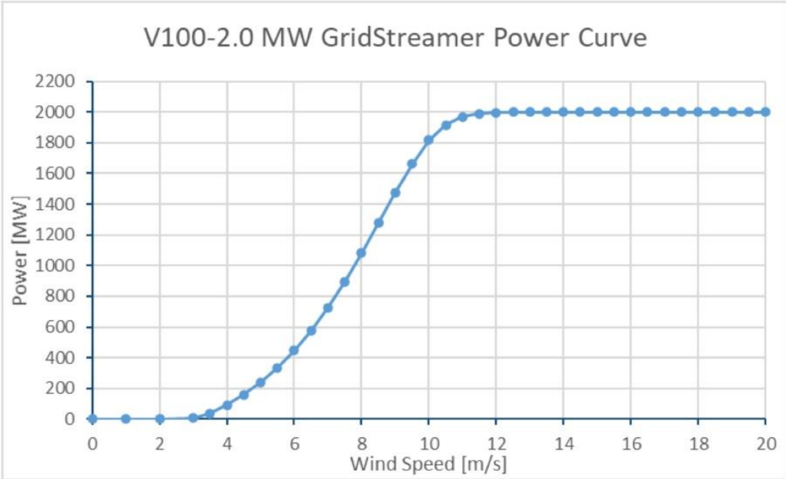


Figure 4.11: Vestas V100-2.0 MW GridStreamer power curve

The technical specifications and the power curves of the turbines presented above have been implemented through a further tool of the WAsP package, i.e. the WAsP Turbine Editor. This allows you to insert new types of turbines in the WAsP - Wind Turbine Generators samples, already included in the software since its installation. At this point, all that remains is to place the turbines in accordance with the regulatory and technical constraints previously presented.

4.2.4 Micro-site wind farm configuration

The fourth step consists in siting the wind turbines inside the wind farm. This is, in the design phase, a procedure to which particular attention must be paid and whose objective is the maximization of the electrical power extracted through an optimal placement of the turbines [99][100]. In particular, it is necessary to make a trade-off between two factors: on the one hand, the wake loss effect, the main cause of wind energy loss, increases as the proximity between the turbines increases [99]. On the other hand, the space available for the placement of the wind farm is already reduced due to environmental and safety constraints, as well as being affected by the possible investment cost of the land (an economic element not considered in the thesis but actually significantly relevant).

However, it is possible to perform site planning following the rule of thumbs for mutual spacing of wind turbine generators in order to avoid wake losses [69]. For this thesis, a distance of 5 times the diameter was chosen for the crosswind spacing; instead, for downwind spacing, a spacing of ten times the diameter was applied, as shown in figure 4.12 [69]:

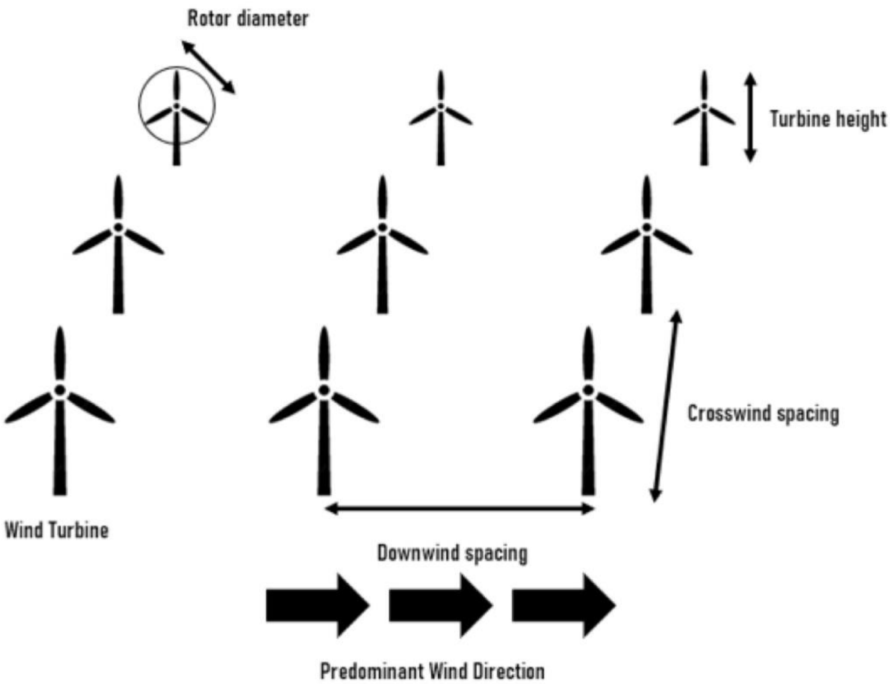


Figure 4.12: Schematic of wind farm micro siting [69]

In order to respect this mutual spacing, WAsP gives the possibility to show in the vector map the diameter of the turbines on the horizontal plane and also its multiples (x5D or x10D). Furthermore, for a more precise collocation, this software can be synchronized with Google Earth, showing in real time all the modifications made on WAsP and allowing the visualization of the real area and surroundings. Furthermore, in order to actually place the turbines in an area that complied with the constraints and technical assumptions made in paragraph 4.2.1, for each island and for each type of turbine, a layer was created on QGIS, which represents the areas suitable for installation of wind turbines, starting from the layers containing the areas identified as unsuitable. This vector layer was imported to Google Earth with a simple drag & drop operation and therefore the placement of the wind turbines could finally take place.

In the figure below [figure 4.13], a wind farm located on the island of Capraia is shown, reporting, in addition to the 3D representation of the wind turbines, the diameter of the distance between them and the area (in green) in which installation is permitted.

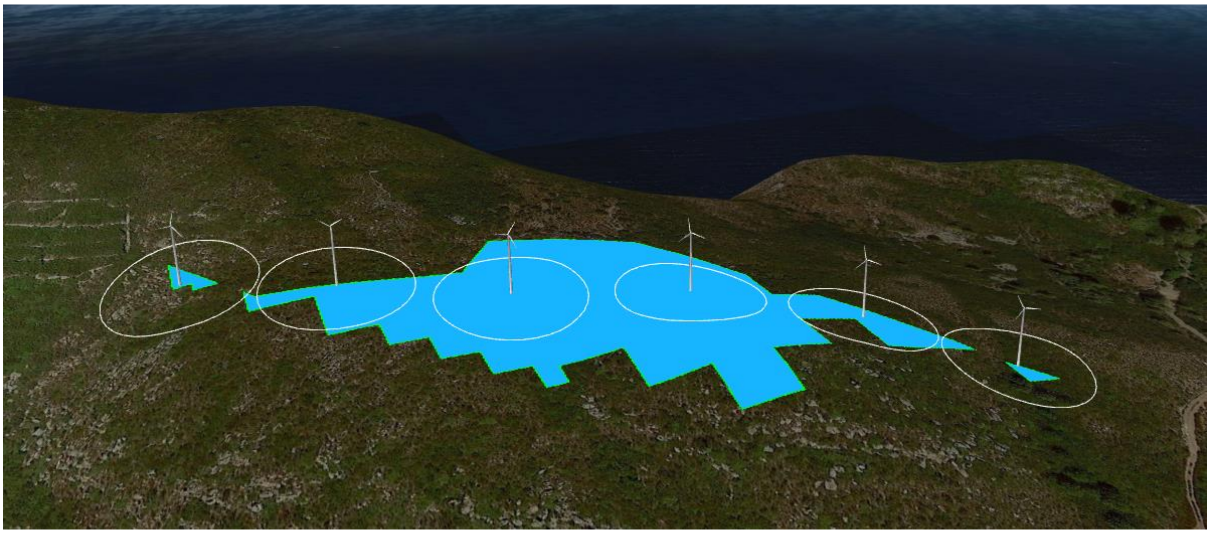


Figure 4.13: Example of wind farm in Capraia Island

4.2.5 Annual Energy Production estimation

The last and decisive step is the calculation of the technical wind energy potential. The conclusive results of this analysis are, fundamentally, the Technical Potential Wind Power (MW) and, subsequently, the Potential Wind Annual Energy Production (GWh/year).

In line with the steps presented, once the eligible area was identified in accordance with the exclusion criteria imposed, the vector map and the GWC were imported into WAsP, and after having created the wind farms by manually inserting the turbines, the calculation AEP on WAsP can be run. For the sake of clarity, figure 4.14, an example of the typical Workspace Hierarchy to follow on WAsP is illustrated:

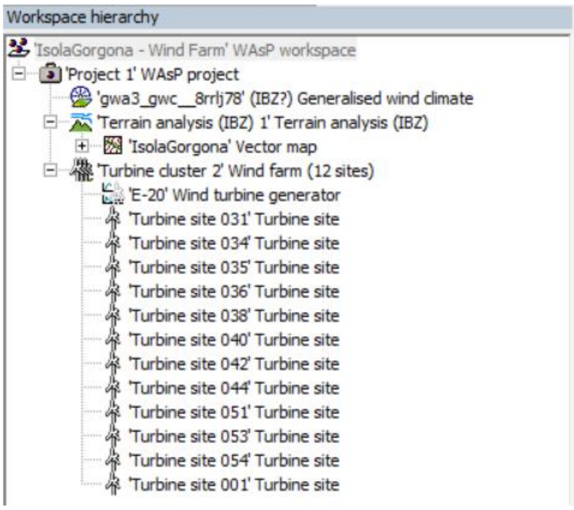


Figure 4.14: Typical WAsP workspace hierarchy

Once the software is run, it provides several interesting and very useful results. First of all, and most important for the thesis, is, as already anticipated, the Annual Energy Production [GWh/year], obtained as the difference between the Total Gross AEP and the Wake Losses. The Technical Potential wind power, on the other hand, will be nothing more than the sum of all the nominal powers of the wind farm's turbines. Subsequently, WAsP reports the statistics of quantities such as Proportional Wake losses [%], total Capacity Factor [%], Mean wind speed in [m/s], Mean wind speed (wake reduced) [m/s]; Air density [kg/m3], Power density in [W/m^2] and RIX (Ruggedness Index) [%].

The results, for each island, are reported and described in the following chapter. In addition to the calculations performed in this last step, for each island of each region, the resource grid relating to the AEP was exported and inserted on QGIS (where it was then vectorized for easier manipulation and visualization). As done for the other two resource grids imported into QGIS (average wind speed and power density), also in the case of this one, the entire extension of the island has been considered, so that also for the areas falling outside the eligible area, their potential can be viewed and consulted, as shown in figure 4.15:

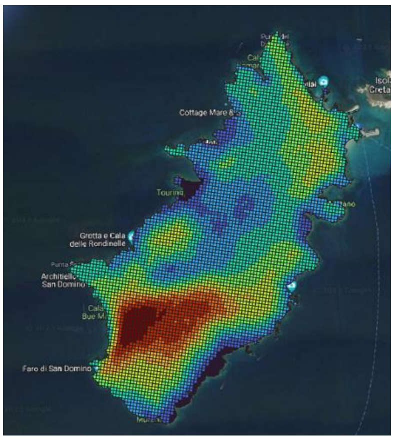


Figure 4.15: AEP 20 kW wind turbine in San Domino Island

4.3 Assessment of Rooftop PV and APV Technical Potential

In this paragraph the steps for calculating the photovoltaic technical potential will be presented, always in line with the methodology presented in [69] and [81]. Although the Rooftop PV and APV systems have decidedly different technical characteristics, scope of application and regulatory frameworks, the methodologies for calculating the technical potential of both share most of the same steps. The calculation of the technical potential, which applies to both systems mentioned above, consists of three general steps [69]:

- Input data collection and preparation;
- Solar irradiation estimation;
- Rooftop PV and APV technical potential evaluation;

Below is a summary workflow of the photovoltaic technical potential for both Rooftop PV and APV [figure 4.16]:

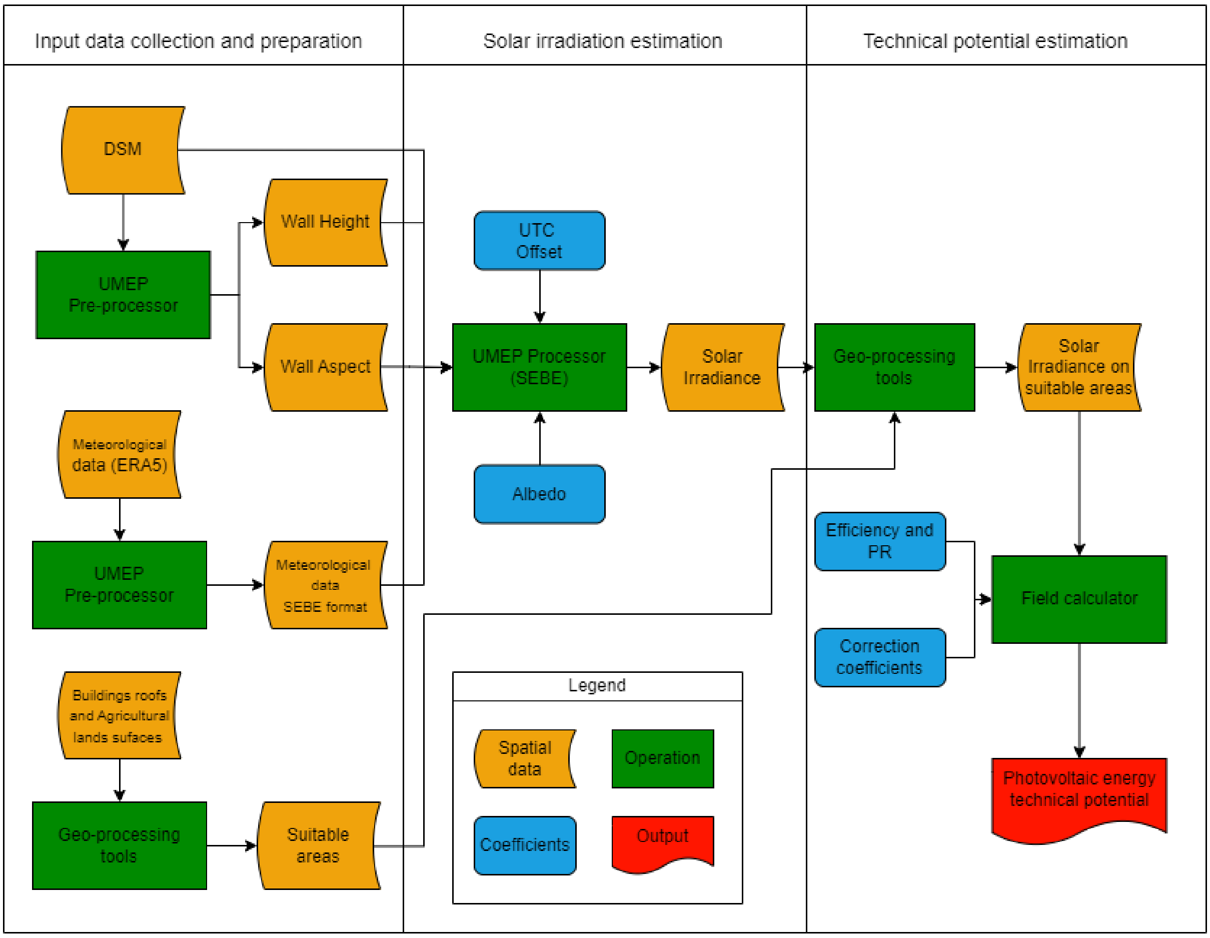


Figure 4.16: PV technical potential workflow

4.3.1 Input data collection and preparation

In this first phase, all the data and files needed to calculate the technical potential were collected and prepared. Some of these, as better shown later, correspond to the inputs of the leading tool of the methodology, i.e. SEBE (Solar Energy on Building Envelopes). This solar radiation model SEBE, developed by Lindberg et al.'s [101] and incorporated in UMEP (Urban Multi-scale Environment Predictor, a QGIS plug-in), allows estimates of solar irradiance on ground surfaces, building roofs and walls. It uses a shadow casting algorithm [102] with a digital surface model (DSM) and the solar position to calculate pixel wise potential solar energy.

The data necessary for the application of this methodology can be grouped into two categories [81]: territorial data and meteorological data. These will subsequently be imported into QGIS, where they will be analyzed and manipulated in order to calculate the technical potential.

4.3.1.1 Territorial data

First of all, starting from the territorial data collection, what is required for each area involved are high-resolution DSMs. These are digital elevation models with the particularity that, besides representing the bare-Earth surface (as Digital Terrain Models do), also contain information relating to both the natural and built/artificial features of the environment, making them widely used in fields such as urban planning [103]. The following figure [figure 4.17] shows the difference between DTM and DSM:

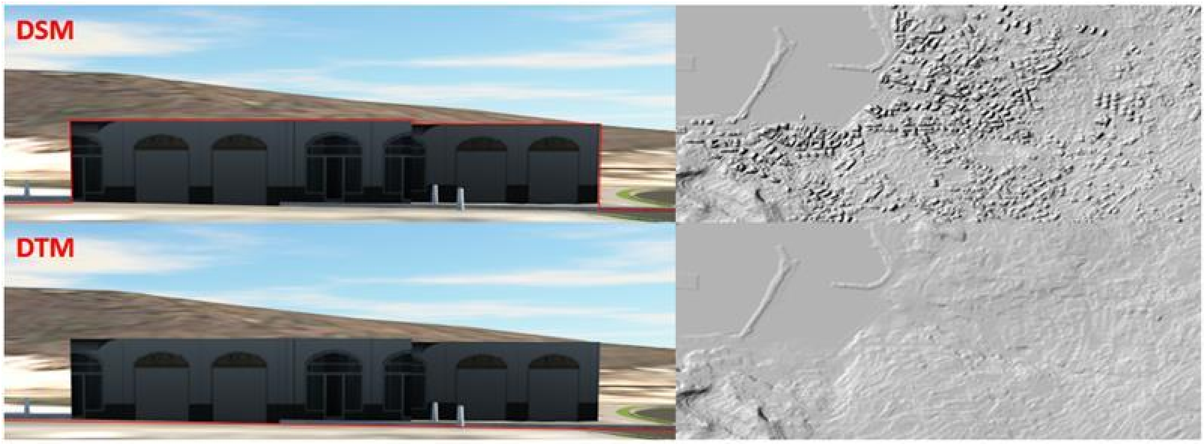


Figure 4.17: Difference between DSM and DTM [69]

Unlike DTMs, high resolution DSMs are difficult to find and download directly from the internet. In fact, they have been recovered in the national geoportal managed by the Ministry of the Environment and the Protection of the Territory and the Sea. A formal request for data was necessary, with the presentation of the specific areas of interest, represented in detail by a particular identification code of the particular parcel and subsequently sent by email to the ministry. Generically, each island is characterized by several DSMs and therefore, once the authorization was obtained and these raster files were downloaded, they were inserted into

QGIS and merged into a single DSM file extended to the whole area of the island, thanks to the "merging" raster miscellaneous tool. Among the DSM types available in the national geoportal, those with 2 x 2 m resolution were considered. These have been chosen in accordance with what was done in the previous thesis work [104]. Clearly, to obtain a higher accuracy of the results, it is also possible to obtain DSMs with a grid resolution of 1 m, however the implementation of these would have resulted in a considerable increase in the computational calculation and therefore in the necessary simulation times. It is now anticipated that, despite the high reliability of these data, the geoportal has flaws: for instance, in the case of island of Elba, most of the DSMs relating to the island's hinterland are missing and therefore it was not possible to carry out analyzes with SEBE on some parts of the territory.

It should also be noted that if the interest were only aimed at assessing the APV technical potential, then, in this case, even the use of the DTMs would have been sufficient. In fact, it is thought that such large and homogeneous surfaces, such as agricultural fields, are generically devoid of imposing and shading elements, such as buildings or other anthropogenic features, and therefore knowledge of the information contained in the DSMs would be superfluous for the purpose of calculating the irradiance. Since, in this thesis work, the use of the DSMs was in any case necessary for the calculation of the Rooftop PV technical potential, the irradiation in the agricultural areas was carried out using the same DSMs as input.

The other territorial data that were used were easily recovered in the geoportals of each region involved. As regards the Rooftop PV, the Numerical Technical Regional Maps (CTRN) were used; these are a type of topographic map produced by the regions of Italy to represent their territory, reporting the elements without changing their size and position, but showing their actual projection. In fact, objects such as buildings are represented with the shape of their perimeter seen from above [104], which can be approximately considered equal to the building roof area [81]. In order to be used and manipulated on QGIS, these maps must be downloaded in shapefile format, containing multiple layers divided into categories, such as, for example, the one relating to roads, residential buildings, industrial warehouses, shacks, commercial and industrial buildings and so on. Each region reproduced its own CTRN, each of which is characterized by different layer categories. In general, in this thesis, for the calculation of the Rooftop PV technical potential, the layers relating to residential buildings, commercial and industrial buildings or public administration ones have been used and, conversely, the layers relating to monuments, churches or abandoned and uninhabited buildings have been excluded.

In the case of the APV, the Land Use and Consumption Maps were of great use. Data on land cover, land use and the transition between the different categories are some of the most frequently requested information for the formulation of sustainable land management and planning strategies, to provide the information elements to support decision-making processes at community, national and local and to verify the effectiveness of environmental policies [105]. These were downloaded from each regional geoportal in shapefile format. Once implemented on QGIS, it is possible to observe how the surface of an administrative area is divided into numerous different layers, as shown in figure 4.18, according to its biophysical coverage, distinguishing, for example, artificial surfaces, historic centers, agricultural areas, woods, forests, semi-natural, wetlands and water bodies [105].

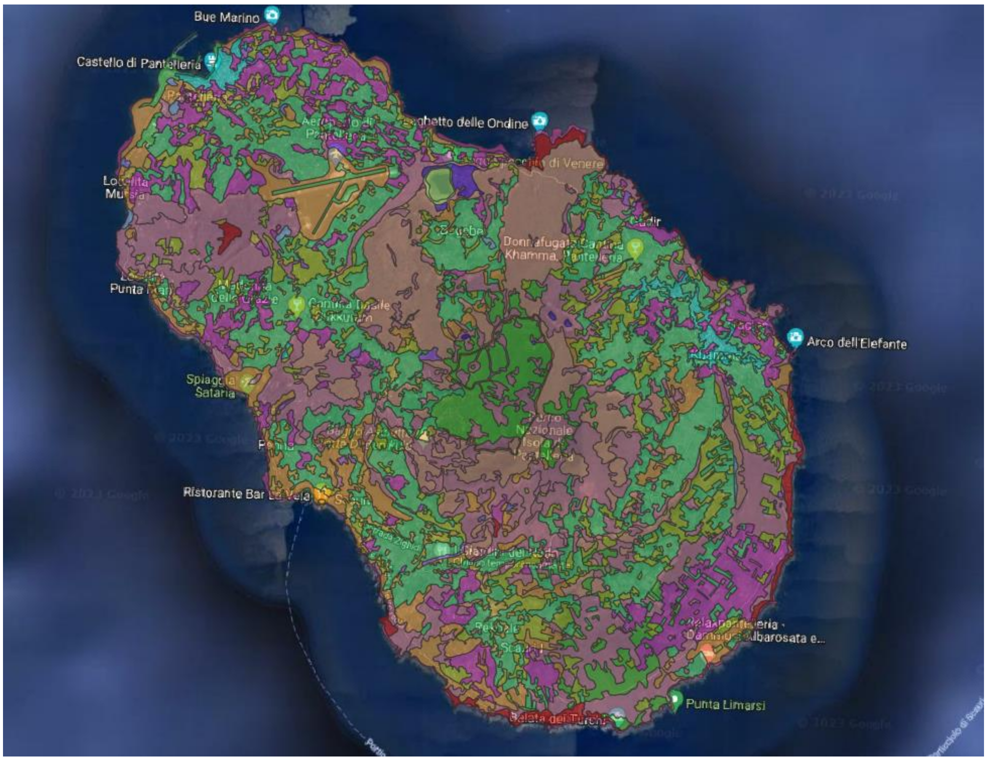


Figure 4.18: Map of land use and consumption in Pantelleria

Of the innumerable layers, only those with affinity to the agricultural sector have been considered for the calculation of the APV technical potential, such as, for example, the layers on vineyards, orchards, crops, arable crops, cropping systems and so on. In order to obtain the Eligible Area for APV, for each region, these aforementioned layers have been merged into one. Subsequently, in line with what was said in paragraph 3.2.3, the portions in which the slope is greater than 15° [63] were subtracted from these areas using the "Difference" geoprocessing tool.

Recalling what was said in paragraph 3.2.3, according to [56], a classification of crops was carried out based on their tolerance to shading by photovoltaic panels and therefore knowledge of the type of crop on which the APV plant will be built is essential. However, information on the current type of cultivation of each agricultural land is practically unobtainable and also difficult to produce. Nonetheless, it is recommended that in a possible feasibility project (and therefore on a considerably narrower territorial scale with respect to this thesis), this information is in any case necessary.

4.3.1.2 Meteorological data

One of the essential inputs for the functioning of SEBE is meteorological data. As described in the official UMEP documentation, this data must be specifically formatted for UMEP and to do this the Pre-processor incorporated in UMEP has been used too. In the case of this thesis the meteorological data have been obtained from the ERA5 dataset, in agreement with [69] and [81], provided by ECMWF (European Center for Medium-Range Weather Forecasts) [106]. This data was downloaded according to the procedure described here [107] and subsequently it was subjected to a preprocessing phase in MATLAB so that it could be used in the UMEP pre-processor. In particular, ERA5 provides hourly estimates of a large number of atmospheric, land and oceanic climate variables. The data cover the Earth on a 30 km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80km [107]. In this case, the data collected relates to a single year but multiple years can also be used to improve the model outcome. Moreover, among all the quantities that can be extracted from the ERA5 dataset, some are specifically required for most calculations in the UMEP processor and therefore must be entered during the pre-processing of the meteorological data:

- Incoming shortwave radiation (W/m^2);
- Wind speed in (m/s);
- Air temperature (°C);
- Relative Humidity (%);
- Barometric pressure (kPa);
- Rainfall (mm);
- Time related variables: Year, Day of the year, Hour and Minute;
- Diffuse shortwave irradiance (W/m^2).
- Direct shortwave irradiance (W/m^2).

From the point of view of the quantities relating to radiation, the only mandatory quantity is global shortwave radiation, but the model will perform best if diffuse and direct components are included too [101], and for this reason these last two have been added. The pre-processing of the meteorological data provides as a result a text file (.txt) formatted in such a way that it can now be used as input for SEBE. In figure 4.19 below, the dialog box relating to the preprocessing of meteorological data is shown:

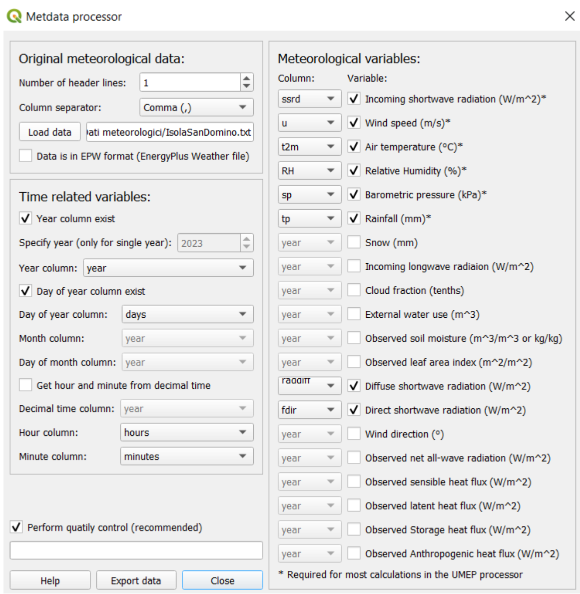


Figure 4.19: UMEP processing of meteorological data dialog box

4.3.2 Solar irradiation estimation

Once the data has been suitably prepared and preprocessed, the second step consists in the actual use of SEBE, which aims at calculating pixel wise potential solar energy using ground and building digital surface models. Depending on the extent of the area involved and, consequently, on the size of the respective DSM, this process may require relatively large computational times, as in the case of the Island of Elba. As already mentioned, the estimate of solar irradiance is extended to the whole island and, therefore, this will be useful both in the case of the evaluation of the Rooftop PV and of the Agro-photovoltaic. As reported in the UMEP Manual, the total irradiance for a roof pixel (R) on a DSM is calculated by summing the direct, diffuse and reflected radiation such as:

$$R = \sum_{i=0}^{p}[(I\cos(\omega)\,S + DS + G(1-S)\alpha)]_i \quad (1)$$

where *p* is the number of patches on the hemisphere. *I* is the incidence direct radiation, *D* is diffuse radiation and *G* is the global radiation originating from the ith patch. α is the surface albedo, S is the shadow calculated to each pixel and ω is the Sun incidence angle. The detailed description of the methodology and of the quantities included in it are described in [101].

To have a better insight into the use of SEBE, figure 4.20 shows its dialog box and, subsequently, the descriptions of each box present in it.

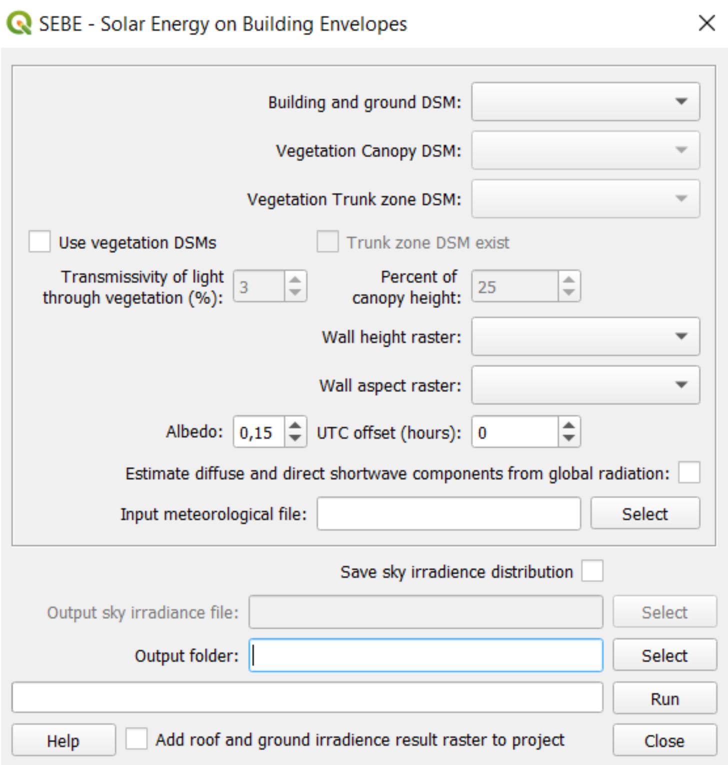


Figure 4.20: SEBE dialog box

As can be seen, this dialog box consists of two sections: the top section is where the input data is to be specified, while the bottom one is for specifying the output and for running the calculations.

- Building and Ground DSM:
  The DSM consisting of ground and building heights is here selected. This dataset also decides the latitude and longitude used for the calculation of the Sun position.

- Vegetation in SEBE:
  When the "Use vegetation DSMs" box is ticked, then SEBE also allows vegetation considerations to be included in the analysis. In particular, Vegetation Canopy DSM and Vegetation Trunk Zone DSM refers to the possibility to add DSMs about, respectively, on the upper part of vegetation and on the area underneath the canopy. Moreover, SEBE also allows specifying the Trasmissivity if light through vegetation [%] and the Percent of canopy height. Although the presence of vegetation can significantly influence the SEBE output due to the shading it can cause, this analysis has not been considered in this thesis and therefore the estimate of the radiation that will be obtained will be slightly overestimated.

- Wall Height and Wall Aspect raster:
  These inputs refer to two raster files of the same size and extent as the Building and ground DSM that are used to estimate irradiance on building walls and can be generated using the UMEP Preprocessor called “Wall Height and Aspect”. In particular, Wall Height includes information of the wall pixels and its height in meters above ground, while Wall Aspect contains information related to their angles.

- Albedo:
  This parameter specifies the reflectivity of shortwave radiation of all surfaces (ground, roofs, walls and vegetation). It should be a value between 0 and 1 and, in the case of this thesis, it is set at its default value, i.e. 0.15.

- UTC Offset (hours):
  The UTC offset is the difference in hours and minutes between Universal Time Coordinated (UTC) and local solar time, at a particular place [108]. This is related to the meteorological forcing data so if ERA5 data is used, UTC should be equal to zero.

- Estimate Diffuse and Direct Shortwave Components from Global Radiation:
  This box should be ticked if only global radiation is present and, doing so, the diffuse and direct shortwave components then would be estimated from global radiation based on the statistical model presented by Reindl et al. (1990) [109]. In the case of this thesis, since, as already anticipated before, both diffuse and direct shortwave radiations have been included, this box has not been ticked.

- Input meteorological file:
  In this phase, the file containing the meteorological data (with a .txt extension), suitably formatted to be included in UMEP, must be inserted. As already anticipated, ERA5 datasets have been considered and subsequently processed in Matlab and then in the

UMEP pre-processor called "Prepare Existing Data".

- Sky Irradiance Distribution
When the box is ticked, it is possible to save the radiation distribution from the sky vault calculated from the meteorological file.

- Output:
A specified folder where the result will be saved should be specified in the “Output folder” box. In particular, the process generates three output datasets: one raster showing irradiance on ground and building roofs named Energyyearroof.tif, containing pixel wise irradiance in kWh/m^2/year in a GeoTIFF file. Secondly, the text file named Energyyearwall.txt is also saved and it shows total wall irradiance for each wall column. If the vegetation DSMs were added, one additional file (Vegetationdata.txt) including information of vegetation height and location, is also saved.

- Add Roof and Ground Irradiance Result Raster to Project:
If this is ticked, Energyyearroof.tif will be loaded into the map canvas of QGIS.

- Run:
By clicking here, the software begins to perform the calculations. As anticipated, depending on the extension of the area and therefore on the size of the DSM, this process may require a non-trivial computational time.

In accordance with the types of renewable energy potential previously described [82], the result of this second phase, since it is extended to the whole island, coincides with the physical/theoretical potential, as it refers to the physically usable amount of energy within a given region and time, without any restriction in terms of area due to regulatory constraints and without specifying the technical characteristics of the technologies used.

As usual, the raster file relating to the irradiance just calculated is vectorized on QGIS in order to be manipulated and more easily used for the purpose of calculating the technical potential, as will be observed in the next paragraph. Below, in figure 4.21, an example of the total irradiance raster output on QGIS:

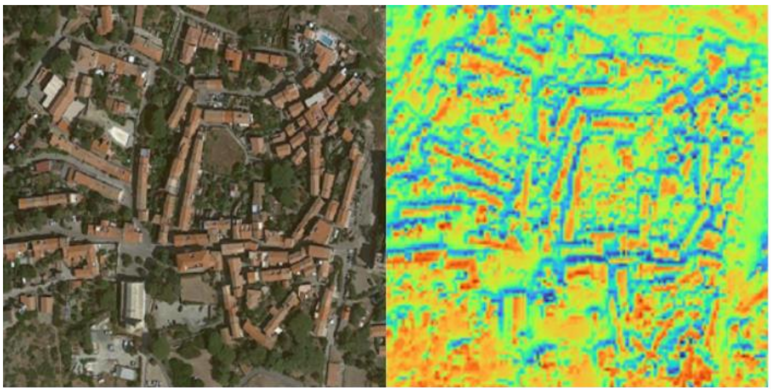


Figure 4.21: Total irradiance raster output on QGIS

4.3.3 Rooftop PV and APV technical potential evaluation

In this last phase, the methodology for calculating the technical potential, for both of the two PV technologies, is presented. In particular, once the physical/theoretical potential has been calculated, as illustrated in the previous paragraph, it is possible to proceed with the evaluation of the geographical potential and the technical potential, defined in accordance with [82]. Clearly, although both the two photovoltaic technologies present common steps in the methodology, they nevertheless present important differences, according to their technical characteristics, field of application and regulatory framework.

4.3.3.1 PV Geographical Potential

Recalling the definition of geographic potential, this is defined as the area available for energy production, taking into account all the constraints and restrictions already discussed in Chapter 3 regarding the legislation framework. In the case of solar PV installation, the geographical potential coincides with the usable area that receives the solar radiation for the PV facility. In both cases, the calculation of the usable area takes place through the reduction of the gross surface area by mean of two types of reductions, Absolute and Relative Reduction, defined in accordance with [110]:

- Absolute reduction: exclusion of buildings or lands that are listed or located in protected areas where the installation of PV systems is prohibited by law.
- Relative reduction: multiplication of the total gross area resulting from the georeferenced layers by various utilization factors, subsequently described, which determine a reduction in order to obtain a more realistic available surface area.

In order to be able to perform these reductions and, in general, perform operations on georeferenced vector layers, QGIS is equipped with numerous and important useful tools, such as, to name the most used, those of Clip, Difference and Intersection, belonging to the category of Geoprocessing tools. In particular, the SEBE output rasters were first converted into vector format through a sampling method, in order to be able to be manipulated on QGIS. In fact, by overlaying and clipping the layers of buildings and agricultural land with irradiance vectors, it was possible to obtain solar irradiance in the roofs and in the areas intended for the installation of APVs.

As regards the case of the Rooftop PV, as already mentioned, the territorial data showing the gross roof area was obtained starting from the CTRNs (numbered regional technical papers) for each region, downloaded in a shapefile format. Of all the layers contained in this type of vector file, for the calculation of the Rooftop PV technical potential, only the layers relating to residential buildings, commercial and industrial buildings or public administration ones have been used. This selection, therefore, represents a first form of absolute reduction. In addition to this, for some regions, in line with their regulatory framework, other buildings were excluded as they fall within areas where the installation of photovoltaics on roofs is not permitted, such as for example in historical centers or in buildings located within homogeneous territorial area of type "A" of the urban planning instruments, according to DM n. 1444 of 1968 [73].

Regarding the APV, of the innumerable layers included in the Land Use and Consumption Maps, only those with affinity to the agricultural sector have been considered for the calculation of the APV technical potential, such as, for example, the layers on vineyards, orchards, crops, arable crops, cropping systems and so on.

As already mentioned, the regulatory framework relating to the installation of the APV is almost absent and therefore there are few spatial restrictions and constraints that can be applied, meaning that, in most of the islands of this thesis, the area destined for the APV is decidedly a disproportionate overestimation of what actually could be installed in the future. From these layers, all those areas and portions of territory occupied by buildings have been removed, in order to obtain not too unrealistic results. As already anticipated, another further criterion that has been included concerns the slope of the land on which to install the APV and, in line with what is done for the ground-mounted PV [63], all the portions with a slope greater than 15° have been removed.

As reported in the UMEP documentation, in order for the photovoltaic modules to be positioned where the amount of energy received makes the installation cost effective, a further reduction of the area has been performed, filtering out all those portions in which the irradiance is less than 900 kWh/m^2/year [101]. In addition, according to [69] and [81], a range of solar irradiance between 1000 and 1200 kWh/m^2/year corresponds to areas that are not suitable for PV panel installation, such as parapets or interior terraces. For this reason, the threshold was set at 1200 kWh/m^2/year, so pixels with a lower value were filtered out. Although these last thresholds refer to the installation of Rooftop PV, this same filtering out has also been applied for the irradiance in agricultural land, so that the cost effectiveness of these is also considered.

Once this absolute reduction has been carried out, the reduction coefficients are introduced, useful for obtaining the effective available area, both of the roof and of the land. In the following, therefore, these coefficients are listed and described. It should be noted that, depending on the type of roof, different considerations will be made, both as regards the cutting coefficients and the method for the final calculation of the technical potential itself.

Among the buildings present in the areas under examination, it is possible to distinguish two main types of roof, flat roofs and double-pitched roofs, more common, respectively, in northern and southern Italy. The use of pitched roofs arises from the need to better adapt to the winter period in which the snow settles on the roofs. Indeed, the slope of the pitch is usually calculated according to the maximum theoretical snow-load and, as a matter of fact, it is steeper in the mountains [111]. The lack of information on the roofing properties, imposes the assumption of a representative roofing typology and its empirical analysis is based on the visual inspection of Google Earth images [111].

In the case of pitched roofs, it was decided to adopt the most common solution, i.e. to install the modules only on one of the two pitches of each roof which usually coincides with the one best exposed to the sun light [111]. For this mode a first reduction coefficient is introduced, which reduces the available roof surface by 50% (*Pitched Roof Coefficient* $C_P = 0.5$).

Unlike pitched roofs, in the case of flat roofs the mutual-shading phenomenon plays a key role as this strongly influences the electrical yield and the useful space in the roof due to the spacing between the modules. In accordance with what was done in [69], in this thesis, for the calculation of the spacing between the modules, the worst case has been assumed: on the day of the winter solstice, the row spacing required to avoid mutual shading is maximum [110]. This distance, schematically illustrated in figure 4.22, can be calculated, according to [112] with the following formula:

$$d = d_1 + d_2 = L\,\left(\frac{\sin\beta}{\tan h_0} + \frac{\sin\beta}{\tan\beta}\right) \tag{2}$$

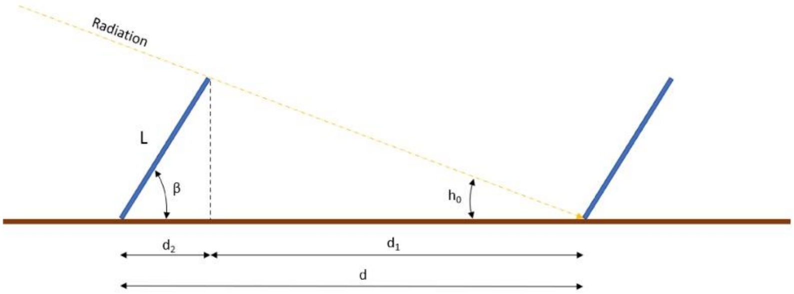


Figure 4.22: Inter row spacing layout

It can be observed that the distance between the rows depends on the variation of the sun's altitude during the day and the year. In turn, the solar elevation angle depends on the declination angle δ, the latitude φ, the hour angle ω. According to [113], it can be calculated for a given latitude and a given day and hour as follows:

$$\sin(\alpha_s) = \sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\omega \tag{3}$$

By combining the two formulas, (2) and (3), and knowing the physical dimensions of the panel, it is possible to calculate the distance between the rows at the winter solstice. The figure 4.23 shows the value of the inter row spacing [m] to be assumed as a function of the tilt angle [°].

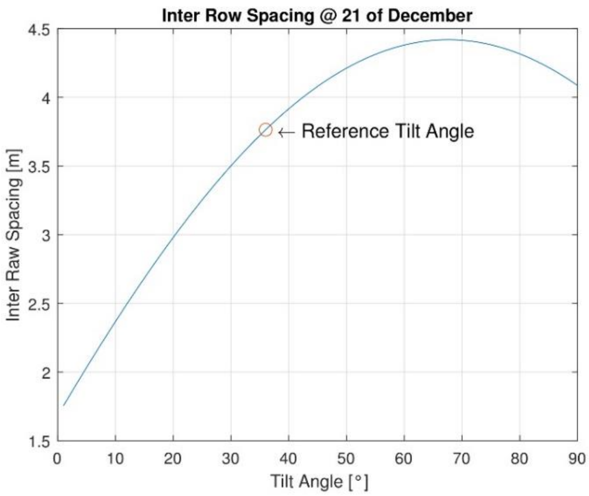


Figure 4.23: Inter row spacing at winter solstice

The optimal tilt angle values are calculated on PVGIS, an online simulator for calculating radiation created in collaboration between the Joint Research Centre, Institute for Energy and Transport and ESTI (European Solar Test) [114]. Here, by simply entering the coordinates or manually selecting the area of interest, the optimal values of the tilt angle have been obtained for all those islands characterized by flat roofs (which coincide with the islands of Sicily and the Pontino archipelago). In this thesis, in accordance with what was done in [69], a JinkoSolar Cheetah HC 60 M-325 W has been considered, whose technical data sheet is available in [115].

At this point, knowing the row spacing D and the physical dimensions L of the panel , it is possible to obtain the reduction coefficient for flat roofs, named *Coverage Index Coefficient* C_{COV}, calculated as follows [116]:

$$C_{COV} = \frac{L}{D} \quad (4)$$

Examining the values of the optimal tilt angles obtained from PVGIS, it was observed that the values, each specific for each island, oscillate around an average value of 36°. Therefore it was decided to assume, for the sake of simplification, this same value for all islands with flat roofs. By doing so, the same value for C_{COV} was obtained, equal to $C_{COV} = 0{,}447$.

In addition, regardless of the type of roof, additional reduction coefficients have been included, in line with [111]: the *Feature Coefficient* C_F considers that part of the space in time may already be occupied by chimneys, aerials or windows (C_F=0.7); the *Solar Thermal Coefficient*, with a value equal to C_{ST}=0.9, assumes that 10% of the roof surface may not be available because it is already occupied by solar thermal systems.

Starting from the coefficients described, it is possible to obtain, for both types of roof, an overall corrective coefficient, which will represent the fraction of the roof surface that can be covered by photovoltaic panels. These are calculated, respectively for double-pitched (C_{DPR}) and flat roofs (C_{FR}), as follows:

$$C_{DPR} = C_P * C_F * C_{ST} = 0.5 * 0.7 * 0.9 = 0.315 \quad (5)$$

$$C_{FR} = C_{COV} * C_F * C_{ST} = 0.447 * 0.7 * 0.9 = 0.282 \quad (6)$$

As regards the parameters to be considered in the case of APV, nowadays there are not yet sufficient studies through which to make considerations on the reduction of available land. However a reduction coefficient has been found and this takes into account that part of the space in an agricultural land may not be available for the installation of APV due to portions intended for general services in accordance with [117]. In conclusion, also in this case, an overall corrective coefficient was calculated for the reduction of the geographical potential of the APV: since the fraction intended for general services is set at 15%, the overall coefficient is equal to C_{APV} = 0.85.

4.3.3.2 PV Annual Electricity Production

In this paragraph the steps for the final calculation of the technical potential are shown. Since both the solar resource and the geographical potential have been obtained, including in the analysis the technical characteristics of the photovoltaic panels it is possible to finally calculate the Annual Electricity Production PV AEP. However, in this phase, the evaluation of the technical potential differs strongly according to whether it is a flat roof, a double-pitched roof or an APV system.

In general, the annual electricity production from a photovoltaic system can be estimated as follows [118]:

$$AEP = H_G * S_{PV} * \eta_{STC} * PR \tag{7}$$

In particular, the factors that contribute to the calculation of the energy produced have the following meaning:

- H_G is the total global in-plane solar irradiation [kWh/m^2/year];
- S_{PV} is the total area available for the PV electricity generation, and this depends on the type of installation [m^2];
- η_{STC} is the efficiency of the PV module at Standard Test Conditions (STC);
- PR coincides with the Performance Ratio, representing the ratio of the final system yield to the reference yield, comparing the energy that is actually generated with the amount of energy produced under the same irradiation but under ideal no-loss conditions.

4.3.3.2.1 Rooftop PV AEP

The S_{PV} factor depends, as anticipated, on the technologies and configuration of the system considered. The knowledge of this is also fundamental for the calculation of the total PV power [MW], which also depends on the characteristics of the PV module itself.

In the case of a double-pitched roof, the panels are adjacent to the surface of the pitch of the roof and therefore the phenomenon of mutual shading between the modules is eliminated. The actual roof area that can be covered by PV modules can be obtained using the following formula:

$$S_{PV} = C_{DPR} * \frac{S_{suitable}}{\cos(\theta)} \tag{8}$$

The first factor is the one obtained in the previous paragraph, which considers all the corrective coefficients presented in the case of a double-pitched roof (the Feature Coefficient C_F, the Solar Thermal Coefficient C_{ST} and the Pitched Roof Coefficient C_P). Assuming a characteristic inclination angle θ for residential roofing of 20° [111], it is possible to derive the $\cos(\theta)$ factor. The latter takes into account the inclination of the roof and therefore the effective surface in which the modules can be placed is greater than the two-dimensional area calculated on QGIS. In line with [69], considering the surface that 1 kWp occupies [m^2/kWp], obtained starting from the real dimensions of the module [115], it is possible to calculate the total photovoltaic power P_{PV} according to the following formula:

$$P_{PV} = \frac{S_{PV}}{\text{Area occupied by 1 kWp}} \quad (9)$$

On the other hand, regarding the flat roofs, different considerations can be made. In fact the modules, in this case, will be placed inclined and not adjacent to the roof surface. Similarly to what was done previously, S_{PV} will turn out to be equal to the product of the suitable surface $S_{suitable}$ and the flat roof corrective coefficient C_{FR}. In doing so, what is obtained is the available flat surface of the roof. To find the photovoltaic surface that will be installed, its inclination must be taken into account, which translates into how much space is occupied horizontally by an inclined photovoltaic panel (the projection of the inclined surface onto a horizontal plane). Knowing the area occupied by 1kWp of PV and assuming a representative tilt angle β of 36°, it is possible to finally calculate the total photovoltaic power P_{PV} as follows:

$$P_{PV} = \frac{C_{FR} * S_{suitable}}{\text{Area occupied by 1 kWp} * \cos(\beta)} \quad (10)$$

Although researchers have developed PV cells with efficiencies approaching 50%, most commercial panels have efficiencies from 15% to 20% [119]. In this thesis, the PV module efficiency is assumed to be equal to 18%, in line with [69] and [81].

The Performance Ratio PR, in this study, considers both physical (shading or differences with STC) and electrical (cable losses, AC-DC conversion) phenomena and it can be calculated considering different loss factors, described as follows [118]:

$$PR = \eta_{mis} * \eta_{d-r} * \eta_{wir} * \eta_{temp} * \eta_{shad} * \eta_{CPU} \quad (11)$$

- η_{mis}: tolerance with respect to STC data and mismatch of module current-voltage characteristics; Value of 0.97 [118]
- η_{d-r}: dirt and reflection of the front glass. Value of 0.976 [120][121];
- η_{wir}: cable losses. Value of 0.994 [122];
- η_{temp}: over temperature compared to STC. Value of 0.89 [115];
- η_{shad}: shading losses. Value of 0.98 [123];
- η_{CPU}: MPP tracker and DC-AC conversion losses. Value of 0.98 [124];

Considering the efficiency of the module and the value of the performance ratio PR, the overall efficiency of the system for converting solar energy into electricity is obtained as follows:

$$\eta_{SYST} = \eta_{STC} * PR = 14.5\% \quad (12)$$

At this point there is nothing left but to calculate the PV AEP and this process is very different for the two different configurations presented:

In the case of a double-pitched roof it was sufficient to perform elementary calculation operations on QGIS itself, multiplying, pixel by pixel, the solar irradiance [kWh/m^2/year] by the area covered by the photovoltaic S_{PV} just calculated [m^2] by the efficiency of the system η_{SYST}.

Since SEBE does not calculate irradiance on sloped surfaces but only in relation to a given DSM, the calculation of the PV AEP has been performed on the PVGIS tool [114]. In this, it was necessary, for each location, to insert the total photovoltaic power P_{PV} and the overall efficiency of the system previously calculated, and, in turn, it gave back the PV AEP.

4.3.3.2.2 APV AEP

In APV systems, to find the geographic potential, it was necessary to multiply the suitable land calculated in QGIS with the corrective coefficient C_{APV}. As already anticipated, in this thesis, in the case of APV systems, a uniaxial tracking system with north-south alignment has been adopted and from this assumption several considerations for the calculation of the technical potential must be included. To ensure the continuity of agricultural activity and the passage of agricultural vehicles, an inter-row spacing of 6 m has been set in accordance with the guidelines [50].

Despite the still modest, but growing, number of APV systems, a model of photovoltaic modules specially designed for these types of systems has been found: in February 2022, Slovenia-based solar panel manufacturer Bisol launched a series of transparent solar modules specifically for agrophotovoltaic projects or solar carports. Bisol Lumina is designed with a matrix and has bigger gaps between solar cells, having a transparency area of 30%, which makes it suitable for agriphotovoltaic projects allowing enough light to shine through [125]. The larger version of BISOL Lumina (BBO 300) with 98 cells (matrix 6 x 8 + 6 x 8) offers output power of 300 W, not even counting in the bifacial gain from the rare side of the module, which can boost the initial power up to 420 W or even more in certain conditions. In particular, the bifacial gain depends on the albedo of the surface, defined as the fraction of light hitting a surface that is reflected [126].

Below, the electrical and mechanical technical specifications of the panels of the model in question:

Module Type	BBO 330					
Number of Cells	96					
Cell Matrix	6 x 8 + 6 x 8					
Transparent Area	0,73 m^2					
	33 %					
	Front	Bifacial Gain				
Light Source [%]	100	5	10	20	30	40
Nominal Power [W]	300	315	330	360	390	420
Short Circuit Current [A]	11,2	11,8	12,4	13,5	14,6	15,7
Open Circuit Voltage [V]	32,9	32,9	32,9	32,9	32,9	32,9
MMP Current [A]	10,7	11,2	11,8	12,8	13,9	15
MPP Voltage [V]	28,1	28,1	28,1	28,1	28,1	28,1
Module Efficiency [%]	13,5	14,2	14,9	16,3	17,6	19
Power Output Tolerance	3%					
Maximum Reverse Current	20 A					
Protection Class	Class II					

Table 4.4: Electrical Specification at STC (AM1.5, 1000W/m^2, 25 °C)

Module Type	BBO 300
Length x Width x Thickness	2,11 x 1,05 x 40 mm
Weight	24,5 kg
Solar Cells	96 Half-Cut mono Bifacial c-Si 166 mm x 166 mm
Junction Box	3 bypass diodes / MC4 compatible / IP 68
Cable Lenght	Default: 1,2 mm
Frame	Anodized Al with drainage holes / rigid anchored corners
Glass	3,2 mm glass with anti-reflective coating / tempered / High-transparency / low- iron content
Packaging	27 modules per pallet / stackable 3 pallets high
Certified Test Load (snow/wind)	5,4 Pa / 2,4 Pa
Impact resistence	Hailstone / 83 km/h

Table 4.5: Mechanical specification

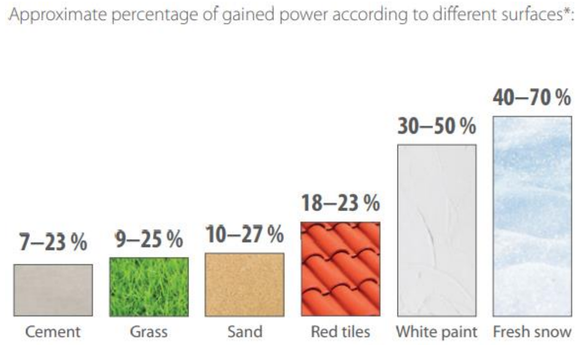


Figure 4.24: Percentage of gained power vs surface type

Since the application of agrophotovoltaic systems is intended to cover agricultural and cultivation fields, it can be assumed, in accordance with figure 4.24, that the surface is fundamentally similar to grass and that the modules benefit from an increase in gain power of 20 %. Therefore, in these conditions, the nominal power of the PNOM module is 360W. Note that, in addition to increasing the power output, the efficiency of the module also benefits from ground reflection due to the albedo, increasing up to a value of $\eta_{APV} = 16.3\%$.

As done in the previous cases, now the surface that 1kWp requires is obtained. This surface takes into account two contributions: the first is related to the surface of the modules themselves required to obtain 1kWp, when placed horizontally, which can be obtained through a simple portion; the second is related to the area of spacing between rows. Considering a spacing D of 6m and the physical dimensions of the modules (Length L= 2,11 m), we obtain the total area that 1kWp requires in an APV system as follows:

$$\text{Required land area for 1 kWp} = \left(Area\ of\ the\ module * \frac{1000}{360}\right) + L * D = 18.81\ m^2 \quad (13)$$

Considering the available area for APV already calculated from QGIS and the C_{APV}, it is possible to obtain the total PV power for an APV system as the ratio between the available area and the required land area from 1 kWp of APV just calculated.

Once the total PV power has been calculated, it is now possible to calculate the Annual Electricity Production from APV through PVGIS. In this, once the location has been selected, it is possible to insert the total power just found, specify that the configuration considered is a tracking PV with north-south alignment and, finally, insert the overall system efficiency, given by the product between the efficiency of the module and the PR (which is assumed to be equal to that in the case of Rooftop PV).

5. Results and observations

In this chapter the results of the implementation of the previously described methodology are presented and commented. Clearly these results refer to the minor islands that have been chosen belonging to the four Italian regions: Sicily, Puglia, Lazio and Tuscany. For each island, the outcomes will be organized in a table, providing an overview of the potential of wind and photovoltaic energy (whether PV Rooftop or APV). This potential is mainly represented in terms of installable capacity (MW) and annual energy production (GWh/year). Due to the regulatory constraints present in the island, the installation of wind turbines was not possible in some islands and therefore, in these cases, in order to provide information on the wind potential, summary statistics of the energy potential have been reported, such as those related to the wind speed, power density and AEP NET resource maps. For sake of clarity, the three turbines chosen and described in paragraph 4.2.3 will be more simply referred to as type 1, 2 and 3 turbines, corresponding respectively to the 20kw, 200kW and 2MW wind turbine model. Furthermore, paragraph 5.5 will summarize all the results and compare them with the current status of energy production of the islands.

The tables showing the numerical results will be accompanied by the graphic representation of the area considered showing the main regulatory constraints, suitable areas, and energy resources, to provide a more concrete vision of the results. Moreover, these maps, prepared and processed on QGIS, will then be reported in the cartography appendix.

5.1 Sicily - Results

The first results shown are related to the minor Sicilian islands. As already anticipated, the calculation of the technical potential has already been addressed and performed in [69] and therefore, for the sake of completeness, these are directly reported also in this thesis. However, in addition to the wind and rooftop PV potential estimates, the APV potential has also been calculated and included here.

It is important to specify that at the basis of the calculation of the wind technical potential an important assumption has been considered: all the Sicilian islands, except Ustica, are completely within IBA, which would determine the non-feasibility for the exploitation of wind energy, in accordance with the Presidential Decree Reg 26/2010. For this reason, for the assessment of the wind potential, the IBA constraint has been relaxed in order to still allow an assessment of the impact that the installation of wind turbines would have.

5.1.1 Pantelleria

To begin with, Pantelleria is the largest among the Sicilian islands, with a territory that extends for 83 km^2. In general, this is characterized by an important abundance of RES and, at the same time, by wide areas subject to environmental and territorial constraints which prevent the exploitation of the potential of the place.

Among all the islands included in this thesis, it presents the largest annual wind energy production calculated, with a production greater than 3 GWh/year. Under the hypothesis of neglecting the IBA constraint, an area of about 9.36 ha has been identified as eligible for the installation of type 1 and 2 wind turbines, while type 3 turbines cannot be placed because there would not be enough land space due to the greater distance required from population centers. However, table 5.1 shows the results of the simulations of all three types of turbines providing an overview of the achievable technical potential. Figure 5.1 illustrates the boundaries of the eligible area and an overview of the wind resource, in this case represented by the mean wind speed at 30m a.g.l.

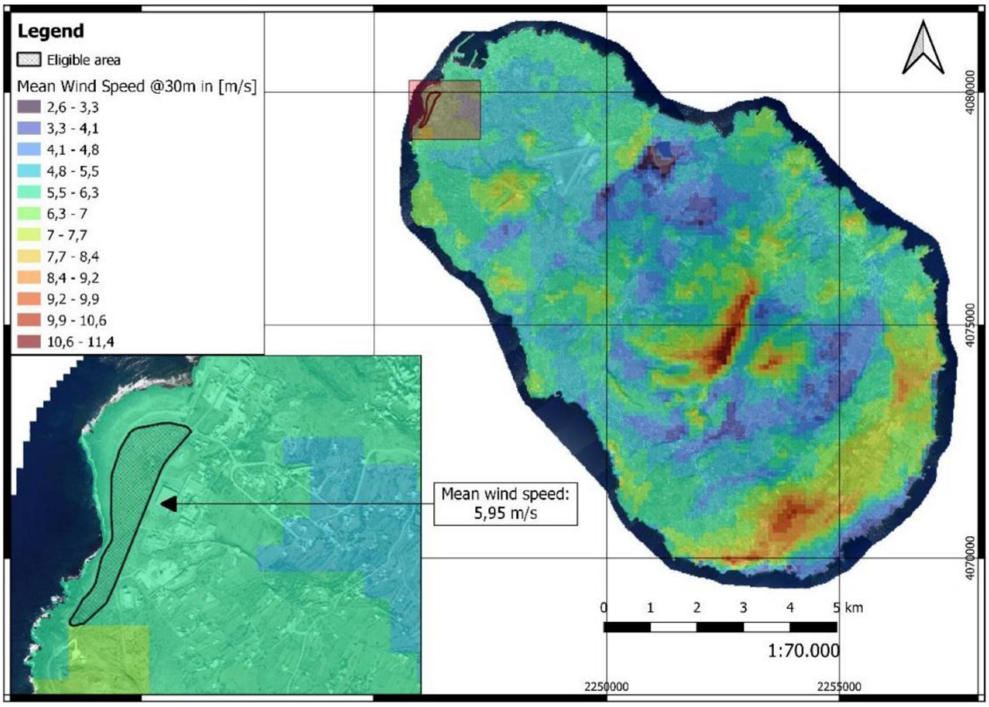


Figure 5.1: Pantelleria eligible area and mean wind speed

WT Pn	Hub Height	Mean wind speed	# WT	Net AEP	Wake Losses	Capacity factor
[kW]	[m a.g.l.]	[m/s]	[No. of WTs]	[MWH/year]	[%]	[%]
20	20	5,45	27	1.111	6,68	27,9
200	30	4,95	7	3.043	3,35	25,7
2000	80	7,1	2	14.404	1,3	41,6

Table 5.1: Pantelleria wind technical potential

Its territory is characterized by a large presence of agricultural land, including vineyards and simple arable land, such as to potentially accommodate more than 700 MW of APV, a result that is clearly impossible to implement. From the point of view of rooftop PV, the territorial landscape plan of Pantelleria limits the installation of PV panels on any building roof outside the main city and its peripheral areas. In addition, a constraint is also related to the traditional house, located throughout the island, called “Dammuso”, which have a domed roof and are protected due to their historical, cultural and landscape value. Therefore, for the evaluation of the rooftop PV technical potential, since it was not possible to distinguish the house typology from the territorial data, all the buildings in the main center and in the peripheral areas have been considered not protected. Figure 5.2 shows the solar radiation on the roofs only, including the restricted areas, while table 5.2 summarizes the results relating to the technical potential of both the rooftop PV and the APV systems.

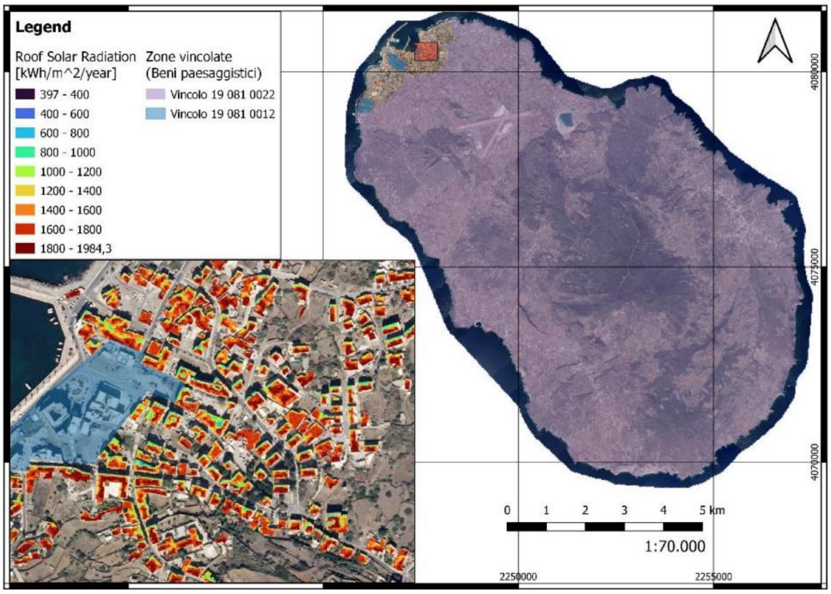


Figure 5.2: Pantelleria solar irradiance on building roofs

Pantelleria	AV. Area	PV Area	Ele. Prod.	PV power
Flat roofs	m^2	m^2	GWh/year	MW
Rooftop PV	194342	54785	18,47	10,72
APV	15531000	13201350	1448	702

Table 5.2: Pantelleria Rooftop PV and APV technical potential

5.1.2 Ustica

Among the Sicilian islands, Ustica has the merit of being the only one to have reached the RES installed power 2020 target with the most electricity needs covered by RES, for a share of about 12%, through the installation of photovoltaic panels. Unlike the other Sicilian islands, this is the only one not to fall under the IBA constraint but, despite this, the presence of other constraints, such as SCI, SPA and nature reserves, limit the installation of wind turbines. The estimated area eligible for the installation of EO1 type turbines is estimated to be 5.43 ha, which is reduced to 2.87 ha for EO2 and EO3 types. Figure 5.3 shows the eligible areas and the mean wind speed at 30m a.g.l are presented, while table 5.3 summarizes the results of the wind simulations for the three types of turbines.

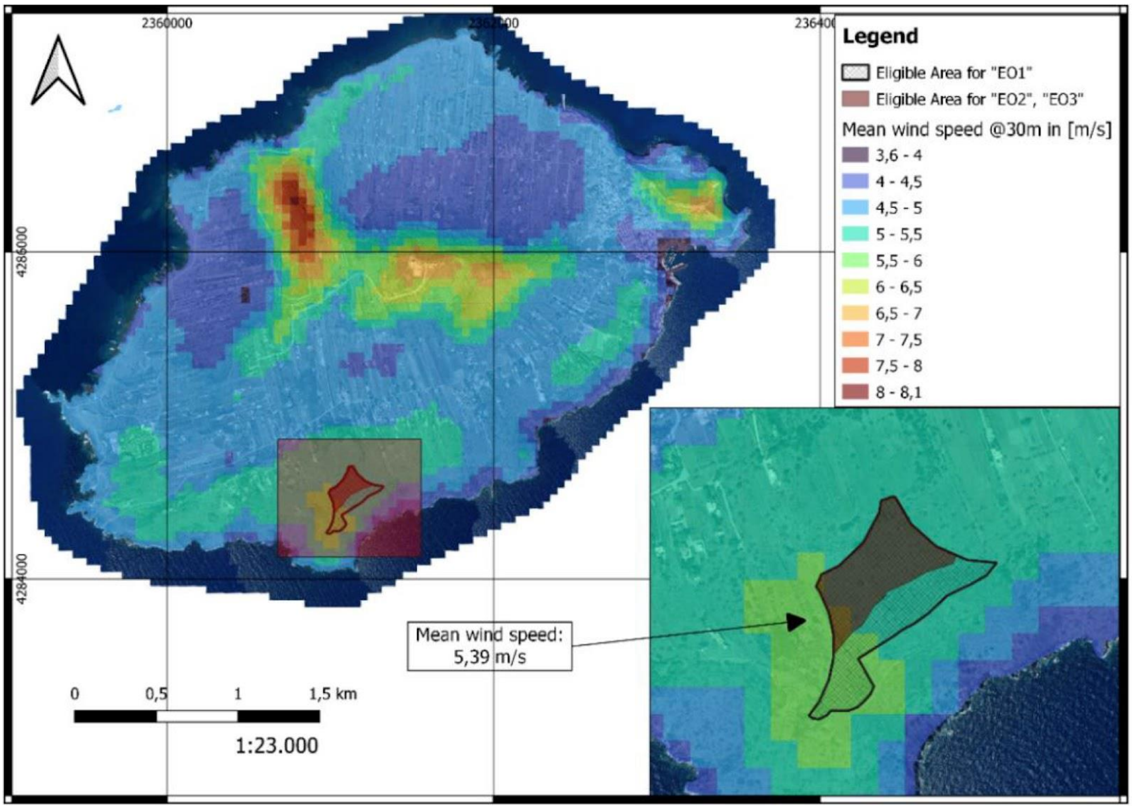


Figure 5.3: Ustica eligible area and mean wind speed

WT Pn	Hub Height	Mean wind speed	# WT	Net AEP	Wake Losses	Capacity factor
[kW]	[m a.g.l.]	[m/s]	[No. of WTs]	[MWH/year]	[%]	[%]
20	20	5,07	10	390	2,07	25,3
200	30	5,39	4	1.513	2,67	22,2
2000	80	5,63	1	5.631	0	32,1

Table 5.3: Ustica wind technical potential

From the point of view of photovoltaic energy, it has a promising potential, with a rooftop PV and APV power of 7 MW and 82 MW, respectively. The production that would also derive from the rooftop PV alone would be such as to largely cover the annual energy needs, with a value of the self-sufficiency rate greater than 160%, which would skyrocket to more than 3700% considering the contribution of the APV. Figure 5.4 shows the solar irradiance on the Ustica building roofs only, while in table 5.4 the geographical and technical potential is reported for the two photovoltaic technologies:

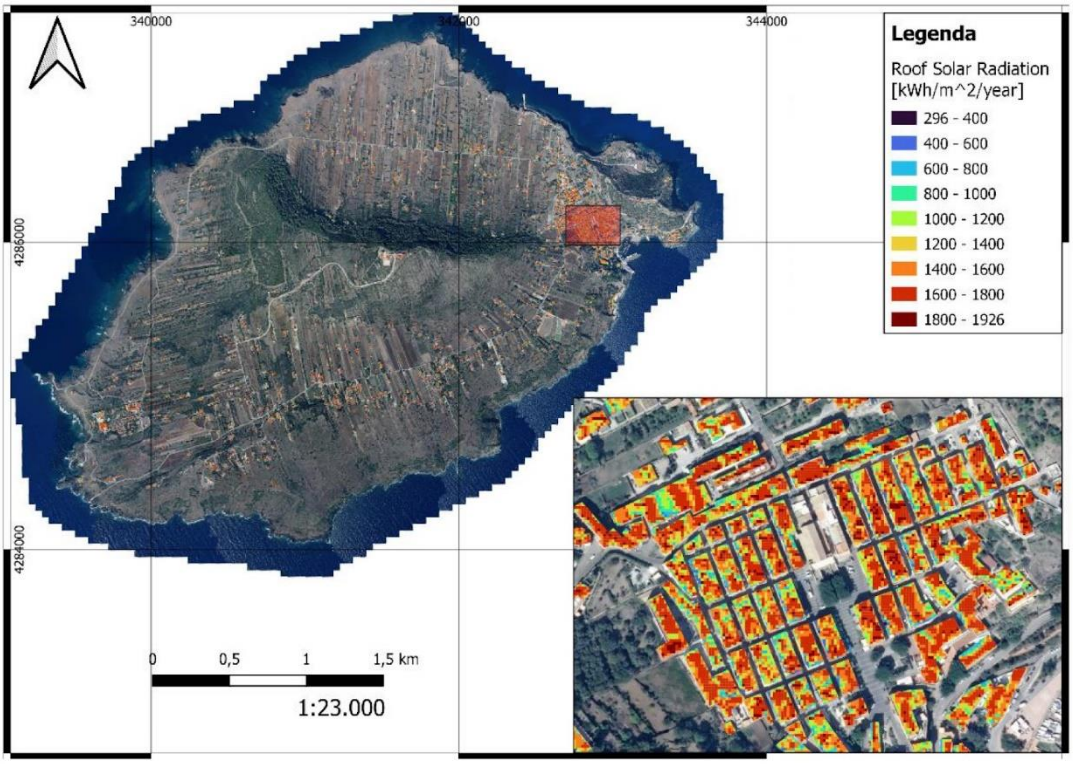


Figure 5.4: Ustica solar irradiance on building roofs

Ustica	AV. Area	PV Area	Ele. Prod.	PV power
Flat roofs	m^2	m^2	GWh/year	MW
Rooftop PV	132888	37461	11,45	7,33
APV	1832920	1557982	169,30	82,809

Table 5.4: Ustica Rooftop PV and APV technical potential

5.1.3 Eolie Islands'

The Aeolian Archipelago is made up of seven islands and four municipalities, three of which belong to the island of Salina, all belonging to the province of Messina.
The constraint analysis performed on QGIS shows that it is not possible to install any wind turbine of any size in the territory despite the IBA relaxation hypothesis. The area of the islands is largely subject to constraints such as SCI, SPA and nature reserves and the only areas that fall outside these coincide with urban centers and surroundings, so it is not possible to install due to proximity to the housing units. It is possible to identify some small unconstrained areas sufficiently far from residential areas, however, in these cases, the installation would still not be possible due to the technical non-adequacy of the terrain due to slopes greater than 20%. Therefore, to give an overview of the archipelago's potential in terms of wind energy, the summary statistics obtained on WAsP for each island calculated for a height of 30 m (type 2 WT) have been reported and shown in the table 5.5.

Island	Mean wind speed		Power density		Net AEP	
	[m/s]		[W/m2]		[MWh/year]	
	Average	Max	Average	Max	Average	Max
Alicudi	4,73	8,99	451	2161	294,4	527,3
Filicudi	4,11	8,5	285	1975	245,5	507,3
Salina	3,87	8,5	274	2104	222,8	517,9
Lipari	3,96	7,46	210	1282	239,4	503,3
Vulcano	4,34	8,13	242	1335	272,7	547,2
Panarea	4,37	9,08	323	2189	270.5	538,7
Stromboli	4,41	10,01	317	2547	272,2	571,8

Table 5.5: Eolie Islands' wind theoretical potential parameters

The territorial landscape plan of the archipelago does not provide specific indications on the restrictions for the installation of photovoltaic modules on building roofs, therefore it is possible to use all suitable roofs even if this solution is not realistically feasible. The results show how the installation of photovoltaic systems alone would already be sufficient to fully cover the needs of the islands. A further and significant contribution is represented by the agro-photovoltaic systems, which goes well with the important agricultural presence in the islands. Generically, the installable capacity of APV is disproportionately greater than the rooftop PV, as in the case of Lipari with a value of about 114 MW, with the exception of some islands where, due to the lower presence of agricultural land, the potential of the two photovoltaic technologies is comparable. The results are summarized in the table 5.6:

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
Alicudi	Rooftop PV	23874	6730	1,99	1,32
	APV	17903	15217	1,42	0,81
Filicudi	Rooftop PV	65394	18434	5,78	3,61
	APV	175740	149379	14,04	7,94
Salina	Rooftop PV	269907	76086	22,10	14,89
	APV	886964	753919	75,23	40,07
Lipari	Rooftop PV	735264	207271	61,73	40,56
	APV	2538110	2157394	234,06	114,67
Vulcano	Rooftop PV	198647	55998	17,22	10,96
	APV	873807	742736	79,67	39,48
Panarea	Rooftop PV	59242	16795	3,50	2,40
	APV	19799	16829	1,74	0,89
Stromboli	Rooftop PV	98224	27689	8,00	5,42
	APV	83475	70954	7,05	3,77

Table 5.6: Eolie Islands' Rooftop PV and APV technical potential

5.1.4 Pelagie Islands’

Lampedusa and Linosa, with an extension of respectively 20.2 km2 and 5.4 km2, are the southernmost Italian territory. Despite the promising position, especially in terms of solar irradiance, the coverage of the energy demand from RES is decidedly low, at around 6.2%. Both islands have important environmental and landscape constraints, such as SCI, SPA, nature reserves and marine protected areas. In addition to these, the local territorial landscape plan prohibits the installation of industrial plants larger than 20 kW for the entire extension of the island, which clearly affects the exploitation of wind energy in the archipelago. Through the analysis of the constraints and the regulatory framework, it is concluded that, under the hypothesis of relaxation of the IBA, it is not possible to install any wind turbine on Linosa, while, regarding Lampedusa, an area of about 2 ha has been identified as eligible for the installation of type 1 wind turbines, as figure 5.5 shows. Table 5.7 and 5.8 respectively show the results of the application of the methodology for both islands:

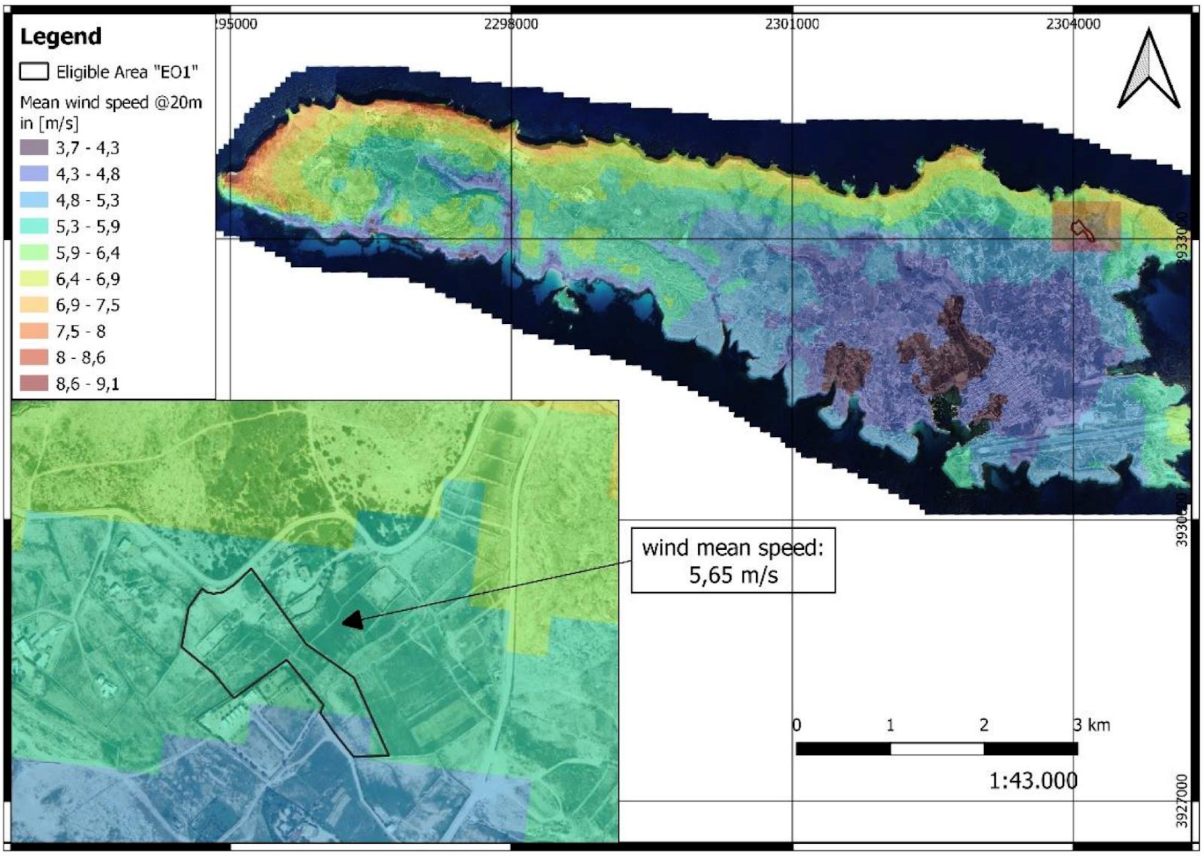


Figure 5.5: Lampedusa eligible area and mean wind speed

WT Pn	Hub Height	Mean wind speed	# WT	Net AEP	Wake Losses	Capacity factor
[kW]	[m a.g.l.]	[m/s]	[No. of WTs]	[MWH/year]	[%]	[%]
20	20	5,52	8	372	3,87	26,4
200	30	5,99	3	1.401	2,26	26,6
2000	80	7,19	1	7.171	1,3	40,9

Table 5.7: Lampedusa wind theoretical potential parameters

WT Pn	Hub Height	Mean wind speed			Power density			Net AEP		
[kW]	[m a.g.l.]	[m/s]			[W/m^2]			[MWh/year]		
-	-	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
20	20	3,92	5,73	9,22	106	317	1.227	24	48	83
200	30	4,82	6,15	9,29	180	372	1.205	303	473	747
2000	80	6,53	7,19	9,35	386	504	6.204	6.204	7.135	9.089

Table 5.8: Linosa wind theoretical potential parameters

From the point of view of the installation of PV panels in building roofs, this is not particularly limited and enjoys the exceptional potential due to the favorable location. The only indication present in the landscape territorial plan is that the installation of the panels visible from the main streets and squares is prohibited. Both islands are characterized by large agricultural land, such as to allow a potential installation of APVs for a capacity of 88 MW and 45 MW respectively for Lampedusa and Linosa, allowing to reach self-sufficient rate values that are way greater than 100%. As usual, to follow, table 5.9 reports the main results of the application of the methodology for both Rooftop PV and APV systems, while figures 5.6 and 5.7 illustrates the solar irradiance on building roofs for both islands:

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
Lampedusa	Rooftop PV	530367	149510	49,11	29,26
	APV	1954410	1661248,5	185,4	88,3
Linosa	Rooftop PV	60710	17114	5,61	3,35
	APV	1007880	856698	89,6	45,5

Table 5.9: Lampedusa and Linosa wind technical potential

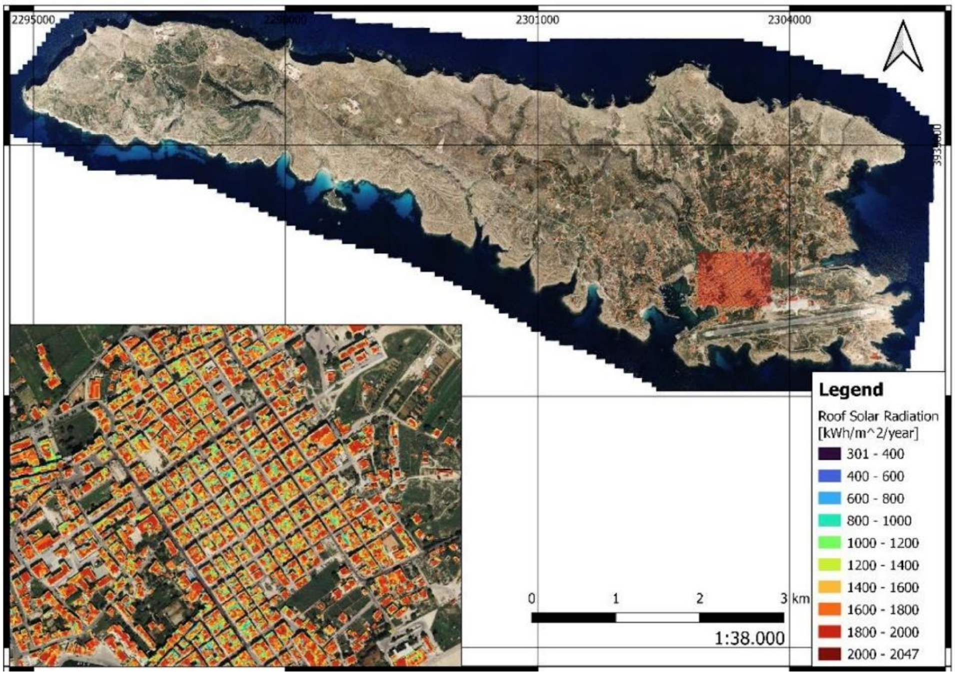


Figure 5.6: Lampedusa solar irradiance on building roofs

Figure 5.7: Linosa solar irradiance on building roofs

5.1.5 Egadi Islands'

The Egadi archipelago consists of three islands: Favignana, Marettimo and Levanzo, with an extension of 19.3 km2, 12.4 km2 and 5.8 km2 respectively. Geographically these are relatively close to Sicily making a submarine connection with the national electricity grid feasible but, however, the three islands are still powered by diesel-powered generators and have a total RES coverage of the electricity needs of 3%, due to the installation of about 404 kW of photovoltaic power.

Through the analysis of the constraints within the archipelago, an area of about 3.5 ha was identified as eligible on the island of Favignana, under the IBA relaxation hypothesis, as shown in figure 5.8. It is specified that although this area is within 150m of the coastline, the installation is still possible if the WTs are identified as "public works or declared to be of primary public interest". In this area it is possible to install type 1 and 2 turbines, while 2 MW turbines are excluded due to proximity to residential areas. The results of the simulation, shown in table 5.10, demonstrate that the installation of type 2 turbines (200 kW) alone would determine a non-trivial self-sufficiency rate value of about 12%, while the installation of a single 2 MW turbine would be capable of achieving more than 45% coverage.

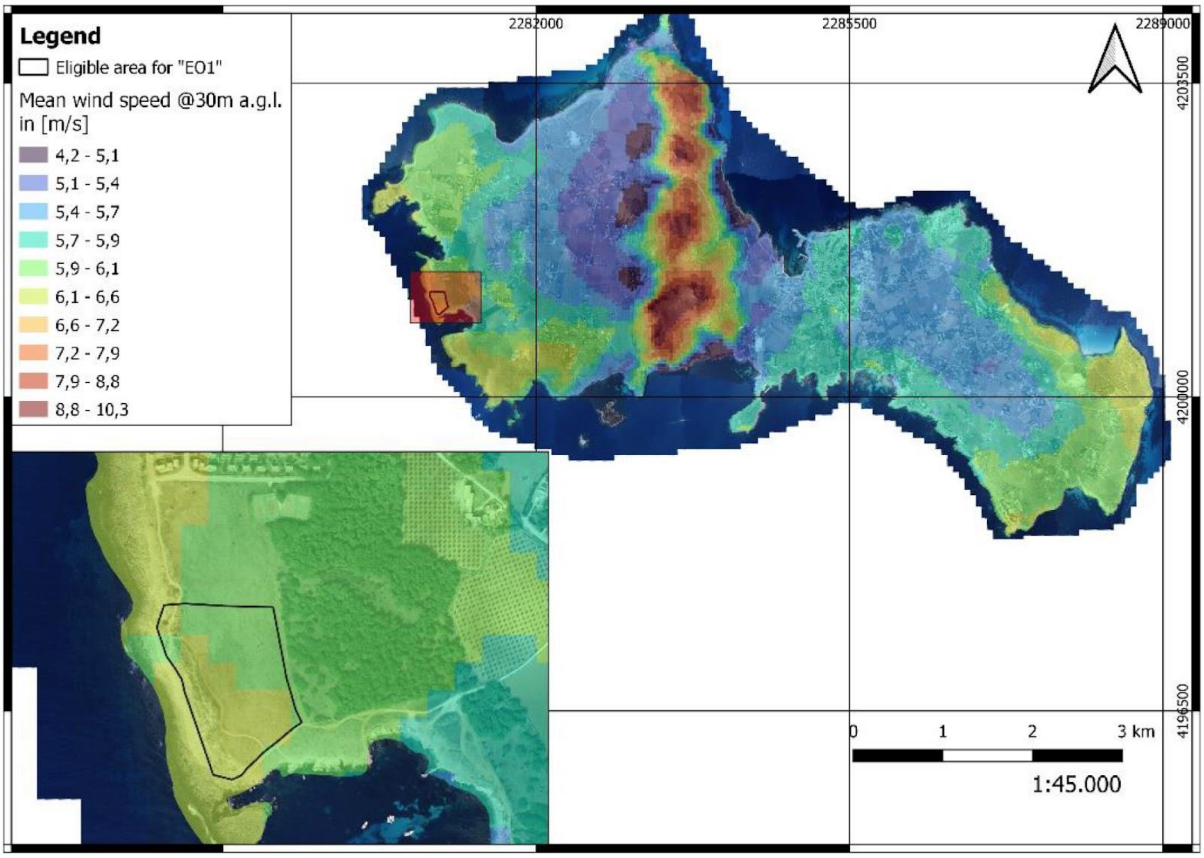


Figure 5.8: Favignana eligible area and mean wind speed

WT Pn	Hub Height	Mean wind speed	# WT	Net AEP	Wake Losses	Capacity factor
[kW]	[m a.g.l.]	[m/s]	[No. of WTs]	[MWH/year]	[%]	[%]
20	20	5,8	8	382	4,04	31,5
200	30	6,14	4	1.887	3,03	27,8
2000	80	7,15	1	7.027	0	40,1

Table 5.10: Favignana wind technical potential

As regards the other two minor islands, it is not possible to install any type of turbine due to the current regulatory framework. The analysis performed on WAsP shows that they have an encouraging, but not exploitable, wind potential, the results of which are shown in table 5.11:

Islands	WT Pn	Hub Height	Mean wind speed			Power density			Net AEP		
	[kW]	[m a.g.l.]	[m/s]			[W/m^2]			[MWh/year]		
	-	-	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Marettimo	20	20	0,1	4,2	10,9	0	175	2357	0,82	50,1	101,7
	200	30	2	6,4	13,1	14	472	3073	36,5	482	812
	2000	80	5,2	7,4	12,7	199	597	2500	4168	7044	9726
Levanzo	20	20	3,2	5,8	9	58	354	1129	14,7	48,4	81,2
	200	30	4	6,2	9,2	102	410	1181	203	477	737
	2000	80	5,9	7,2	9,6	282	555	1193	5391	7012	8948

Table 5.11: Marettimo and Levanzo wind theoretical potential parameters

The regulatory framework and the territorial landscape plan of the archipelago do not highlight any particular constraint for the installation of photovoltaics on building roofs and therefore all the roofs included in the territorial data were taken into consideration. Although the annual electricity production from rooftop PVs already makes a huge contribution, the installation of APVs does nothing but provide other important elements towards energy self-sufficiency. Apart from Marettimo, for which no agricultural land has been identified in relation to the land use map categorization, Favignana and Levanzo have an installable capacity potential of an order of magnitude greater than the respective Rooftop PV potential installable capacity. The main results of the assessment of the geographical and technical solar potential are shown in table 5.12 below:

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
Favignana	Rooftop PV	303734	85622	27,51	16,76
	APV	3115590	2648251,5	286,1	140,8
Marettimo	Rooftop PV	26057	7345	2,12	1,44
	APV	0	0	0	0
Levanzo	Rooftop PV	18038	5085	1,57	1
	APV	539727	458768	44,7	24,4

Table 5.12: Pelagie Islands' Rooftop PV and APV technical potential

5.2 Puglia - Results

The archipelago of the Tremiti islands belongs to the homonymous municipality, in the province of Foggia. The archipelago, surrounded by the Adriatic Sea, is about 22 km from the Gargano promontory and includes 5 islands, of which only two are inhabited (San Domino and San Nicola), for a total of less than 500 inhabitants.

There are several constraints that prevent the installation of any type of wind turbines: first, the archipelago belongs to the Gargano national park, which prohibits the installation of type 2 and 3 turbines. In addition, the entire extension of the islands falls within the areas of SCI, SPA, IBA, and Properties of notable public interest. Despite the impossibility of installing wind turbines, the wind resource assessment and potential analysis was still performed: the summary results of are reported in table 5.13, while figure 5.9 reports the mean wind speed at 30m a.g.l for both islands.

Island	WT Pn	Hub Height	Mean wind speed			Power density			Net AEP		
	[kW]	[m a.g.l.]	[m/s]			[W/m^2]			[MWh/year]		
	-	-	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
San Domino	20	20	3,7	4,68	6,32	115	216	498	23,3	34,7	54,7
	200	30	4,24	5,03	6,76	175	255	600	256,2	344,6	535,4
	2000	80	5,43	5,84	7,04	277	337	575	4563	5185	6615
San Nicola	20	20	4,11	4,96	6,63	157	249	575	28	38	58
	200	30	4,53	5,18	6,6	194	272	544	286	362	517
	2000	80	5,6	5,83	6,78	289	335	506	4823	5189	6411

Table 5.13: Tremiti Islands' wind theoretical potential parameters

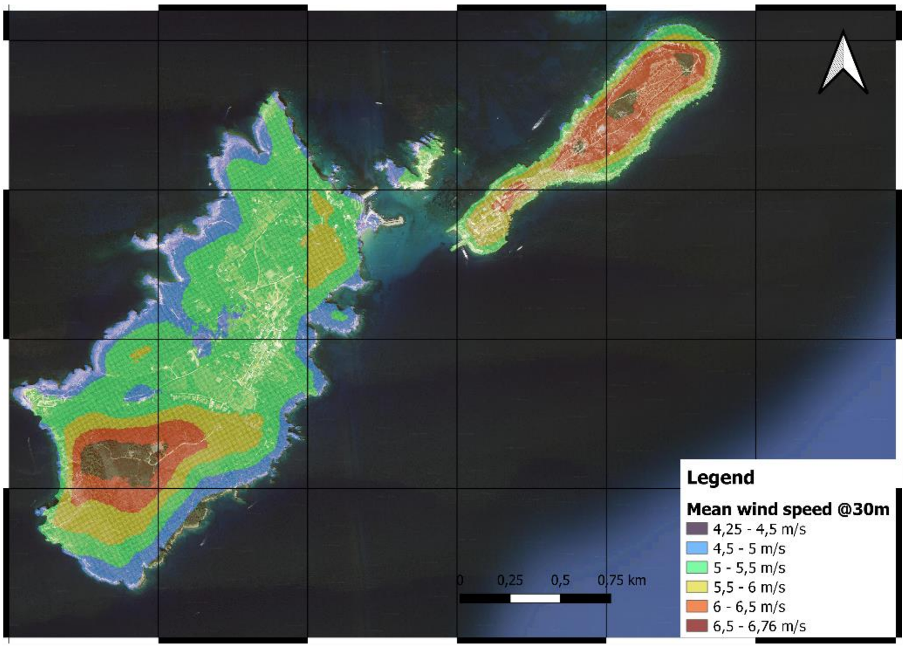


Figure 5.9: Tremiti Islands Mean wind speed

The Regional Territorial Landscape Plan (PPTR) lists the constraints on the installation of photovoltaics according to the type, configuration, and size of the PV plant. As regards the Rooftop PV, in order to simultaneously satisfy all the different constraints present in the islands, it is necessary that the photovoltaic systems are built without connection works (electrodes, transformer cabin) and that the buildings fall outside the Homogeneous Territorial Zones of type A, as identified by the urban planning instruments in force. For this reason, some buildings on the island of San Nicola have been excluded as they fall within zone A, as shown in figure 5.10, which also illustrates the irradiance on the building roofs of the two islands.

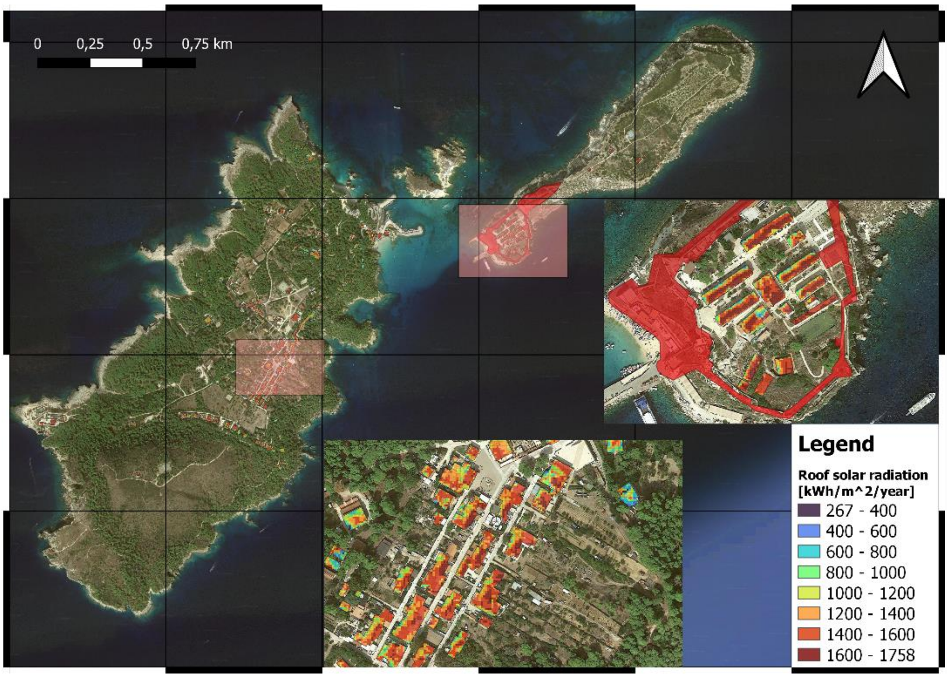


Figure 5.10: Tremiti Islands solar radiation on building roofs

As already anticipated, there is no regional regulation relating to the APV. If the legislation relating to ground-mounted photovoltaics were taken into consideration for the feasibility of an APV systems, then they would not be installable anywhere. However, having assessed that these two configurations, although they have similar fields of application, have structural characteristics such as to distinguish them significantly, the APV potential was nonetheless evaluated in those areas classified as Vineyards, Simple Arable Crops and Crop and Particle Systems complexes, according to the categorization of the regional land use map. For the sake of completeness, figure 5.11 displays the agricultural areas on the island of San Domino on the basis of which the technical potential for the APV systems has been calculated.

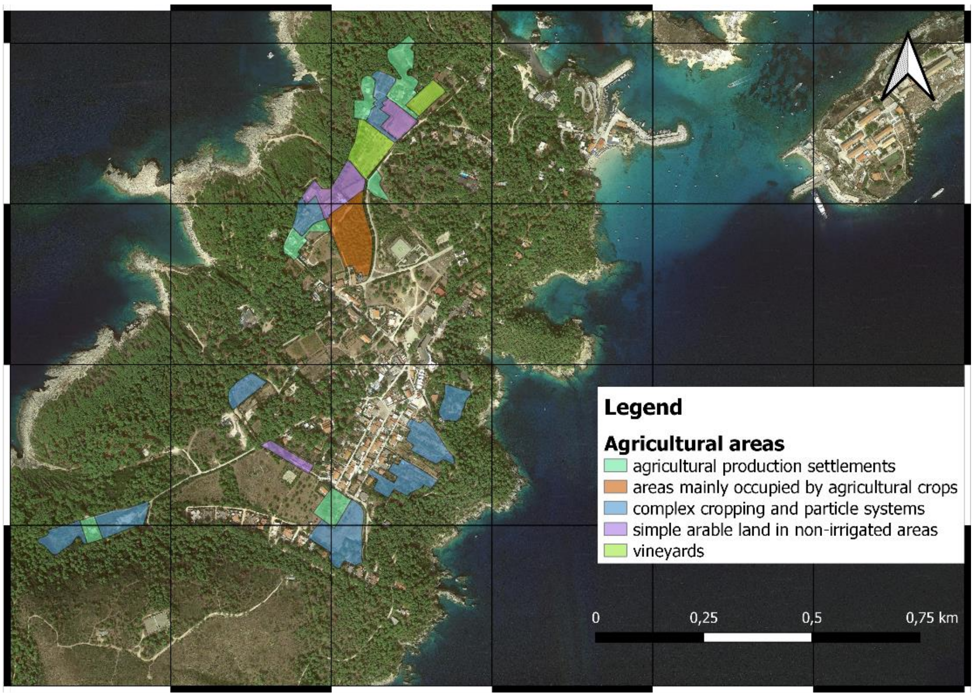


Figure 5.11: San Domino agricultural areas

What emerges from the assessment of the potential of the APV is that no land classifiable as agricultural land was identified on the island of San Nicola, while San Domino has a geographical potential of approximately 6.4 ha, for a consideration of almost 3 MW that can be installed, as shown in table 5.14. Considering the annual production from Rooftop PV and APV, a self-sufficiency rate of 187% was calculated for the entire archipelago.

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
San Domino	Rooftop PV	23577	7903	1,43	1,13
	APV	64789	55070	5,49	2,93
San Nicola	Rooftop PV	4927	1652	0,32	0,24
	APV	0	0	0	0

Table 5.14: Tremiti Islands' wind theoretical potential parameters

5.3 Lazio - Results

The only inhabited islands not interconnected to the national electricity system belonging to the Lazio region are Ponza and Ventotene, both belonging to the Pontino archipelago. These two islands belong to the homonymous municipalities, for a total number of inhabitants of about 4000 inhabitants, that considerably grow in the summer period. From the point of view of energy production, none of the two islands have reached the RES installed power 2020 target. Currently Ponza and Ventotene have a RES installed power of approximately 289 kW and 115 kW respectively, consisting almost exclusively of photovoltaic systems. Ventotene, to be precise, is the only island, together with Pantelleria, to also have micro-wind power (technology not contemplated in this thesis) as another source of renewable energy, for a markedly low value of installed power of 3.16 kW.

Here it is recalled that the Regional Territorial Landscape Plan (PTPR) of the Lazio relates the compatibility of RES plants with the landscape system or with the specific area of the territory according to their technical characteristics or potential negative impacts. Although the area of the two islands is divided in detail into portions representing a particular territory or landscape system for which a specific compatibility with a RES system is envisaged, the presence of constraints such as SPA and IBA, extended to the whole island, is already sufficient not to allow the installation of wind turbines of any type investigated in the thesis. Therefore, also in this case, the wind resource assessment and potential analysis was still performed, the results of which, for both islands, are shown in table 5.15.

Island	WT Pn	Hub Height	Mean wind speed			Power density			Net AEP		
	[kW]	[m a.g.l.]	[m/s]			[W/m^2]			[MWh/year]		
	-	-	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Ponza	20	20	2,03	4,46	9,65	23	215	1955	9	32	77
	200	30	2,85	4,72	9,39	50	238	1704	105	310	647
	2000	80	4,39	5,42	8,35	164	291	1026	3073	4606	7379
Ventotene	20	20	3,51	4,61	8,43	96	229	1269	20	34	72
	200	30	3,97	4,86	7,78	130	244	953	218	322	591
	2000	80	5,06	5,48	6,76	232	296	541	4027	4639	6189

Table 5.15: Ponza and Ventotene wind theoretical potential parameters

From the observation of the values reported in the previous table it is undeniable how the regulatory framework is currently limiting an important exploitation of the wind resource on the island, whose representation, for both islands, is shown in figure 5.12 by means of the mean wind speed at 30m a.g.l:

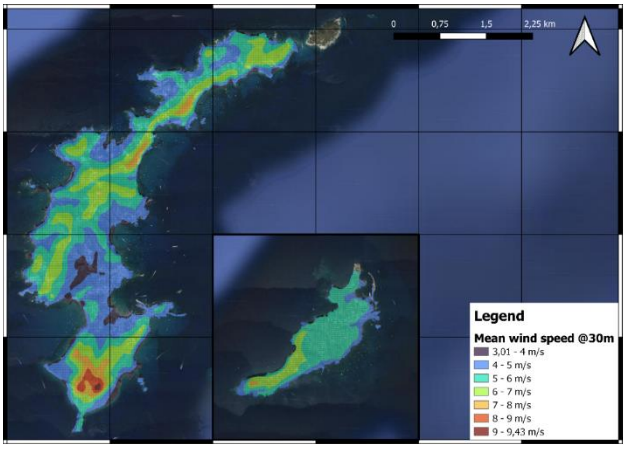


Figure 5.12: Ponza e Ventotene Mean wind speed

As regards the Rooftop PV, in accordance with the already mentioned classification present in the PTPR, if the power of the system is greater than 20 kW, the system is generally "Non Compatible" or "Partially Non Compatible". Assuming that this value is respected and if it is an integrated PV then all the building roofs of the islands can be considered as suitable areas. However, a further assumption was made: the buildings belonging to historic centers, due to their historical and cultural value, were excluded from the assessment of the rooftop PV technical potential and this was possible thanks to the categorization already included in the territorial shapefile data. In figure 5.13 and figure 5.14, the irradiance on the building roofs of the two islands is shown, to give a visual overview of the solar potential on these territories:

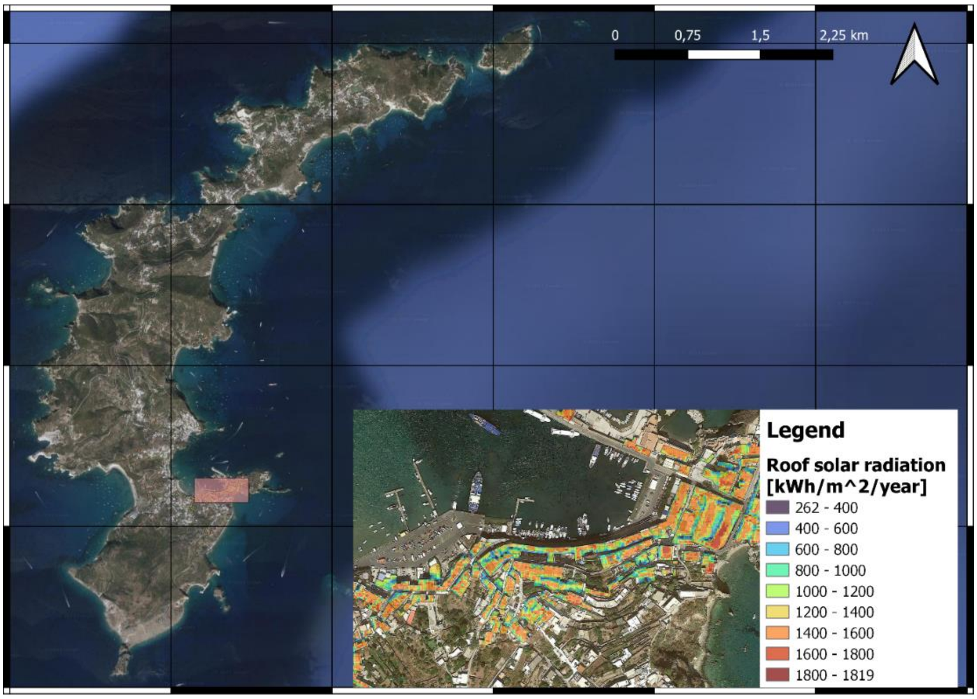


Figure 5.13: Ponza solar radiation of building roofs

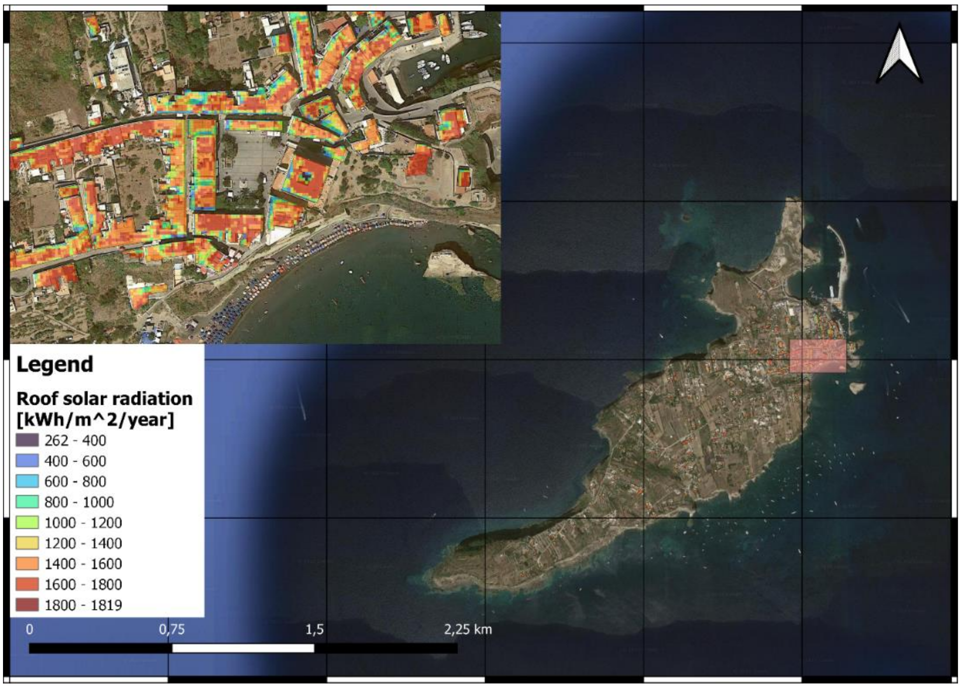


Figure 5.14: Ventotene solar radiation of building roofs

The Lazio region is the only region, among the ones included in this thesis, provides indications on the realization of APV systems within its regulatory framework, although they are not entirely accurate. According to the guidelines, their compatibility with the type of area depends on the Land Capability Classification (LCC) of the land. Through the spatial analysis of the constraints, what stands out is that part of the agricultural land of both islands has been classified with an LCC III-VI, meaning that approximately 50% of these lands are classified with an LCC III and for the remaining half with LCC VI. According to what reported by the PTPR, the higher the class, the fewer constraints there are on the land and, in addition, for a value of LCC > II, the construction of APV plants is allowed. Therefore, the lands classified as agricultural have been clipped within the area identified as suitable for the installation of APV. Figure 5.15 shows the agricultural areas and the portion of land with LCC > II.

Figure 5.15: Ponza & Ventotene agricultural areas and LCC

As can be seen from the previous image, almost the entire territory of the two islands has an LCC value such as to allow the installation of APVs. In the case of Ponza, the only land identified as agricultural coincides with a vineyard in the south of the island, while, as regards Ventotene, this has an agricultural area of approximately 42.5 hectares, covering practically the total width of the island. Table 5.16 summarizes the outputs of the evaluation of the geographical and technical potential for the two islands, relating to both the Rooftop PV and the APV. It is clearly intuitable that an installation of APV as impressive as the one calculated for Ventotene is unattainable, although the important presence of agricultural land on the island can really offer a great contribution to the energy transaction.

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
Ponza	Rooftop PV	52131	14681	4,1	2,6
	APV	77064	65504	6,8	3,5
Ventotene	Rooftop PV	36966	10410	2,9	1,8
	APV	425427	361613	37,9	19,2

Table 5.16: Ponza and Ventotene Rooftop PV and APV technical potential

5.4 Tuscany – Results

The Tuscan archipelago is made up of a group of seven major islands: Gorgona, Capraia, Elba, Pianosa, Giglio, Giannutri and Montecristo. The latter, in particular, was excluded from the thesis because it is currently uninhabited. As already anticipated, some islands of this archipelago represent exceptions to the study done so far. As a matter of fact, Elba and Pianosa are currently connected to the national electricity system and, in addition, Pianosa is sparsely inhabited but has nevertheless been included due to the ongoing project "Pianosa Rebirth", which aims at the repopulation of the ancient villages; Gorgona is a penitentiary island and therefore mostly host to prisoners. Finally, Giannutri is also sparsely inhabited but whose population grows exponentially during the summer.

As regards the regulatory framework on the wind energy sector, the PAER (Regional Environmental and Energy Plan) contains all the information about the constraints to be included and considered in the assessment of the wind energy technical potential. From the spatial analysis carried out on QGIS and from the study of landscape and environmental constraints, it is observed that the legislation strongly discriminates against the installation of large size turbines, such as type 2 and 3 WTs. In fact, the mere presence of the constraint "Buildings and areas of notable public interest", extended practically to the entire area of all the islands (except for an irrelevant small part in the hinterland of Pianosa), is already sufficient to exclude the possibility of installing type 2 and 3 WTs.

Unlike the two regions previously examined, in some of the Tuscan islands it was possible to identify some areas classifiable as eligible for the installation of type 1 WTs for which in-depth WAsP analyzes were carried out, with the simulation of possible examples of wind farms consisting of 20 kW wind turbines. To do this it was firstly necessary to exclude restricted areas, in accordance with the PAER, such as residential areas, urban centers, General Oriented Reserves and Integral Natural Reserves. The islands in which it was possible to simulate the installation of 20 kW WTs are the following: Gorgona, Capraia, Elba and Giglio. The following figures show (5.16, 5.17, 5.18 and 5.19) show the boundaries of the eligible area and an overview of the wind resource, in this case represented by the mean wind speed at 20m a.g.l, for each island presenting eligible areas.

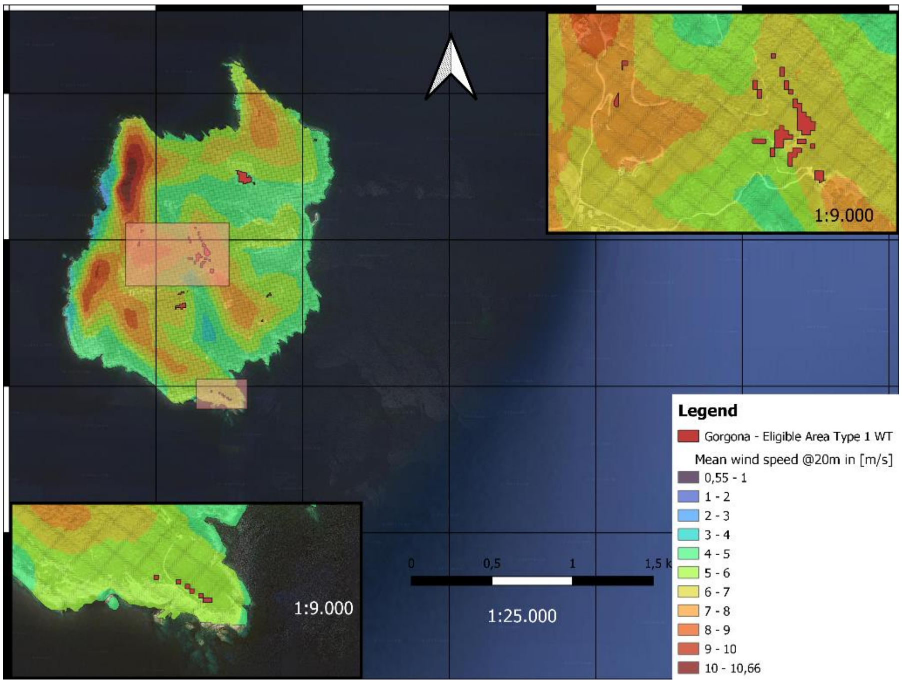


Figure 5.16: Gorgona Eligible areas and mean wind speed

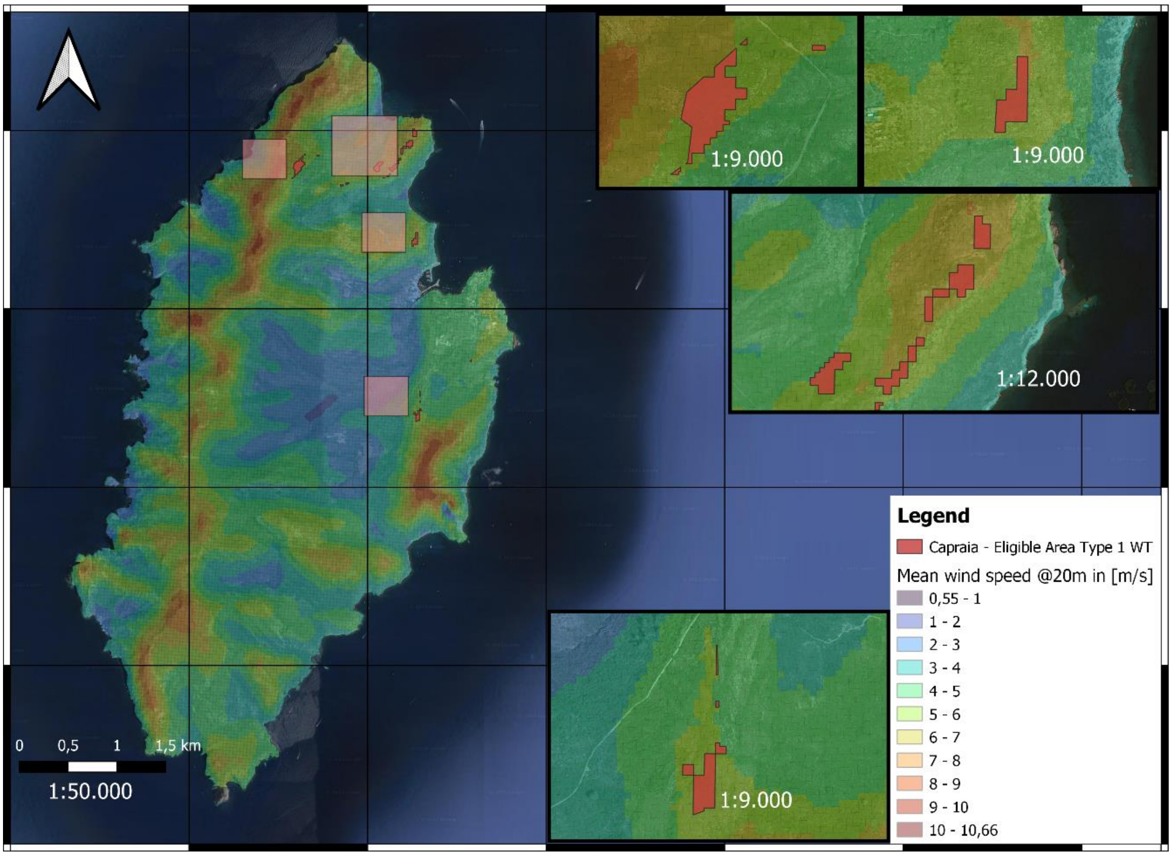


Figure 5.17: Capraia Eligible areas and mean wind speed

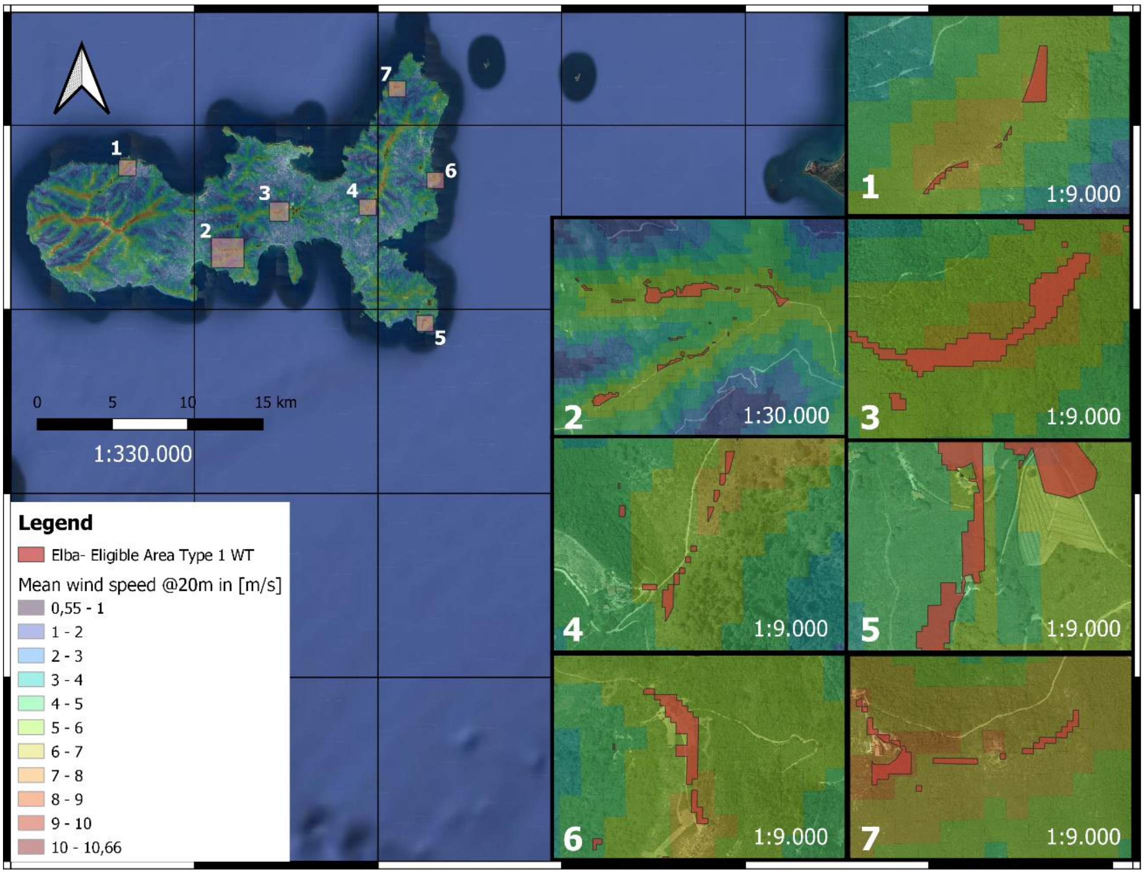


Figure 5.18: Elba Eligible areas and mean wind speed

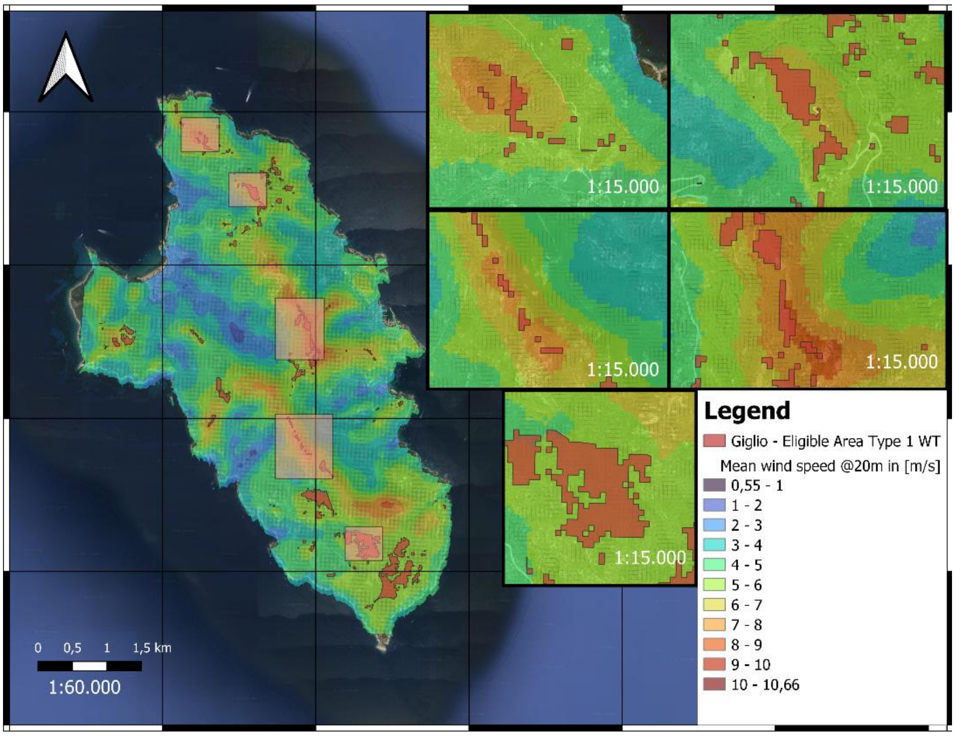


Figure 5.19: Giglio Eligible areas and mean wind speed

It should be remembered that the identification of the eligible area, in addition to considering the regulatory and environmental constraints, also takes into consideration, as explained in detail in the chapter on methodology, technical and economic factors, such as the maximum slope of the land and the minimum wind speed. As a matter of fact, in the case of the island of Pianosa, although it presented a suitable inland area, the wind speed was not sufficient to satisfy the lower threshold of 5 m/s. The opposite situation is present in Giannutri, which is characterized by areas with excellent wind conditions but whose territory is entirely within environmental restrictions which prohibit the installation of type 1 wind turbines.

Table 5.17 shows the main results of the simulation of the wind farms of these four islands obtained by means of WAsP:

Island	WT Pn	Hub Height	# WT	# Cluster	Net AEP	Wake Losses	Capacity factor
	[kW]	[m a.g.l.]	[No. of WTs]	[No. of Clusters]	[MWH/year]	[%]	[%]
Gorgona	20	20	12	3	638,004	1,48	33,7
Capraia			27	4	1334,069	1,07	31,3
Elba			52	7	2452,537	0,9	29,9
Giglio			55	5	2890,314	2,17	33,3

Table 5.17: Gorgona, Capraia, Elba, Giglio wind technical potential

From the previous table it can be seen, in addition to the annual energy production, how this production was obtained, in terms of number of turbines and in how many clusters these turbines were grouped. Although this simulation provides promising values in terms of overall Capacity Factor, it is nevertheless necessary to highlight a critical point: to obtain these production levels, a large number of turbines have been installed, especially in the case of Elba and Giglio. The installed power for each of these two islands is approximately 1MW, i.e., half the power that would be obtained with a single type 3 WT (2 MW). Although the regulatory framework of the region has the objective of preserving the territory and the environment, from the simulation it can be seen how, for the purposes of the energy transition, the possibility of installing turbines with a higher unit power would not only allow to obtain a good annual production, but it would also sharply reduce the environmental impact that wind farms made up of innumerable smaller size turbines would cause.

For the sake of completeness table 5.18 summarizes the statistics relating to the wind resource of all the islands of the archipelago:

Island	WT Pn	Hub Height	Mean wind speed			Power density			Net AEP		
	[kW]	[m a.g.l.]	[m/s]			[W/m^2]			[MWh/year]		
	-	-	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max
Gorgona	20	20	2,41	5,29	10,6	42	388	2895	10	42	79
	200	30	3,06	5,67	10,25	82	436	2358	150	404	662
	2000	80	5,12	6,43	8,81	236	495	1253	4142	5776	7583
Capraia	20	20	1,38	4,45	8,8	9	232	1824	2	32	73
	200	30	1,98	4,83	8,83	22	275	1419	51	318	637
	2000	80	4,06	5,95	9,14	116	397	1399	2566	5141	7655
Elba	20	20	0,52	4,13	9,35	0	164	1669	0,05	28	77
	200	30	1,07	4,41	9,04	4	184	1340	8	271	640
	2000	80	2,37	5,24	8,85	37	243	1058	805	4258	7843
Pianosa	20	20	3,17	4,25	4,84	73	175	247	16	29	37
	200	30	3,8	4,55	5,02	125	203	264	200	287	341
	2000	80	5,09	5,37	5,58	238	280	306	4084	4518	4837
Giglio	20	20	1,62	4,66	8,41	12	220	1181	3	34	73
	200	30	2,48	5,02	8,62	31	256	1173	72	335	656
	2000	80	4,59	6,05	8,81	153	354	1157	3260	5407	8168
Giannutri	20	20	3,7	4,85	6,62	98	219	518	21	36	58
	200	30	4,41	5,27	6,72	157	263	519	260	365	533
	2000	80	5,88	6,2	7,04	309	360	526	5238	5725	6754

Table 5.18: Tuscan Islands' wind theoretical potential parameters

The Tuscan legislation does not directly identify the building roofs that are unsuitable for the installation of PVs, however it describes in detail the authorization procedures and paths to be followed for the installation of the systems according to the sizes. Starting from the investigation of these, it was observed how the installation of Rooftop PV is strongly limited in the case of buildings falling within the Homogeneous Territorial Zones of type A, as identified by the urban planning instruments in force. For this reason, these were excluded from the evaluation of the Rooftop PV technical potential. To do this it was necessary to explore each website of the municipalities involved and search the regulatory plans containing information on Zone A. These, usually available in the form of PDF or PNG, and therefore not georeferenced, have been imported on QGIS and processed in order to overlap with the georeferenced territorial data showing the buildings. To give an idea of the assessment of solar radiation on roofs on the Tuscan islands, figure 5.20 illustrates the irradiance on the building roofs and the Homogeneous Territorial Zones of type A on the island of Capraia:

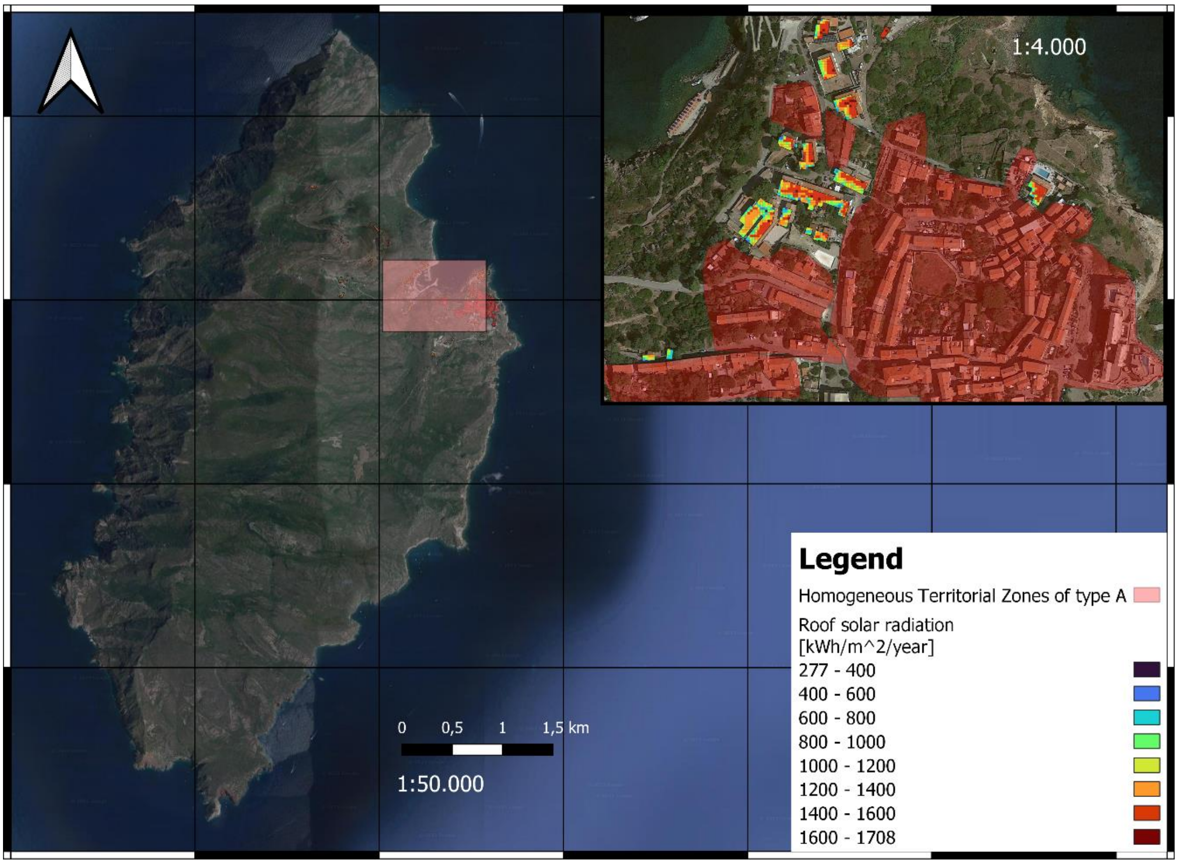


Figure 5.20: Capraia solar radiation on building roofs and protected building area

Within the PAER it is possible to find a detailed description of the suitability of ground-mounted photovoltaic systems according to their size and the constraints insistent on the area. However, the regulatory framework does not present anything on the feasibility of APV systems. Consequently, also in this case, the evaluation of the geographical and technical potential of the APV was carried out starting from the identification of the agricultural lands, as shown in figure 5.21 in the case of Pianosa and Gorgona:

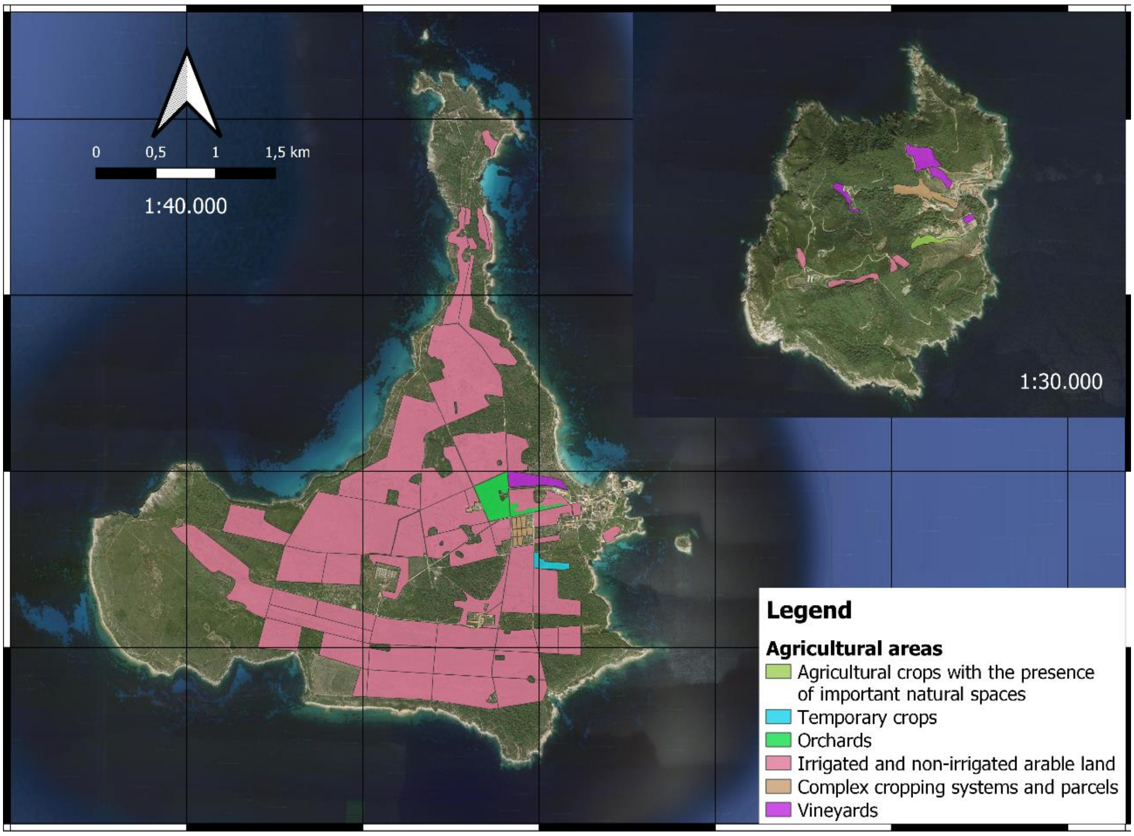


Figure 5.21: Pianosa Agricultural areas

For completeness, table 5.19 summarizes the outputs of the evaluation of the geographical and technical potential for each island of the Tuscan archipelago, relating to both the Rooftop PV and the APV.

Island		AV. Area	PV Area	Ele. Prod.	PV power
		m2	m2	GWh/year	MW
Gorgona	Rooftop PV	8567	2872	0,51	0,41
	APV	6620	5627	0,53	0,30
Capraia	Rooftop PV	15617	5235	0,96	0,75
	APV	59533	50603	4,81	2,69
Elba	Rooftop PV	-	-	-	-
	APV	10832500	9207625	846	489,4
Pianosa	Rooftop PV	12084	4051	0,77	0,58
	APV	4389650	3731203	385,02	198,32
Giglio	Rooftop PV	60737	20360	3,71	2,91
	APV	66252	56314	5,78	2,99
Giannutri	Rooftop PV	8667	2905	0,55	0,42
	APV	0	0	0	0

Table 5.19: Tuscan Islands' Rooftop PV and APV technical potential

Starting from the data in the previous table, it is possible to make observations on some critical aspects: Pianosa is among the smaller islands of the archipelago (thus excluding Elba), the one with the greatest APV potential, with an installable power of almost 200 MW. This result derives from the fact that most of its territory is classified as agricultural. It is easily conceivable that completely covering the whole island with photovoltaic modules is impracticable and with an immense environmental impact. However, this result could suggest the idea of exploiting the island's potential through the APV, in order to be able to supply energy to the mainland as it is electrically connected to it. Opposite result for Giannutri, whose APV potential is null due to the absence of land classified as agricultural. Elba clearly shows the greatest potential for APV, due to the fact that it is the largest island of all, with a greater agricultural lands. Moreover, as already anticipated, the Rooftop PV technical potential for this island was not possible to calculate due to the absence of the island's DSMs, indispensable input for the application of the methodology.

5.5 Summary

This paragraph has the objective of summarizing the results obtained from the application of the methodology, to provide an overview of the potential of the territories investigated, comparing these results with the current status of energy production of the islands. Table 5.20 presents, for each island, the wind and PV technical potential (distinguished into Rooftop PV and APV), in terms of both installable power [MW] and annual energy production [GWh/year]. To give an idea of the contribution that these technologies could make, the Self-Sufficiency parameter [%] has been introduced, defined as the sum of the annual energy production from RES divided by the annual energy production from diesel thermoelectric plants.

Region	Island	Potential Wind AEP	Potential Wind Power	Rooftop PV AEP	Rooftop PV Power	APV AEP	APV Power	AEP from Diesel	Self- Sufficiency w/o APV	Self- Sufficiency w/ APV
		GWh/year	MW	GWh/year	MW	GWh/year	MW	GWhel/year	%	%
Sicily	Pantelleria	3,04	1,4	18,47	10,72	1448,35	701,67	39,0	55	3769
	Ustica	1,51	0,8	11,45	7,33	169,30	82,81	4,9	266	3743
	Alicudi	0	0	1,99	1,32	1,42	0,81	0,4	498	853
	Filicudi	0	0	5,78	3,61	14,04	7,94	1,4	413	1416
	Lipari	0	0	61,73	40,56	234,06	114,67	34,8	177	850
	Vulcano	0	0	17,22	10,96	79,67	39,48	7,3	237	1331
	Panarea	0	0	3,50	2,40	1,74	0,89	3,1	111	167
	Stromboli	0	0	8,00	5,42	7,05	3,77	3,9	207	389
	Salina	0	0	22,10	14,89	75,23	40,07	9,2	241	1063
	Lampedusa	0,374	0,16	49,11	29,26	185,37	88,30	10,3	478	2271
	Linosa	0	0	5,61	3,35	89,64	45,53	2,8	200	3402
	Favignana	0,19	0,8	27,51	16,76	286,13	140,76	15,5	179	2029
	Marettimo	0	0	2,12	1,44	-	-	2,0	104	104
	Levanzo	0	0	1,57	1,00	44,68	24,38	0,6	262	7709
Puglia	San Domino	0	0	1,758	1,36	5,485	2,927	3,9	45	187
	San Nicola	0	0							
Lazio	Ponza	0	0	4,10	2,56	6,84	3,48	11,5	36	95
	Ventotene	0	0	2,93	1,82	37,92	19,22	2,7	109	1513
Tuscany	Gorgona	0,638	0,24	0,51	0,41	0,53	0,30	-	-	-
	Capraia	1,334	0,54	0,96	0,75	4,81	2,69	2,8	83	257
	Elba	2,453	1,04	No DSM	No DSM	846	489,4	-	-	-
	Pianosa	0	0	0,77	0,58	385,02	198,32	-	-	-
	Giglio	2,890	1,1	3,71	2,91	5,78	2,99	10,3	64	120
	Giannutri	0	0	0,55	0,42	0	0	-	-	-

Table 5.20: Wind, Rooftop PV and APV technical potential of minor Italian islands

As can be seen from the previous table, two self-sufficiency parameter columns have been added, one that does not include production from APV and the other that does. This distinction was made precisely to highlight the enormous contribution that could derive from the inclusion of APV systems in the energy mix. It is observed that, generically, the annual energy production from APV drastically increases the self-sufficiency values, as in the exceptional cases of Levanzo, Pantelleria or Ustica. Although it is clear that it is realistically unfeasible to be able to install such a quantity of APVs in the islands, the importance that APV systems could bring to the energy transition process should not be underestimated. The only exceptions are Marettimo (Sicily), San Nicola (Puglia) and Giannutri (Tuscany) which, according to the information in the territorial data relating to land use, do not have lands classifiable as agricultural.

Of the 24 islands included in the thesis, only in 8 of these it was possible to insert wind turbines in accordance with the legislative framework and, in particular, in the case of the Sicilian islands, it is recalled that an important relaxing assumption was made relating to neglecting the IBA constraint. This is nothing more than the effect of the strong environmental and territorial constraints insistent on the islands which, if on the one hand preserve the vulnerability of these areas, on the other they slow down and hinder the process of energy transition and the abandonment of fossil fuels.

As far as the Rooftop PV is concerned, overall, it plays a key role since, even in the absence of wind farms and APV systems, it has the potential to make an island self-sufficient. Clearly, a project of this magnitude and impact must take into account countless other factors, such as, first of all, economic feasibility. In addition to this, there are other technical factors to consider, such as variability in production, discontinuity, and mismatch with energy demand.

Overall, all the islands, even without including the APV systems, achieve a self-sufficiency value greater than 100%. Exceptions are Pantelleria, the Tremiti Islands, Ponza, Capraia and Giglio, which, not including the APV systems, do not reach self-sufficiency. Furthermore, among this, Ponza is the only case in which, although production from APV is included, it still fails to achieve 100% self-sufficiency. In the cases of Elba and Pianosa, since these are interconnected, it is senseless, as well as impossible, to calculate the self-sufficiency value. For Gorgona and Giannutri, on the other hand, although not interconnected, there are no data relating to production from diesel plants.

Figure 5.22, for the sake of clarity, shows the bar chart that compares the annual energy production from RES, distinguished into onshore wind farms and Rooftop PV, compared with the current energy production from fossil sources, if known. Figure 5.23, instead, compares the annual electricity production from APVs between the different islands.

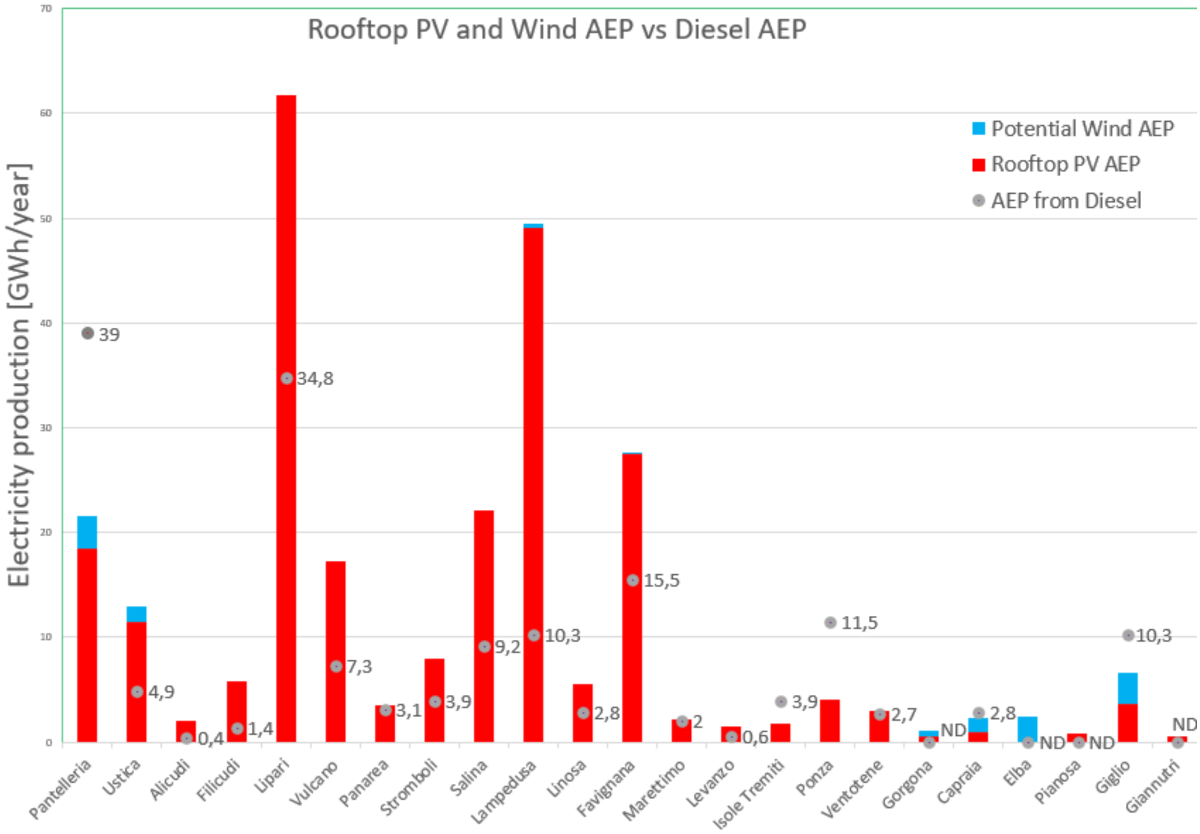


Figure 5.22: Rooftop PV and Wind AEP vs Diesel AEP

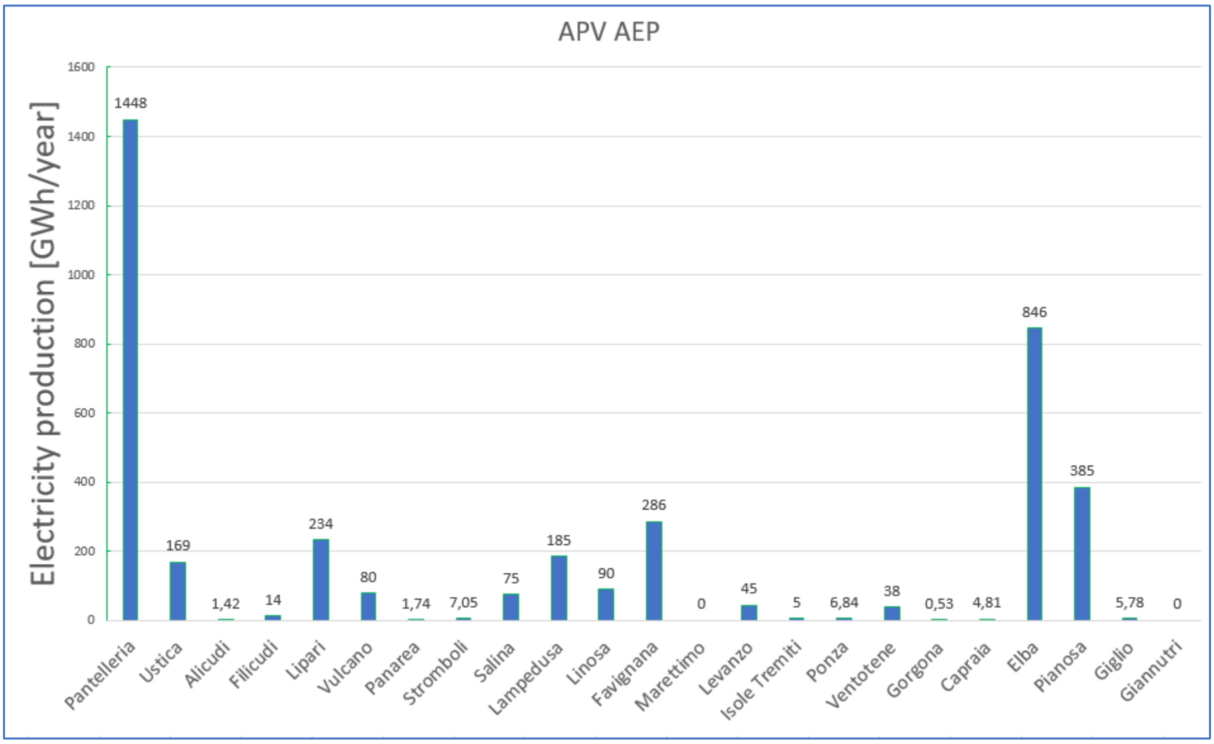


Figure 5.23: Comparison of annual energy production from APV

6. Conclusions

The main objective of this thesis is to evaluate the technical potential of wind power and photovoltaics on the minor Italian islands that are not connected to the national grid. These areas are isolated and characterized by a unique and rare natural environment that has led to the introduction of laws and regulations that protect them from an environmental point of view, but also pose challenges for the deployment of renewable energy technologies. To better understand the context, Chapter 2 describes the state of the art, highlighting the main critical issues related to sustainable development, such as the energy supply system that operates today thanks to highly polluting thermoelectric diesel power plants.

A relevant contribution of this thesis is the analysis and summary of the complex regulatory framework at European, national, regional and local level, highlighting the main barriers to the diffusion of RES technologies, as shown in Chapter 3, also distinguishing how the four Italian regions involved (Sicily, Puglia, Lazio, Tuscany) pay attention to the issues related to energy transition.

The regulatory and technical constraints, resulting from the various legislative frameworks, form the starting point for the methodology used: the scalable methodology, described in detail in Chapter 4, is based on a spatial energy planning approach that allows for the graphical processing and manipulation of geo-referenced data implemented with the QGIS geographic information system software. In this way, it was possible to identify eligible areas for the RES technologies considered in this work using the different geoprocessing and analysis tools available. In particular, two different methods for assessing wind and photovoltaic potential were described. WAsP was the main software for calculating onshore wind potential, starting from the analysis of local wind resource, and considering the technical specifications of wind turbines of different sizes. The calculation of annual electricity production from photovoltaics is essentially based on the use of the solar radiation model SEBE, which is integrated into the QGIS plug-in UMEP and enables the estimation of solar radiation on ground surfaces and building roofs. In addition, depending on the type of photovoltaic configuration, PVGIS, an online tool that provides information on solar radiation and PV system performances, was also used to finally calculate annual productivity. This last procedure differs according to the two photovoltaic technologies included, namely rooftop PV and agro-photovoltaic. In particular, the technical potential of APV was studied, as this technology could contribute greatly to the production of renewable energy saving the land and promoting the integration of RES production and agricultural activities.

The results obtained from the application of the methodology, discussed in Chapter 5, illustrate the enormous potential that RES technologies would have in the minor Italian islands. They show the great availability of the resource and, at the same time, highlight the severe obstacles imposed by the in-force environmental and landscape constraints. In particular, the results show that onshore wind power is the technology whose implementation is most limited due to its significant environmental and landscape impacts. In fact, only some Sicilian and Tuscan islands have been able to install wind turbines, albeit small ones, with a total installable capacity of approximately 6 MW, generating about 12.4 GWh/year. It is noted that in the Tuscan archipelago, in compliance with environmental constraints, only small turbines (20 kW) could be installed, while the siting of wind turbines on the Sicilian islands was only possible due to the introduction of the relaxation hypothesis for the IBA constraint. Among the technologies, rooftop PV is the one that is relatively easiest to implement on the islands today and thus makes an important contribution to the energy transition. It was possible to install it on all islands, certainly excluding the protected buildings. Overall, the application of the methodology showed that it is possible to achieve an annual electricity production of 251 GWh with an installation of about 160 MW. Finally, the results of the estimation of the technical potential show that this technology could play a key role in the energy transition, presenting, in some cases, an annual electricity production orders of magnitude higher compared to the other two technologies. This is mainly due to the fact that it is a relatively modern and little-used technology that is poorly regulated nowadays and therefore few constraints were considered for it. Thus, the installed capacity was proportional to the extent of agricultural land on the island. The island of Elba, the largest of the islands, can accommodate the largest amount of APVs, with an installable capacity value of about 490 MW, followed by Pantelleria (~ 700 MW) and by Pianosa, Favignana and Lipari, which have values above 100 MW. Overall, a total power of about 2 GW has been calculated, producing 3930 GWh of electricity per year.

In addition, regardless of whether or not it was possible to install any type of RES technology in accordance with the legislative framework, for each island both the wind and solar resources were calculated and reported in this thesis, in order to give an idea on the great potential of the territories in question.

The total annual production from RES for each island was compared with the AEP of diesel thermoelectric power plants to assess the impact of these technologies on the current energy mix. It showed that a self-sufficiency value of more than 100% was achieved for almost all islands, even when excluding the disproportionate contribution of APV. Among the outstanding results, the island of Levanzo (Egadi archipelago) is the one for which the highest self-sufficiency value was calculated, exceeding 7700% due to the current low electricity consumption and the high availability of agricultural land. Ponza, on the other hand, remains the only island with a value of 95% and thus does not reaching self-sufficiency. This is due to the fact that no wind turbines can be installed, that the many protected buildings are not able to accommodate PV roofs and that relatively little agricultural land is available.

In summary, this thesis was able to show that the large and abundant energy resources that characterize the minor Italian islands are decidedly underused. Apart from the technical and economic obstacles, the main barrier to the diffusion of RES technologies is certainly the current regulatory framework. Consequently, in order to embark on a sustainable path towards complete self-sufficiency of the islands, the regulatory framework must be modified by relaxing the current restrictions and simplifying and speeding up the authorization procedures for the installation of RES technologies, while always ensuring the protection of this exceptional and fragile environment. Finally, the work also aims to serve as an important consultative tool for policy-makers in decision-making by providing information on energy resources and current constraints in order to better intervene in these areas.

6.1 Possible future research developments

This concluding paragraph aims to suggest possible future developments and improvements to this work. One of the most time-consuming and repetitive operations is the processing and manipulation in QGIS. It is possible to speed up this process considerably, depending on the nature of the study, by working from the command line and automating various processes. Another important criticism arose when searching for environmental and landscape constraints at the regional level: this is because they have their own online geoportal, and sometimes downloading the materials is not easy and immediate. What we need is a standardization of the different geoportals in order to more easily access and download the georeferenced data of interest.

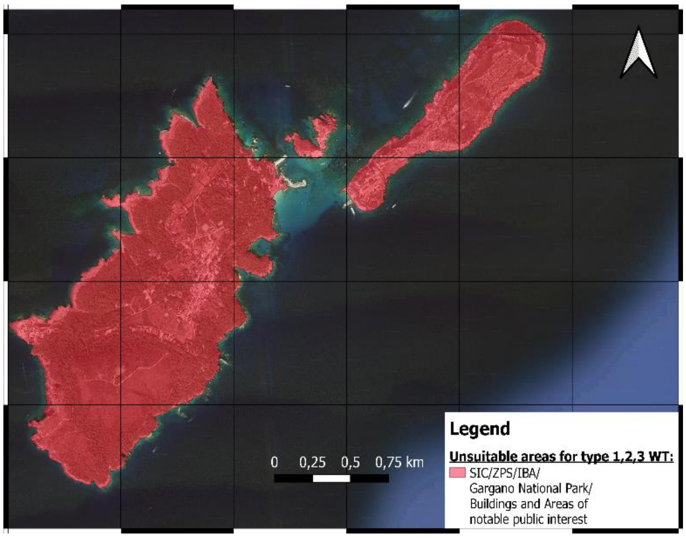
To obtain more precise results, it is possible from a technical point of view to increase the resolution in the assessment of resources, both for wind and solar energy. This is only possible if sufficiently powerful computers are available to cope with the high computing costs of these processes.

It is recalled that the results obtained are strictly related to the evaluation of the technical potential only. This means that additional essential factors have not been taken into consideration, such as those relating to economic and feasibility aspects. Although the results obtained are decidedly promising, they are undoubtedly an overestimation and the effective implementation must consider other important elements such as market, organizational and social barriers.

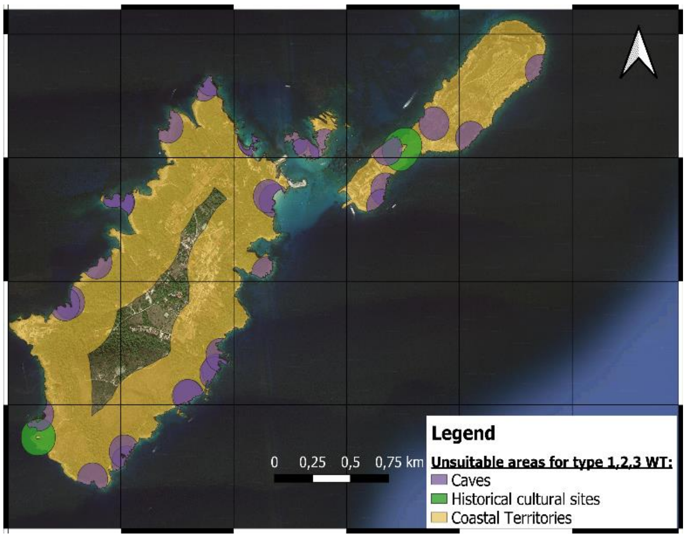
Finally, this work only examined the potential impacts of three RES technologies (onshore wind turbines, rooftop photovoltaics and APV). A possible extension of this work could be to investigate other RES technologies that are widely used or promising today, such as offshore wind turbines or wave energy, which have the important advantage of not consuming usable soil, especially in limited areas such as islands. This would provide the opportunity to include and consider elements that accelerate the energy transition process.

Appendix: Cartography

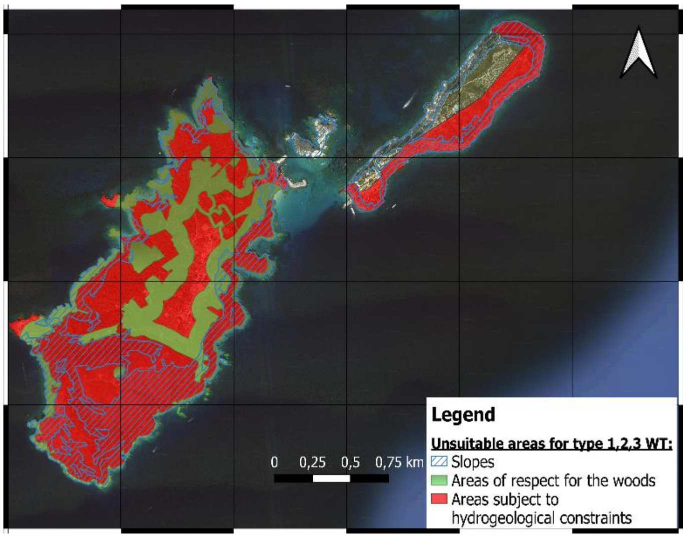
Puglia



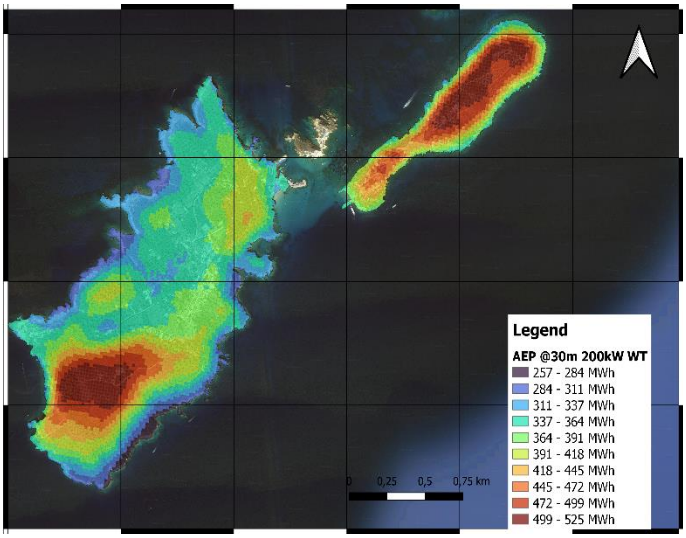
MAP 1: Tremiti Islands' unsuitable areas for WT installation



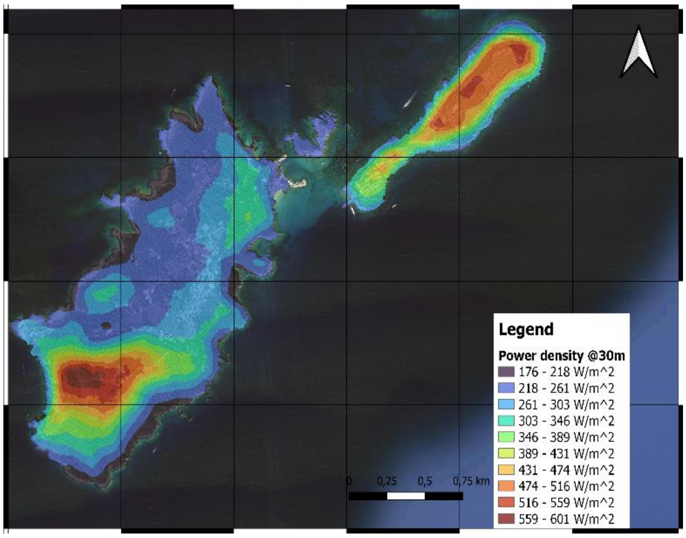
MAP 2: Tremiti Islands' unsuitable areas for WT installation



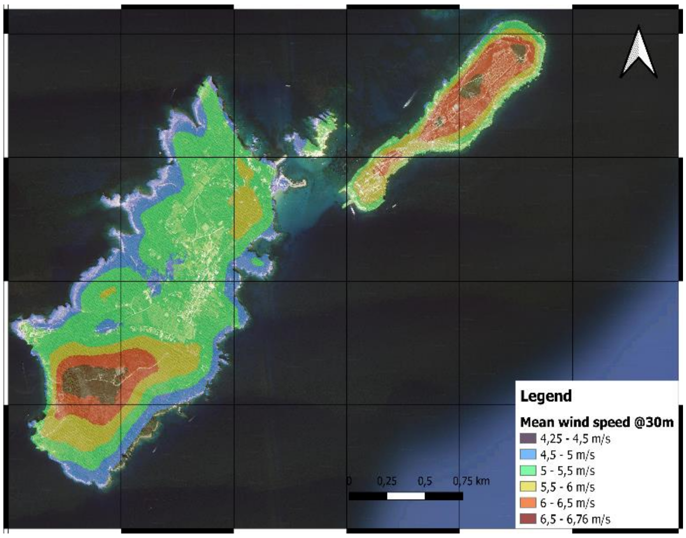
MAP 3: Tremiti Islands' unsuitable areas for WT installation



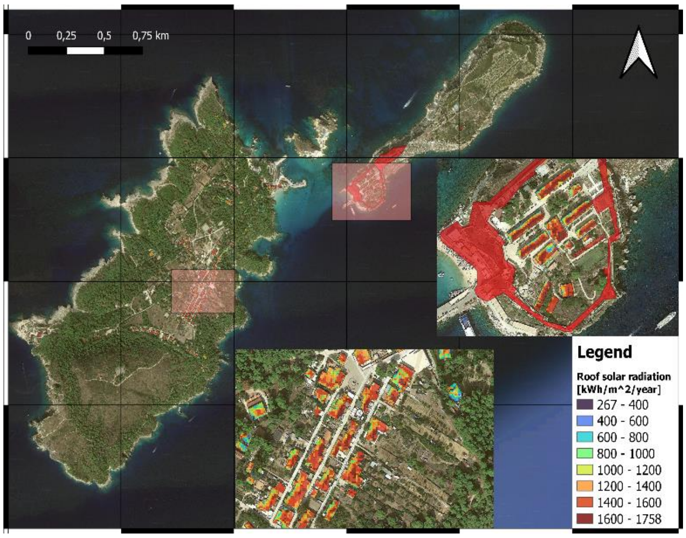
MAP 4: Tremiti Islands' AEP



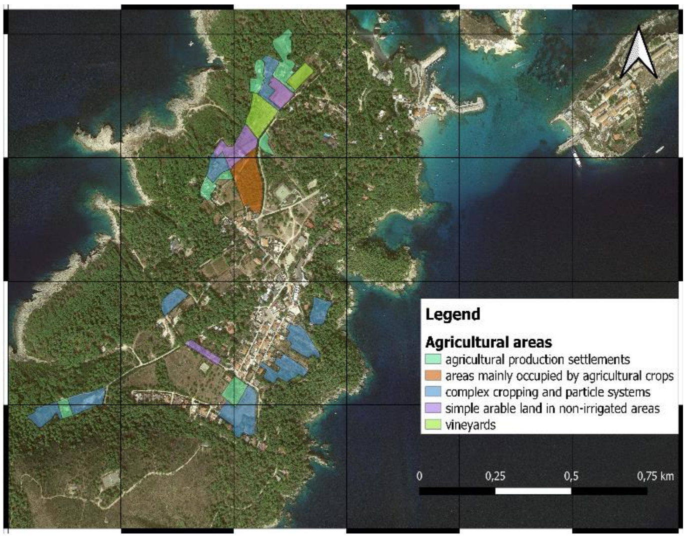
MAP 5: Tremiti Islands' power density



MAP 6: Tremiti Islands' mean wind speed

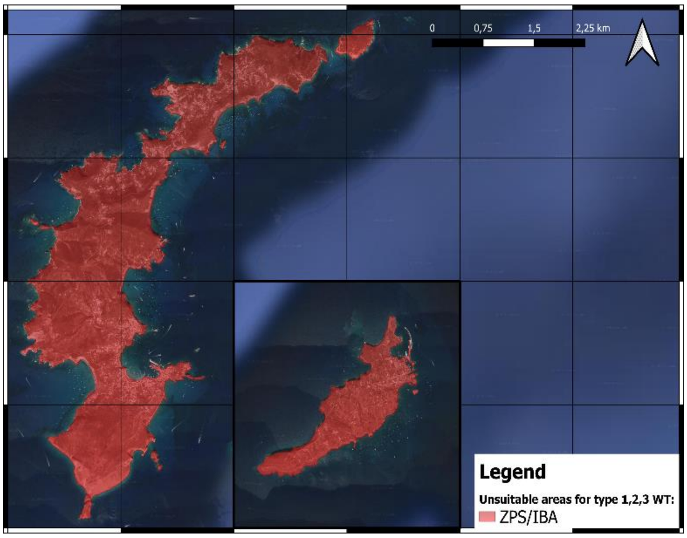


MAP 7: Tremiti Islands' solar radiation on building roofs

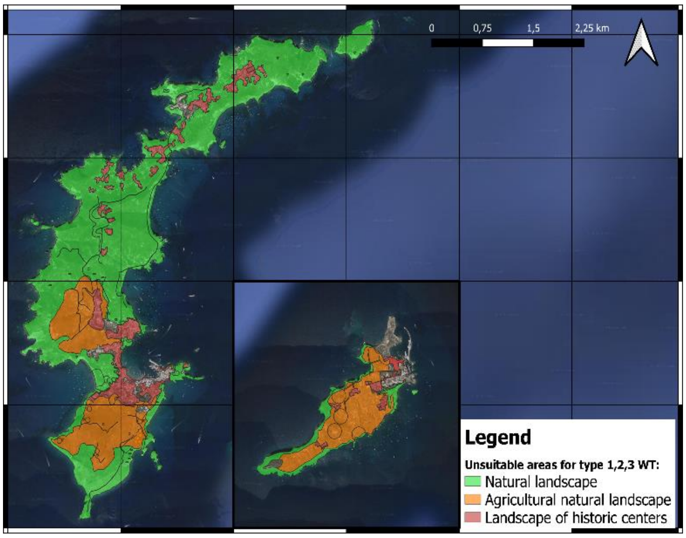


MAP 8: Tremiti Islands' agricultural areas

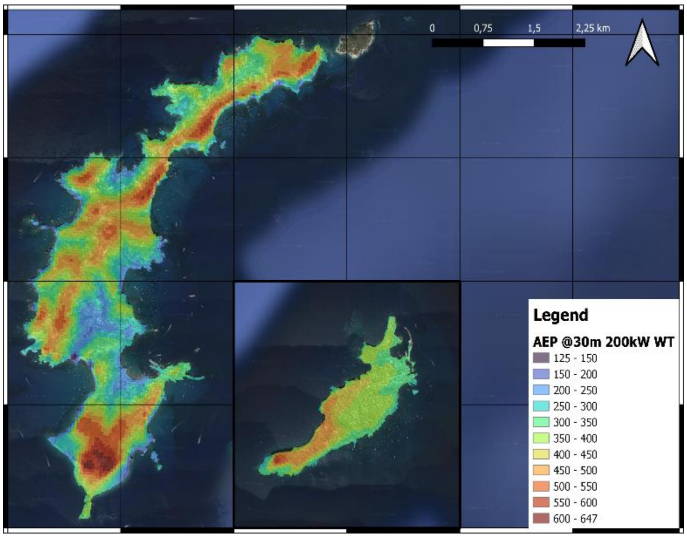
Lazio



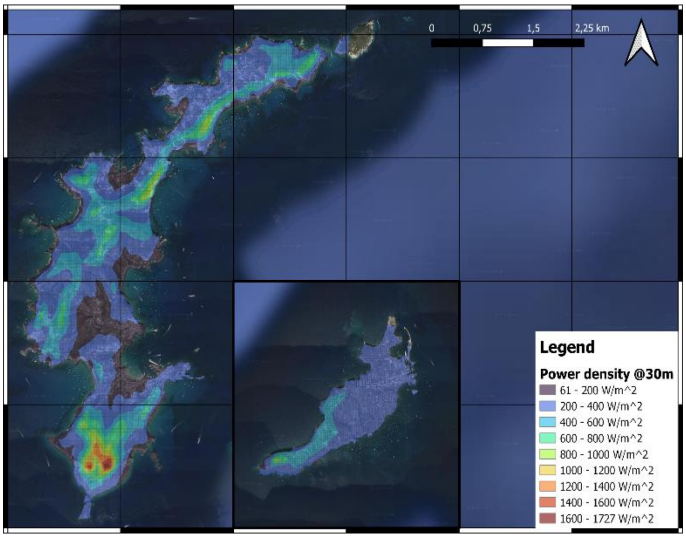
MAP 9: Ponza & Ventotene unsuitable areas for WT installation



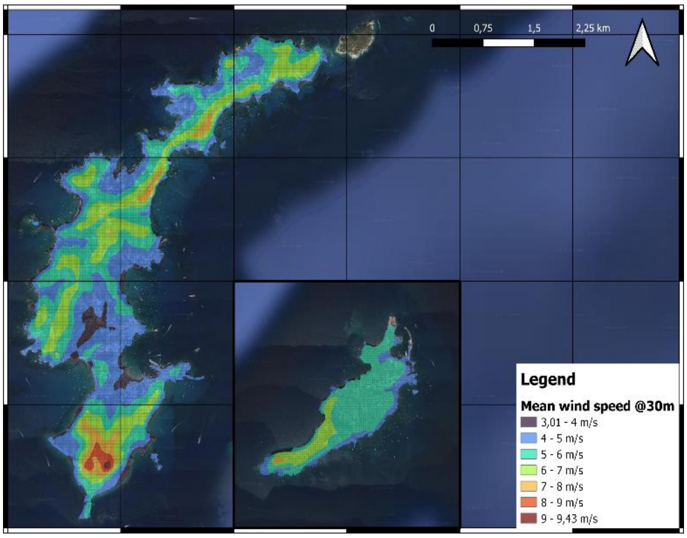
MAP 10: Ponza & Ventotene unsuitable areas for WT installation



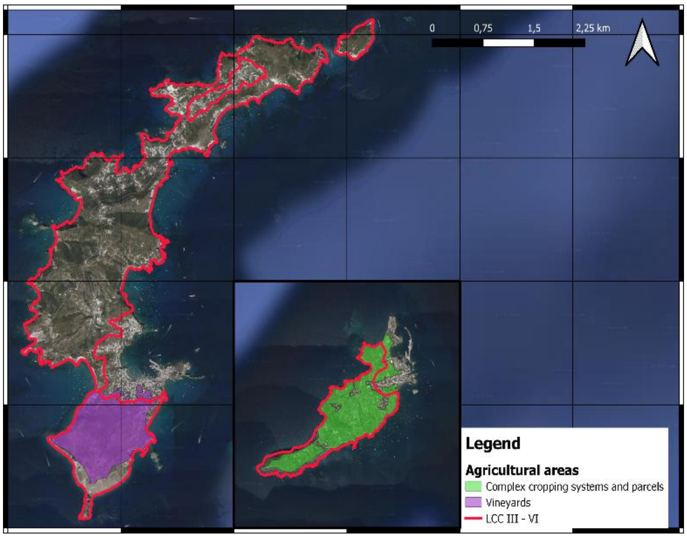
MAP 11: Ponza & Ventotene AEP



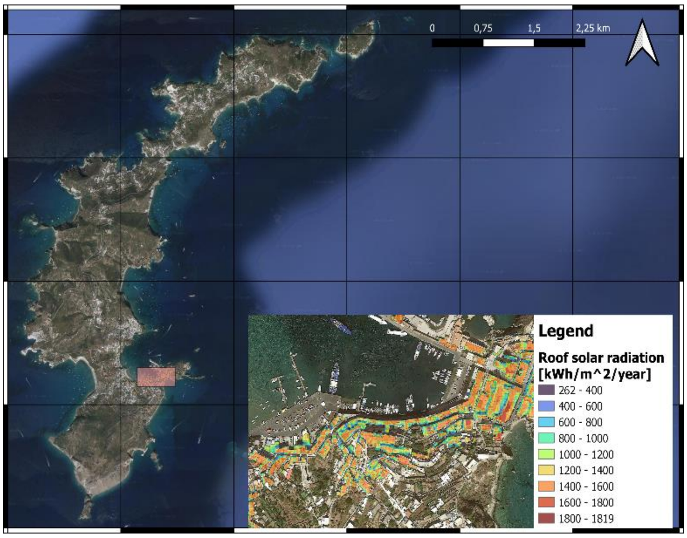
MAP 12: Ponza & Ventotene power density



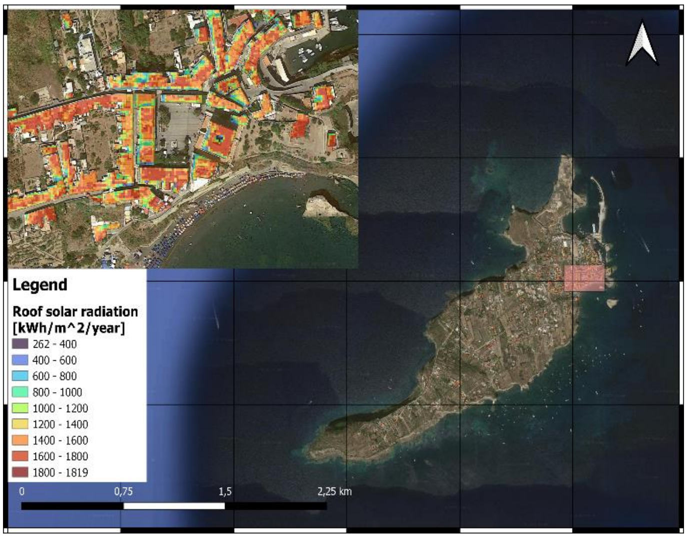
MAP 13: Ponza & Ventotene mean wind speed



MAP 14: Ponza & Ventotene agricultural areas



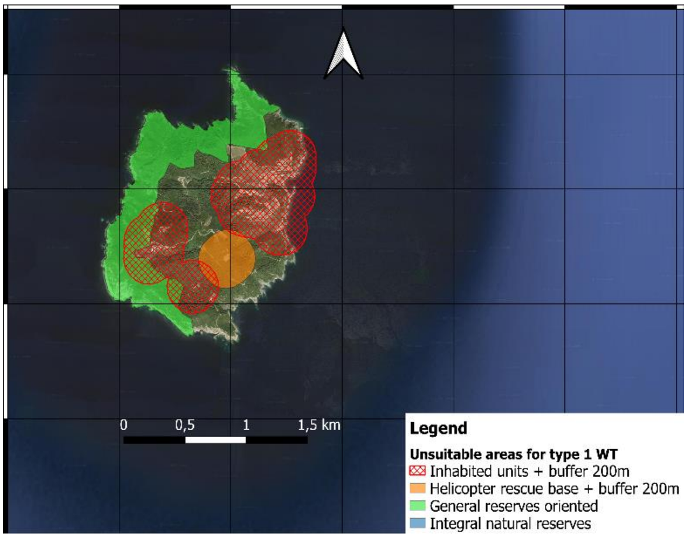
MAP 15: Ponza solar radiation on building roofs



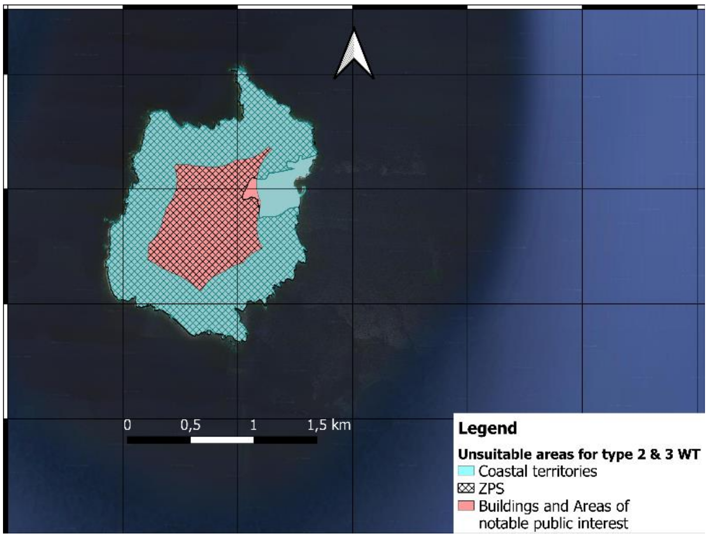
MAP 16: Ventotene solar radiation on building roofs

Tuscany

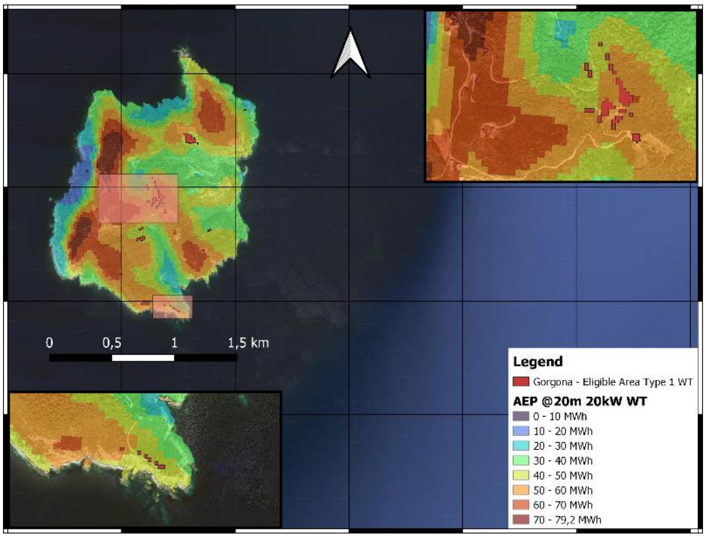
Gorgona



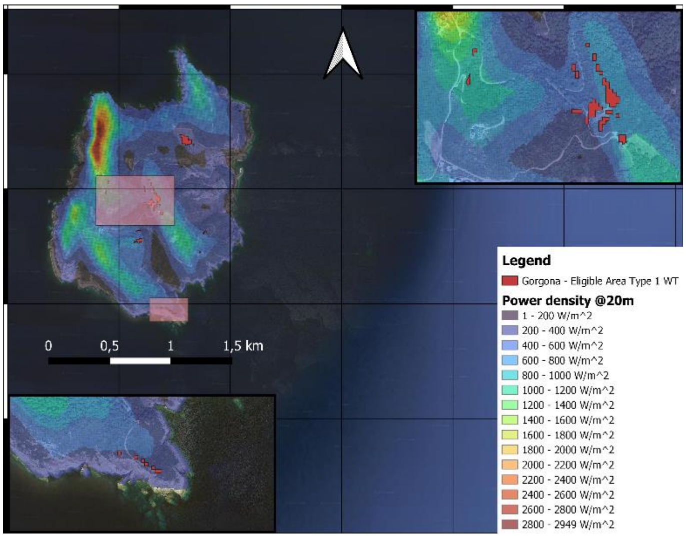
MAP 17: Gorgona unsuitable area for type 1 WT



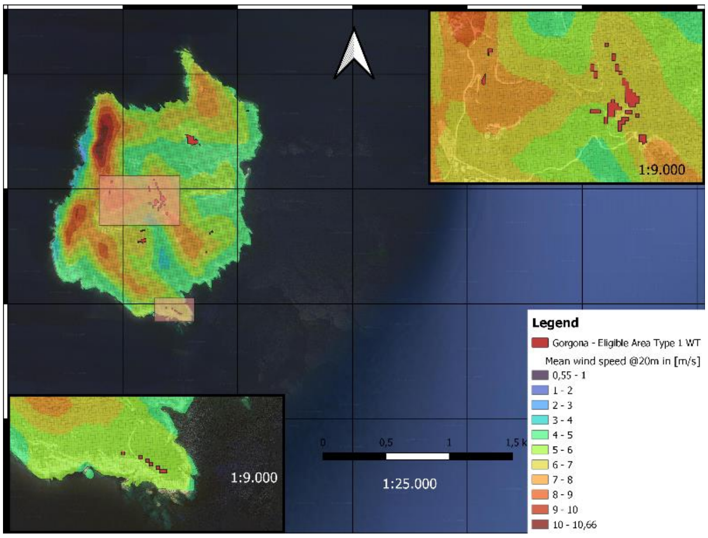
MAP 18: Gorgona unsuitable area for type 2 & 3 WT



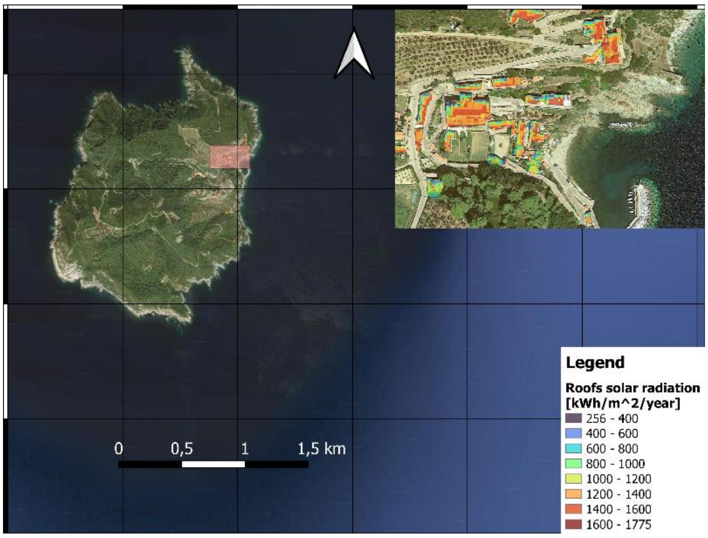
MAP 19: Gorgona AEP



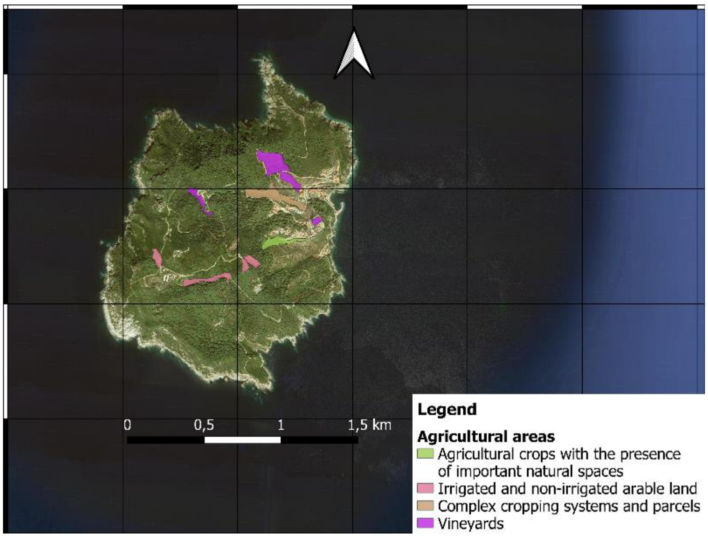
MAP 20: Gorgona power density



MAP 21: Gorgona mean wind speed

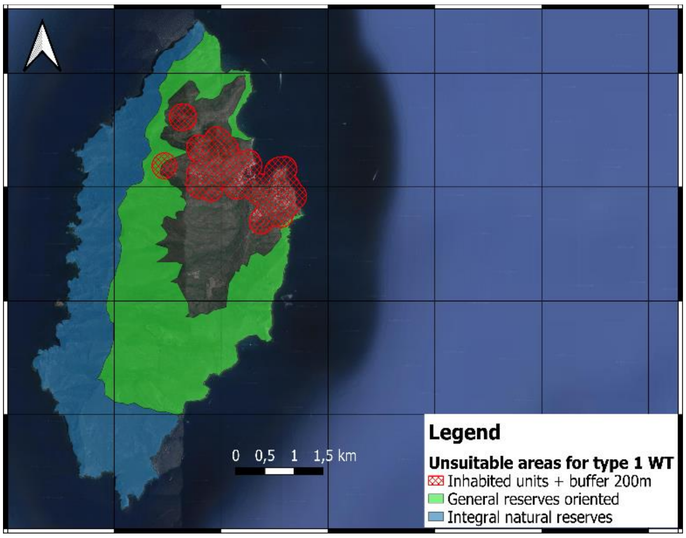


MAP 22: Gorgona roof solar radiation

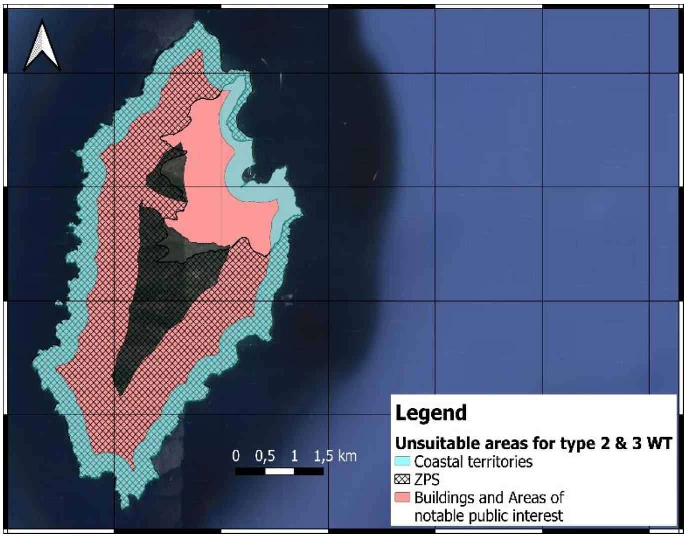


MAP 23: Gorgona agricultural areas

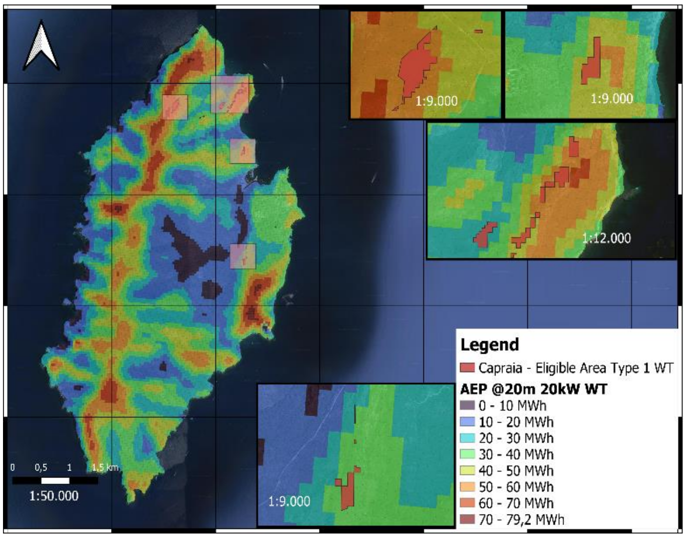
Capraia



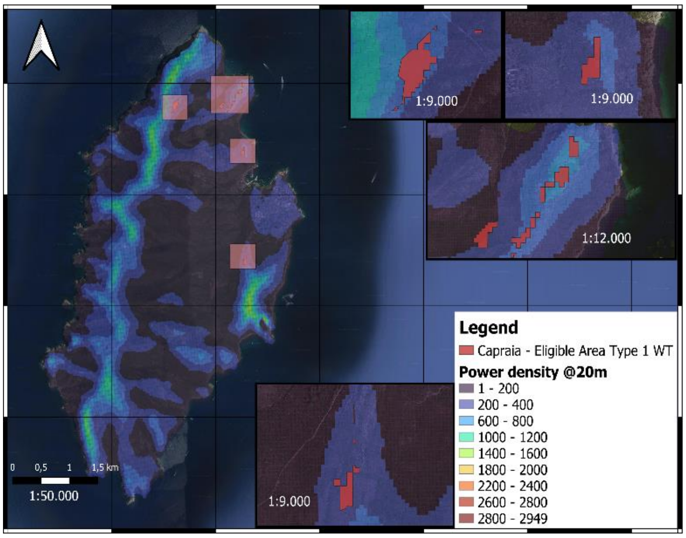
MAP 24: Capraia unsuitable area for type 1 WT



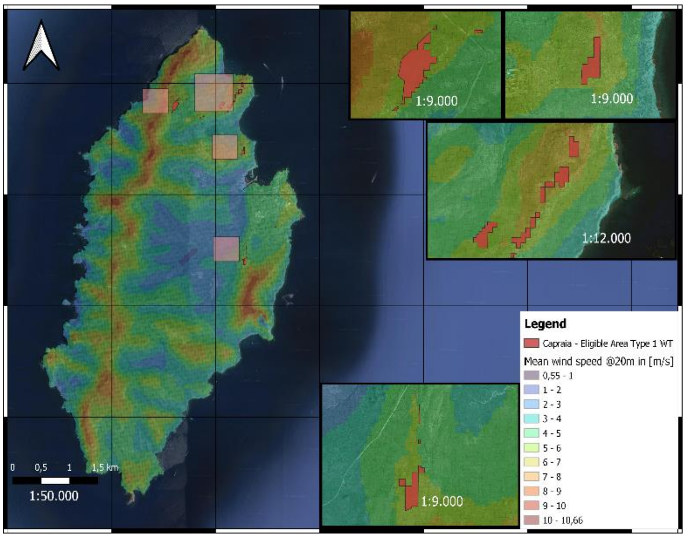
MAP 25: Capraia unsuitable area for type 2 & 3 WT



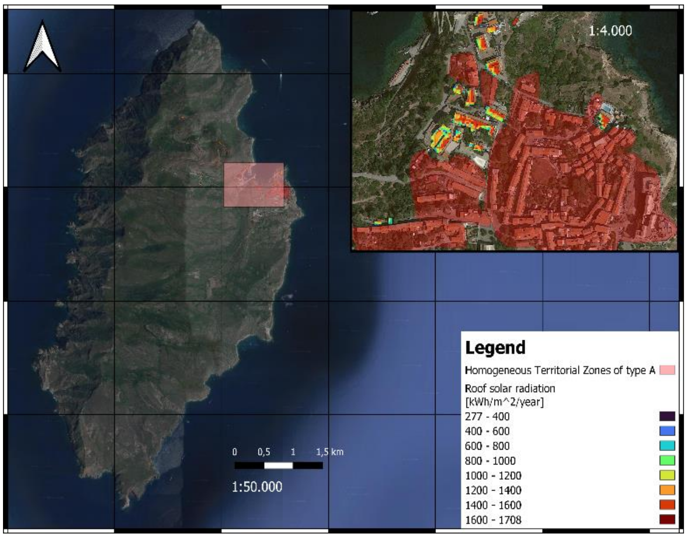
MAP 26: Capraia AEP



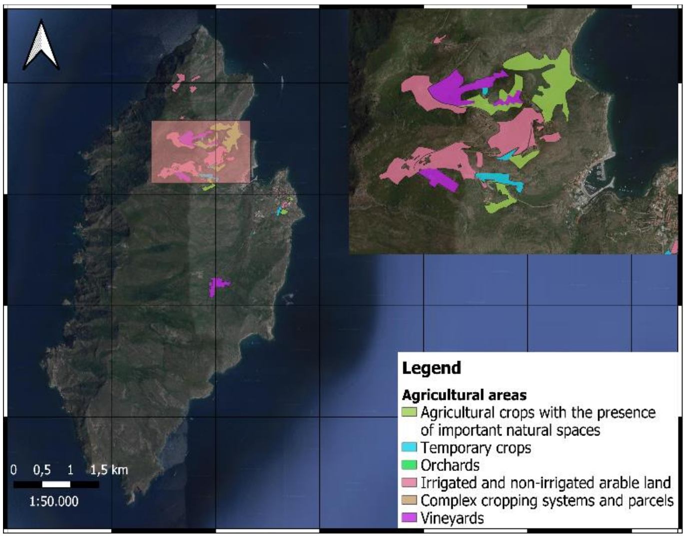
MAP 27: Capraia power density



MAP 28: Capraia mean wind speed

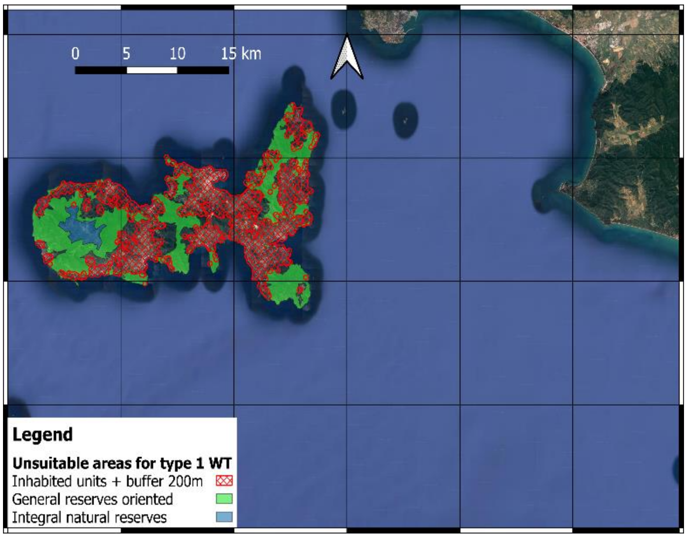


MAP 29: Capraia roof solar radiation

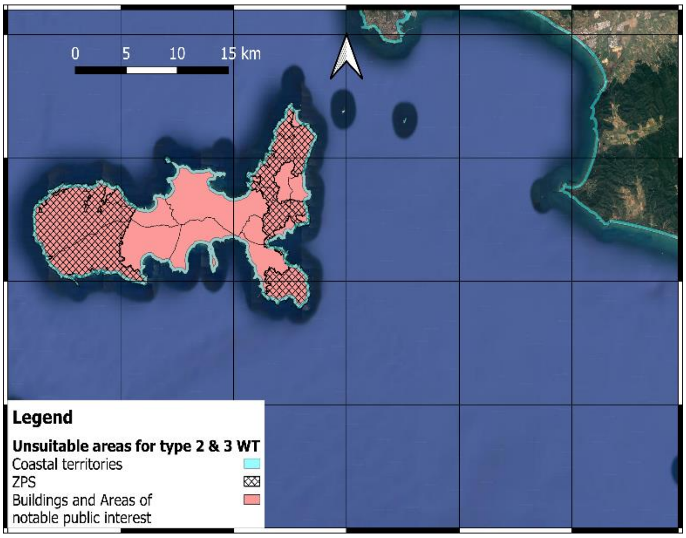


MAP 30: Capraia agricultural areas

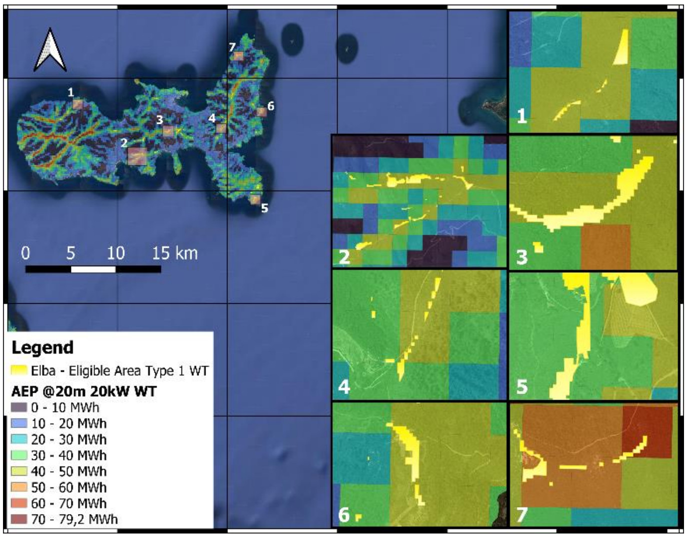
Elba



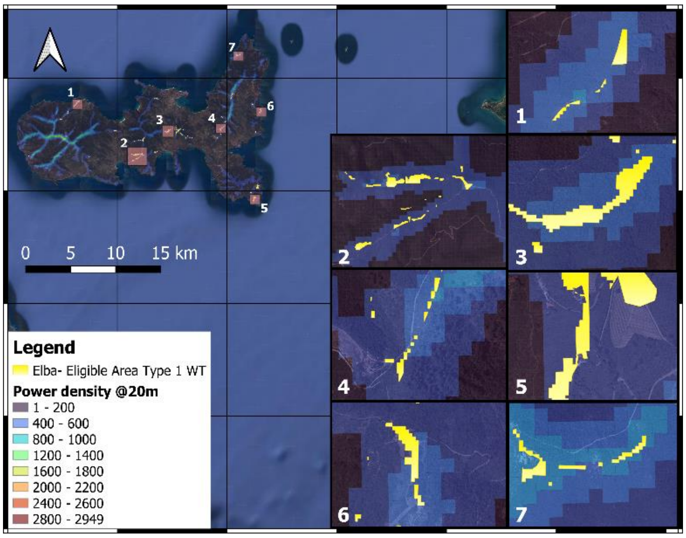
MAP 31: Elba unsuitable areas for type 1 WT



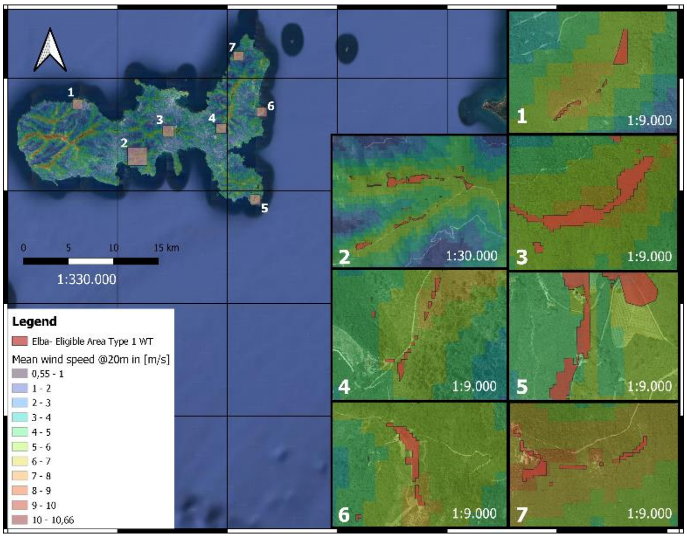
MAP 32: Elba unsuitable areas for type 1 WT



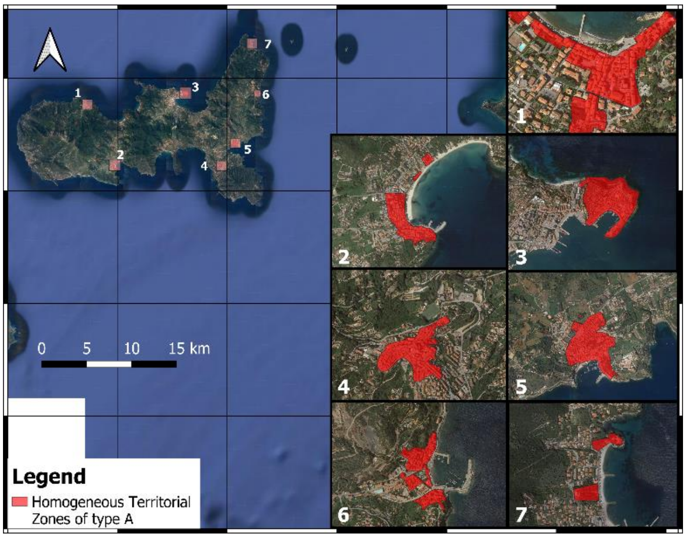
MAP 33: Elba AEP



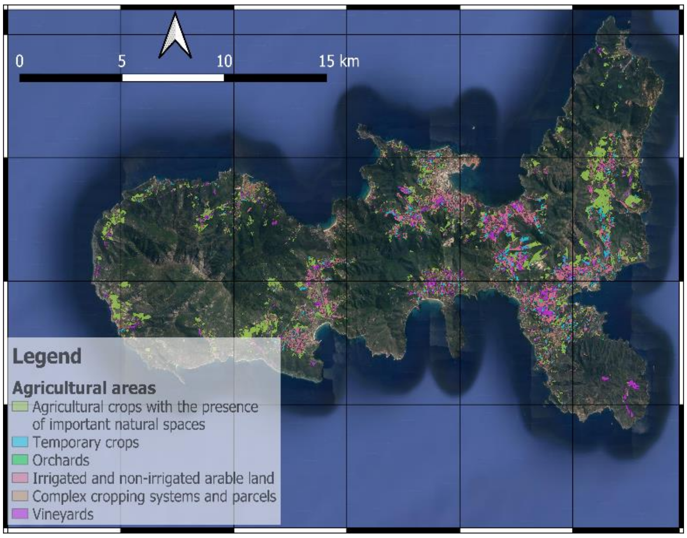
MAP 34: Elba power density



MAP 35: Elba mean wind speed

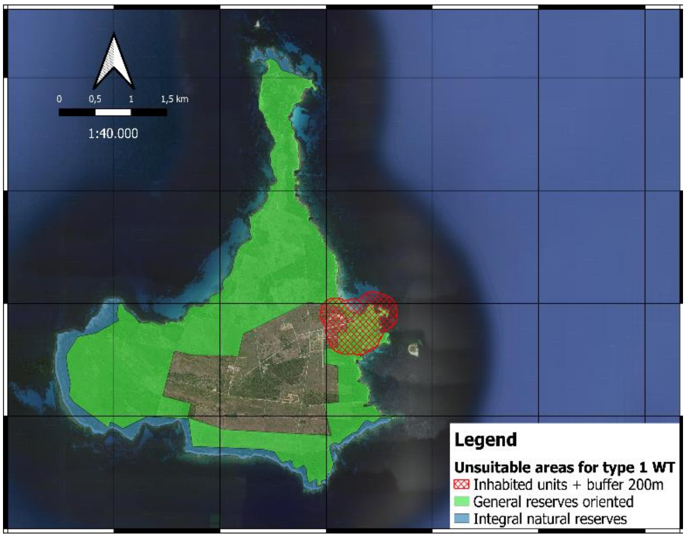


MAP 36: Elba homogeneous territorial zones of type A

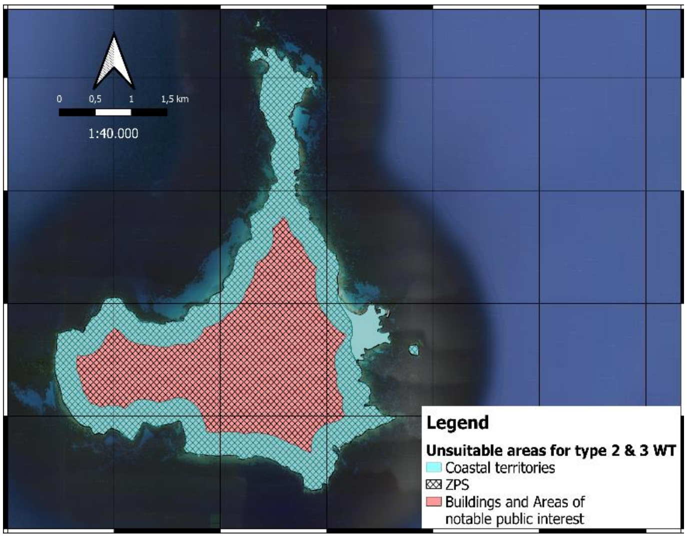


MAP 37: Elba agricultural areas

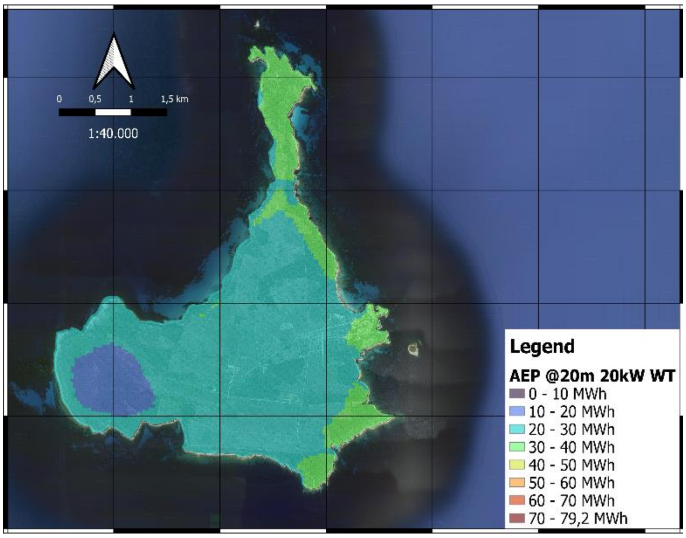
Pianosa



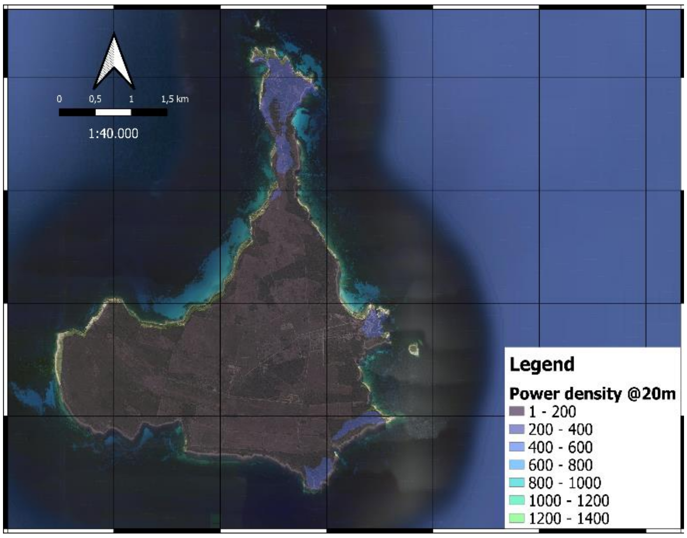
MAP 38: Pianosa unsuitable area for type 1 WT



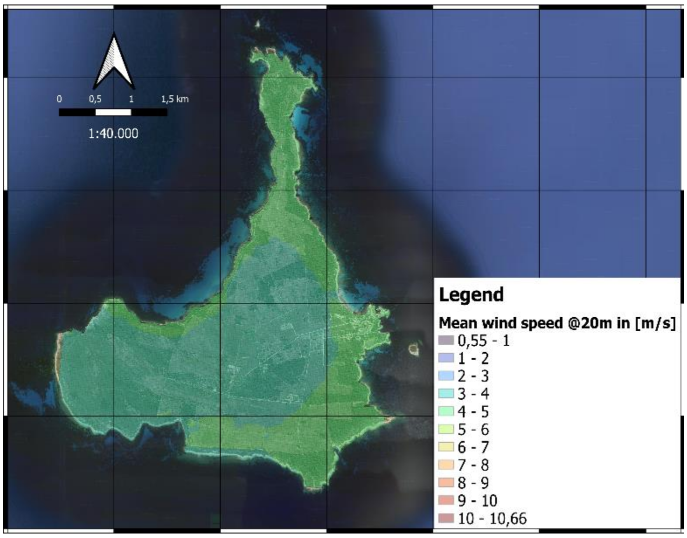
MAP 39: Pianosa unsuitable area for type 2 & 3 WT



MAP 40: Pianosa AEP

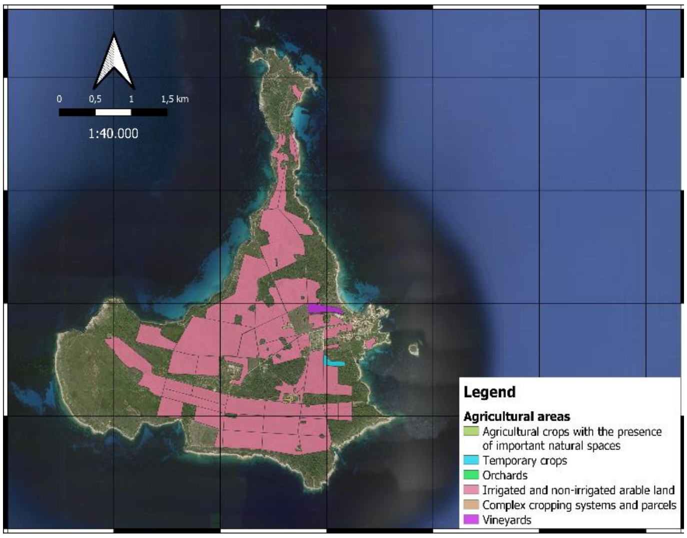


MAP 41: Pianosa power density



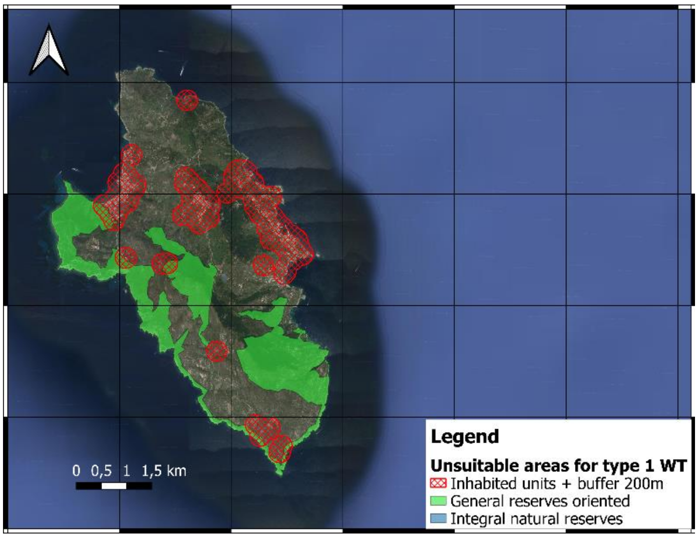
MAP 42: Pianosa mean wind speed

MAP 43: Pianosa roof solar radiation

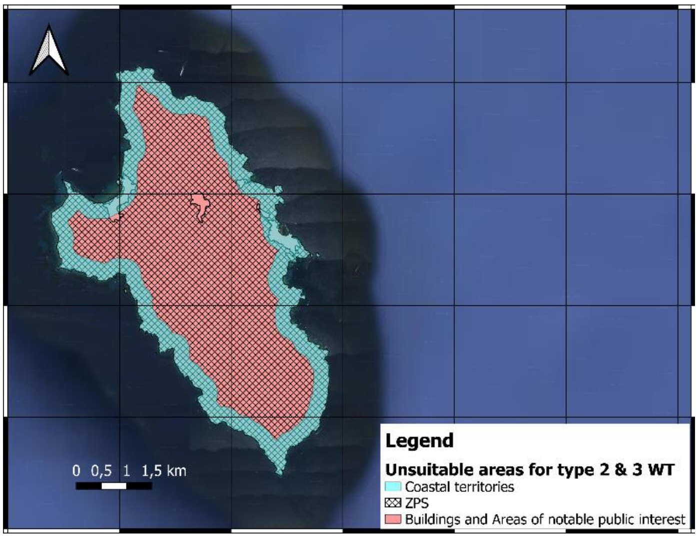


MAP 44: Pianosa agricultural areas

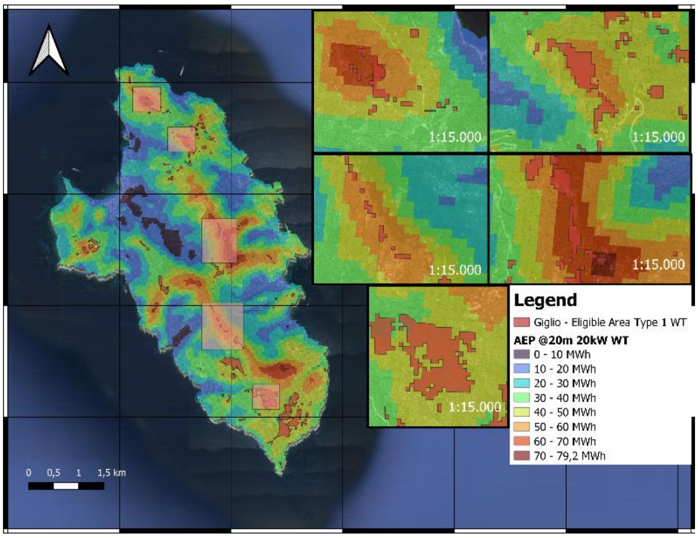
Giglio



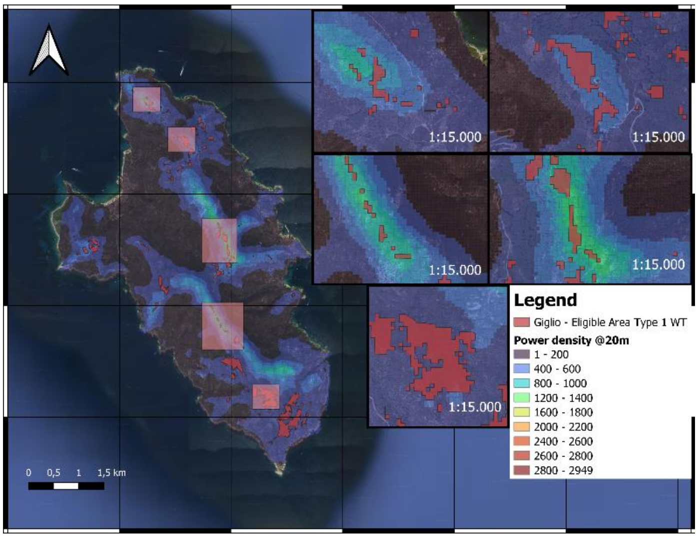
MAP 45: Giglio unsuitable areas for type 1 WT



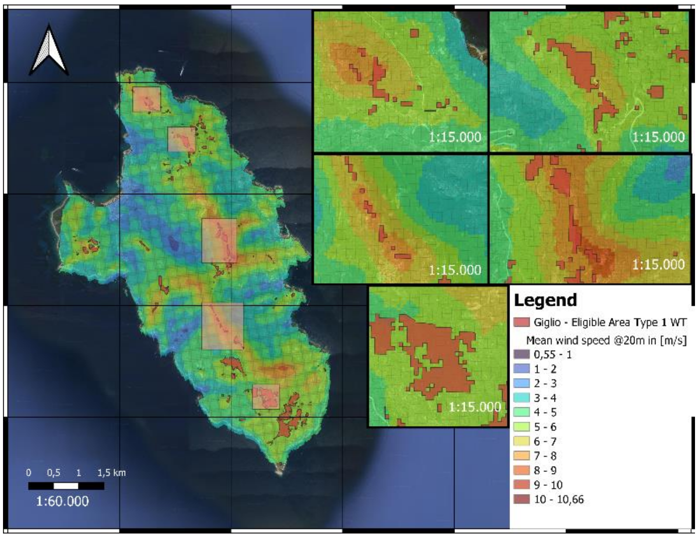
MAP 46: Giglio unsuitable areas for type 2 & 3 WT



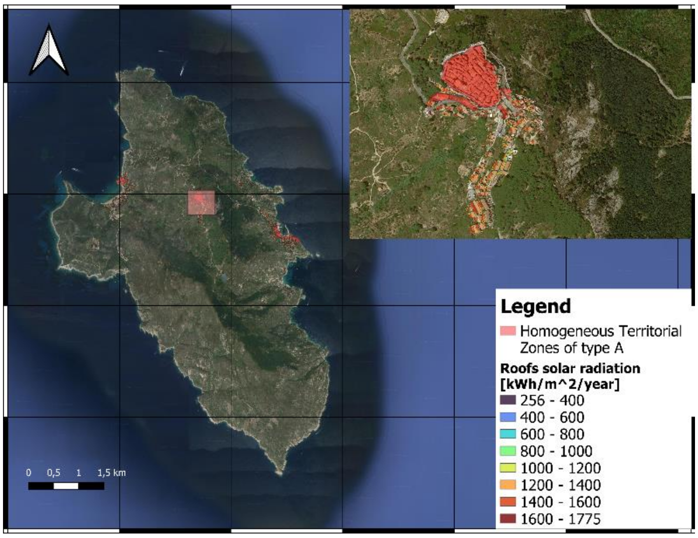
MAP 47: Giglio AEP



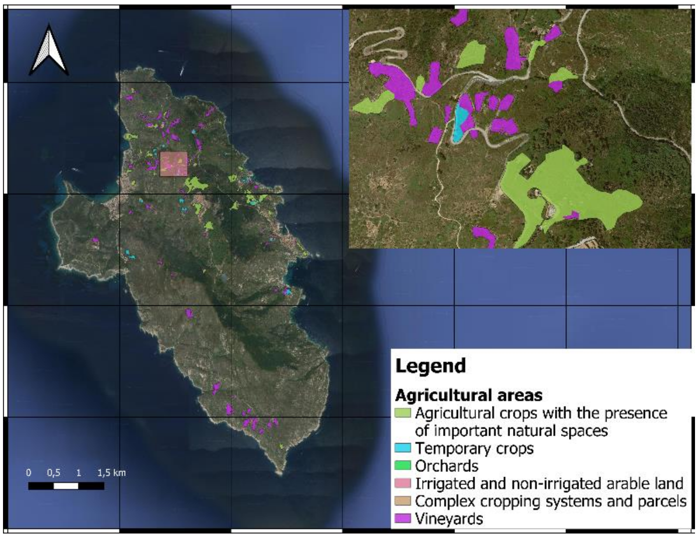
MAP 48: Giglio power density



MAP 49: Giglio mean wind speed

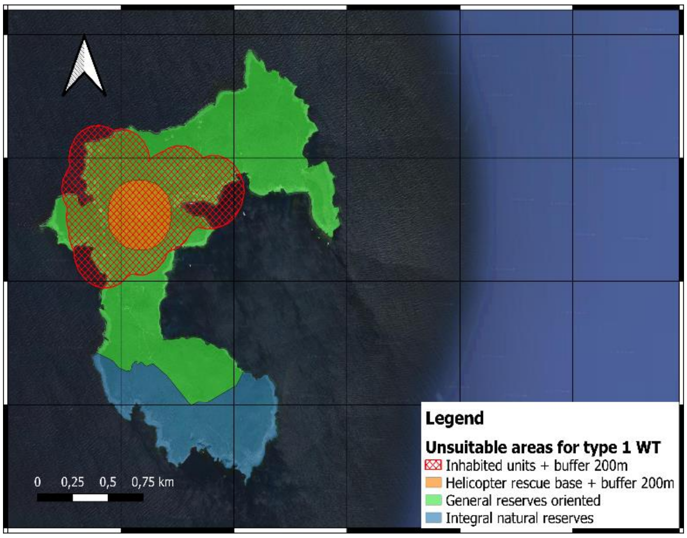


MAP 50: Giglio roof solar radiation

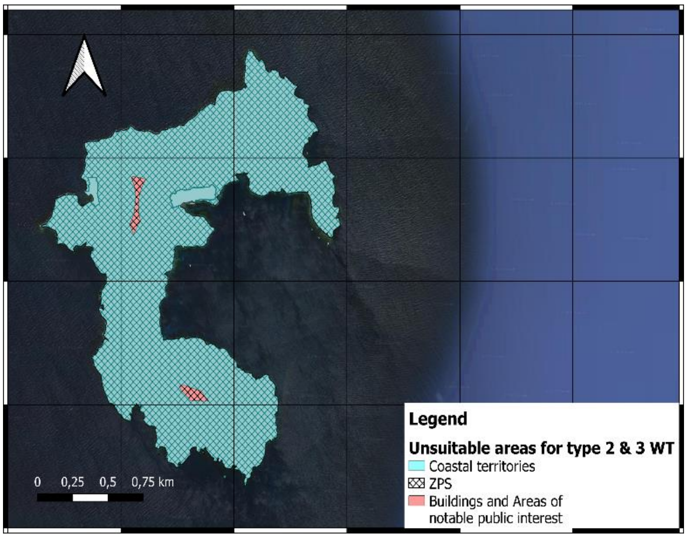


MAP 51: Giglio agricultural areas

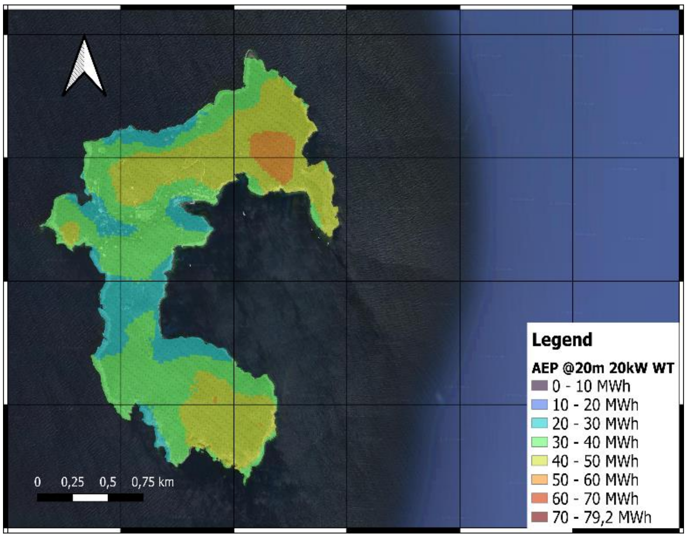
Giannutri



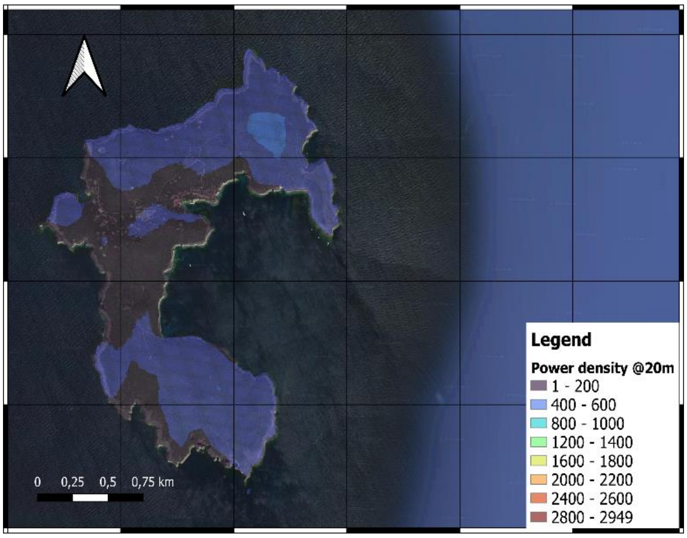
MAP 52: Giannutri unsuitable areas for type 1 WT



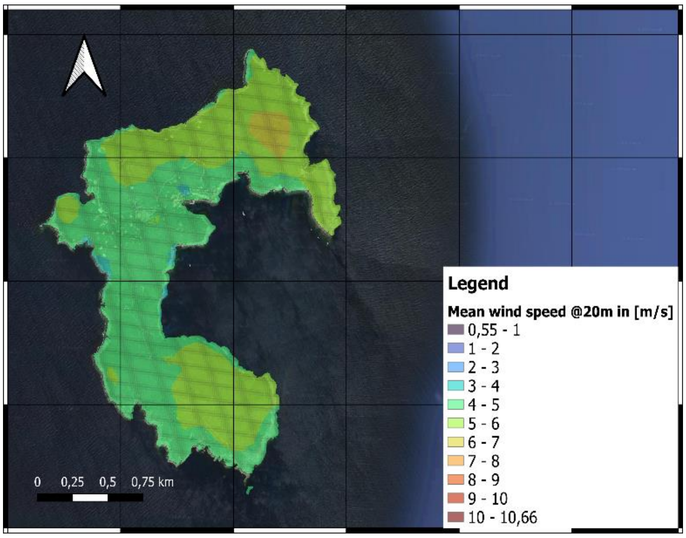
MAP 53: Giannutri unsuitable areas for type 2 and 3 WT



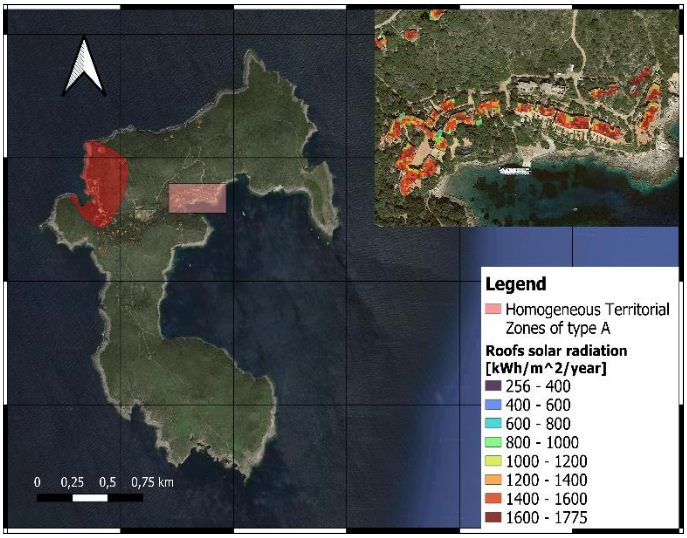
MAP 54: Giannutri AEP



MAP 55: Giannutri power density



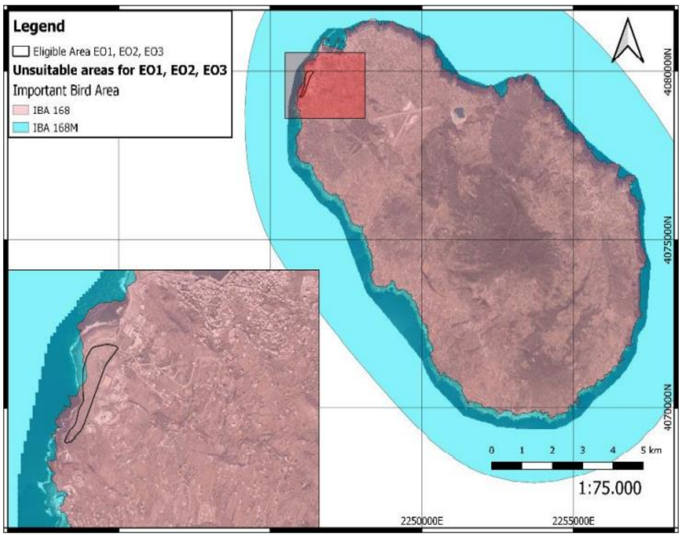
MAP 56: Giannutri mean wind speed



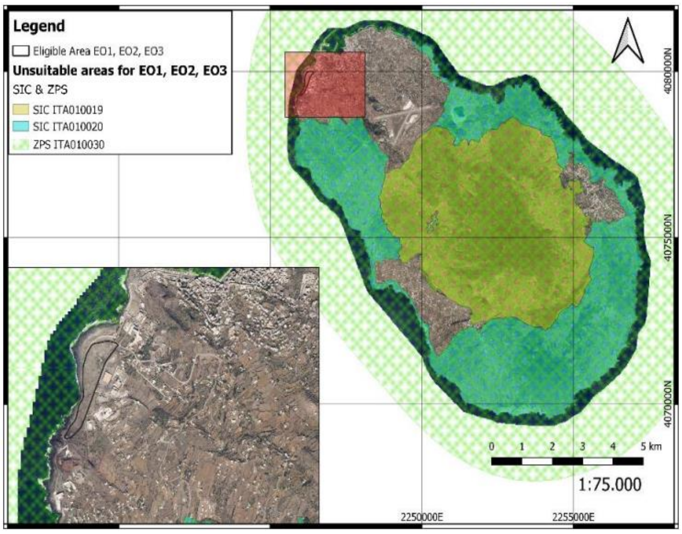
MAP 57: Giannutri roof solar radiation

Sicily

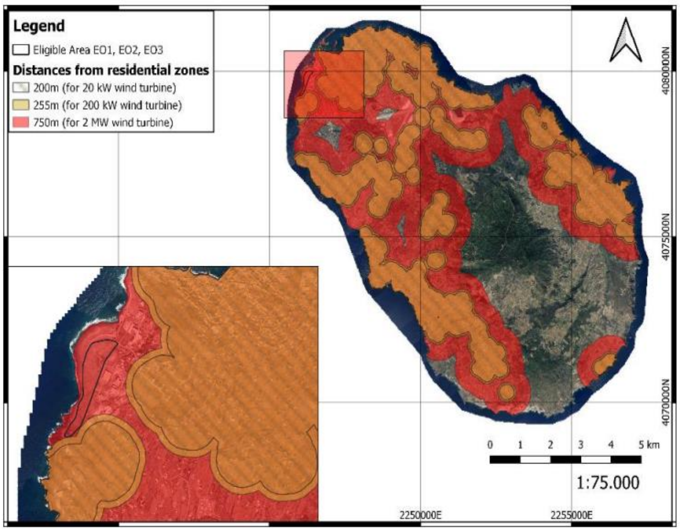
Pantelleria



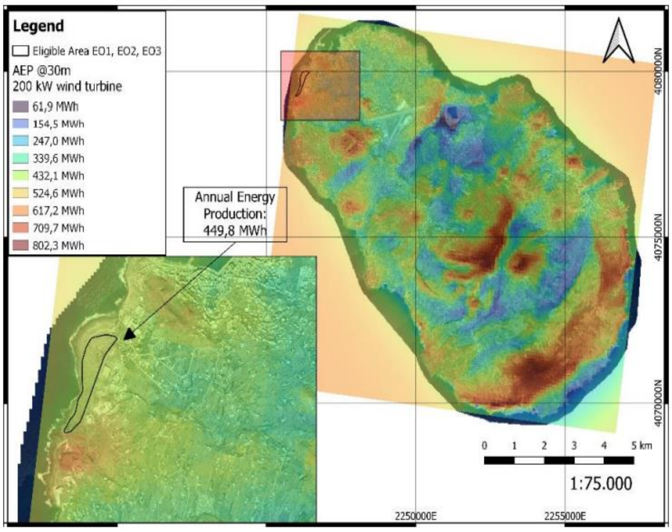
MAP 58: Pantelleria unsuitable areas for type 1,2,3 WT



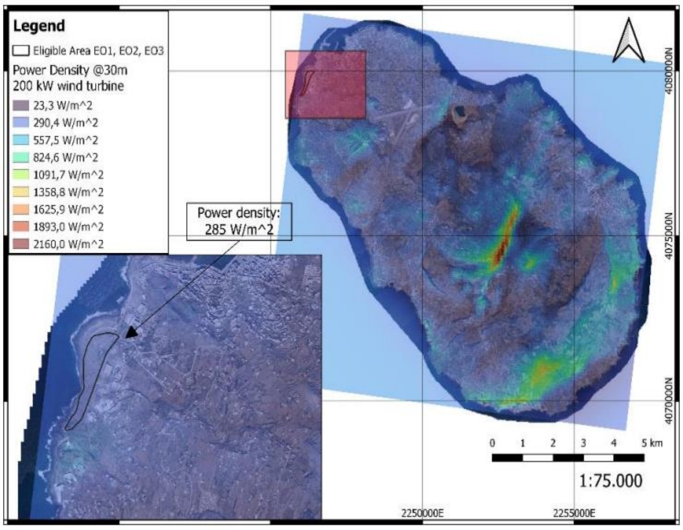
MAP 59: Pantelleria unsuitable areas for type 1,2,3 WT



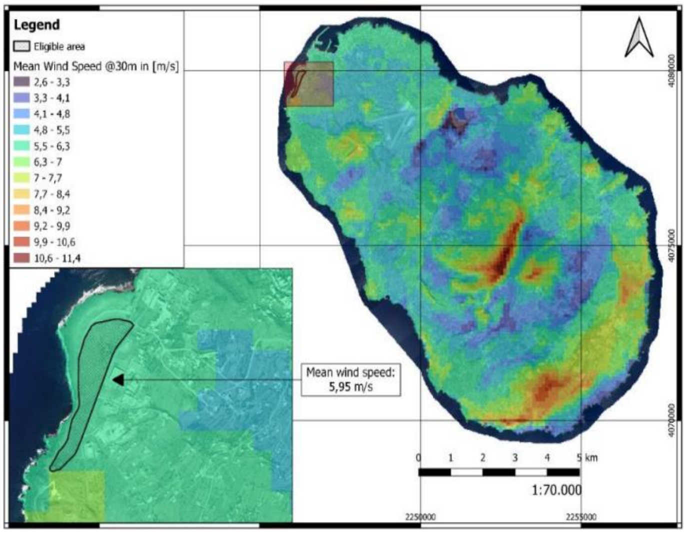
MAP 60: Pantelleria distances from residential zones



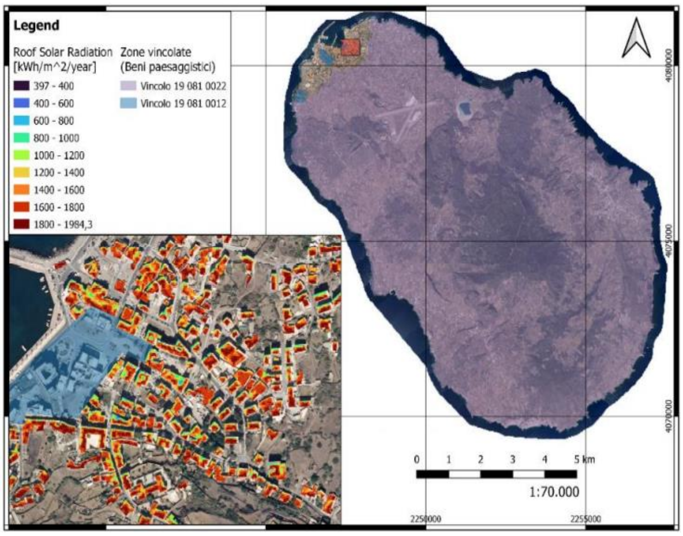
MAP 61: Pantelleria AEP



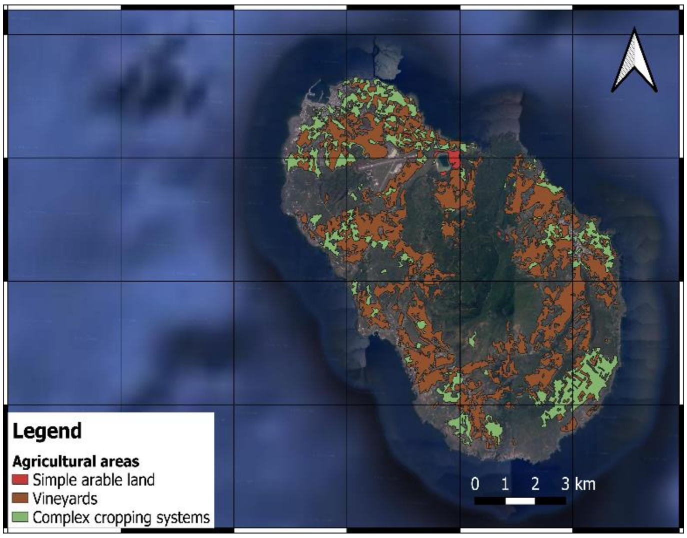
MAP 62: Pantelleria power density



MAP 63: Pantelleria mean wind speed

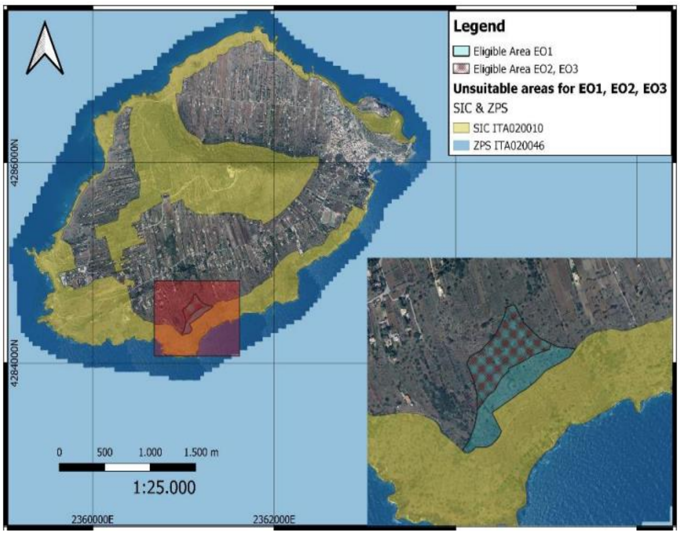


MAP 64: Pantelleria roof solar radiation

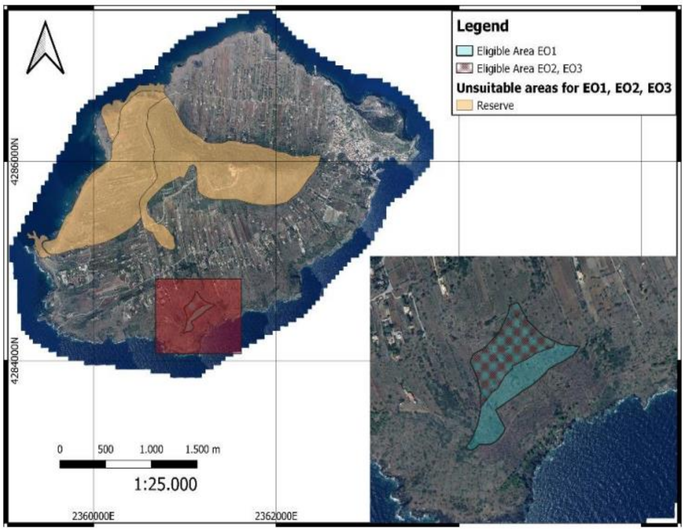


MAP 65: Pantelleria agricultural areas

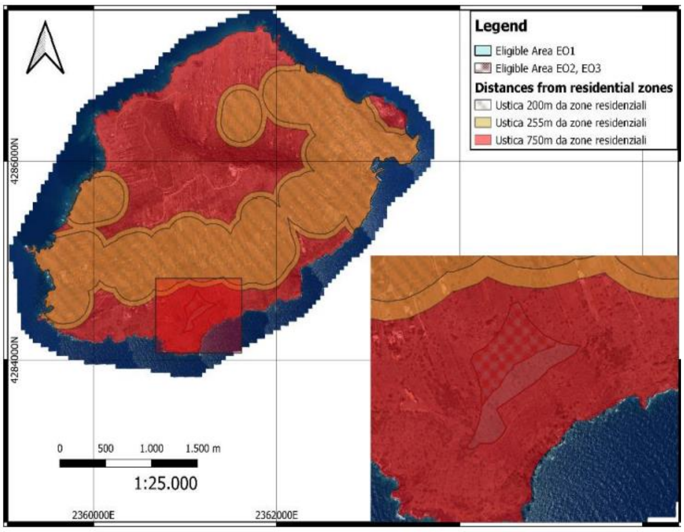
Ustica



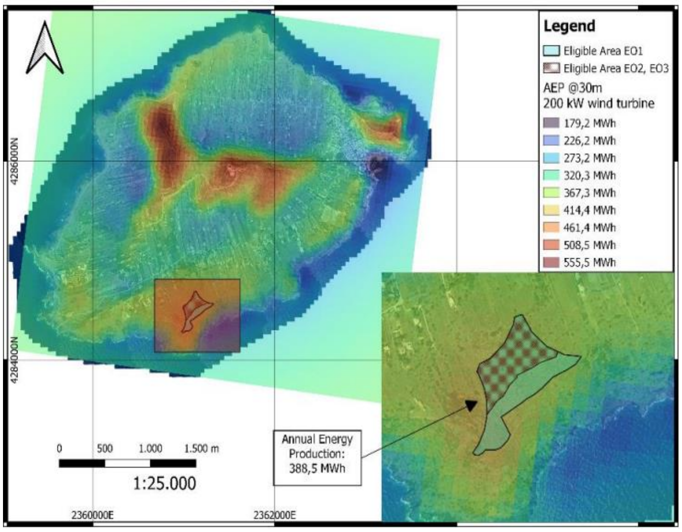
MAP 66: Ustica unsuitable areas for type 1,2,3 WT



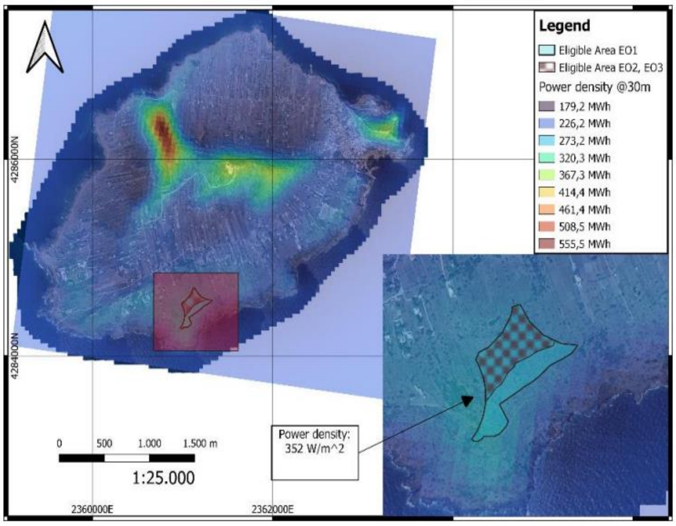
MAP 67: Ustica unsuitable areas for type 1,2,3 WT



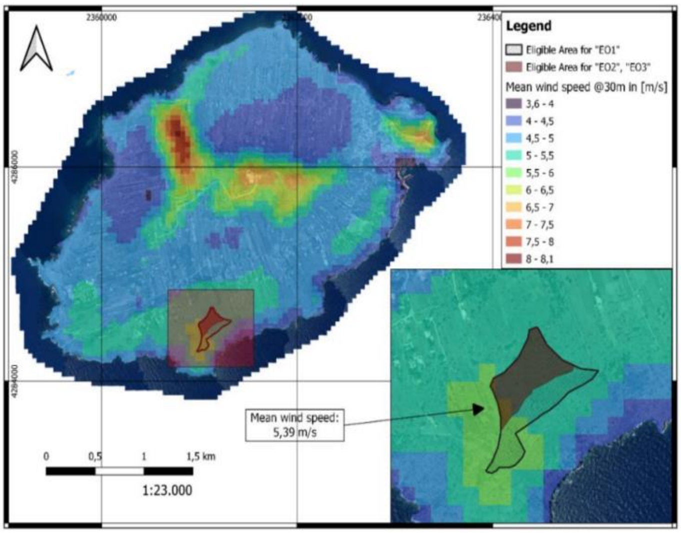
MAP 68: Ustica distances from residential zones



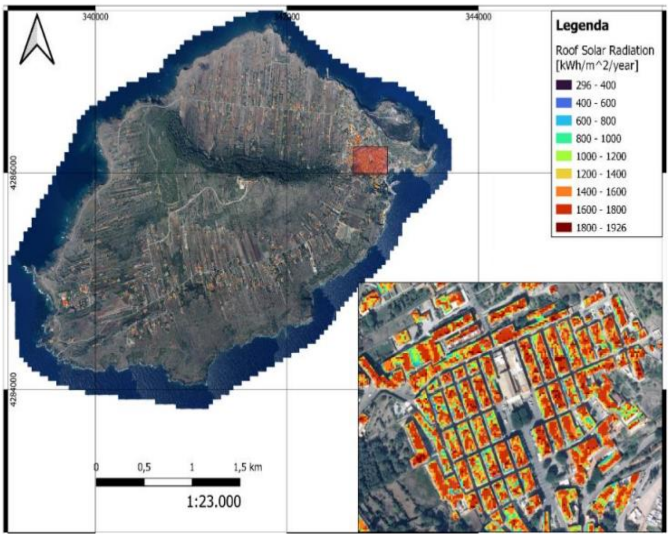
MAP 69: Ustica AEP



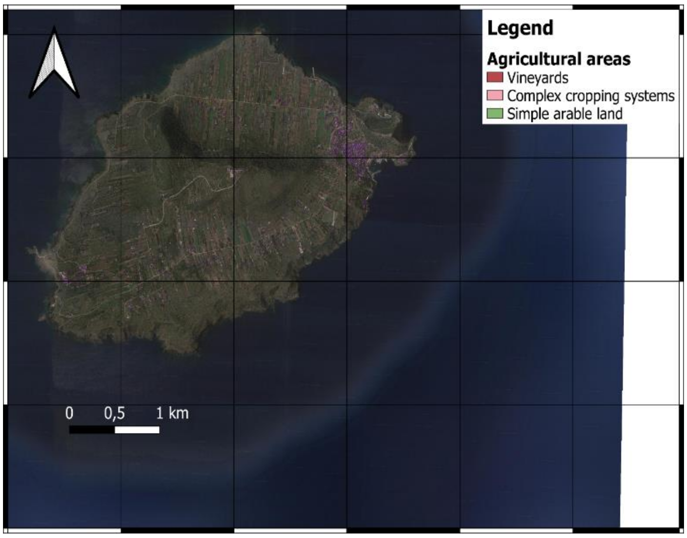
MAP 70: Ustica power density



MAP 71: Ustica mean wind speed

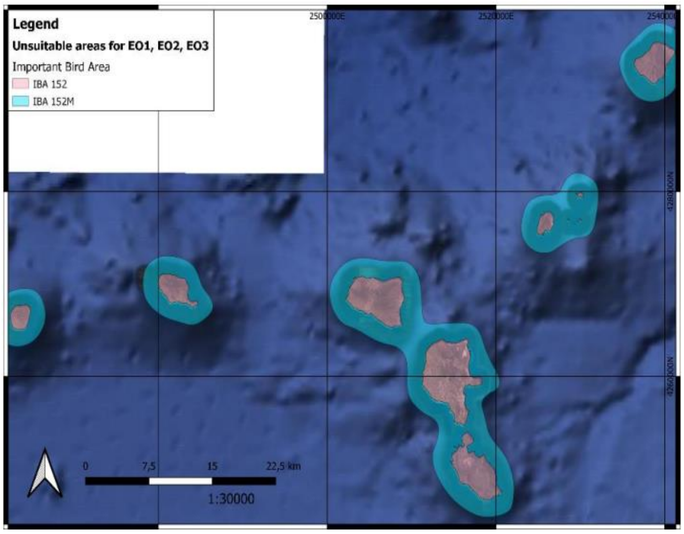


MAP 72: Ustica roof solar radiation

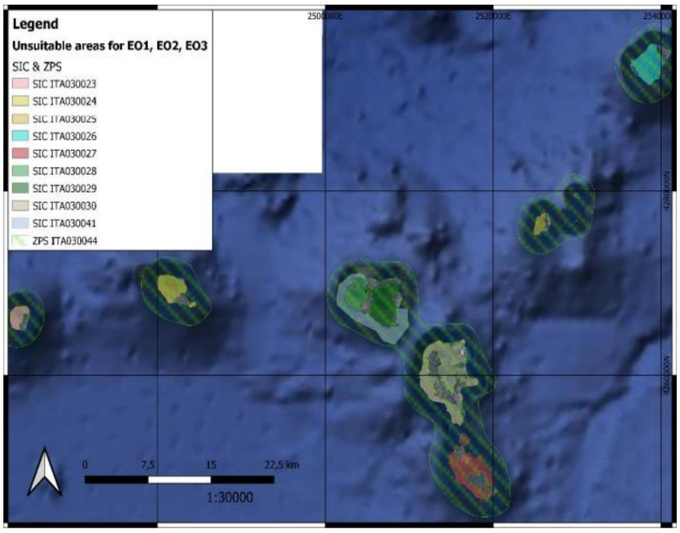


MAP 73: Ustica agricultural areas

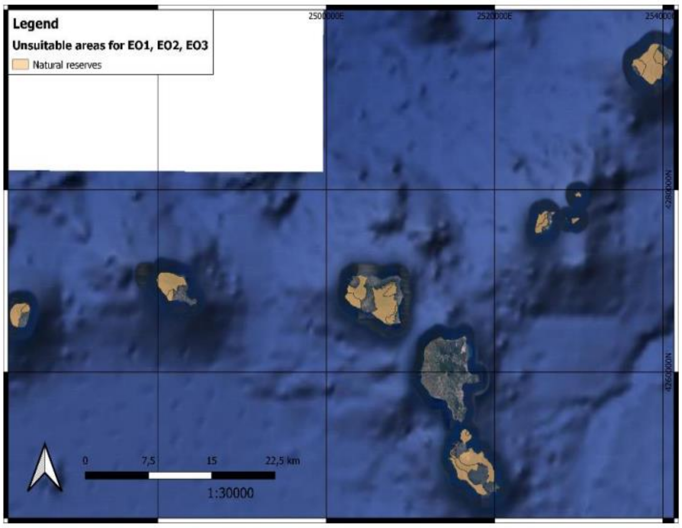
Eolie



MAP 74: Eolie unsuitable areas for type 1,2,3 WT

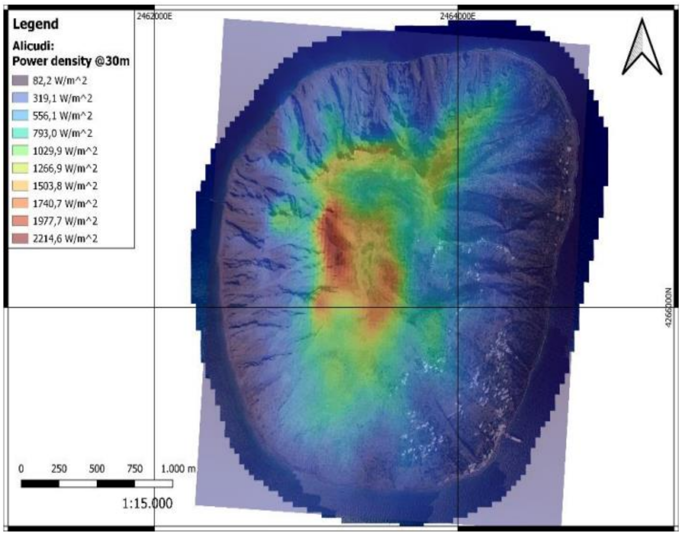


MAP 75: Eolie unsuitable areas for type 1,2,3 WT

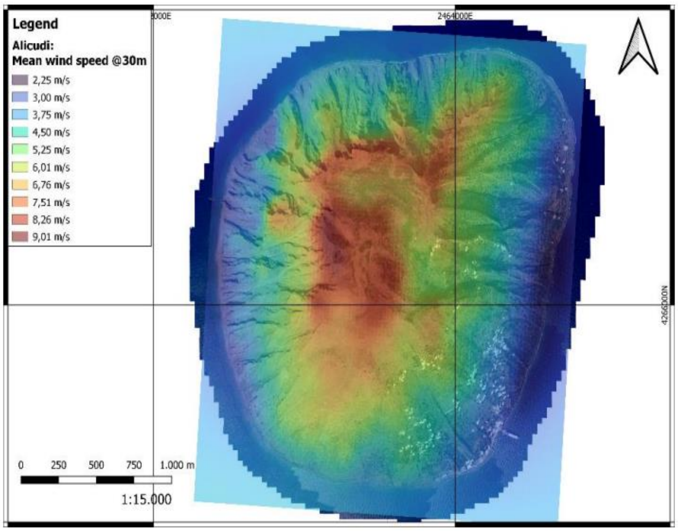


MAP 76: Eolie unsuitable areas for type 1,2,3 WT

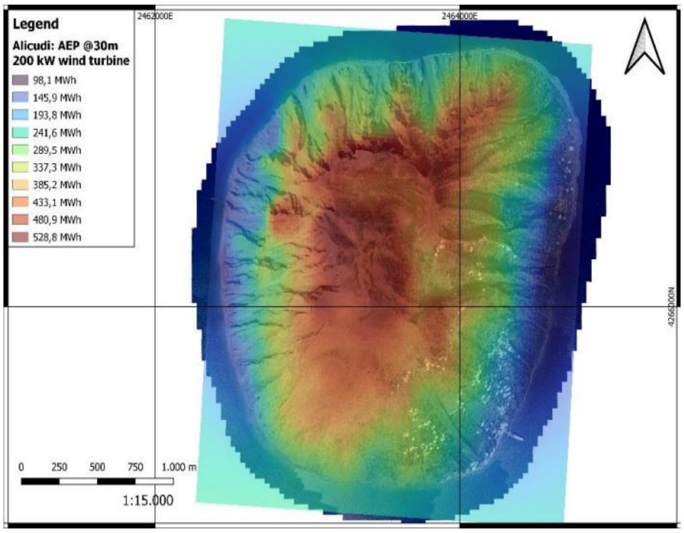
Alicudi



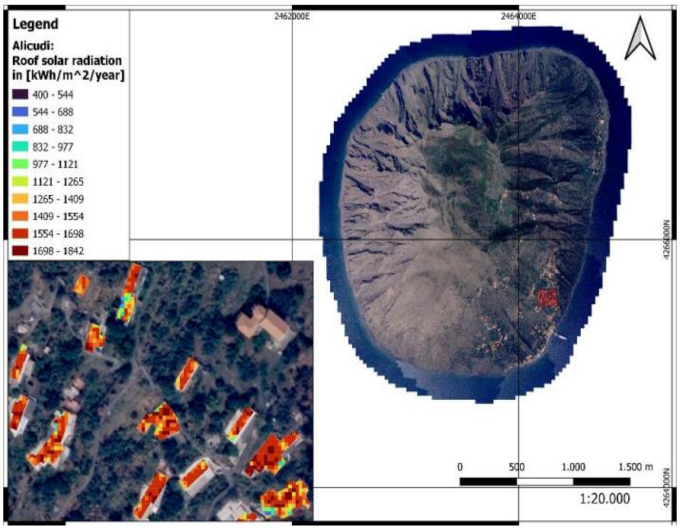
MAP 77: Alicudi power density



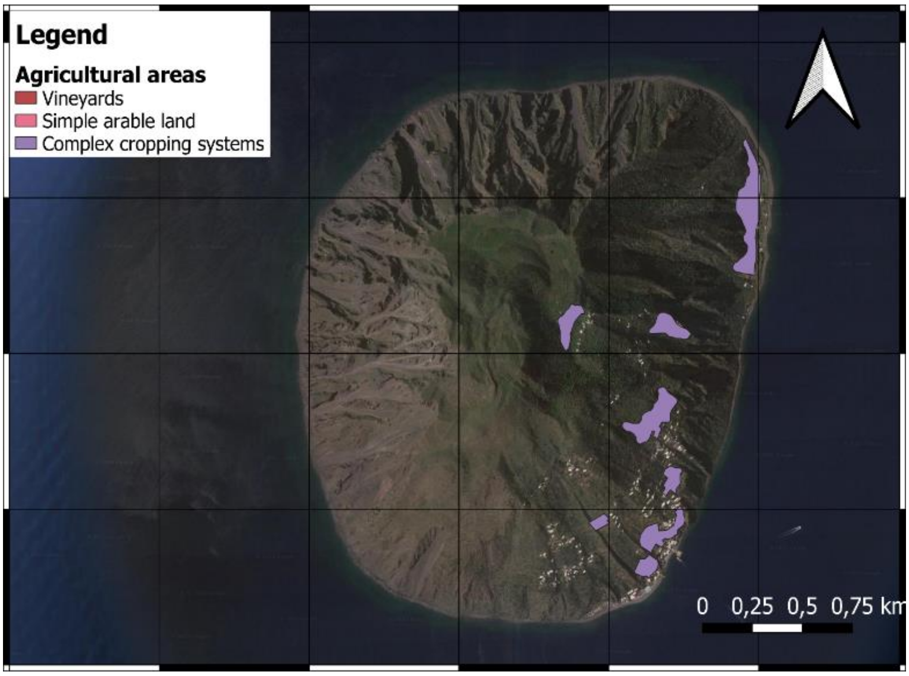
MAP 78: Alicudi mean wind speed



MAP 79: Alicudi AEP

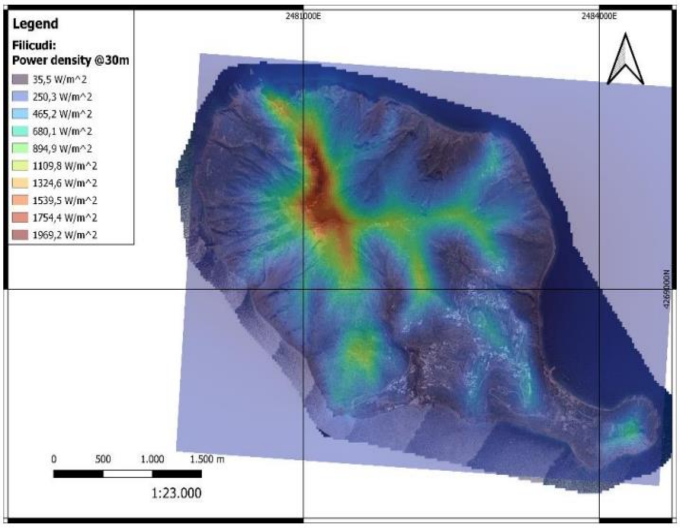


MAP 80: Alicudi roof solar radiation

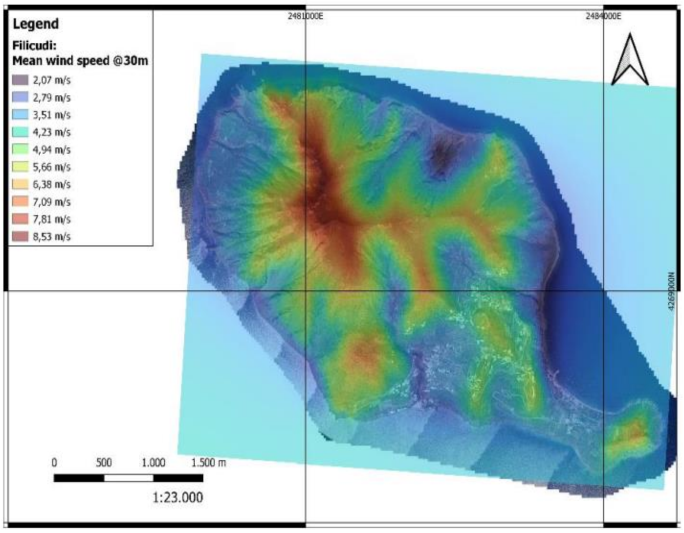


MAP 81: Alicudi agricultural areas

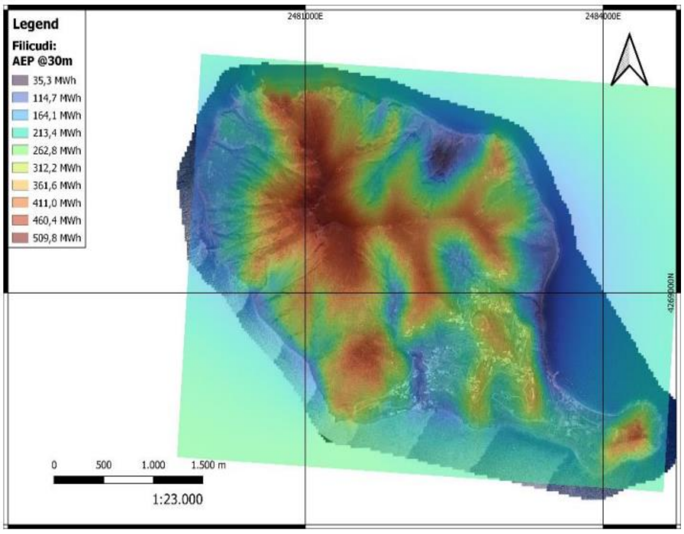
Filicudi



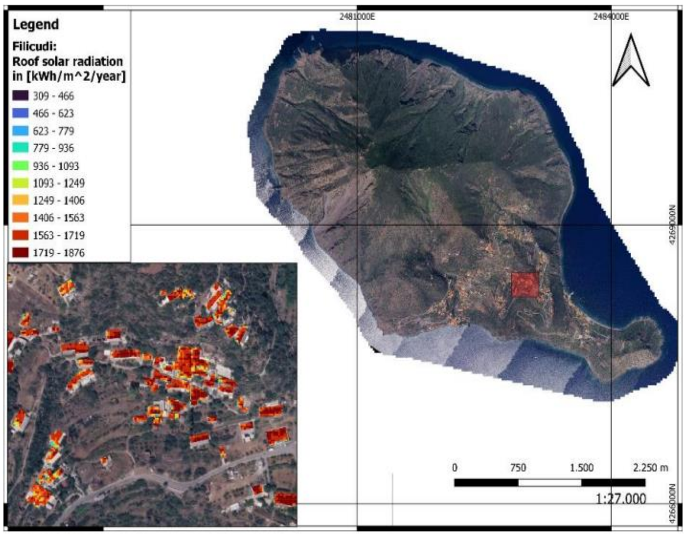
MAP 82: Filicudi power density



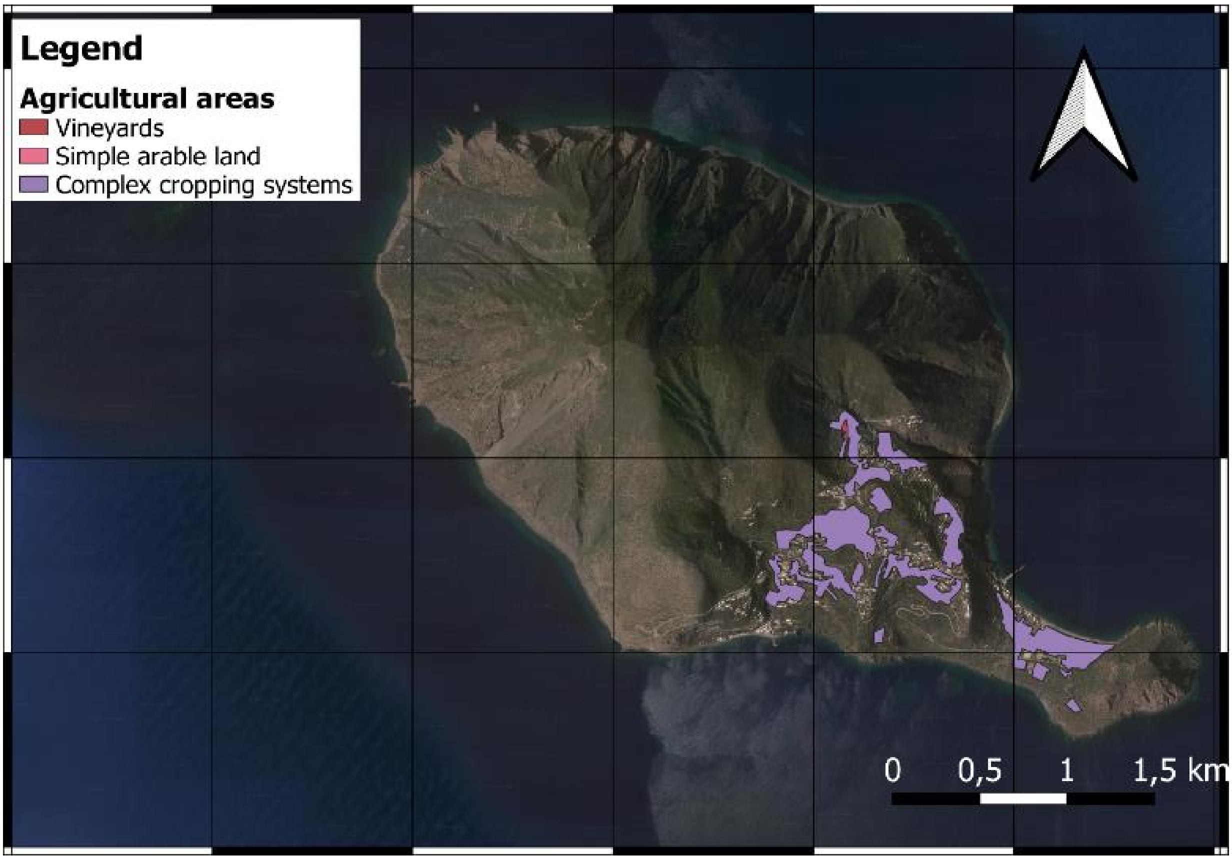
MAP 83: Filicudi mean wind speed



MAP 84: Filicudi AEP

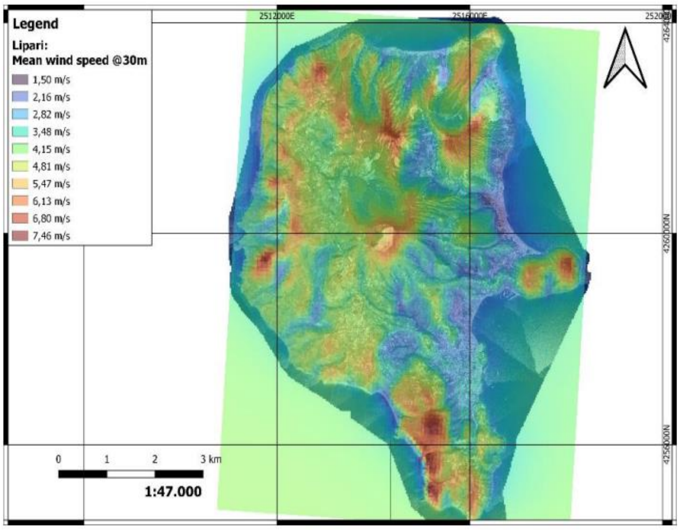


MAP 85: Filicudi roof solar radiation

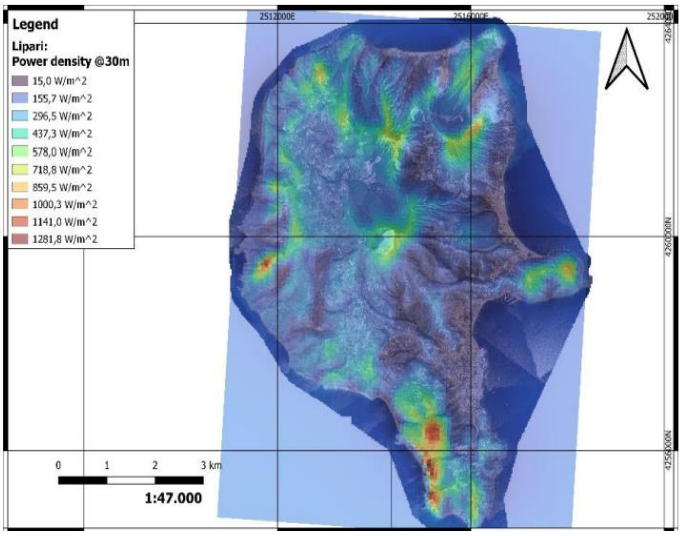


MAP 86: Filicudi agricultural areas

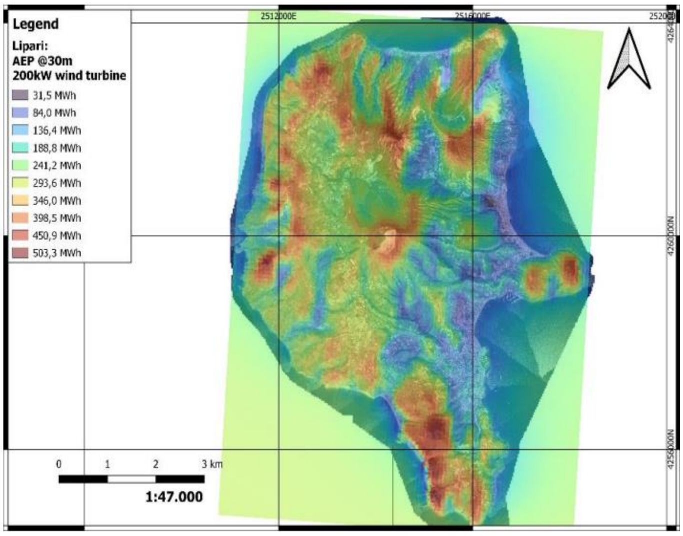
Lipari



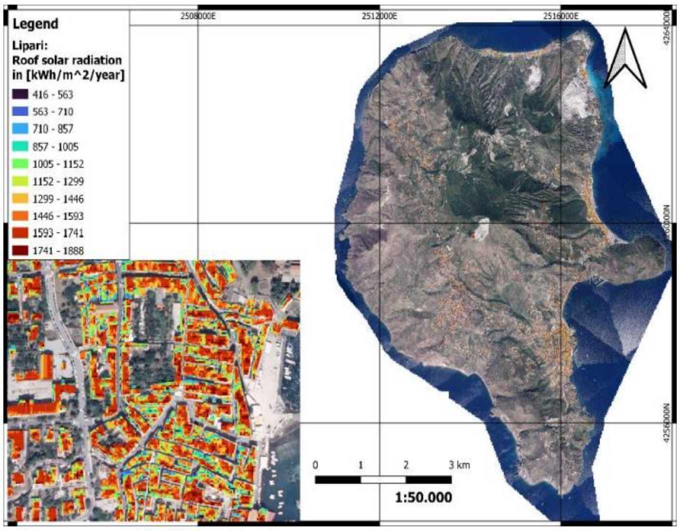
MAP 87: Lipari mean wind speed



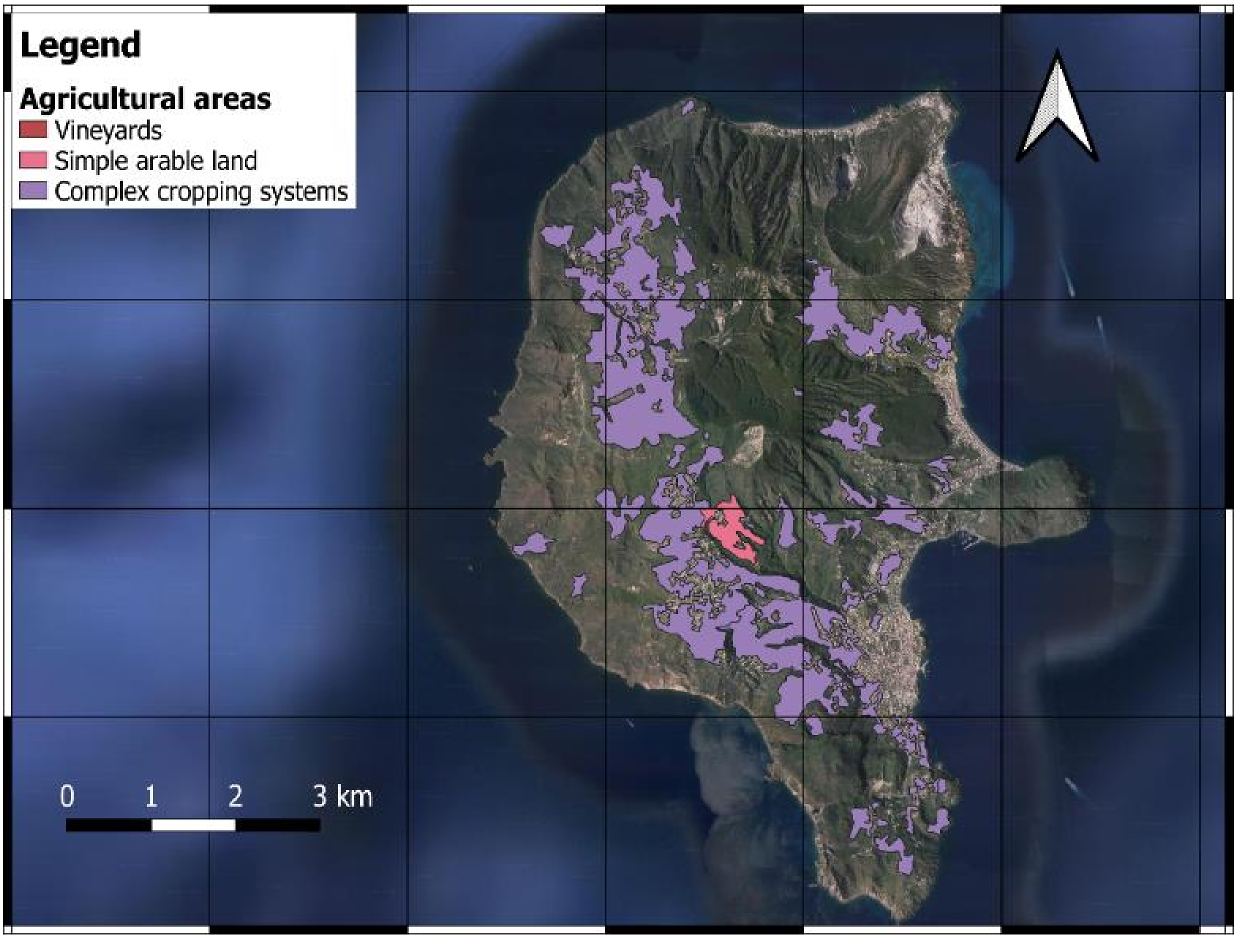
MAP 88: Lipari power density



MAP 89: Lipari AEP

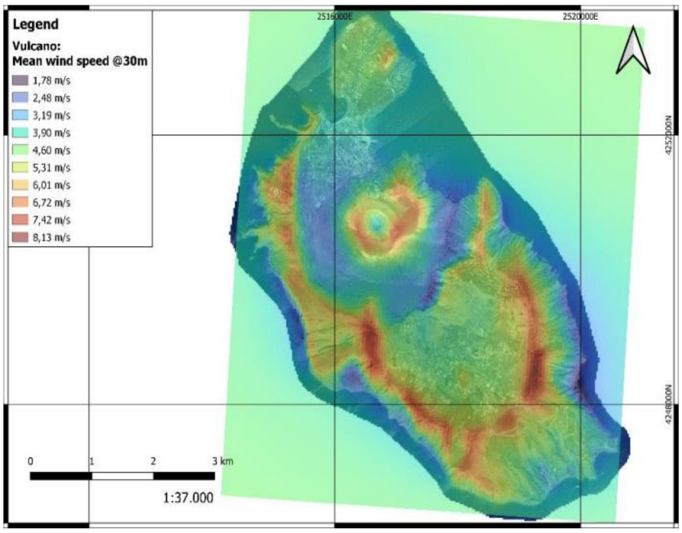


MAP 90: Lipari roof solar radiation

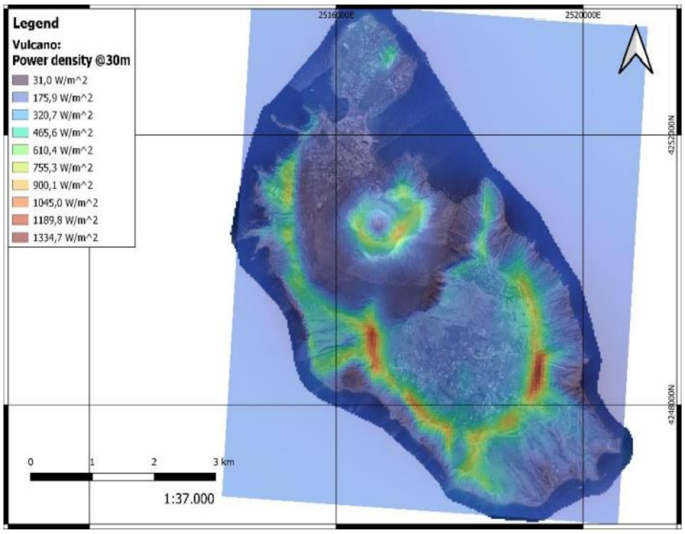


MAP 91: Lipari agricultural areas

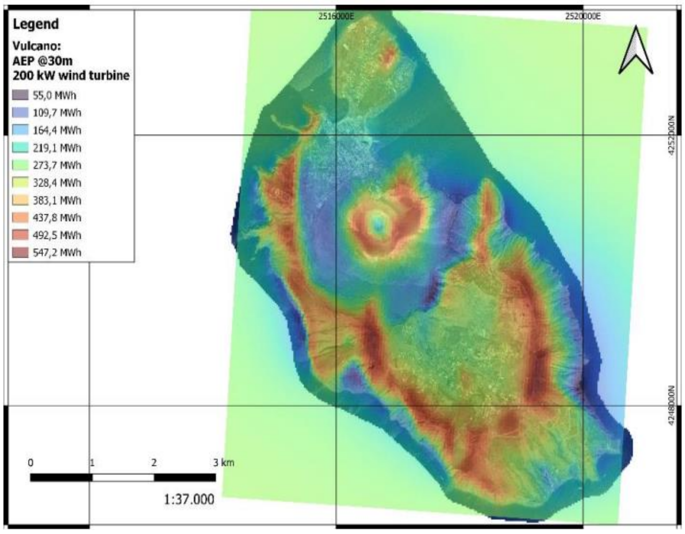
Vulcano



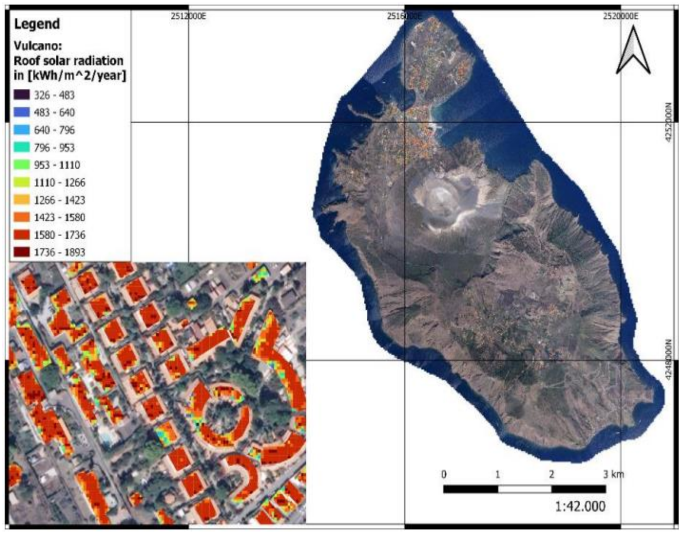
MAP 92: Vulcano mean wind speed



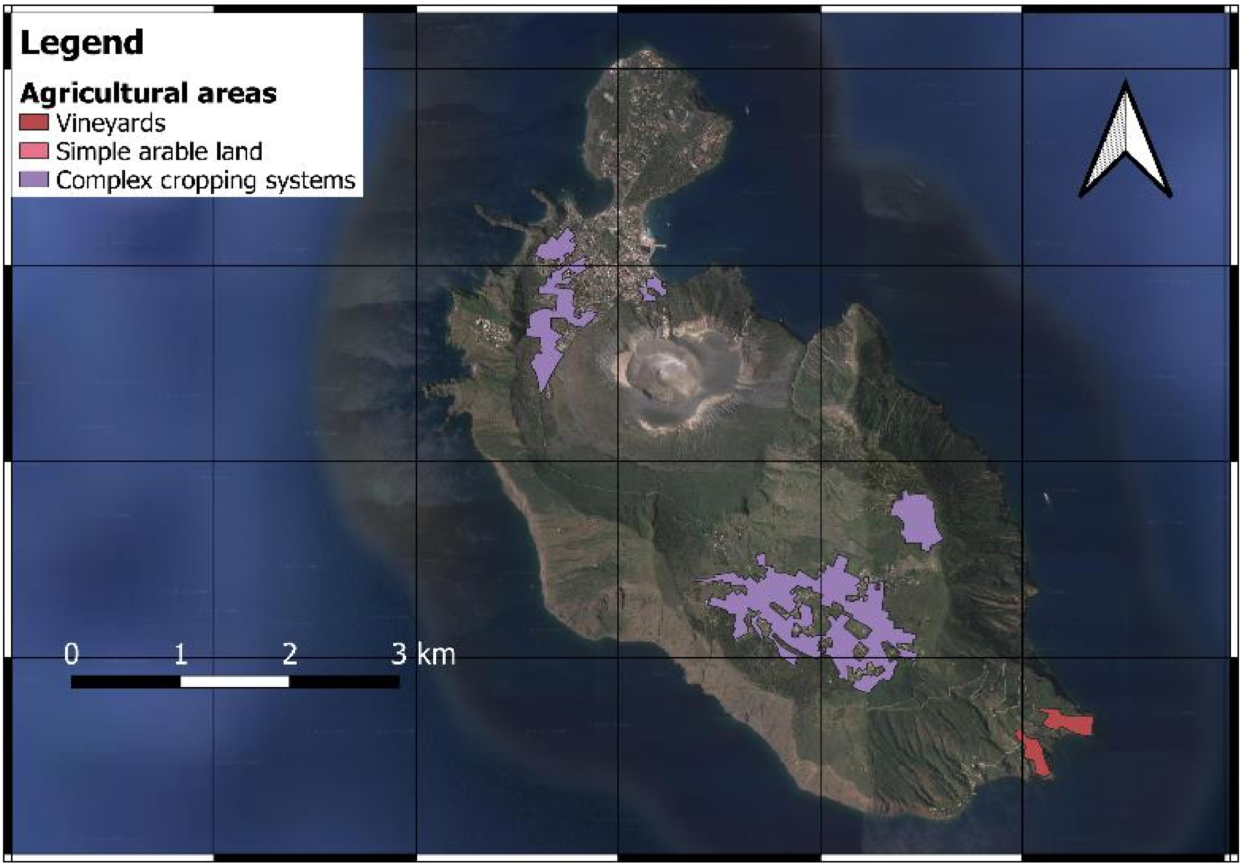
MAP 93: Vulcano power density



MAP 94: Vulcano AEP

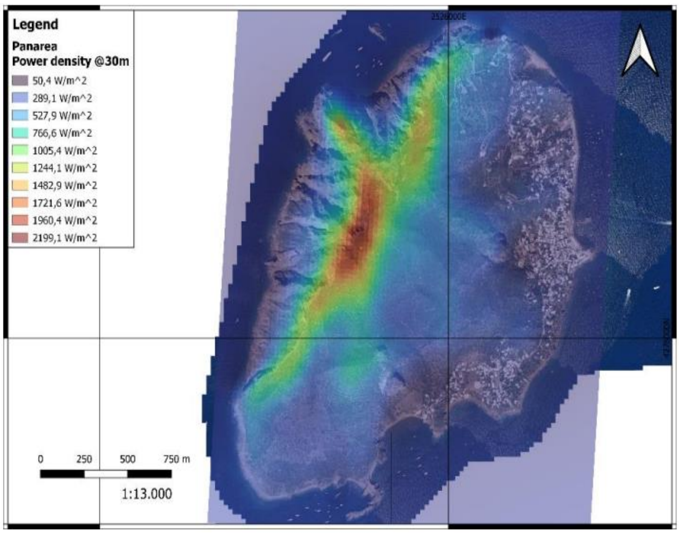


MAP 95: Vulcano roof solar radiation

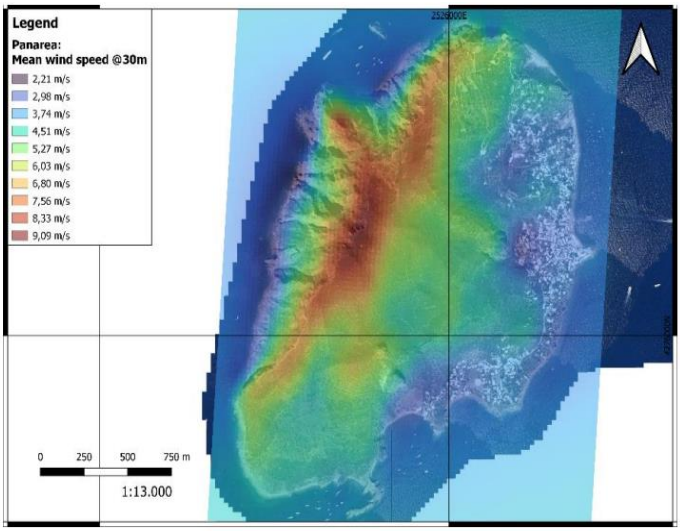


MAP 96: Vulcano agricultural areas

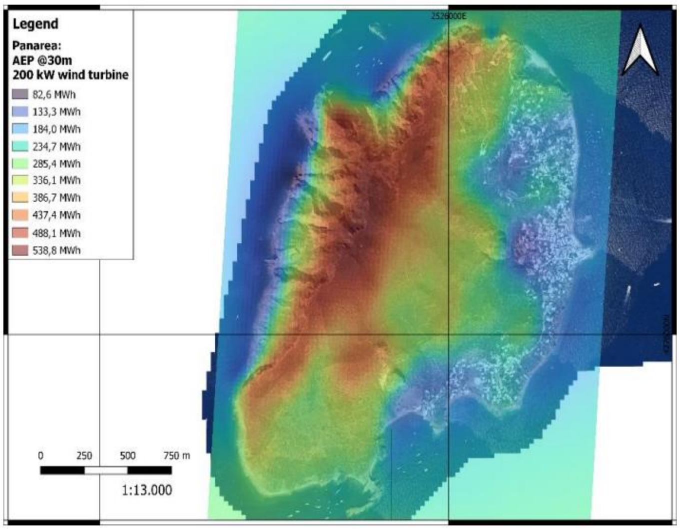
Panarea



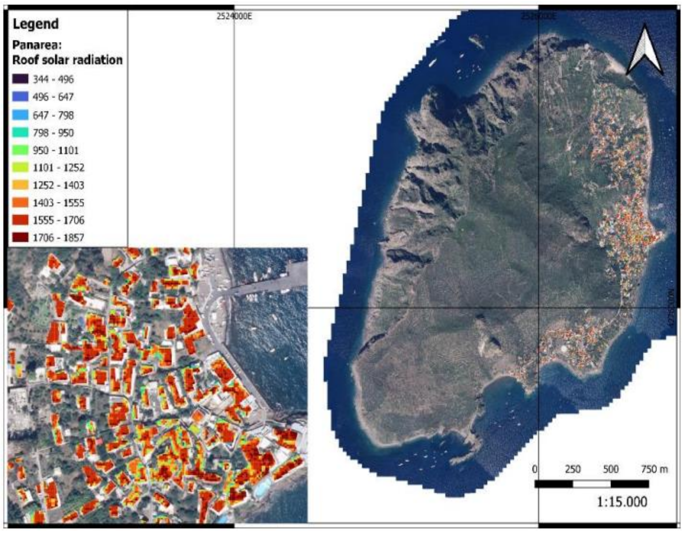
MAP 97: Panarea power density



MAP 98: Panarea mean wind speed



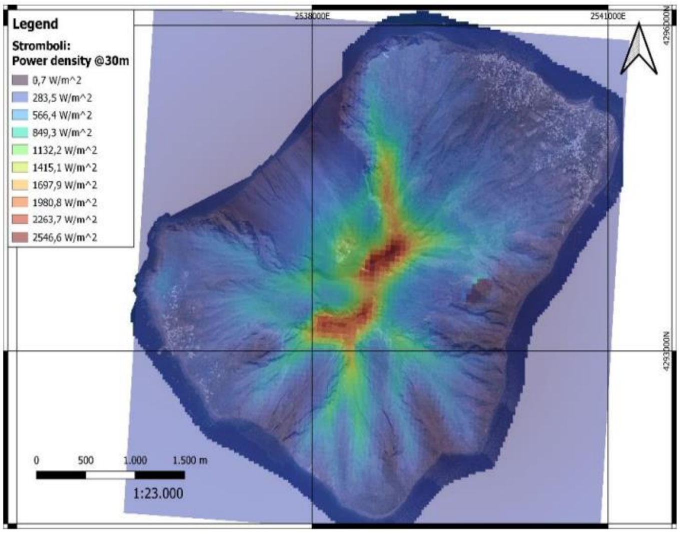
MAP 99: Panarea AEP



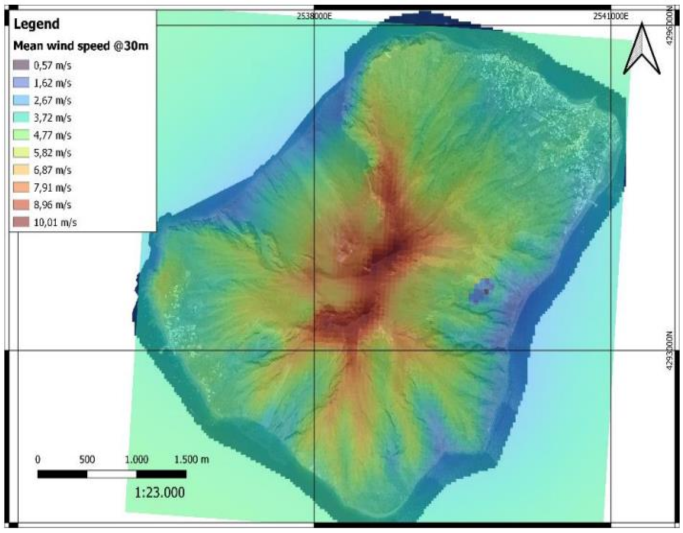
MAP 100: Panarea roof solar radiation

MAP 101: Panarea agricultural areas

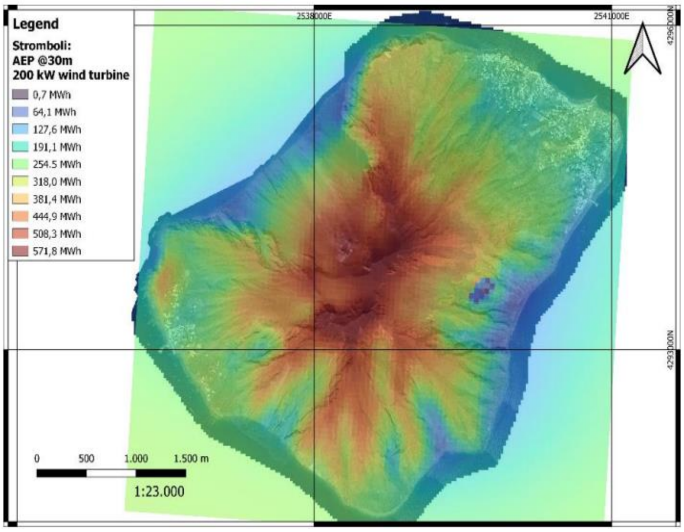
Stromboli



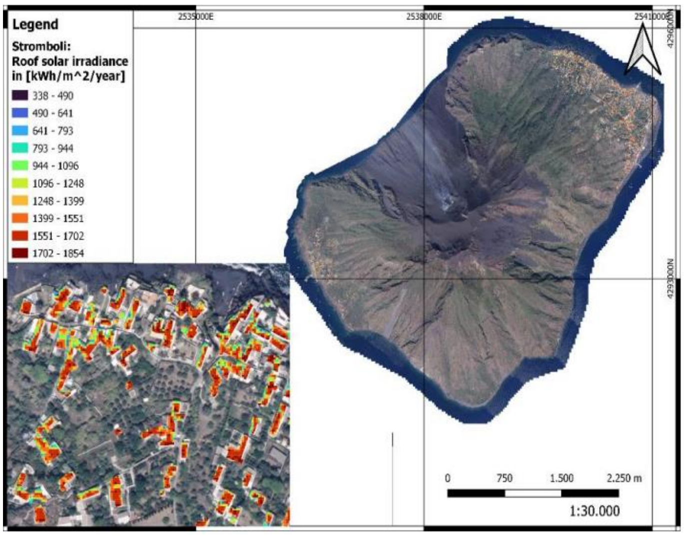
MAP 102: Stromboli power density



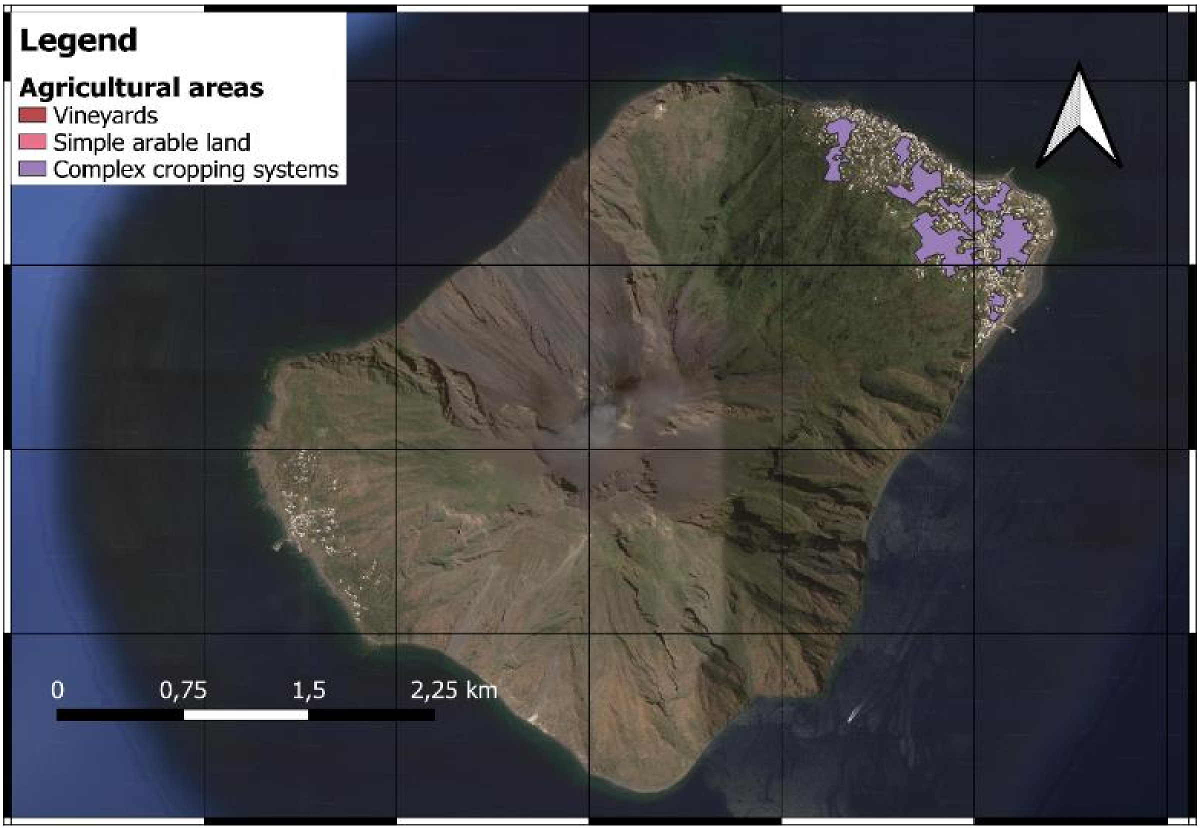
MAP 103: Stromboli mean wind speed



MAP 104: Stromboli AEP

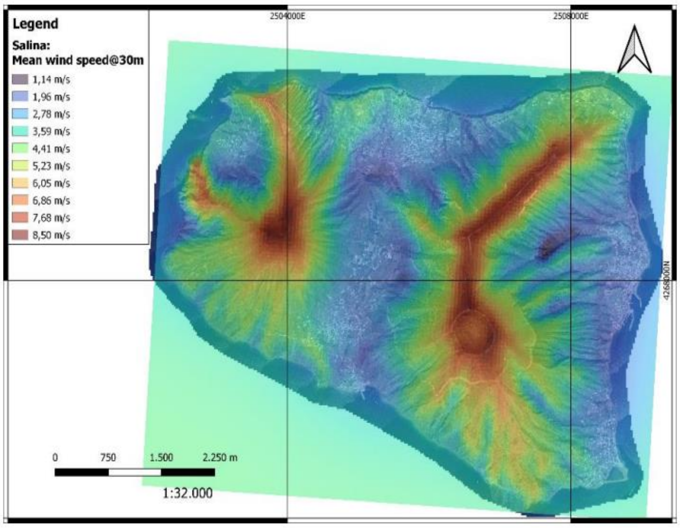


MAP 105: Stromboli roof solar radiation

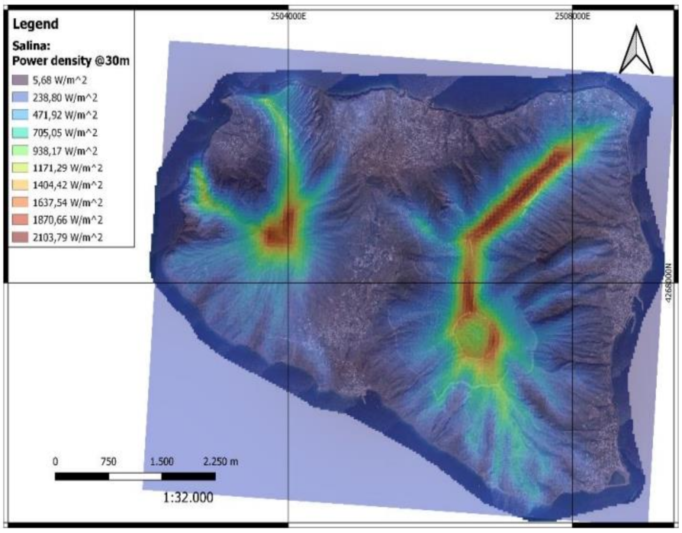


MAP 106: Stromboli agricultural areas

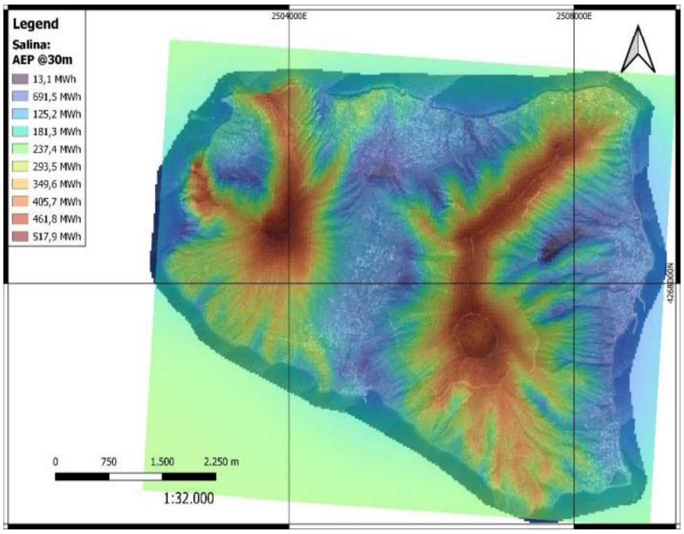
Salina



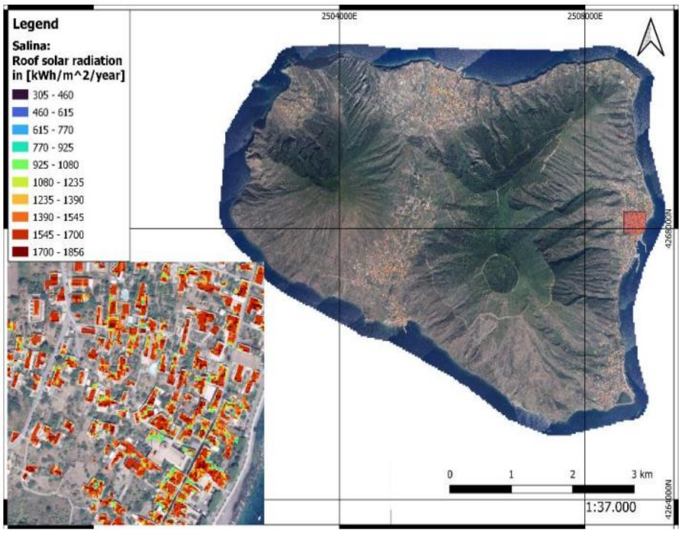
MAP 107: Salina mean wind speed



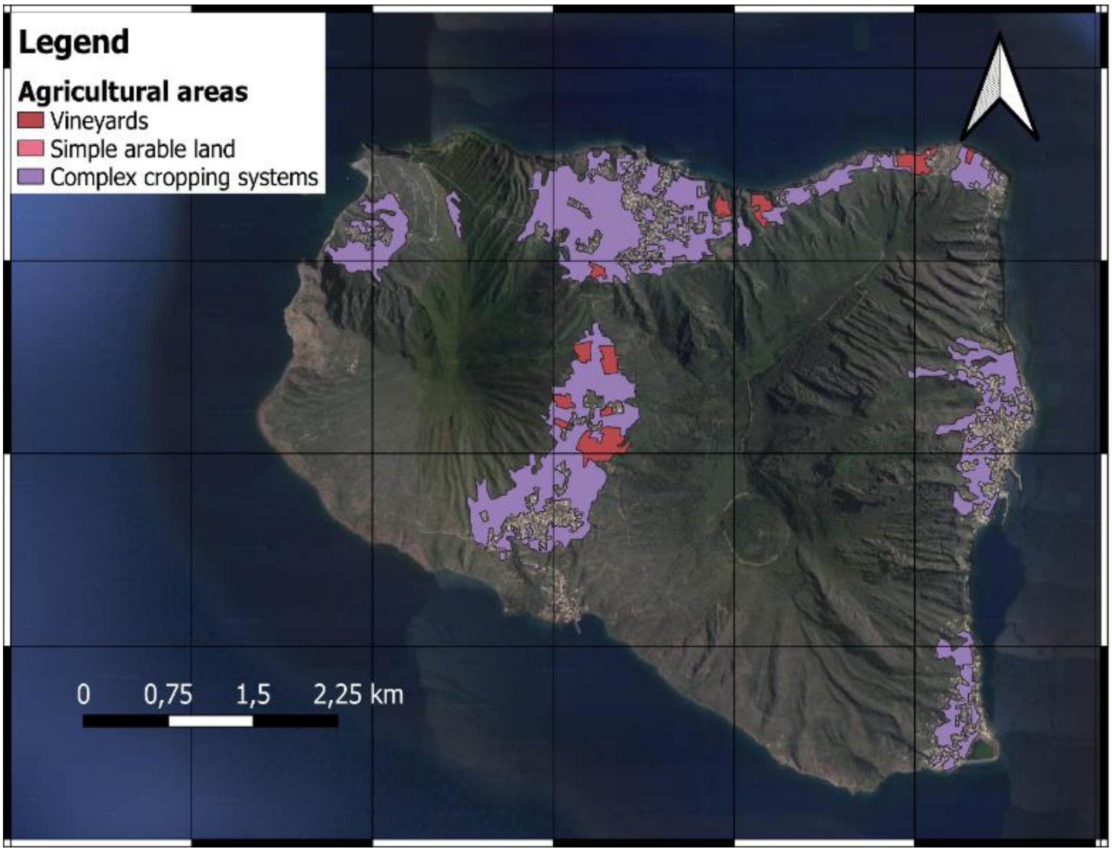
MAP 108: Salina power density



MAP 109: Salina AEP



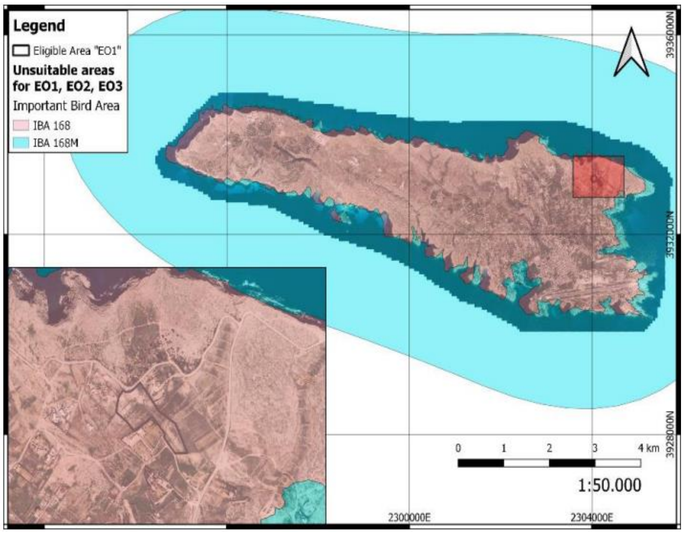
MAP 110: Salina roof solar radiation



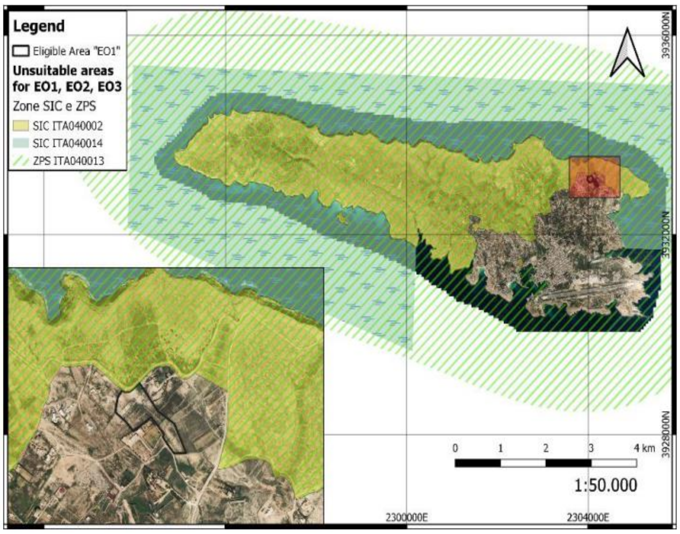
MAP 111: Salina agricultural areas

Pelagie

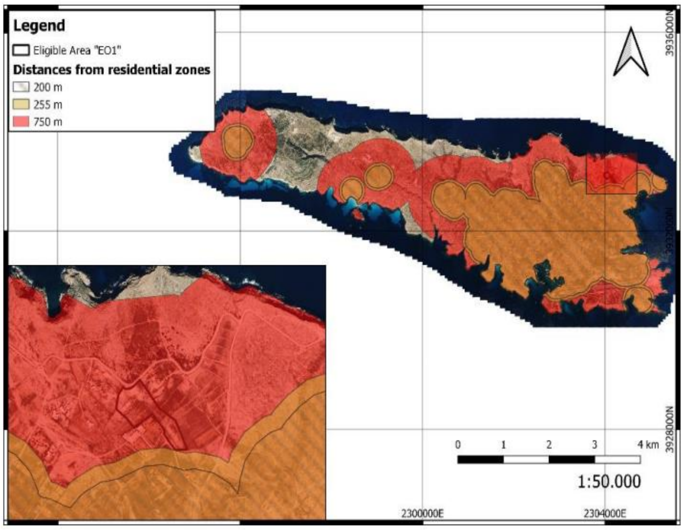
Lampedusa



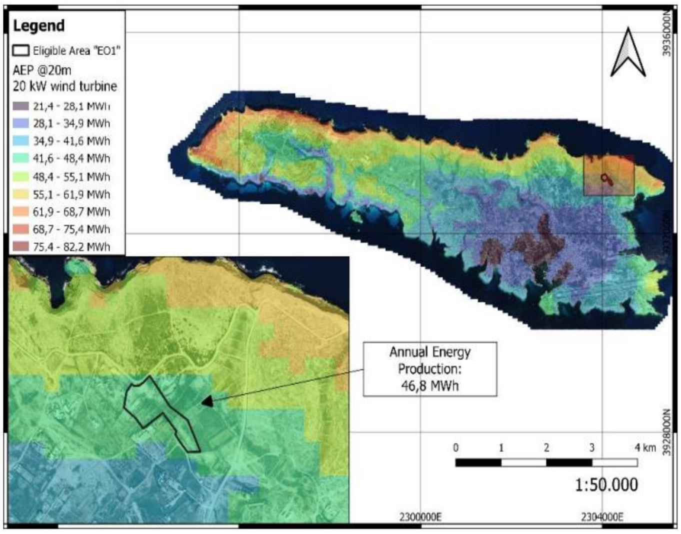
MAP 112: Lampedusa unsuitable areas for type 1,2,3 WT



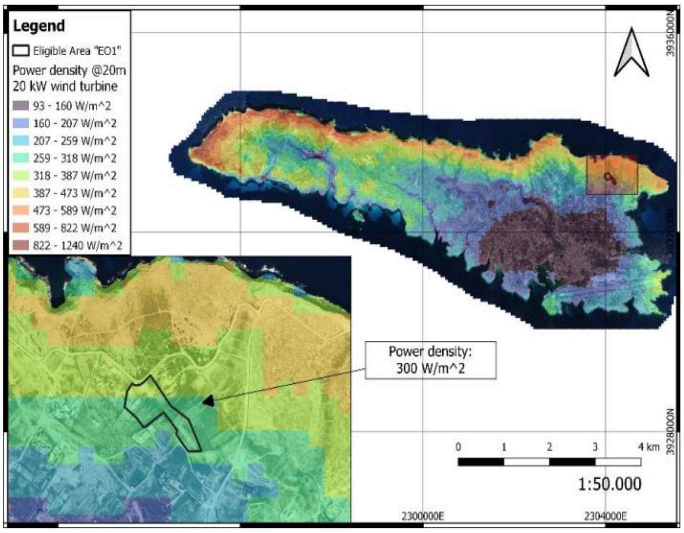
MAP 113: Lampedusa unsuitable areas for type 1,2,3 WT



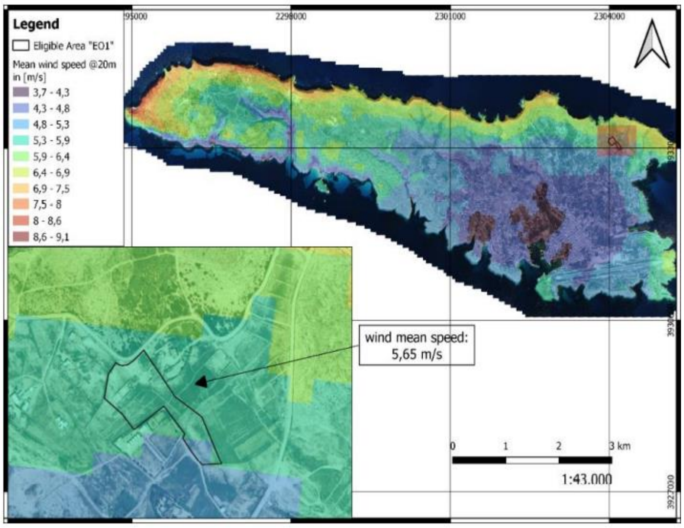
MAP 114: Lampedusa distances from residential zones



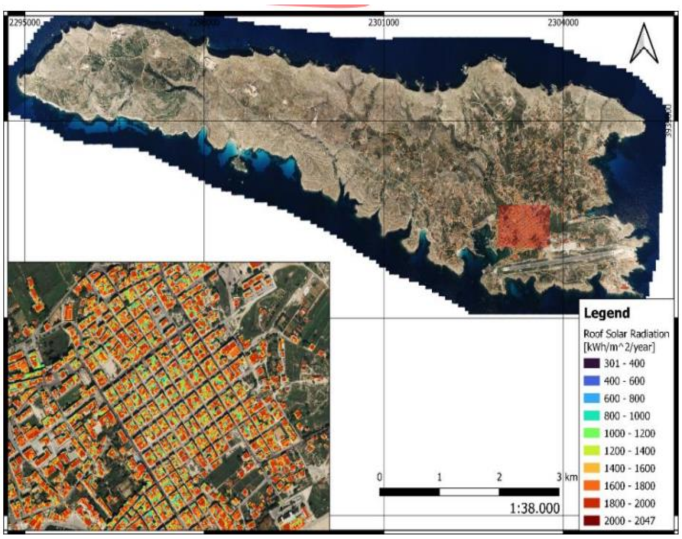
MAP 115: Lampedusa AEP



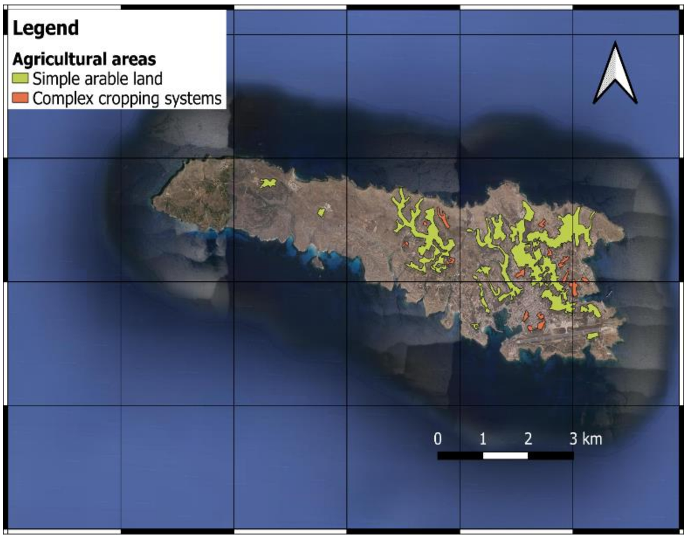
MAP 116: Lampedusa power density



MAP 117: Lampedusa mean wind speed

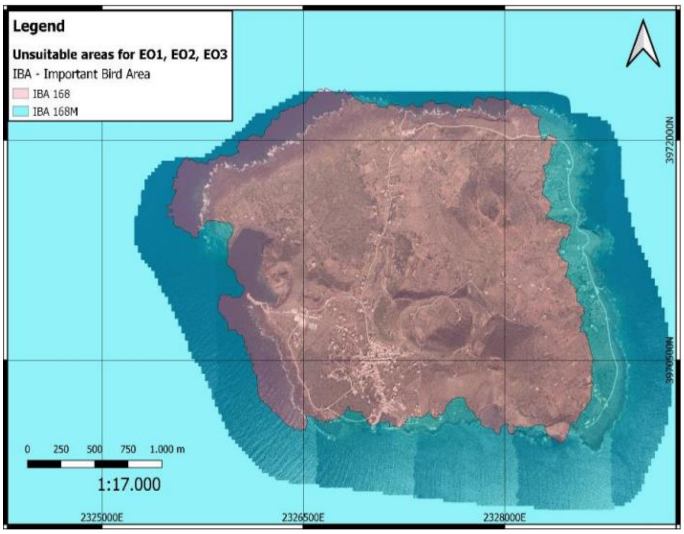


MAP 118: Lampedusa roof solar radiation

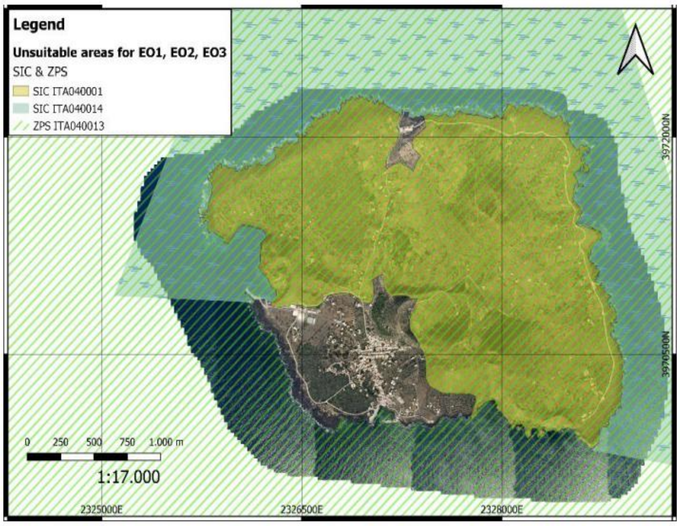


MAP 119: Lampedusa agricultural areas

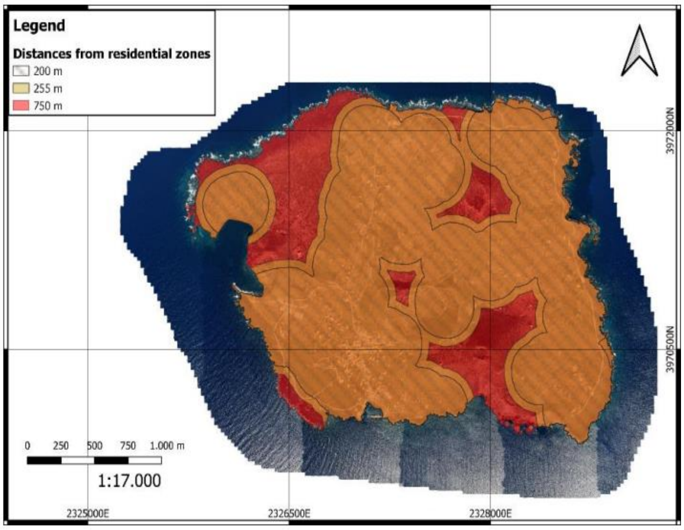
Linosa



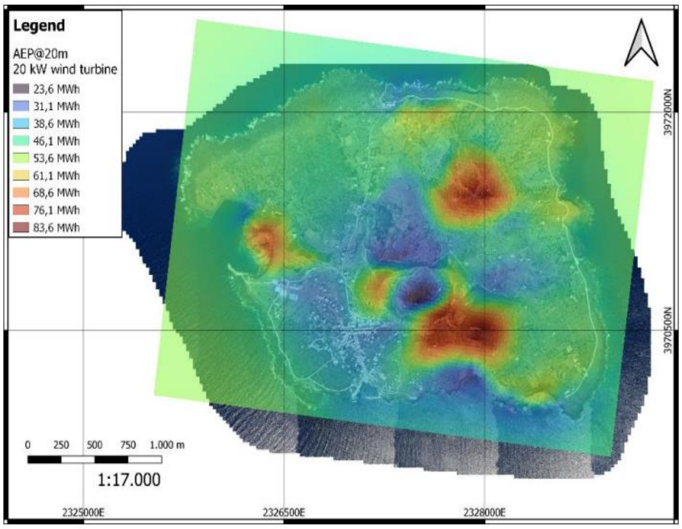
MAP 120: Linosa unsuitable areas for type 1,2,3 WT



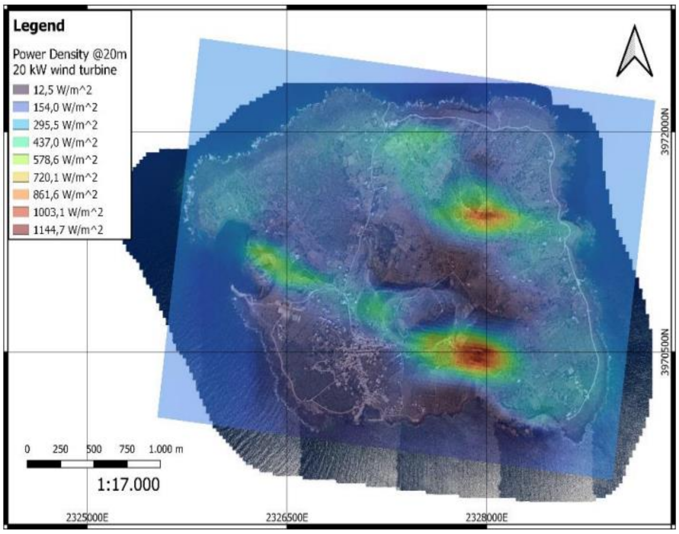
MAP 121: Linosa unsuitable areas for type 1,2,3 WT



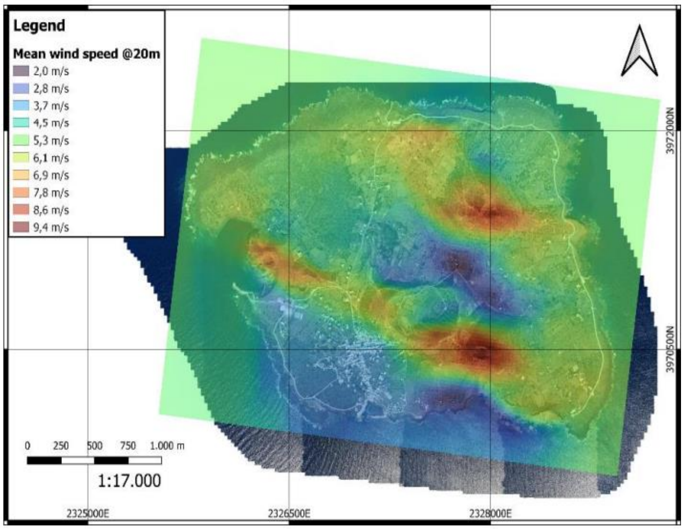
MAP 122: Linosa distances from residential zones



MAP 123: Linosa AEP

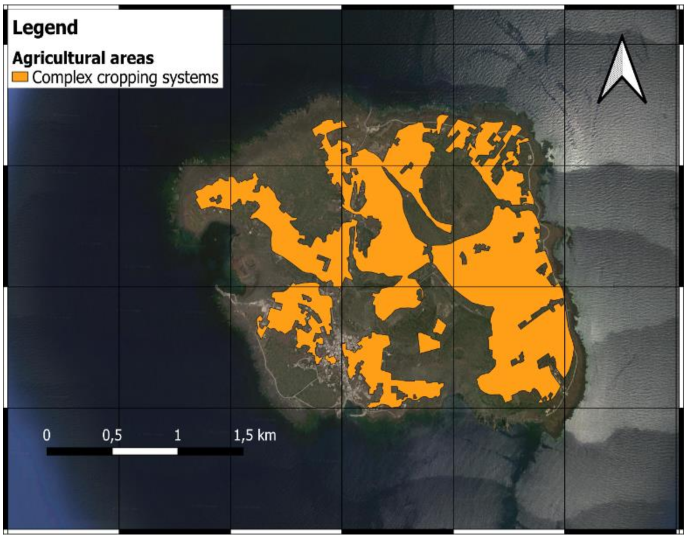


MAP 124: Linosa power density



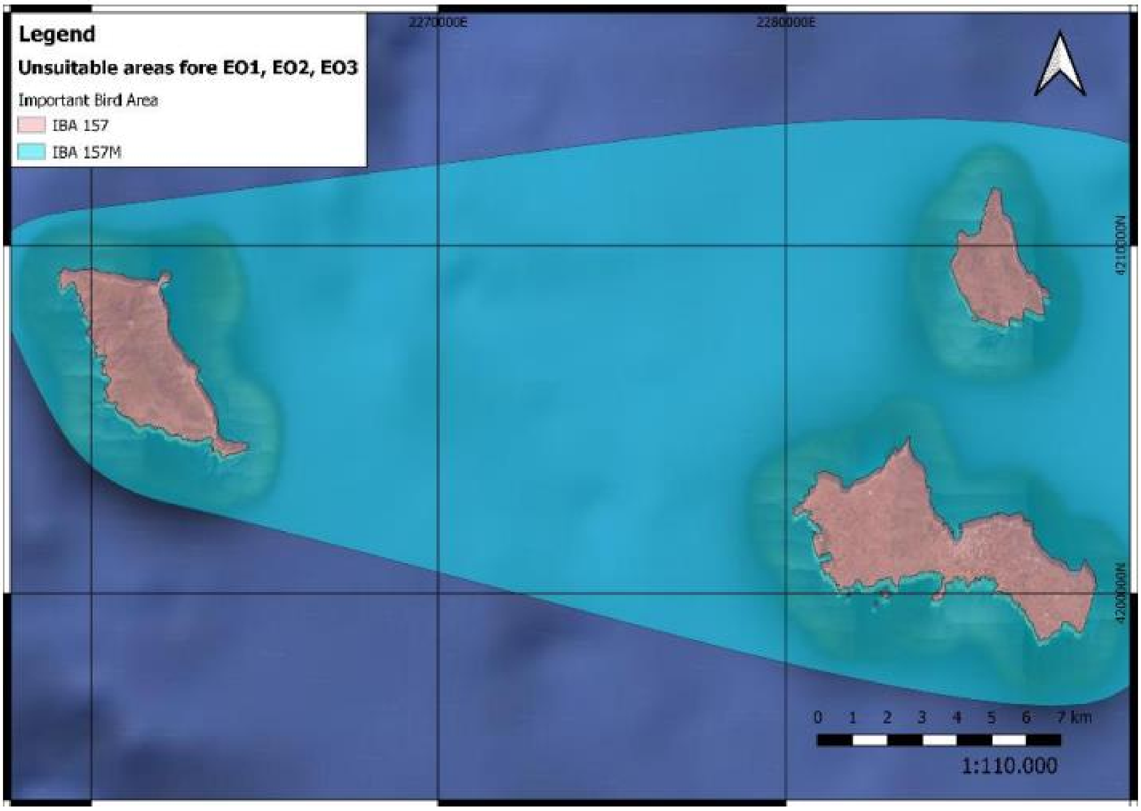
MAP 125: Linosa mean wind speed

MAP 126: Linosa roof solar radiation



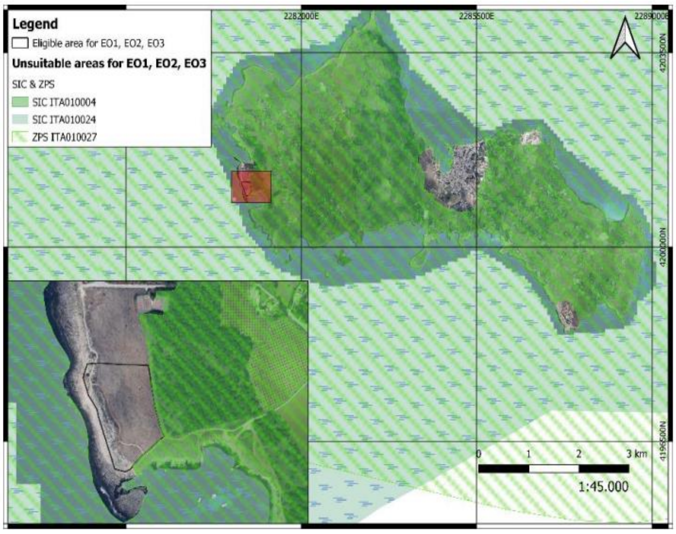
MAP 127: Linosa agricultural areas

Egadi

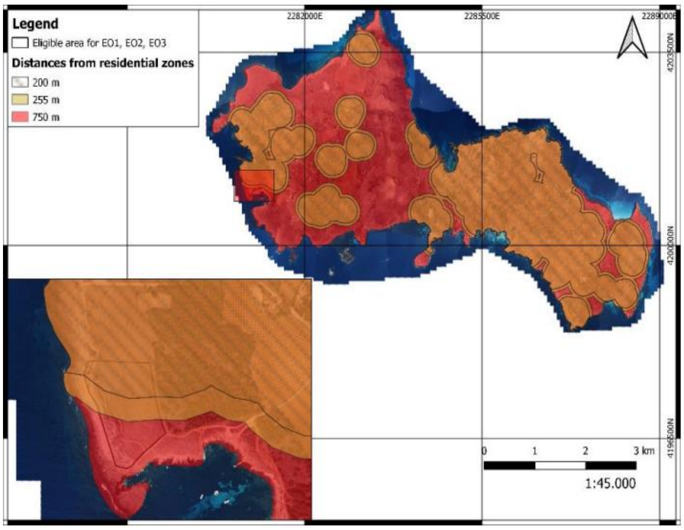


MAP 128: Egadi Islands' unsuitable areas for type 1,2,3 WT

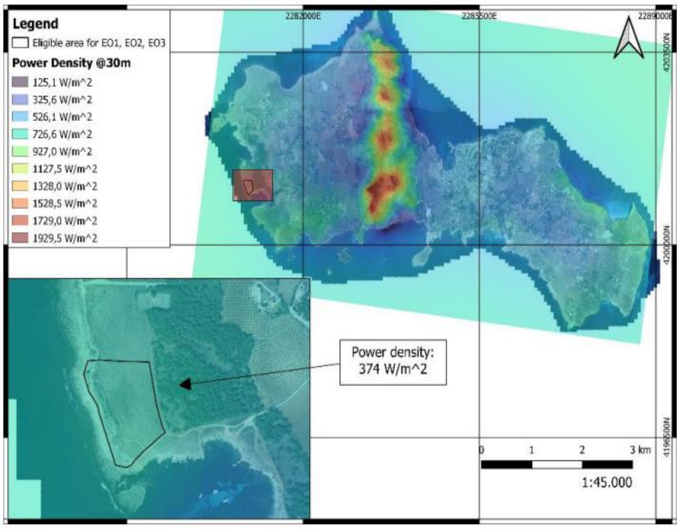
Favignana



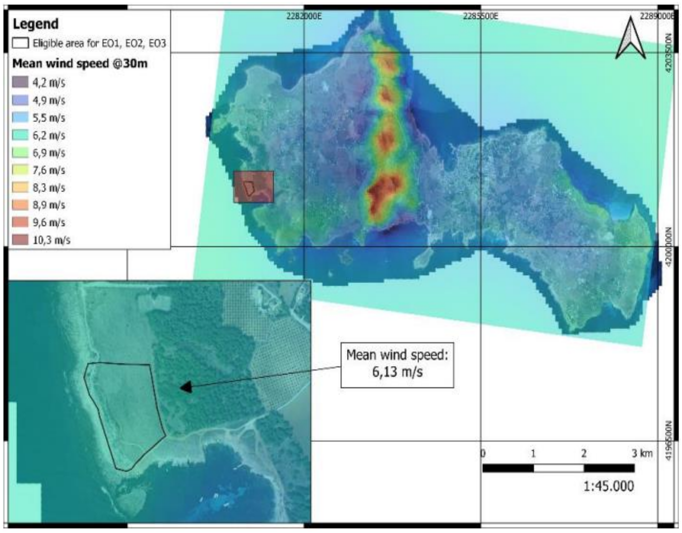
MAP 129: Favignana unsuitable areas for type 1,2,3 WT



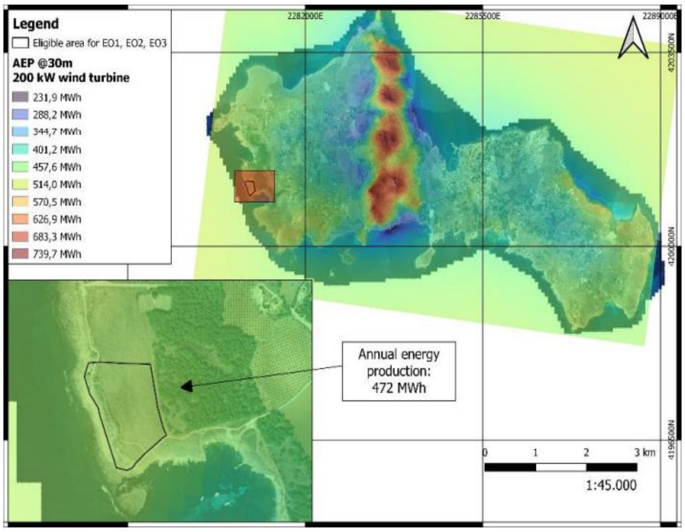
MAP 130: Favignana distances from residential zones



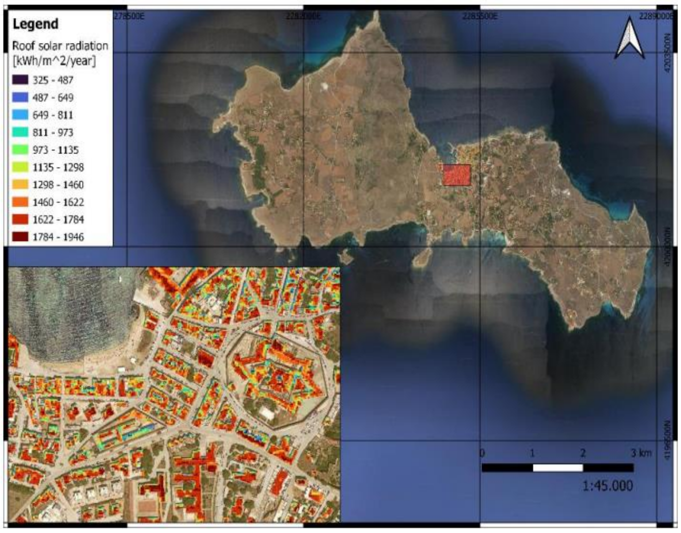
MAP 131: Favignana power density



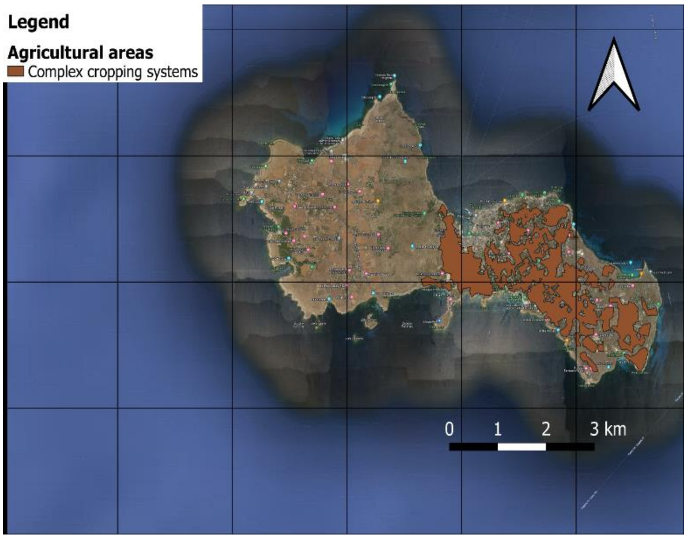
MAP 132: Favignana mean wind speed



MAP 133: Favignana AEP

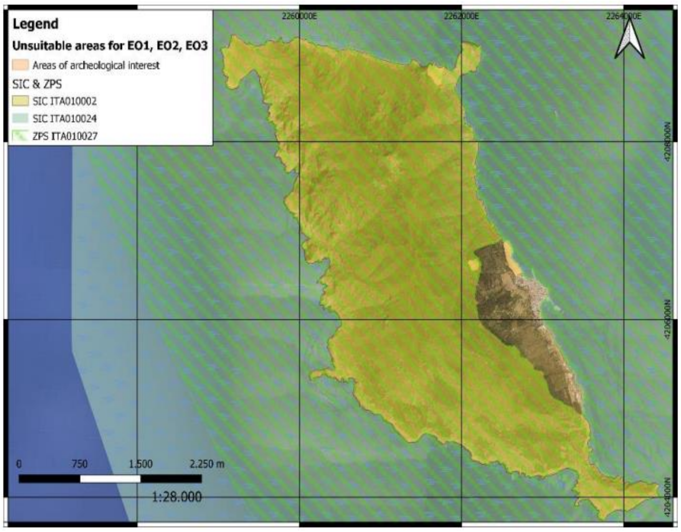


MAP 134: Favignana roof solar radiation

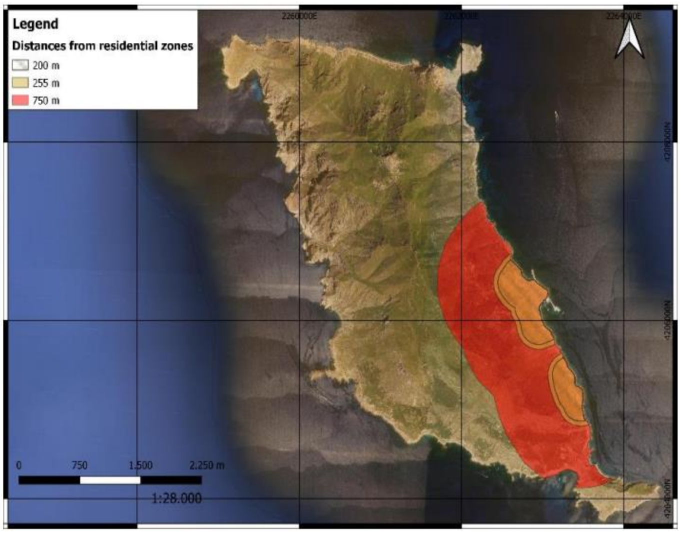


MAP 135: Favignana agricultural areas

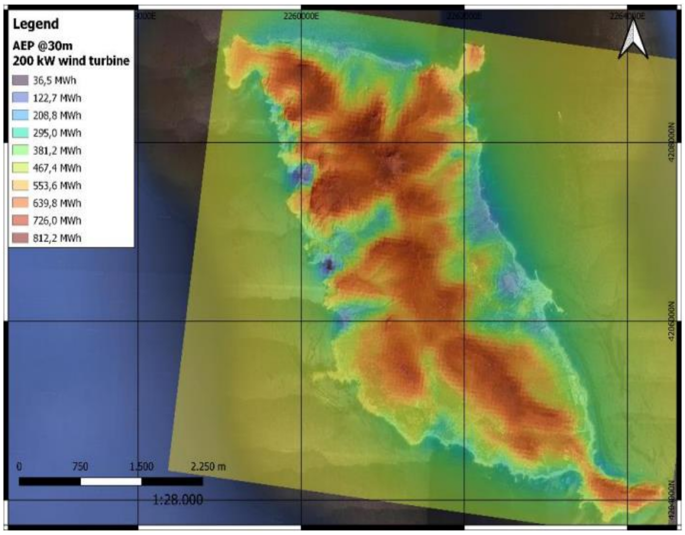
Marettimo



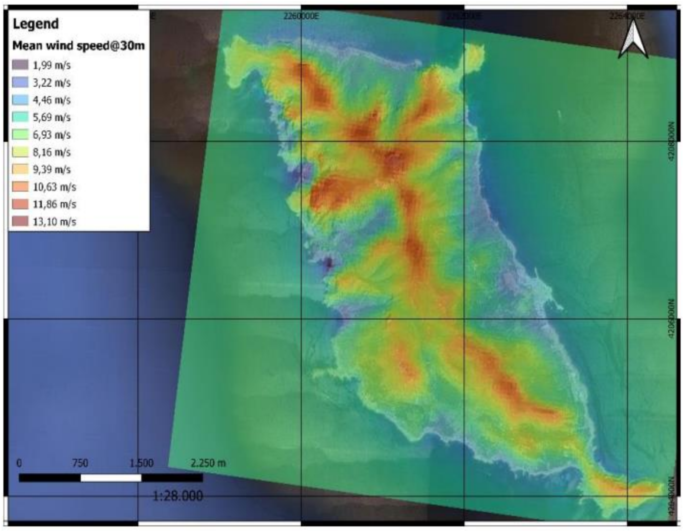
MAP 136: Marettimo unsuitable areas for type 1,2,3 WT



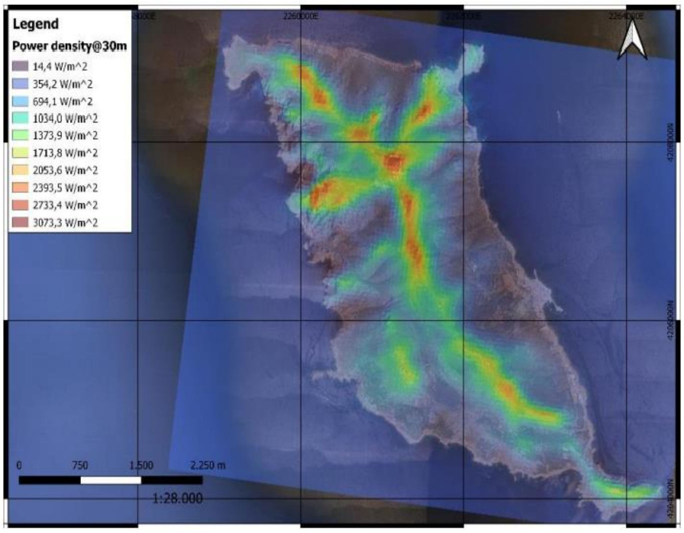
MAP 137: Marettimo distances from residential zones



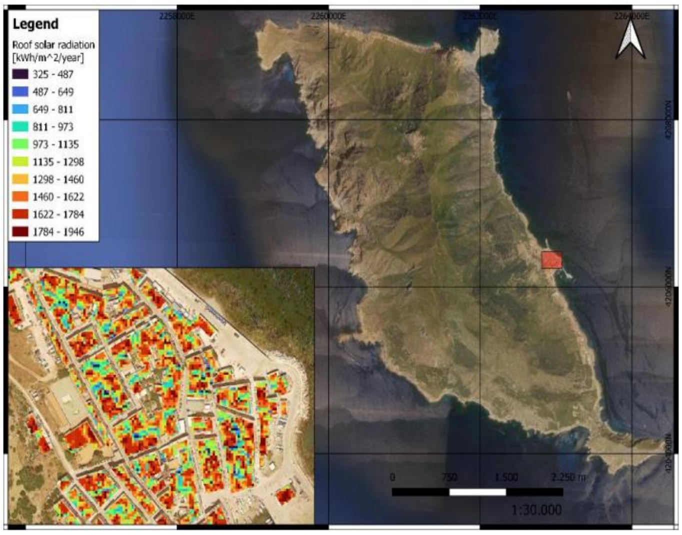
MAP 138: Marettimo AEP



MAP 139: Marettimo mean wind speed

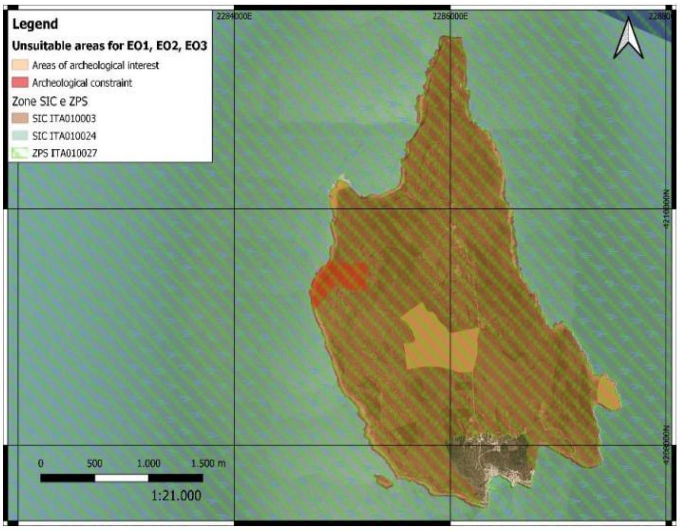


MAP 140: Marettimo power density

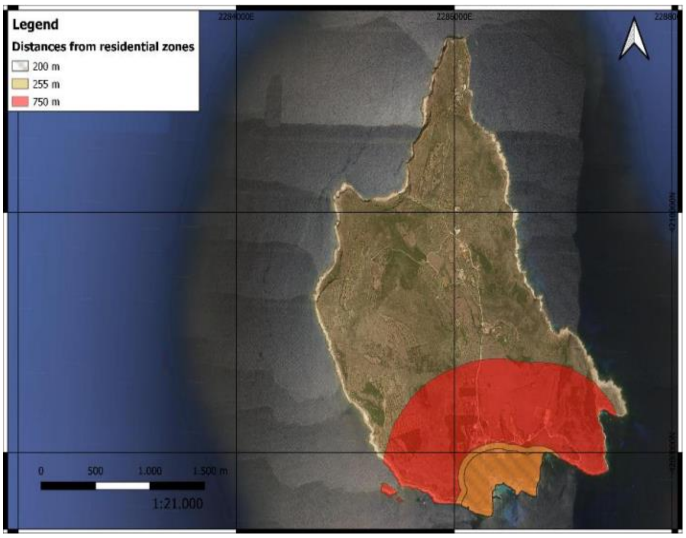


MAP 141: Marettimo roof solar radiation

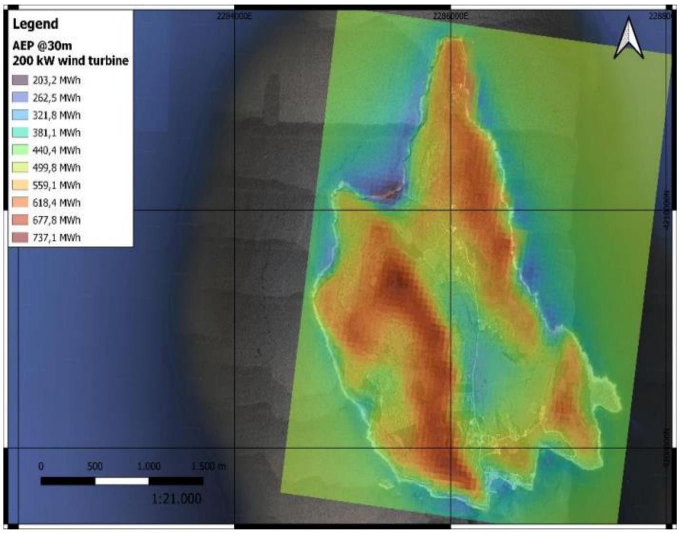
Levanzo



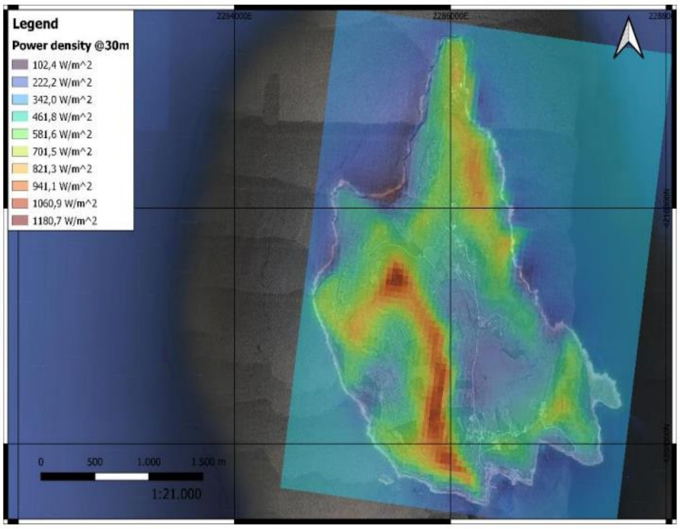
MAP 142: Levanzo unsuitable areas for type 1,2,3 WT



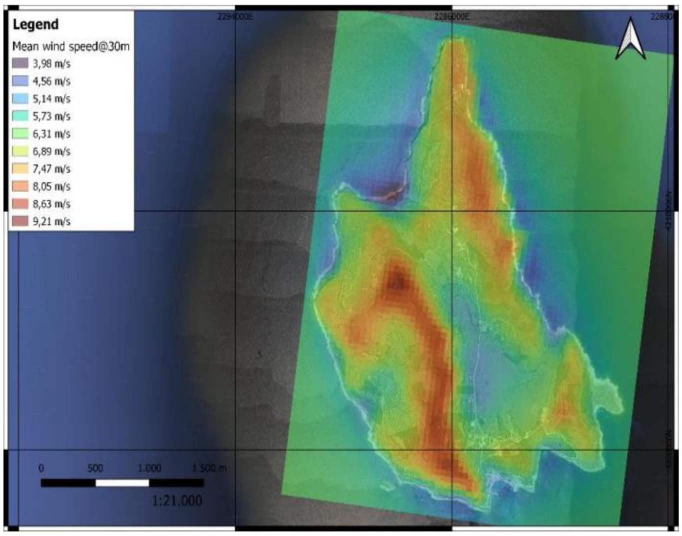
MAP 143: Levanzo distances from residential zones



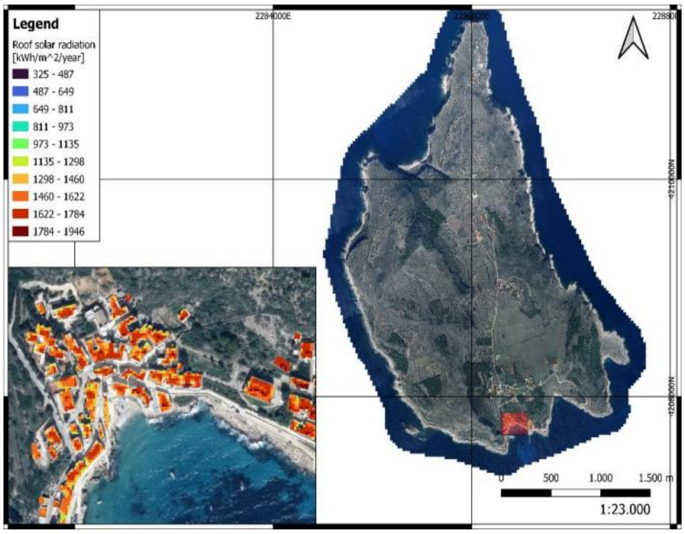
MAP 144: Levanzo AEP



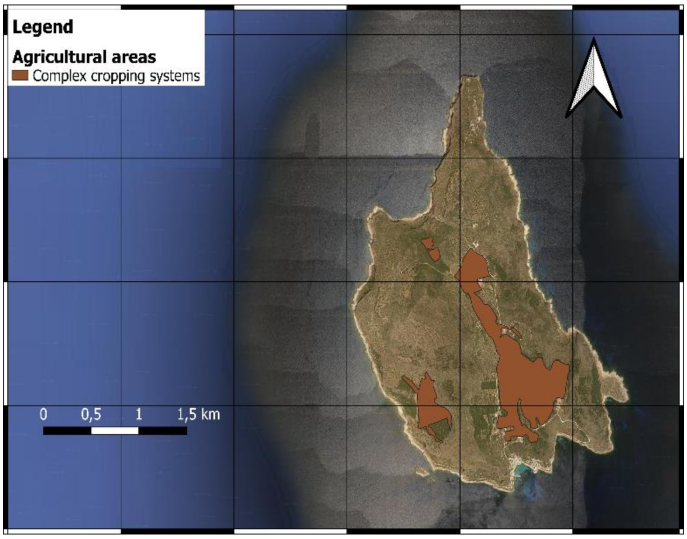
MAP 145: Levanzo power density



MAP 146: Levanzo mean wind speed



MAP 147: Levanzo roof solar radiation



MAP 148: Levanzo agricultural areas

References

[1] IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

[2] United Nations General Assembly. Report of the world commission on environment and development: Our common future. Oslo, Norway: United Nations General Assembly, Development and International Cooperation: Environment. (1987).

[3] UNFCCC. The Paris Agreement; UNFCCC, United Nations Framework Convention on Climate Change: Paris, France, 2015.

[4] European Commision, "European Green Deal Communication" 2019.

[5] Italian Government, Presidenza del Consiglio dei Ministri. "Piano Nazionale di Ripresa e Resilienza".

[6] Theodora, Y., Stratigea, A. (2021). Climate Change and Strategic Adaptation Planning in Mediterranean Insular Territories: Gathering Methodological Insights from Greek Experiences. In: , et al. Computational Science and Its Applications – ICCSA 2021. ICCSA 2021. Lecture Notes in Computer Science, vol 12958. Springer, Cham. https://doi.org/10.1007/978-3-030-87016-4_8

[7] Demo - Statistiche demografiche ISTAT. https://demo.istat.it/?l=it [Accessed January 2023]

[8] Isole Tremiti - Economy http://www.isoletremiti.it/#:~:text=L'economia%20delle%20Isole%20Tremiti,un'atmosfera%20sobria%20e%20familiare.

[9] Arcipelago Pontino - http://www.arcipelagopontino.com/ [accessed January 2023]

[10] Isola Di Montecristo - https://www.infoelba.it/isola-d-elba/parco-nazionale-arcipelago-toscano/isole-arcipelago/montecristo/#:~:text=Montecristo%20ad%20oggi%20%C3%A8%20praticamente,nella%20localit%C3%A0%20chiamata%20il%20Convento. [accessed January 2023]

[11] Borghi abbandonati, il progetto: "Riapriamo Pianosa, torniamo ad abitare sull'isola" - https://firenze.repubblica.it/cronaca/2022/02/05/news/il_progetto_torniamo_ad_abitare_sull_isola_di_pianosa_-336482712/ [accessed January 2023]

[12] ELBA – Nuovo cavo sottomarino di ENEL per la linea elettrica - https://toscananews.net/elba-nuovo-cavo-sottomarino-di-enel-per-la-linea-elettrica/

[13] Casa di Reclusione Gorgona - https://www.antigone.it/osservatorio_detenzione/toscana/159-casa-di-reclusione-di-gorgona

[14] Gorgona, Toscana: un'isola carcere ancora attiva https://ilbolive.unipd.it/it/news/gorgona-toscana-unisola-carcere-ancora-attiva#:~:text=Il%20centro%20di%20Gorgona%20%C3%A8,(estivo)%2C%20in%20vacanza.

[15] OSSERVATORIO ISOLE SOSTENIBILI - RAPPORTO 2022 https://www.isolesostenibili.it/il-rapporto-2022/

[16] Isola di Giannutri https://www.isoladelbaapp.com/arcipelago-toscano/isola-di-giannutri

[17] Nelle Isole piccole ci sarà soltanto energia buona. L'impegno di Terna per Pantelleria e Giannutri - https://qds.it/nelle-isole-piccole-ci-sara-soltanto-energia-buona-limpegno-di-terna-per-pantelleria-e-giannutri/

[18] CENSIMENTO DELLE ACQUE PER USO CIVILE. ISTAT. https://www.istat.it/it/archivio/279363

[19] HYDROUSA Project. https://www.hydrousa.org/

[20] Tassi di Motorizzazione ISTAT. http://dati.istat.it/Index.aspx?DataSetCode=DCCV_TRASPRIV#

[21] "Life for Silver Coast": biciclette e scooter elettrici - https://www.giglionews.it/al-via-life-for-silver-coast-biciclette-e-scooter-elettrici

[22] Produzione e raccolta comunale - Catasto Rifiuti - Ispra https://www.catasto-rifiuti.isprambiente.it/index.php?pg=findComune

[23] Nota Stampa - Consiglio Nazionale delle Ricerche https://www.cnr.it/it/nota-stampa/n-10466/isole-sostenibili-2021-nel-rapporto-dell-osservatorio-di-legambiente-e-cnr-iia-buone-pratiche-e-criticita-nelle-27-isole-minori-italiane-abitate

[24] D.M. Decreto Ministeriale del 14 febbraio 2017: Copertura del Fabbisogno delle Isole Minori non Interconnesse Attraverso Energia da Fonti Rinnovabili. Ministero dello Sviluppo Economico. Available online: https://www.mise.gov.it/images/stories/normativa/decreto_ministeriale_14_febbraio_2017_energia_isole_minori.pdf

[25] Come funziona la centrale a biodiesel di Capraia, l’isola con l’elettricità a zero CO2 - Green Report. https://greenreport.it/news/aree-protette-e-biodiversita/come-funziona-centrale-biodiesel-capraia-lisola-lelettricita-zero-co2/ [Accessed January 2023]

[26] Regione Siciliana, “Piano Energetico Ambientale della Regione Siciliana, PEARS 2030,” 2019.

[27] Gli ostacoli alla transizione energetica: i problemi che scontano oggi le rinnovabili - https://www.infobuildenergia.it/approfondimenti/ostacoli-transizione-energetica-problemi-sviluppo-rinnovabili/

[28] Isole minori, istituita la 73ma Area Interna Ultraperiferica - https://www.isolesostenibili.it/2022/02/14/isole-minori-istituita-la-73ma-area-interna-ultraperiferica/

[29] Comitato Aree Interne - Agenzia per la Coesione Territoriale - https://www.agenziacoesione.gov.it/strategia-nazionale-aree-interne/la-selezione-delle-aree/

[30] Aree Interne - Openpolis https://www.openpolis.it/parole/che-cosa-sono-le-aree-interne/

[31] Resto al Sud, incentivi estesi al commercio e alle isole minori del Centro-Nord - https://www.invitalia.it/chi-siamo/area-media/notizie-e-comunicati-stampa/resto-al-sud-esteso-al-commercio-e-alle-isole-centro-nord

[32] POC Energia e Sviluppo dei Territori 2014-2020 - https://www.invitalia.it/cosa-facciamo/affianchiamo-la-pa-per-gestire-i-fondi-europei-e-nazionali/programmi-operativi/poc-energia-e-sviluppo-dei-territori

[33] Interventi di efficienza energetica, mobilità sostenibile e adattamento agli impatti ai cambiamenti climatici nelle isole minori - https://www.mite.gov.it/pagina/interventi-di-efficienza-energetica-mobilita-sostenibile-e-adattamento-agli-impatti-ai

[34] Fondo per gli investimenti poer le isole minori - https://www.affariregionali.it/attivita/aree-tematiche/ripartizione-dei-fondi-e-azioni-di-tutela/isole-minori/fondo-investimento-isole-minori/

[35] Parchi per il Clima: al via il nuovo programma per l'efficientamento energetico - https://www.mite.gov.it/notizie/parchi-il-clima-al-il-nuovo-programma-l-efficientamento-energetico#:~:text=2021%20%E2%80%93%20Al%20via%20la%20terza,nei%20territori%20dei%20Parchi%20nazionali.

[36] Aree Marine Protette per il Clima - MASE - https://www.mite.gov.it/pagina/corso-il-programma-aree-marine-protette-il-clima-2021

[37] Unesco - PROGRAMMA DI INTERVENTI PER L’ADATTAMENTO AI CAMBIAMENTI CLIMATICI A FAVORE DEI COMUNI DI SITI ED ELEMENTI UNESCO D’INTERESSE NATURALISTICO E NEI PARCHI NAZIONALI” https://www.unesco.it/it/News/Detail/1104#:~:text=Il%20nuovo%20programma%20di%20interventi,interesse%20naturalistico%20e%20nei%20parchi

[38] Leary, David and Miguel Esteban. “Climate Change and Renewable Energy from the Ocean and Tides: Calming the Sea of Regulatory Uncertainty.” The International Journal of Marine and Coastal Law 24 (2009): 617-651.
[39] Energie Rinnovabili - Note tematiche sull'Unione europea. Parlamento Europeo. https://www.europarl.europa.eu/factsheets/it/sheet/70/energie-rinnovabili

[40] DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources, amending and subsequently repealing of directives 2001/77/EC and 2003/30/EC. https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:it:PDF

[41] Clean energy for all Europeans package - https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

[42] Clean energy for EU islands - https://energy.ec.europa.eu/topics/markets-and-consumers/clean-energy-eu-islands_en#:~:text=As%20part%20of%20the%20'Clean,increased%20production%20of%20renewable%20energy

[43] Clean Energy Transition Agenda https://clean-energy-islands.ec.europa.eu/assistance/clean-energy-transition-agenda

[44] Decreto legislativo n. 387/2003 http://leg15.camera.it/cartellecomuni/leg14/RapportoAttivitaCommissioni/testi/10/10_cap04_sch01.htm

[45] Decreto legislativo 3 marzo 2011, n. 28 https://www.bosettiegatti.eu/info/norme/statali/2011_0028.htm

[46] Ministerial Decree No. 219 of 10 September 2010 “Guidelines for the authorization of plants powered by renewable sources” https://www.gazzettaufficiale.it/eli/id/2010/09/18/10A11230/sg

[47] Polatidis, H. Micro-siting/positioning of wind turbines: Introducing a multi-criteria decision analysis framework EU FP5 project MCDA-RES View project. In Proceedings of the 7th International Multi-Conference on Engineering and Technological Innovation (IMETI 2014), Orlando, FL, USA, 15–18 July 2014.

[48] Decreto legge 1 marzo 2022, n. 17 - Gazzetta Ufficiale - https://www.gazzettaufficiale.it/eli/id/2022/04/28/22A02680/sg

[49] A pilot plant built by Le Greenhouse. https://www.legreenhouse.it/

[50] LINEE GUIDA PER L'APPLICAZIONE DELL'AGRO-FOTOVOLTAICO IN ITALIA. https://ecquologia.com/wp-content/uploads/2021/12/Linea-Guida-Agroftv_30_11_2021_VDS.pdf

[51] Enti Pubblici e Privati che hanno partecipato alla redazione delle Linee Guida: Università Degli Studi Della Tuscia - Dipartimento Di Scienze Agrarie E Forestali; Confagricoltura; Enel Green Power; Consiglio Per La Ricerca In Agricoltura E L'analisi Dell'economia Agraria; Solarfields; Consiglio Nazionale Delle Ricerche; Ef Solare Italia; Le Greenhouse; S.E.A Tuscia S.R.L.; Consiglio Ordine Nazionale Dei Dottori Agronomi E Dottori Forestali; Federazione Dottori Agronomi E Forestali Del Lazio;

[52] Solarpower Europe - Agrisolar best practice guidelines 2021 https://solargrazing.org/wp-content/uploads/2021/06/SPE-Agrisolar-Best-Practices-Guidelines.pdf

[53] Dinesh, H., & Pearce, J. M. (2016). The potential of agrivoltaic systems. In Renewable and Sustainable Energy Reviews (Vol. 54, pp. 299–308). Elsevier Ltd
https://doi.org/10.1016/j.rser.2015.10.024

[54] 10 BENEFICI DELL'AGRO-FOTOVOLTAICO - https://www.efsolareitalia.com/agro-fotovoltaico/transition2green/

[55] H. Marrou, J. Wery, L. Dufour, C. Dupraz, Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels, European Journal of Agronomy, Volume 44, 2013, Pages 54-66, ISSN 1161-0301,
https://doi.org/10.1016/j.eja.2012.08.003.
(https://www.sciencedirect.com/science/article/pii/S1161030112001177)

[56] Obergfell T., 2013. Agro-Voltaik: Landwirtschaft unter Photovoltaik-Anlagen (German). Master thesis. University of Kassel

[57] Northrup J., Wittemyer G., 2013. Characterizing the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecol. Lett., 16, 112-125.

[58] Horváth, Gábor, György Kriska, Péter Malik, and Bruce Robertson. 2009. "Polarized Light Pollution: A New Kind of Ecological Photopollution." Frontiers in Ecology and the Environment 7(6):317–25. doi: 10.1890/080129.

[59] Fritz, Benjamin, Gábor Horváth, Ruben Hünig, Ádám Pereszlényi, Ádám Egri, Markus Guttmann, Marc Schneider, Uli Lemmer, György Kriska, and Guillaume Gomard. 2020. "Bioreplicated Coatings for Photovoltaic Solar Panels Nearly Eliminate Light Pollution That Harms Polarotactic Insects." PLoS ONE 15(12 December):1–22. doi: 10.1371/journal.pone.0243296.

[60] Criteri e modalità per incentivare la produzione di energia elettrica mediante conversione fotovoltaica della fonte solare, in attuazione dell'articolo 7 del decreto legislativo 29 dicembre 2003, n. 387.
https://www.gazzettaufficiale.it/eli/id/2007/02/23/07A01710/sg

[61] Incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare.
https://www.mase.gov.it/sites/default/files/dim_06_08_2010.pdf

[62] Decreto Legislativo 05/07/2012 - Attuazione dell'art. 25 del decreto legislativo 3 marzo 2011, n. 28, recante incentivazione della produzione di energia elettrica da impianti solari fotovoltaici
https://www.gazzettaufficiale.it/eli/id/2012/07/10/12A07629/sg

[63] R. McKenna, I. Mulalic, I. Soutar, J.M. Weinand, J. Price, S. Petrović, K. Mainzer, Exploring trade-offs between landscape impact, land use and resource quality for onshore variable renewable energy: an application to Great Britain, Energy, Volume 250, 2022, 123754, ISSN 0360-5442,
https://doi.org/10.1016/j.energy.2022.123754.
(https://www.sciencedirect.com/science/article/pii/S0360544222006570)

[64] Linee guida in materia di impianti agrivoltaici - MITE;
https://www.mase.gov.it/sites/default/files/archivio/allegati/PNRR/linee_guida_impianti_agrivoltaici.pdf

[65] "Le isole minori tra sole, mare e vento" - Libro bianco Isole Minori - ANCIM.
https://www.enea.it/it/seguici/pubblicazioni/pdf-volumi/2019/libro_bianco_isole_minori.pdf

[66] Presidential Decree of the 10th October 2017 -
https://www.gse.it/normativa_site/GSE%20Documenti%20normativa/SICILIA_DPR__10_10_2017.pdf

[67] D.P.R. Decreto Legislativo 22 Gennaio 2004 n.42: Codice dei Beni Culturali e del Paesaggio. 2004. Available online: https: //www.bosettiegatti.eu/info/norme/statali/2004_0042.htm

[68] Presidential Decree 18/07/2012, n.48
https://www.gse.it/normativa_site/GSE%20Documenti%20normativa/SICILIA_Decreto_Presidenziale_n48__18_07_2012.pdf

[69] Moscoloni, C.; Zarra, F.; Novo, R.; Giglio, E.; Vargiu, A.; Mutani, G.; Bracco, G.; Mattiazzo, G. Wind Turbines and Rooftop Photovoltaic Technical Potential Assessment: Application to Sicilian Minor Islands. Energies 2022, 15, 5548.
https://doi.org/10.3390/en15155548

[70] PAERS 2030 -
http://pti.regione.sicilia.it/portal/page/portal/PIR_PORTALE/PIR_LaStrutturaRegionale/PIR_AssEnergia/PIR_DipEnergia/PIR_Areetematiche/PIR_Altricontenuti/PIR_PianoEnergeticoAmbientaledellaRegioneSicilianaPEARS/Preliminare%20PEARS_rev_5_6_19%20(1).pdf

[71] Regional regulation of 30 December 2010, n. 24 http://cartografia.sit.puglia.it/doc/Aree_non_idonee_def.pdf

[72] PPTR - Portale pianificazione regione Puglia
http://www.sit.puglia.it/portal/portale_pianificazione_regionale/Piano+Paesaggistico+Territoriale/Documenti/PPTRAdottato/Portlet+Visualizza+PPTRWindow?idCat=28&azionelink=dettaglio&action=2

[73] Decreto Ministeriale 2 aprile 1968, n. 1444
- https://www.bosettiegatti.eu/info/norme/statali/1968_1444.htm

[74] Linee guida e di indirizzo regionali di individuazione delle AREE NON IDONEE per la realizzazione di impianti alimentati da fonti energetiche rinnovabili (FER) -
https://www.regione.lazio.it/sites/default/files/documentazione/AMB_DGR_390_07_06_2022_Allegato_1.pdf

[75] PTPR - Regione Lazio - https://www.regione.lazio.it/enti/urbanistica/ptpr

[76] Deliberazione del Consiglio Regionale n.5 del 21/04/2021 - Regione Lazio -
https://www.regione.lazio.it/sites/default/files/ptpr-dc5-2021/01_delibera_atti/BURL_n_56_del_10-06-2021_-_Supplemento_n_2.pdf

[77] Legge Regionale 21 Marzo 2011 -
http://raccoltanormativa.consiglio.regione.toscana.it/articolo?urndoc=urn:nir:regione.toscana:legge:2011-03-21;11

[78] PAER - Regione Toscana - Allegato 1 - aree non idonee agli impianti eolici.
https://www.regione.toscana.it/documents/10180/11279974/A.3_Allegato_1_Aree+non+idonee+agli+Impianti+Eolici.pdf/bfb23747-e00e-493a-b84a-b7328b969c50

[79] Wang, Y.; Tao, S.; Chen, X.; Huang, F.; Xu, X.; Liu, X.; Liu, Y.; Liu, L. Method multi-criteria decision-making method for site selection analysis and evaluation of urban integrated energy stations based on geographic information system. Renew. Energy 2022, 194, 273–292.

[80] Malczewski, J. GIS-based multicriteria decision analysis: A survey of the literature. Int. J. Geogr. Inf. Sci. 2006, 20, 703–726.

[81] Zarra Fernando, Master's Degree "Scalable methodology for wind and photovoltaic energy technical potential assessment: Application to Sicilian minor Islands" (2022). Politecnico di Torino.

[82] Jäger, T.; McKenna, R.; Fichtner, W. The feasible onshore wind energy potential in Baden-Württemberg: A bottom-up methodology considering socio-economic constraints. Renew. Energy 2016, 96, 662–675

[83] Osorio-Aravena, Juan & Frolova, Marina & Terrados, Julio & Muñoz-Cerón, Emilio. (2020). Spatial Energy Planning: A Review. Energies. 13. 10.3390/en13205379.

[84] John van Zalk, Paul Behrens, The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S.,
Energy Policy, Volume 123, 2018, Pages 83-91, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2018.08.023.
(https://www.sciencedirect.com/science/article/pii/S0301421518305512)

[85] Ramesh Janipella, Vikash Gupta, Rucha V. Moharir, Chapter 8 - Application of Geographic Information System in Energy Utilization, Editor(s): Sunil Kumar, Rakesh Kumar, Ashok Pandey,
Current Developments in Biotechnology and Bioengineering, Elsevier, 2019, Pages 143-161,
ISBN 9780444640833,
https://doi.org/10.1016/B978-0-444-64083-3.00008-7.

[86] Chang, K. Geographic Information System; Wiley: Hoboken, NJ, USA, 2019; pp. 1–10.

[87] Sito ufficiale di QGIS - https://www.qgis.org/it/site/about/index.htmL

[88] Difference Between Raster and Vector Data - https://pediaa.com/what-is-the-difference-between-raster-and-vector-data/

[89] DTU - WAsP Software; https://www.WAsP.dk/

[90] Kalliopi F. Sotiropoulou, Athanasios P. Vavatsikos, Onshore wind farms GIS-Assisted suitability analysis using PROMETHEE II, Energy Policy, Volume 158, 2021,112531, ISSN 0301-4215,
https://doi.org/10.1016/j.enpol.2021.112531.
(https://www.sciencedirect.com/science/article/pii/S0301421521004018)

[91] Digital elevation model and digital surface model - Qiming Zhou - Hong Kong Baptist University, China.
https://www.researchgate.net/profile/Qiming-Zhou-

2/publication/315383809_Digital_Elevation_Model_and_Digital_Surface_Model/links/59ed4c8d0f7e9bfdeb71af54/Digital-Elevation-Model-and-Digital-Surface-Model.pdf

[92] Jorge Morales Pedraza, Chapter 4 - Current Status and Perspective in the Use of Coal for Electricity Generation in the North America Region, Editor(s): Jorge Morales Pedraza,
Conventional Energy in North America, Elsevier, 2019, Pages 211-257, ISBN 9780128148891,
https://doi.org/10.1016/B978-0-12-814889-1.00004-8.
(https://www.sciencedirect.com/science/article/pii/B9780128148891000048)

[93] Dimitrios Mentis, Sebastian Hermann, Mark Howells, Manuel Welsch, Shahid Hussain Siyal,
Assessing the technical wind energy potential in Africa a GIS-based approach, Renewable Energy,
Volume 83, 2015, Pages 110-125, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2015.03.072.
(https://www.sciencedirect.com/science/article/pii/S0960148115002633)

[94] Wind energy in Europe: 2021 Statistics and the outlook for 2022-2026. https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026/

[95] Global Wind Atlas - Department of Wind Energy at the Technical University of Denmark and World Bank Group.
https://globalwindatlas.info/en/

[96] Ryse Energy. E-20 HAWT Datasheet. Available online: https://www.ryse.energy/wp-content/uploads/2020/07/Ryse-Energy-Data-Sheet-E-20.pdf

[97] Società Elettrica Italiana srl. SEI-NV 200/29 HAWT Datasheet. Available online:
http://www.societaelettricaitaliana.it/documents/MINIEOLICO_SEI-NW_200KW.pdf

[98] Vestas. V100-2.0 MW Gridstreamer Datasheet. Available online:
https://nozebra.ipapercms.dk/Vestas/Communication/2mw-platform-brochure/?page=1

[99] Chunqiu Wan, Jun Wang, Geng Yang, Huajie Gu, Xing Zhang, Wind farm micro-siting by Gaussian particle swarm optimization with local search strategy, Renewable Energy, Volume 48,
2012, Pages 276-286, ISSN 0960-1481,
https://doi.org/10.1016/j.renene.2012.04.052.
(https://www.sciencedirect.com/science/article/pii/S0960148112003096)

[100] H. Polatidis, "Micro-siting/positioning of wind turbines: introducing a multi-criteria decision analysis framework," 2014.

[101] F. Lindberg et al., "Urban Multi-scale Environmental Predictor (UMEP) Manual," 2019. [Online]. Available: https://umep-docs.readthedocs.io/.

[102] Ratti and Richens 1999. Shadow casting algorithm.

[103] DEM, DSM & DTM: DIGITAL ELEVATION MODEL – WHY IT'S IMPORTANT.
https://geodetics.com/dem-dsm-dtm-digital-elevation-models/

[104] Elementi di Cartografia - https://e-l.unifi.it/pluginfile.php/271788/mod_resource/content/1/01_Presentazione_Cartografia_GIS.pdf#:~:text=La%20carta%20tecnica%20regionale%20(abbreviato,ma%20mostrandone%20l'effettiva%20proiezione.

[105] Uso, copertura e consumo di suolo
https://www.isprambiente.gov.it/it/banche-dati/banche-dati-folder/suolo-e-territorio/uso-del-suolo

[106] ECMWF - https://www.ecmwf.int/

[107] How to install and use CDS API -
https://confluence.ecmwf.int/display/CKB/How+to+install+and+use+CDS+API+on+Windows

[108] UTC Offset https://en.wikipedia.org/wiki/UTC_offset

[109] D.T. Reindl, W.A. Beckman, J.A. Duffie, Diffuse fraction correlations, Solar Energy, Volume 45, Issue 1, 1990, Pages 1-7, ISSN 0038-092X,
https://doi.org/10.1016/0038-092X(90)90060-P.
(https://www.sciencedirect.com/science/article/pii/0038092X9090060P)

[110] Yang, Y.; Campana, P.E.; Stridh, B.; Yan, J. Potential analysis of roof-mounted solar photovoltaics in Sweden. Appl. Energy 2020,
279, 115786

[111] Luca Bergamasco, Pietro Asinari, Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: Application to Piedmont Region Italy), Solar Energy, Volume 85, Issue 5, 2011, Pages 1041-1055, ISSN 0038-092X,
https://doi.org/10.1016/j.solener.2011.02.022.
(https://www.sciencedirect.com/science/article/pii/S0038092X11000752)

[112] Martinez-Gracia, A.; Arauzo, I.; Uche, J. Solar Energy Availability; Elsevier: Amsterdam, The Netherlands, 2019; pp. 113–149.

[113] Rosa-Clot, M.; Tina, G.M. Photovoltaic Electricity; Elsevier: Amsterdam, The Netherlands, 2018; pp. 13–32.

[114] PVGIS online website - https://joint-research-centre.ec.europa.eu/pvgis-online-tool_en

[115] JinkoSolar. Cheetah HC 60M Datasheet. Available online: https://www.jinkosolar.com/uploads/Cheetah%20JKM325-345M-60H-(V)-A4-EN-F30.pdf

[116] Deline, C.; Sekulic, B.; Stein, J.; Barkaszi, S.; Yang, J.; Kahn, S. Evaluation of Maxim module-Integrated electronics at the DOE. Regional Test Centers. In Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), Denver, CO, USA, 8–13
June 2014; pp. 0986–0991.

[117] Cossu, S.; Baccoli, R.; Ghiani, E. Utility Scale Ground Mounted Photovoltaic Plants with Gable Structure and Inverter Oversizing for Land-Use Optimization. Energies 2021, 14, 3084. https://doi.org/10.3390/en14113084

[118] F. Spertino, “Assessment of Energy Production from a Photovoltaic System,” 2020.

[119] Photovoltaic Energy Factsheet -
https://css.umich.edu/publications/factsheets/energy/photovoltaic-energy-factsheet#:~:text=PV%20conversion%20efficiency%20is%20the,that%20is%20converted%20to%20electricity.&text=Though%20most%20commercial%20panels%20have,cells%20with%20efficiencies%20approaching%2050%25.

[120] Pavan, A.M.; Mellit, A.; Pieri, D.D. The effect of soiling on energy production for large-scale photovoltaic plants. Solar Energy
2011, 85, 1128–1136.

[121] Alamoud, A. Performance Evaluation of Various Flat Plate Photovoltaic Modules in Hot and Arid Environment. J. King Saud Univ. Eng. Sci. 2000, 12, 235–242.

[122] Ekici, S.; Kopru, M.A. Investigation of PV System Cable Losses. Int. J. Renew. Energy Res. 2017, 7, 807–815.

[123] Varga, N.; Mayer, M.J. Model-based analysis of shading losses in ground-mounted photovoltaic power plants. Solar Energy 2021,
216, 428–438.

[124] Huawei. SUN2000-2/3/3.68/4/4.6/5/6KTL-L1 Datasheet. Available online: https://solar.huawei.com/en-GB/download?p=%2F-%2Fmedia%2FSolar%2Fattachment%2Fpdf%2Feu%2Fdatasheet%2FSUN2000-2-6KTL-L1.pdf

[125] Bisol Lumina - https://dl.bisol.com/files/Lumina%20Brochure/BISOL_Lumina_brochure_EN.pdf

[126] Jennifer A. Dunne, Stacy C. Jackson, John Harte, Greenhouse Effect, Editor(s): Simon A Levin, Encyclopedia of Biodiversity (Second Edition), Academic Press, 2013, Pages 18-32, ISBN 9780123847201,
https://doi.org/10.1016/B978-0-12-384719-5.00068-X.
(https://www.sciencedirect.com/science/article/pii/B978012384719500068X)