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Renewable Energy Communities on the Island of Ischia

A feasibility study of island energy self-sufficiency and local energy sharing.

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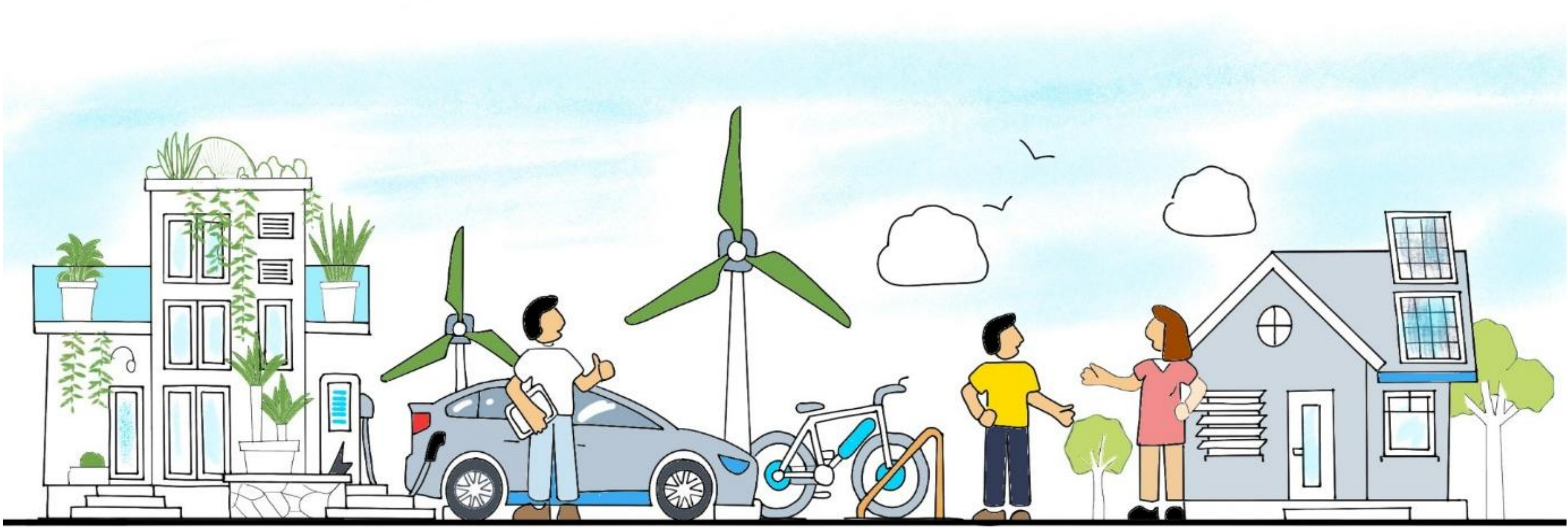
Renewable Energy Communities



on the Island of Ischia

ABSTRACT

This thesis assesses the feasibility of developing a Renewable Energy Community (REC) on the island of Ischia by assessing the balance between solar photovoltaic (PV) generation and electricity demand in the island, through the prism solely of resident and tourist demand. Being an extremely seasonal tourist island, the island experiences significant changes in population and consumption of energy. To represent these dynamics with accuracy, the analysis develops load profiles on hourly basis which are calibrated by matching residential use with monthly tourist presences, which are then translated to equivalent electrical demand. This approach harnesses the seasonal peaks that critically influences self -consumption, self-sufficiency and possible effectiveness of energy sharing.

Geospatial building-scale photovoltaic model is coupled with hourly demand patterns (constituted and extended to include the presence of tourist and room occupancy as well as accommodation energy use multipliers) to establish spatially distributed hourly power balance of the island. Italian time-of-use bands (F1-F2-F3) are used as the standard to determine the possibilities of self-consumption and energy sharing. The review is also enhanced by modelling of energy demand of the proposed open-air light rail / electric bus line over the coastline between Ischia Ponte and Lacco Ameno that aims at reducing congestion, emissions and reliance on private vehicles. An hourly electric vehicle transport load profile is built using fleet specifications, bus timetables, ticketing records and operational trends implemented in overall energy demand of the island.

Through comparison of the local renewable generation and combined residential, tourist and mobility loads, the study measures indicators of self-sufficiency, self-consumption and hourly grid imports or exports. The case of renewable energy community feasibility is analysed by clustering buildings into sharing zones consistent with primary substation boundaries and experimenting situations with and without the presence of tourist peaks and mobility electrification. This combined solution determines which rooftops and areas can achieve self-sufficiency throughout the year, where energy sharing is most beneficial and when storage or flexibility measures are required to compensate for seasonal demand spikes.

The findings give an empirical, data-driven framework to design a Renewable Energy Community (REC) in tourist dependent island. They provide implementing advice to local authorities about two main priorities related to deployment of photovoltaic, the zoning of the areas of REC and the planning of sustainable public transport as well as assurance that Ischia may move towards a cleaner and more resilient domestic and locally powered energy supply delivering services to residents and tourists.

Keywords: Renewable Energy Community; Ischia; tourist energy consumption; electric mobility; open air light rail service; island energy system; self-sufficiency; rooftop photovoltaic; hourly load profile; geospatial modelling; local energy sharing; seasonal demand

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With gratitude in my heart, I dedicate this achievement to all of you.

LIST OF ABBREVIATIONS

EU — European Union

REC — Renewable Energy Community (IT: Comunità Energetica Rinnovabile, CER)

CER — Comunità Energetica Rinnovabile (IT term for REC)

CEC — Citizen Energy Community

RED II — Recast Renewable Energy Directive, Directive (EU) 2018/2001

RED III — Renewable Energy Directive, Directive (EU) 2023/2413 (updated targets/provisions)

IEMD — Internal Electricity Market Directive, Directive (EU) 2019/944

D.Lgs. — Decreto Legislativo (Legislative Decree, e.g., D. Lgs. 199/2021)

ARERA — Autorità di Regolazione per Energia Reti e Ambiente (Italian energy regulator)

TIAD — Testo Integrato Autoconsumo Diffuso (integrated rules for energy sharing/self-consumption)

DM — Decreto Ministeriale (Ministerial Decree, e.g., DM 7/12/2023 n. 414)

GSE — Gestore dei Servizi Energetici (Italian energy services operator)

PNRR — Piano Nazionale di Ripresa e Resilienza (National Recovery and Resilience Plan)

DSO — Distribution System Operator

POD — Punto di Prelievo (electricity supply point/meter point)

GDPR — General Data Protection Regulation

O&M — Operations and Maintenance

EPC — Engineering, Procurement and Construction

CAPEX — Capital Expenditure

OPEX — Operating Expenditure

RES — Renewable Energy Sources

PV — Photovoltaic

CACER — Configurazioni di Autoconsumo per la Condivisione di Energia Rinnovabile

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Chapter 1: INTRODUCTION

In Europe, there are a growing trend towards the distributed, low-carbon, and participatory energy systems. To achieve a decarbonisation, affordability and resiliency objective, citizens, small and medium sized enterprises, and local authorities increasingly form organisational structures to plan, own, as well as operate energy assets. In this regard, the concept of energy communities has become a tool that mobilises human investment locally, adopts a wider range of citizens as participants, and supports it with the vision of electricity consumption corresponding to locally produced renewable energy (Caramizaru, 2020).

The European Union has reacted through coming up with legal entities through which communities can engage in the energy markets and sharing of locally generated renewable electricity, on the same non-discriminatory terms in proportional amounts. Such regulation regime is supported by the Renewable Energy Directive (RED II)[1] (European Parliament and Council of the European Union, 2018). These principles are nationally operationalised by use of specific laws, which entail the clarification of eligibility requirements, grid integration strategies, metrology, and compensation systems. Legislative Decree 199/2021, in Italy, provides the practical implementation of RED II and introduces Renewable Energy Communities on the national level (Italy, 2021).

At the same time, the decarbonisation of the transport sector has also become a similar acute priority. Sustainable mobility solutions are needed in islands and tourist destinations

[1] Renewable Energy Directive (RED II) is Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, which updates the EU renewable framework and introduces Renewable Energy Communities as a legal concept

where the rate of car dependency and road congestion on narrow coastal roads is high since this diversity is a threat and a life-quality determinant. Local air pollution and greenhouse gas emissions can be improved using electrified public transport[2].

As compared to local renewable electricity generation, these systems raise a strategic question: how can local energy and mobility transitions be co-designed in a consistent way?

This thesis is the point of intersection between these debates. It provides a feasibility study of Renewable Energy Communities[3] (RECs), alongside an equivalent study of the energy demand related to a proposed open air light rail/electric shuttle line along the central coastline. Even though the REC analysis and the electric mobility analysis are modelled, they do so within the identical context of the territory and of the policy, and they therefore collectively provide the more comprehensive view of how the Ischia can be transforming into cleaner and more self-reliant and self-powered systems.

1.1 Renewable Energy Communities vs. Citizen Energy Communities

EU legislation draws the distinction between Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs). There are fundamental principles common to both two mechanisms; these are open participation, control by members and community benefit; however, both vary in technological scope and spatial connectivity. Under RED II, a REC is a separate legal person whose members or shareholders are within a geographical vicinity of the

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[2] like an open-air light rail / electric shuttle 1 planned service that uses small electric vehicles or minibuses and serves the needs of both residents and tourists to reduce local auto traffic, congestion, and emissions

[3] a Renewable Energy Community is a legal entity that admits voluntary participation and local member control with the main goal of offering environmental, economic or social benefits to the community and is the development of renewable energy projects nearby its members

renewable energy projects that it develops. It has its main goal to provide environmental, economic, or social advantages to its members or to localities in which it functions instead of focusing on the financial eventuality (European Parliament & Council, 2018). Citizens, local authorities, small and medium- sized enterprises might be members of a REC.

The Internal Electricity Market Directive[4] (IEMD) as a formally Directive (EU) 2019/944 in the electricity sector envisages common regulations to the internal electricity market and accepts Citizen Energy Communities[5] as valid entities. It thus explains the place of CECs in the market (European Parliament and Council of the European Union, 2019).

The civil-society guidance also expounds on the difference in practice: CECs tend to increase the engagement of citizens in the electricity market in general, whereas RECs tend to particularize a place-based paradigm of renewable energy sharing (REScoop & ClientEarth, 2019).

Within the scope of this thesis, the case of RECs is checking on the implementation of Comunità energetica rinnovabili (CERs) in Italy, under which Comunità energetica rinnovabili (CER) refers to the Renewable Energy Community, a structure established by Italy law to encourage certain incentives and settlement regulations, and CECs refers to a Community of this kind, which is mentioned on a more conceptual scale.

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[4] Internal Electricity Market Directive(IEMD) is a Directive (EU) 2019/944, sets common rules for the internal electricity market and introduces Citizen Energy Communities as recognised actors.

[5] A Citizen Energy Community (CEC) is a legal entity in the electricity industry that will allow open participation in and unelected participation, and possibly generation, supply, aggregation, or other electricity related activities outside of being limited to renewable sources or geographic proximity.

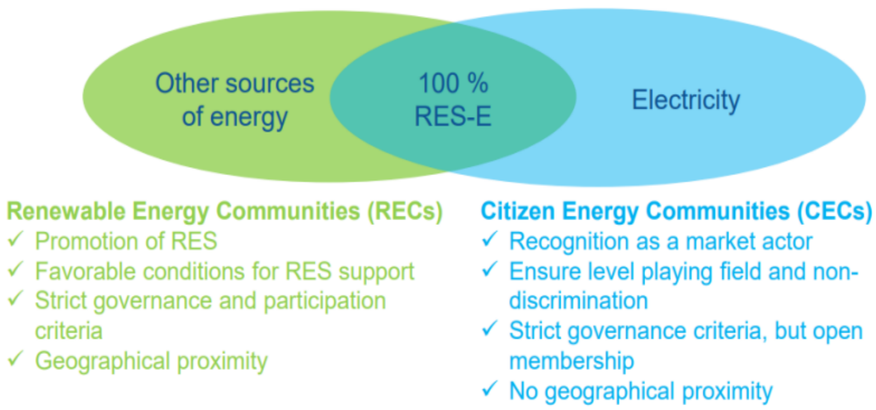

Figure 1: RECs vs CECs

1.2 European Policy Architecture (RED II/RED III, IEMD)

The modern regulatory framework that operates in the sphere of community energy in the European Union is largely supported by three main legislative pillars that are the Renewable Energy Directive (RED) II, the Renewable Energy Directive (RED) III, and the Citizens Energy Initiative of the Market Development (IEMD).

RED II[6] (Directive (EU) 2018/2001) came up with a specific legal definition of Renewable Energy Communities (RECs) and required Member States to come up with enabling frameworks to support activities of communities as generation, consumption, storage, sale and sharing of renewable energy. The directive required such structures to create equitable market access and equal proportional regulation that would organize a favourable environment of community energy operations (European Parliament & Council, 2018). In 2023, the Union updated the renewable energy targets that it has in place by 2030 through the RED III[7]

[6] RED II is Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. It updates the EU renewable energy framework and introduces the legal definition of Renewable Energy Communities.

[7] RED III is Directive (EU) 2023/2413, which amends RED II and related legislation, raises 2030 renewable-energy targets and introduces measures to accelerate permitting and grid integration

(Directive (EU) 2023/2413) and has put in place a body of measures to speed up permitted procedures and grid reintegration. Such amendment, in turn, empowered the space of operation of the citizen-led receptive and local energy-sharing initiatives (European Parliament and Council of the European Union, 2023).

At the same time, the IEMD operationalised Citizens Energy Communities through defining the rights, functions, and relationships among the sister organisations in the communities and the operators of the distribution systems. The clarity of the rules in the provision relates to access to the network, control of distribution grids, and tailor-made unbundling provisions that would be applicable to community-owned distribution operators (European Parliament and Council of the European Union, 2019).

The above orders are then condensed by the expert entities into a set of building blocks that comprise an enabling framework of energy communities. These aspects include non-discriminatory access to grids, fair network tariffs, detailed advisory one-stop shops, regular access to metering and consumption data, and strong consumer protection (REScoop & ClientEarth, 2019). These constituent elements will be necessary in the process of making the transition between the official status of such legal recognition and the actual uses of bank-issued community projects.

1.3 Italy's transposition and regulatory instrument

Italy translated RED II into a piece of legislation, Legislative Decree 199/2021, through which Comunità energetiche rinnovabili (CERs) are formally recognised and the principles of open participation, community control and community benefit are established as the main purpose of its objectives (Italy, 2021). In the decree, the eligibility criteria of the participant, the possible technological options that can be used and the interaction of the national support schemes with the community-based projects are specified.

The energy regulator Autorità di Regolazione per Energia Reti e Ambiente[8] **(ARERA)** translated these principles into operational rules through the Testo Integrato Autoconsumo Diffuso[9] (**TIAD**), approved with Delibera 727/2022 (ARERA, 2022). TIAD defines REC/CER, collective and remote self-consumption configurations and provides the measurement basis for shared energy.

On the incentive part, the national tariff on shared renewable electricity is established by the **Decreto CER**, which is the Ministerial Decree of 7 December 2023 (n. 414), setting the national tariff of shared renewable electricity in REC/CER and further arrangements by determining the conditions of eligibility and access to it. The Gestore dei Servizi Energetici (**GSE**) publishes Regole Operative, which explains how projects are taking part in incentives, what documentation is required, and which procedures they must pass through (Gestore dei Servizi Energetici, 2024).

On the incentive category, **Decreto CER** (Ministerial Decree No. 414 of 7 December of 2023) introduces a national tariff on shared renewable electricity. This decree report exists in a 2023 report to design the tariff framework in REC/CER compliance and defines the conditions of eligibility and access (MASE, 2023). The Gestore dei Servizi Energetici [10](GSE)

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[8] Autorità di Regolazione per Energia Reti e Ambiente (ARERA) Is Italy's independent regulatory authority for energy, networks and the environment, responsible for tariff setting and for issuing regulatory texts that govern self-consumption and energy sharing.

[9] Testo Integrato Autoconsumo Diffuso (TIAD) is ARERA's integrated regulatory text that defines eligible self-consumption and energy-sharing configurations and the rules for calculating and settling shared energy at hourly resolution.

[10] Gestore dei Servizi Energetici (GSE) is the Italian state-owned company that manages incentive schemes for renewable energy and energy efficiency and operates the portals, data flows and procedures through which RECs and other configurations apply for and receive incentives

also issues operating rules; these are the rules which spell out how projects gain access to incentives, the required documents and how verification is undertaken.

Together these legislative and regulatory tools outline the institutional structure on the basis of which the REC projects, including the ones examined on Ischia, should be run.

1.4 Legal and operational notions

The workings of Renewable Energy Communities (RECs), which are legal structures based on open, voluntary membership and local member control, whose purpose is to produce both environmental, economic and social good to the communities in which they reside, and to develop renewable energy projects near their respective members- are organised in Italy around three main notions:

1) The ethics and legal facts of the community.
2) The grid -proximity perimeter of the grid of the primaria cabina[11]
3) The hourly settlement regulation which regulates exchange of shared energy

First, a renewable energy community (REC) should be a separate body of law, e.g., cooperative, association, company, but must be open and voluntary, with effective member control and with having a key purpose supplies community benefits other than profit maximisation. They are the preconditions of RED II and are included in the Italian legislation with the help of a Legislative Decree, 199/2021 (Italy, 2021). Currently, the conditions affect how some community energy resources (CERs) will be designed, governed and packaged to potential members.

[11] Cabina primaria (primary substation) is a high-/medium-voltage node in the distribution grid; in Italy, REC eligibility is limited to plants and consumption points that fall within the same cabina primaria

Second, Italy has a strict spatial delineation that is based on the cabina primaria. To be considered shared, generation facilities and the constituent PODs should have a connexion under a single primary substation. Gestore degli Servizi Energetici (GSE) publishes an interactive map displaying these perimeters and spreads special provisions on small islands and complex network topologies (Gestore dei Servizi Energetici, 2024). This rule makes REC design part of the physical medium voltage grid and forms a significant germane assumption of any spatial modelling of the future communities.

Third, the amount of shared energy[12] is specified under the hourly minimum rule[13], as specified in TIAD, under the title of the quantity of shared energy. Shared energy at each configuration and at each hour is defined as the minimum of

(i) the aggregate of renewable injections of the participating plants and

(ii) the aggregate of withdrawals at the member PODs in the cabina primaria.

This is done by rule, to make sure that only the overlapping part of local production and local consumption is compensated as being shared, and any excess exports and remaining imports are dealt with under ordinary market conditions.

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[12] Shared energy (energia condivisa) is, for each hour, the portion of renewable electricity that is simultaneously produced by REC plants and consumed by member points within the same cabina primaria. Only this overlapping part is recognised as "shared" and eligible for REC incentives.

[13] The shared energy is determined within a specific hour as the minimum of (i) total renewable electricity put into REC plants and (ii) summation of withdrawal at member consumption points that are within the eligible perimeter. This definition makes sure that it is only simultaneous, locally produced and consumed energy, which is recognized.

For this thesis, these three notions—legal form and purpose, cabina primaria perimeter and hourly minimum rule, define the operational boundary conditions within which REC configurations on Ischia are identified, modelled and evaluated.

1.5 Incentives

Italy's REC framework combines operational incentives linked to shared energy and investment support for new plants and community projects. Together, these instruments are designed to lower both the upfront and ongoing cost barriers that communities face, particularly in smaller municipalities and peripheral areas such as islands.

On the operational side, Decreto CER gives rise to a tariff on shared renewable electricity that is paid on every kilowatt -hour of shared energy according to TIAD regulations (MASE, 2023). Precisely, the incentive is not based on overall production, but rather on that percentage of PV generation that is consumed concurrently within the REC perimeter, hour by hour and pegged on the hourly minimum rule. This design is motivated to promote communities to strive towards configurations and load-management practises that promote the maximising of local self-consumption and minimising exports.

The tariff level and duration determined by the Decreto CER[14] is normally based on a finite term starting when the plant enters commissioning and specifies the technologies and scale that are allowed. Broadly that support is restricted to renewable plants either newly built or substantially rebuilt, and with a capacity which is not exceeded by a specified amount per unit. These requirements are meant to encourage suitably scaled PV projects and rationalise

[14] Decreto CER is the Ministerial Decree 7 December 2023, n. 414, which establishes the national tariff for shared renewable energy in REC/CER and related configurations and sets eligibility and access conditions.

against overreliance on massively large installations that may no longer follow the community-scale ethos of RECs. The GSE determines the incentive retrospectively based on the injections and withdrawals as measured and pays them directly to the community or configuration (Gestore dei Servizi Energetici, 2024).

The tariff of operation exists alongside economic value of self-consumption: electricity produced and used in a renewable energy community (REC) system eliminates retail purchases and related network fees, but any unused electricity remains compensated by the existing market forces. The reference rules of how to measure, settle, and differentiate these flows are codified in the Testo Integrato Autoconsumo Diffuso (TIAD) as the rules of such flows vis-a-vis those of shared energy (ARERA, 2022). As a result, the project developers and community stakeholders have their own business case, comprised of

(i) savings made in self-consumption,

(ii) revenue made in the shared-energy tariff

(iii) any remuneration left over in export.

Renewable energy sources, new construction or repowering, commissioning after mid-December 2021, and capacity ≤ 1 MW per plant are usually required for eligibility; plants with capacity greater than 1 MW may be able to obtain valorisation of self-consumed energy without the tariff. (MASE, 2023)

On the investment side, Piano Nazionale di Ripresa e Resilienza [15](PNRR) provides capital grants, which can potentially compensate part of the initial cost of renewable energy certificate (REC) projects, especially with consideration of smaller municipalities and

[15] PNRR(Italy's National Recovery and Resilience Plan) is the national plan under the EU Recovery Fund, which allocates financial resources, including capital grants, to support renewable energy and Renewable Energy Communities

disadvantaged regions. This type of grant alleviates the need that the entirety of capital be contributed by the community either in monetary form or in incumbency and could be used synergistically with the operational tariff that is the subject of the Decreto CER, should the communities comply with the cumulation of aid rules (Gestore dei Servizi Energetici, 2024). As a matter of fact, PNRR funding is selective and time based, but it depends on application windows and geographical boundaries, whereas the tariff approach is structured to provide a more predictable and long-term compensation scheme to shared energy.

The combination of the operational tariff, PNRR grants and the intrinsic value of self-consumption is a multi-layered incentive scheme. In ideal cases, these tools make community-scale projects using photovoltaic a potentially economical investment in a setting that would otherwise have longer payback intervals, such as with islands where grid tariffs are high, or where there is a lack of access to capital. However, they come with some level of complexity since societies must deal with the eligibility requirements, application processes and changing regulatory interpretations. It is not the detailed quantification of financial returns that forms a key objective of this thesis but, instead, the supply of vigorous, settlement-consistent estimates of shared energy and self-consumption which is the energetic basis through which any financial measure is conducted, in the present system of Italian incentives.

1.6 Scope and limitations of this study

This thesis comprises two connected but distinct analytical components:

1. a REC-focused energy analysis, centered on rooftop PV and electricity consumption by residents and tourists; and

2. a sustainable mobility analysis of a proposed open-air light rail / electric shuttle system[16].

Both components refer to the same spatial context (the island of Ischia) and policy framework (RED II, Italian CERs and related regulations), but they are modelled separately and do not form a single integrated optimisation.

1.6.1 REC and Building-Scale PV component

The REC component focuses on analysing the potential of rooftop photovoltaic and the electricity demand of buildings on a building scale. It:

(i) measures building-specific technical rooftop potential.

(ii) calculates hourly PV production profiles, based on solar irradiance, orientation and slope.

(iii) builds hourly profile demand model that merges residential demand with tourist demand.

(iv) calculates variables like self-sufficiency, self-consumption, shared energy and net imports/exports of groups of buildings in each cabina primaria.

The analysis is clearly correlated with the rules of TIAD and GSE of identifying shared energy and REC arrangements (ARERA, 2022) (Gestore dei Servizi Energetici, 2024). It excludes the dynamic electricity tariff modelling, power flow, network reinforcement and voltage concerns. Similarly, it has no optimisation effect on the size or functioning of storage; storage and demand-side flexibility are conceptualised as possible solutions to residual

[16] open-air light rail / electric shuttle refers to a proposed coastal public transport system using small electric vehicles or minibuses operating mostly in open air, designed to reduce private car traffic, congestion and emissions while offering a low-emission mobility option for residents and tourists.

mismatches in the hourly energy balance, between local production and demand, as postulated by the existence of hourly balance. The modelling focuses on the residential and tourist electricity demand and roof PV integration on buildings.

Other end applications, including industrial loads of large scale, the public lighting and non-building renewable, are outside the quantitative realm and are only considered qualitatively where they have an implication to the interpretation of the results.

1.6.2 Open-Air Light Rail and EV Consumption Component

The mobility aspect is used to evaluate the electricity demand related to the proposed open-air light rail or electric shuttle service operating along the seacoast of the area between Ischia Ponte and Lacco Ameno. It deals with the current environment of excessive motorisation, constant traffic jams, and safety issues on the coastal road, and the need to provide a more sustainable and appealing mobility service within a tourist island environment.

With the use of route geometry, vehicle specifications, service frequency, operating schedule, stop patterns, and available ticketing or passenger information, the component produces an hourly and annual electricity consumption profile of the planned electric fleet. This profile is an indicative approximation of future transport demand that would arise because of electrifying one major travel way of transport. Notably, this demand is an electric vehicle-based demand that is independent of the REC consumption model; it is not reflected in the residential and tourist load that is utilised to examine self-sufficiency and shared energy.

Instead, it contextualises REC returns by giving hint of the size of electricity that might be required in case Ischia electrifies a large portion of its mass transit vehicles. There are certain limitations with the mobility component. It is based on simplified bus timetables, passenger loads and regularity of operation; it lacks an overall model of transport demand, cost benefit analysis and infrastructure design. Therefore, it serves the purpose of providing an energetic benchmark in this thesis as opposed to investigating the transport project in terms of a comprehensive feasibility study.

This thesis scope, in general, is mainly energetic and spatial: the author aims to describe the interaction of the rooftop photovoltaic generation, residential and tourist demand, and a future EV shuttle system regarding the volumes and time-dependence of the electricity under the legal and operational parameters presented in the Italian framework of the REC. It is not in the scope of economic, social, or network-engineering analysis, but such studies are suggested as future research directions.

1.7 Problem statement

Planners and local actors do not always have spatially and temporally sorted evidence of the impact rooftop PV and legally determined shared energy in the determination of self-sufficiency and grid dependency at hourly time scales regardless of the existence of EU and national frameworks (Caramizaru, 2020). This dilemma is exceptionally high on the islands, whereby importation reliance, seasonal tourism and network limitation overlap.

In the absence of a context-related examination:

(i) PV and storage systems can be committed to an over- or undersized size.

(ii) assets can be found in part external to the corresponding cabina primaria.

(iii) anticipated advantages will be exaggerated in case the hourly minimum regulation is disregarded (ARERA, 2022)

(iv) tourism induced seasonal effects can be represented in an inefficient way.

Meanwhile, such islands like Ischia have major pressures in terms of mobility by the vehicles. Unless steps are taken to switch to a more sustainable form of public transport, possibly even an electric shuttle system, decarbonising the electricity supply will not be sufficient to meet climate and liveability objectives. Nevertheless, there is hardly any calculation of upheaval of the supplementary electricity needs of transport electrification against the numbers of local renewable materials.

The gaps in this thesis are bridged by offering:

i) spatially explicit and in real time (hourly) estimate of the rooftop PV and electricity demand (residents + tourists), in line with the Italian REC guidelines.

ii) an independent calculation of the electricity usage of a proposed open-air light rail / electric shuttle line 15, to align REC outcomes in a wider jump-point of carving decarbonisation upon the Island.

Recent possible modelling research of the Italian minor islands has chiefly focused on long-term transition scenarios and the world take-up of renewable technologies by consisting of integrating multi-carrier energy balances with techno-economic analysis of solar, wind, biomass and waste resources: Including electricity, LPG, petrol and diesel (Peretti, 2019) (Onlus, 2020). Even though such works offer useful information regarding the technical potential of renewables, as well as laying out those steps to very high renewable shares, they typically do not specify REC-specific provisions like the cabina primaria perimeter, or the hourly settlement of shared energy under the Testo integrato autoconsumo diffuso (TIAD) (ARERA, 2022).

Likewise, decarbonisation of transport on islands is also generally investigated by modal-shift and vehicle-technology cases, instead of introducing electric fleets, as an elastic load in REC networks (Agency I. E., 2020). The current thesis fills this gap by utilising the Italian regulatory framework of REC, as well as an hourly spatial explicit energy balance on a tourist island, directly linking building-specific rooftop PV with the proposed electric shuttle straightway amidst the REC-compliant sharing zones. (MASE, 2023) (Autorità di Regolazione per Energia Reti e Ambiente (ARERA), 2022).

1.8 Objectives and research question

1.8.1 REC Component

The REC-oriented element has the following goals:

(i) Measure the photovoltaic potential of the rooftop at the building level and obtain hourly profiles of production on the island of Ischia.

(ii) Develop exemplary hourly demand modeling, i.e. warehouse consumption combined with tourist consumption and seasonality.

(iii) Assess clusters that are compliant with the requirements of REC (per cabina primaria) on the basis of indicators that are consistent with the requirement of TIAD and GSE regulations, i.e. self-sufficiency, self-consumption, joint energy, and net imports/exports.

It is presumed that REC configurations may be adjusted to this or that degree of isolated self-consumption or avoided and utilized at rates transparent to both sides to compare the additional value of establishing RECs. These aims result into the following research questions:

RQ1: Which areas of annual and seasonal self-sufficiency are possible using rooftop PV in accordance with the existing Italian REC regulations in the Ischia Island?

RQ2: How much does the energy sharing of the perimeters under the REC-compliant increase the share of locally supplied demand of the isolated self-consumption?

RQ3: Which perimeters of cabina primaria compress best the relative gains at the formation of RECs and in which way contributes the presence of load shaping and a location of PV?

RQ4: What are the remaining displacements between it and local production and demand, and how have they impacts on storage, demand-side flexibility, or complementary renewables?

1.8.2 EV Mobility Component

The mobility component has one main objective:

- **M-O1**: Estimate the hourly and annual electricity consumption of a proposed open-air light rail / electric shuttle line between Ischia Ponte and Lacco Ameno and compare its magnitude qualitatively with the island's rooftop-PV generation potential.

1.9 Case selection: why the Island of Ischia

The Island of Ischia is a particularly suitable case study for this thesis.

First, Ischia benefits from favorable solar conditions and a diverse building stock, offering substantial potential for rooftop PV deployment.

Second, it is a tourist island with pronounced seasonal fluctuations in population and electricity demand, providing a real-world setting to explore how PV production aligns with both residential and tourist loads.

Third, Ischia is geographically bounded and connected to the mainland through limited infrastructure, making changes in imports and exports salient for planning. Clear cabina primaria perimeters make it straightforward to apply REC eligibility rules spatially (Gestore dei Servizi Energetici, 2024).

Fourth, the island faces serious mobility and congestion issues along its coastal road network, motivating the exploration of an open-air light rail / electric shuttle system.

Finally, Ischia operates within a well-defined Italian REC framework (Italy, 2021) (ARERA, 2022) (MASE, 2023) and the broader EU directives (European Parliament and Council of the European Union, 2019), making it a relevant testbed whose insights can be adapted to other Mediterranean islands.

In addition to the local details, Ischia becomes a part of the group of small Italian islands that policy makers and scholars have continued to believe are natural laboratories of energy transition. This appreciation is based on the fact that the islands have clearly defined physical boundaries, strong dependence on foreign energy, and strong seasonality of tourism (Onlus, 2020). In comparative analysis of Pantelleria and the Egadi archipelago, recurrent impediments, i.e. diesel-dependent generation, high unit energy cost, limited grid redundancy, and recurrent opportunities, i.e. high solar presence, small settlements and a real local co-benefit of applying renewable energy, are apparent in both cases (Peretti, 2019). Because the research places Ischia in the context of the smart islands discussion, the results of this thesis obtain significance not just to the stakeholders direct on the island, but also to other Mediterranean tourist islands that may face similar and comparable tensions among energy security and environmental integrity on one side, and economic dependence upon seasonal tourism, on the other side.

1.10 Structure of thesis

The remainder of this thesis is organized as follows:

- **Chapter 2 – Literature Review**

  Reviews the academic and grey literature on energy communities, self-consumption and self-sufficiency metrics, island and tourist-driven energy systems and sustainable mobility in island contexts.

- **Chapter 3 – Case Study and Data**

  Provides the description of the island of Ischia, its demographic and touristic characteristics, electricity-system features, network layout which is relevant to REC, and mobility, and the datasets which are to be used.

- **Chapter 4 – Methodology**

  Defines the methodological solution of the REC analysis (rooftop PV mapping, hourly production and demand modelling, REC clustering and indicator calculation) and the electric mobility analysis (definition of routes, vehicle energy modelling, calculation of hourly and annual electricity consumption).

- **Chapter 5 – Results**

  Reports the quantitative results of the REC analysis—self-sufficiency, self-consumption, shared-energy patterns and ranking of cabina primaria perimeters—and presents the estimated electricity demand of the open-air light rail / shuttle system.

- **Chapter 6 – Discussion**

  Interprets the findings in terms of REC design, the role of tourist demand, implications for storage and flexibility, and the strategic relationship between local renewable deployment and the electrification of mobility on Ischia.

- **Chapter 7 – Conclusion**

  Summarizes the main contributions, outlines implications for local authorities and stakeholders and suggests directions for future research.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2: LITERATURE

This chapter synthesizes policy, technical and socio-economic literature relevant to Renewable Energy Communities (RECs) in Italy, with an emphasis on how law and grid practice translate into hourly energy sharing, incentive recognition and design choices in mountain versus island contexts.

The chapter first situates RECs within the **Sustainable Development Goals**[17] **(SDGs)** and Italy's broader energy transition. It then surveys decentralized energy options at community scale, including rooftop photovoltaics, storage and other distributed renewables, before turning to the conceptual foundations and legal framing of RECs at the European and Italian levels.

Subsequent sections review:

- REC definitions, history, composition, membership, benefits and limitations.
- eligibility requirements, key steps and relevant laws.
- RED II, the Italian system and European system of regulation, such as the RED II, IEMD, TIAD, Decreto CER and PNRR, form the legislative foundation to the renewable energy certifications and incentive systems.
- Comparative determinants of renewable energy certificates in mountain and island territories assess the impact of the geographic, climatic, and socio-economic factors on the value of certificates and its distribution.

[17] Sustainable Development Goals are the United Nations' 17-goal framework for sustainable development up to 2030, including goals on energy, cities, climate and inequality.

- incentives and settlement logics (especially the GSE operating tariff and TIAD's valuation of energy autoconsumata/condivisa).
- methods for production–consumption analysis with energy sharing; and
- approaches for rooftop PV potential and hourly yield modelling, demand profiling and context datasets.

Finally, the chapter integrates literature on sustainable mobility and electric public transport, including the concept of an open-air light rail / electric shuttle in order to situate the Ischia case within emerging work on coupling local energy communities with transport electrification.

2.1 Sustainable Development Goals

The 2030 Agenda frames renewable energy as a lever for development and climate action. Renewable Energy Communities (RECs) directly contribute to **SDG 7** (affordable, reliable, sustainable energy), **SDG 11** (sustainable cities and communities), and **SDG 13** (climate action), while also supporting **SDG 9** (resilient infrastructure, innovation) and **SDG 10** (reduced inequalities) by enabling citizen participation and local value retention (United Nations, n.d.). RECs embed governance, participation, and distributional choices—features that map naturally to several SDG targets and indicators (e.g., 7.2 on renewable shares; 11.3 on participatory urban planning; 13.2 on climate policies). Using SDGs as a normative compass strengthens policy relevance and provides a common language when results are communicated to municipalities and funders (United Nations, n.d.).

Global progress toward the SDGs has been uneven, underscoring the importance of locally anchored interventions that are resilient to shocks (e.g., price spikes, supply-chain disruptions). RECs—by design—localize assets, diversify participation, and can target vulnerable groups with tailored allocation rules, positioning them as pragmatic vehicles for

SDG delivery rather than merely technical arrangements for kilowatt-hours (United Nations, n.d.).

Figure 2: Sustainable Development Goals (SDGs)

2.2 Italy’s energy system: present baseline and 2030 trajectory

Italy’s energy system can be described as an unstable reliance on outside fossil fuels and, at the same time, a gradually growing role played by renewable sources. Such dual reality influences the policy of the nation and local-level projects like Renewable Energy Communities. On the one hand, Italy has a high level of imported natural gas, oil and coal, thus the country is exposed to the risk of geopolitics and price. Conversely, it has gone a long way in the implementation of hydropower, solar photovoltaics and wind particularly during the past 20 years (International Energy Agency, 2023).

According to the International Energy Agency [18] Italy has a structural change in its electricity mix whereby coal and oil were no longer the main contributors, but natural gas and renewable sources became their new choice. The major backbone of renewable generation remains hydropower; solar photovoltaics, developed after the subsidy programmes of the 2000s (Conto Energia) is now a substantial and increasing proportion; and wind energy plays an important role in a couple of regions, especially the southern of the country and on larger islands. However, when we consider the total final consumption of energy, or the sum of the energy consumed in transport, heating, cooling, industry and services, the percentage of renewable sources consumed is lower than in the case of the electricity industry alone. Transport is mainly supplied with petrol and diesel, and a significant portion of the buildings depend on natural gas, or other fossil-based heating systems. This means that the decarbonisation policy of Italy, should not rely solely on the greening of the electrical supply but also puts it on the electrification of the end uses (like the replacement of combustion-engine vehicles with electric vehicles and gas-fired boilers with heat pumps) as well as the energy efficiency of the entire sectors (International Energy Agency, 2023).

A central reference document is the **Piano Nazionale Integrato Energia e Clima**[19]. The PNIEC sets out Italy's integrated energy and climate strategy up to 2030, including:

- targets for greenhouse gas-emissions reductions relative to 1990 levels,

[18] International Energy Agency is an intergovernmental organisation based in Paris that provides data, analysis and policy recommendations on global energy systems, including regular in-depth reviews of member countries' energy policies

[19] Piano Nazionale Integrato Energia e Clima – PNIEC – is Italy's National Energy and Climate Plan submitted to the European Commission; it outlines strategies and quantitative targets to 2030 for greenhouse-gas reductions, renewable energy, energy efficiency, security of supply and internal energy-market functioning.

- target shares of renewable energy in gross final consumption,
- and energy-efficiency improvements in terms of primary and final energy demand (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

Tabella 11 - Obiettivi di crescita della potenza da fonte rinnovabile al 2030 (MW) [Fonte: RSE, GSE, Terna]

	2021	2022	2025	2030
Idrica*	19.172	19.265	19.410	19.410
Geotermica**	817	817	954	1.000
Eolica	11.290	11.858	15.823	28.140
- di cui off shore	0	0	0	2.100
Bioenergie	4.106	4.050	4.038	3.240
Solare***	22.594	25.064	44.173	79.253
- di cui a concentrazione	0	0	0	80
Totale	**57.979**	**61.055**	**84.398**	**131.043**

**sono esclusi gli impianti di pompaggio puro e misto*

Figure 3:PNIEC 2030: the new renewable capacity

The new National Plan for Energy and Climate report a renewable capacity in operation of 131 GW adding the contribution of wind, photovoltaic, hydroelectric, geothermal and bioenergy. The share of consumption covered by renewable sources is expected to reach 63.4% by 2030, driving the entire FER sector.

The **Ministero dell'Ambiente e della Sicurezza Energetica[20]** in the 2023 PNIEC revision highlights several priority directions:

- a strong acceleration of renewable electricity capacity, especially solar PV and wind,
- reinforcement and extension of transmission and distribution grids (for example, the Tyrrhenian and Adriatic interconnectors) to integrate more variable renewables,

[20] Ministero dell'Ambiente e della Sicurezza Energetica – MASE – is the Italian Ministry responsible for environmental policy, climate policy and energy strategy, including preparation and updating of the PNIEC and the national REC framework

- and the development of flexibility resources, including storage, demand response and digitalization of networks (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

In photovoltaic energy, the PNIEC forecasts a very steep growth in installed capacity by 2030, the large part of which is expected to be in rooftop and other built-in installations. This orientation is the direct way of achieving Renewable Energy Communities (RECs) to organise and promote rooftop PV at the building and neighbourhood levels. In this way, RECs are considered one of the tools according to which the distributed solar power provided by the PNIEC sees an opportunity to be socially integrated and technically orchestrated. The PNIEC also highlights the key role of electricity grid. The high-voltage transmission system is managed by Terna.

Tabella 12 - Obiettivi di crescita al 2030 della quota rinnovabile nel settore elettrico (TWh) [Fonte: RSE, GSE, Terna]

	2021	2022	2025	2030
Numeratore – Produzione di energia elettrica lorda da FER*	**118,7**	**120,6**	**158,4**	**227,8**
Idrica (effettiva)	45,4	28,4		
Idrica (normalizzata)	48,5	48,1	47,5	46,9
Eolica (effettiva)	20,9	20,5		
Eolica (normalizzata)	20,3	21,0	30,8	64,8
Geotermica	5,9	5,8	7,3	7,5
Bioenergie**	19,0	17,5	15,8	10,9
Solare ***	25,0	28,1	57,0	97,6
Denominatore - Consumo interno lordo di energia elettrica	**329,8**	**325,1**	**334,0**	**359,3**
Quota FER-E (%)	**36,0%**	**37,1%**	**47,4%**	**63,4%**

** Si riporta la produzione elettrica al netto degli impieghi negli elettrolizzatori per la produzione di idrogeno, in coerenza con quanto previsto dai criteri contabili della RED II così come modificata dalla RED III. Considerando anche i consumi degli elettrolizzatori, la produzione lorda da FER attesa al 2030 sarebbe di circa 237 TWh.*
*** Si riporta il contributo di biomasse solide, biogas e bioliquidi che rispettano i requisiti di sostenibilità.*
**** in questa tabella la produzione solare al 2030 non comprende i circa 10 TWh destinati al funzionamento degli elettrolizzatori per la produzione di idrogeno verde.*

Figure 4: Projected growth in renewable electricity under PNIEC, showing target contributions by source (e.g., solar, wind, hydro, geothermal, bioenergy), measured in TWh.

Terna[21] publishes monthly and annual system reports that include:

(i) hourly and daily load curves for the country and macro-regions,

(ii) the breakdown of electricity generation by source (gas, coal, oil, hydro, solar, wind, etc.),

(iii) and data on imports and exports through international interconnectors (Terna S.p.A, 2023).

These are official datasets that are important baseline of localised research. E.g. although Ischia is of relatively small size, given the reasonably well-known shape of its daily demand, such as morning and evening peaks and low loads at night, a qualitative comparison between the shape of the national load curve Terna and Ischia load curve can be used to validate the level of realism in the assumed residential and tourist consumption attitudes. On the same note, national statistics on solar PV generation may be made to confirm the fact that the simulated annual yields of PVGIS based modelling of Ischia lies within the plausible limits of a central southern Italy.

The Italian energy-system context framed by PNIEC and Terna has three main functions:

1. *Contextualization* – It situates the Ischia case within a national trajectory where renewables are expected to supply a much larger share of electricity by 2030, and where distributed PV, storage and demand-side flexibility become key pillars of the system

[21] Terna S.p.A. is Italy's national electricity transmission system operator; it plans, builds and operates the high-voltage grid and publishes official statistics and reports on electricity demand, generation and cross-border flows

(Ministero dell'Ambiente e della Sicurezza Energetica, 2023) (International Energy Agency, 2023).

2. *Benchmarking* – It provides reference indicators and curves (e.g., the typical daily load profile, seasonal variations, national solar capacity factors) that help assess whether the assumptions used to build Ischia's hourly production and consumption profiles are coherent with broader Italian patterns (Terna S.p.A, 2023).
3. *Policy coherence* – It ensures that the proposed REC and EV corridor scenarios are aligned with national policy priorities, such as expanding rooftop PV, modernizing distribution grids and promoting zero-emission public transport and electrified mobility, which are also supported by Italy's Piano Nazionale di Ripresa e Resilienza (Presidenza del Consiglio dei Ministri, 2021).

The **Presidenza del Consiglio dei Ministri** [22] coordinates the Piano Nazionale di Ripresa e Resilienza (PNRR), which complements the PNIEC by providing EU recovery funds for green investments. Within the PNRR, specific measures support:

- the deployment of renewable energy communities and collective self-consumption,
- upgrades to public transport fleets including electric buses,
- and energy-efficiency interventions in buildings (Presidenza del Consiglio dei Ministri, 2021).

These national funding instruments are important for localities such as Ischia, because they can significantly improve the financial viability of projects that combine rooftop PV, RECs and electrified public transport. Even if this thesis does not perform detailed financial

[22] The Presidenza del Consiglio dei Ministri is the Office of the Italian Prime Minister; among other responsibilities, it coordinates the National Recovery and Resilience Plan – PNRR – which includes funding lines for green transition, renewable energy communities and zero-emission public transport

modelling for each measure, it interprets technical results (such as self-sufficiency levels and the share of EV corridor energy covered by local PV) within this national policy and funding landscape, where REC incentives and PNRR grants are available.

Italy's current energy system and 2030 trajectory—documented by the International Energy Agency, structured by the PNIEC of MASE, quantified by Terna and financed in part through the PNRR coordinated by the Presidenza del Consiglio dei Ministri—provide the **macro-level framework** in which the Ischia case study is embedded. The local analysis of building-level rooftop PV potential, residential and tourist electricity demand, and an EV-based open-air light rail corridor is thus not an isolated academic exercise, but a detailed exploration of how one specific island could contribute to and benefit from Italy's broader clean energy transition.

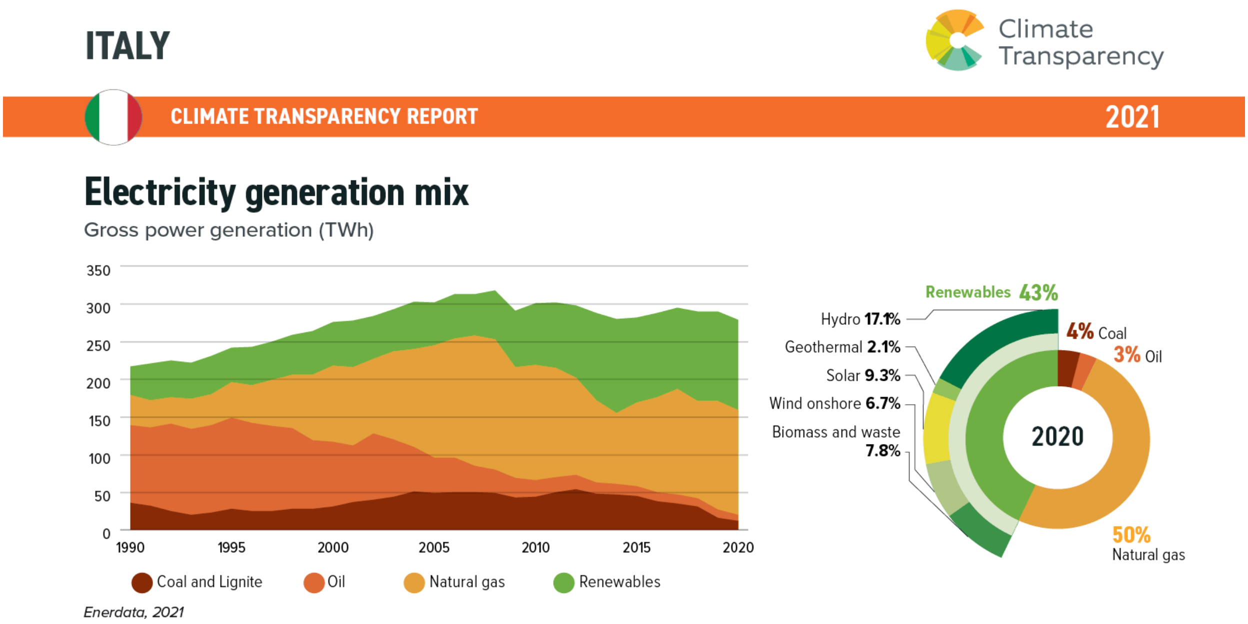


Figure 5:Italy's electricity generation mix (approx. 1990–2020), illustrating the changing shares of coal, oil, natural gas, and renewables.

Figure 5 illustrates the historical decline of fossil fuels, particularly coal and oil, alongside the steady rise of hydroelectric power and the accelerating contributions of solar and wind. The persistence of natural gas as a substantial slice of the generation mixes highlights ongoing dependency risks.

2.3 Decentralized Energy Options for Communities

Decentralized energy systems are characterized by generation, storage and control located close to end-users, in contrast to centralized power plants feeding distant loads through long transmission lines. At the community scale, decentralized options include:

- Rooftop and façade-integrated solar photovoltaic (PV) on residential, commercial and public buildings.
- Small-scale wind and micro-hydropower, where local resources and environmental rules allow.
- Biomass and biogas systems, often linked to agricultural or waste streams.
- Heat pumps, solar thermal and district heating for low-carbon heating and cooling.
- Battery Energy Storage Systems (BESS[1]) ([1]Battery Energy Storage Systems (BESS) are stationary electrochemical storage systems, typically based on lithium-ion batteries, installed at building, community or grid level to shift energy in time and provide flexibility services) and smart controls for demand response.

International assessments highlight rooftop PV as the dominant decentralized technology for urban and peri-urban areas because it is modular, uses existing surfaces and can be rapidly deployed (International Energy Agency, 2024).

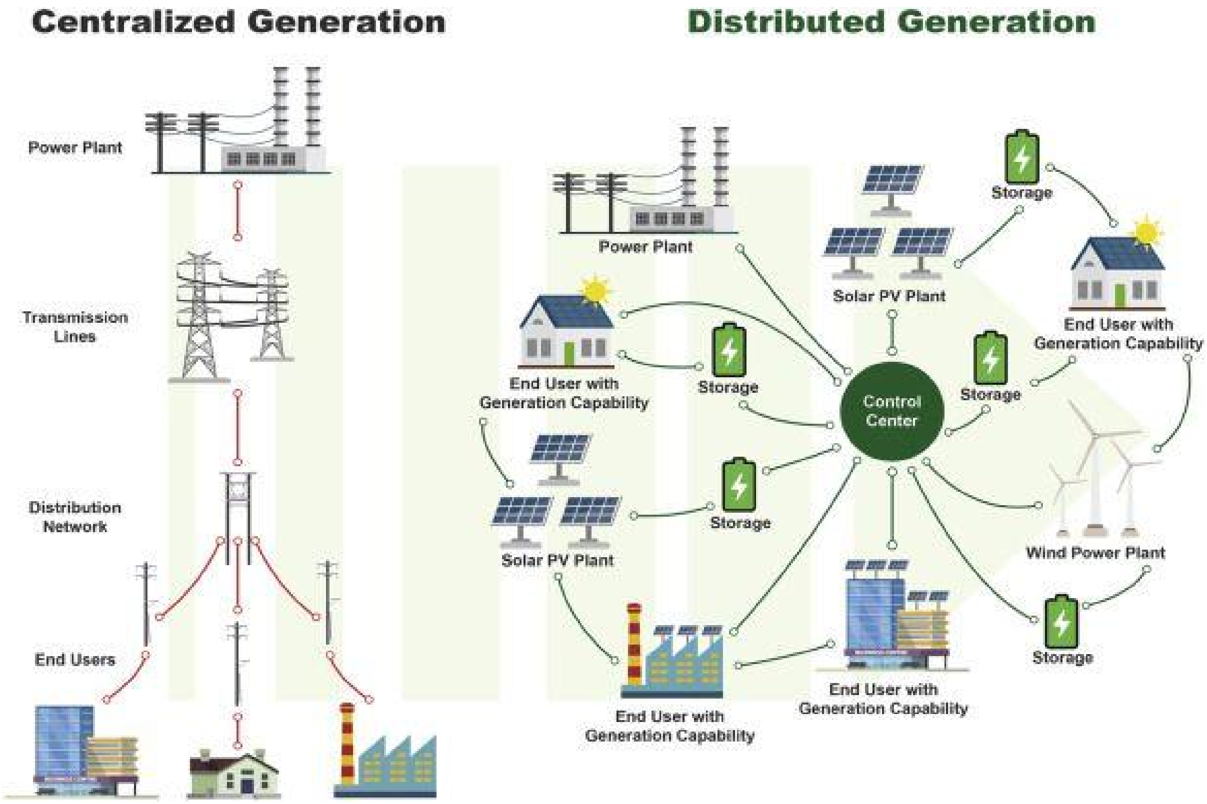


Figure 6: Overview of central and distributed generation systems

In Italy, the updated Piano Nazionale Integrato Energia e Clima (PNIEC) explicitly emphasizes distributed rooftop PV as a key pillar of the energy transition, particularly in built environments and small municipalities (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

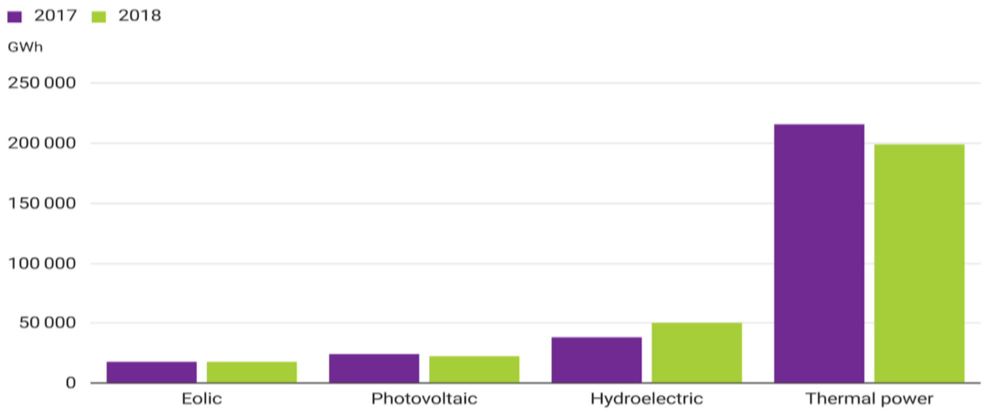


Figure 7: Photovoltaic versus Hydropower and thermal electricity contributions from Terna's "Annual Statistical Report"

Figure 7 illustrates Italy's current electricity generation mix from Terna's annual statistical report. It highlights the growing role of solar PV within the mix, contrasted with the long-standing contributions of hydropower and the still-dominant share of thermal generation. The figure underscores how rooftop and distributed PV installations are progressively reshaping the Italian energy system.

For communities, the main decentralized options can be grouped as follows:

1. Rooftop PV and BESS
    - It can be installed on residential, commercial and public roofs.
    - Produces electricity close to where it is consumed, minimizing network losses.
    - When paired with BESS, it allows time-shifting of surplus midday generation into evening hours, improving self-consumption and REC shared energy.
2. Community-scale PV and canopies
    - Ground-mounted PV fields or carpark canopies can provide larger capacities, but on islands such as Ischia land use, landscape and tourism constraints limit the acceptability of large ground-mounted systems.

- Canopy PV over parking lots and bus depots is particularly attractive when integrated with EV charging and public-transport operations, directly linking RECs to mobility.

3. Small wind and micro-hydro
   - More relevant in certain mountain or rural settings, where resource quality and planning permissions align.
   - On Ischia, topography, visual impact and heritage considerations make large onshore wind contentious; small turbines may be feasible only in limited zones, if at all.
4. Thermal renewables and heat pumps
   - Heat pumps can dramatically reduce fossil-fuel use for space heating and domestic hot water and can be coupled with PV and smart controls to operate preferentially in high-solar hours, thus acting as a form of thermal storage.
   - On islands with mild winters, heat pumps are particularly efficient and could be integrated into future REC expansion scenarios.
5. Electric mobility as a decentralized option
   - Battery electric vehicles (EVs) and electric buses are mobile loads that can be scheduled to charge at times and locations that support local self-consumption and reduce grid peaks.
   - In advanced configurations, Vehicle-to-Grid (V2G) (Vehicle-to-Grid (V2G) refers to technologies and market arrangements that allow parked EVs to discharge electricity back into the grid or local loads, providing flexibility and ancillary services) can turn EVs into distributed storage units, although regulatory and technical frameworks are still emerging in Italy.

For Ischia, the most relevant decentralized options are therefore rooftop PV, BESS and electric mobility, integrated through Renewable Energy Communities that coordinate the timing and location of production and consumption. The proposed EV corridor (Chapter 3) can be seen as a flexible **demand and potential storage asset** interacting with REC-based PV generation.

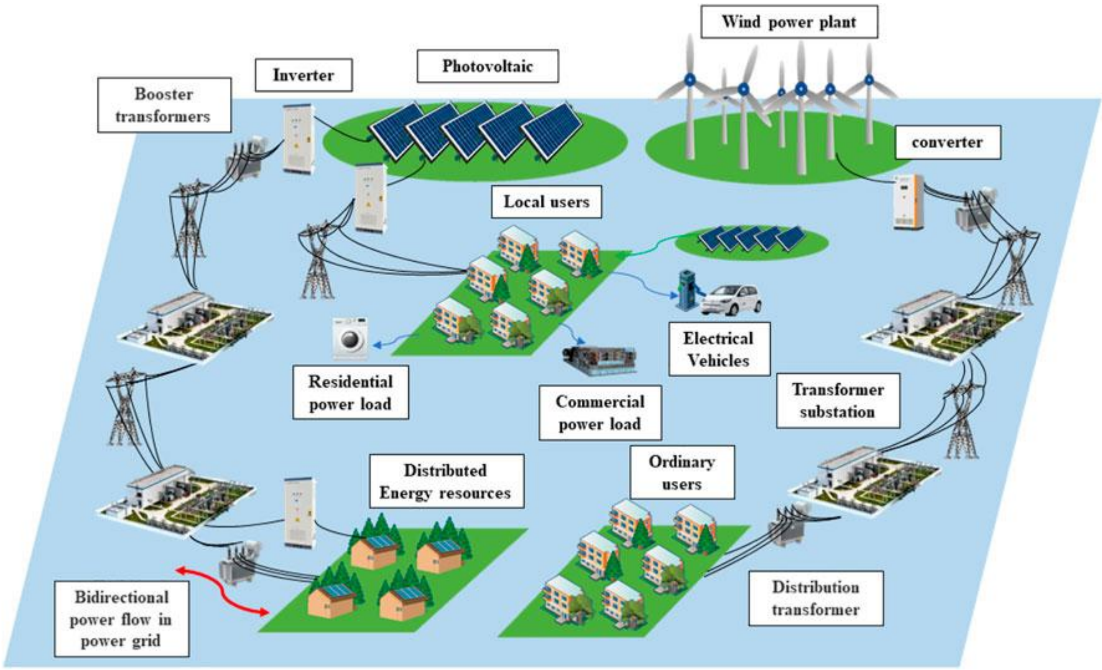


Figure 8:Schematic representation of a community-scale distributed energy system integrating solar PV, wind power, storage, local consumption, and electric vehicle charging infrastructure (adapted from Feng et al., 2022).

2.4 Renewable Energy Communities

Renewable Energy Communities (RECs) sit at the heart of the European Union's strategy to democratize energy systems and accelerate renewable deployment. Under the EU's recast Renewable Energy Directive (RED II), RECs are recognized as distinct actors with specific rights and protections, bridging the gap between citizens, local authorities and the formal electricity market (European Parliament and Council, 2018).

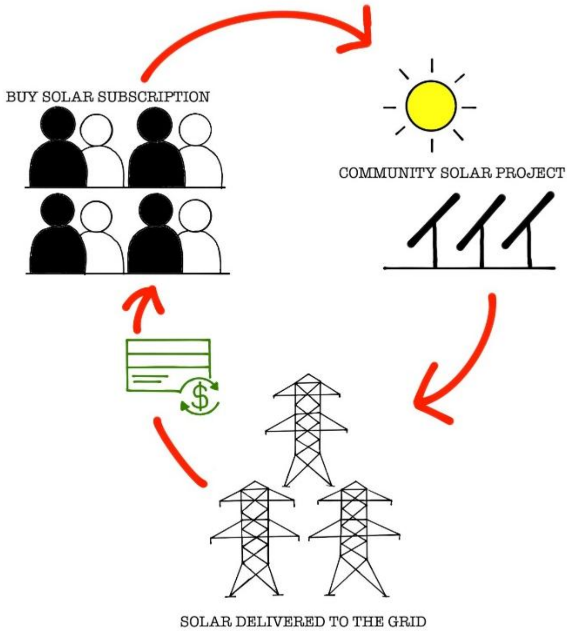
They are deliberately designed to address three deficits in traditional energy systems:

(i) participation – citizens and local entities historically had limited influence over energy infrastructure decisions;

(ii) distribution of benefits – financial and environmental gains often accrued to distant investors; and

(iii) spatial mismatch – renewable potential on buildings and local sites was underused even when communities were willing to invest (Caramizaru, 2020).

In the Italian context, RECs are implemented as Comunità Energetiche Rinnovabili (CER), governed by Legislative Decree 199/2021[23] . The Italian framework translates EU principles into very concrete grid boundaries (primary-substation areas), metering rules and incentive schemes, which this thesis explicitly respects in its modelling.



[23] D.Lgs. 8 novembre 2021, n. 199 – transposition of RED II in Italy – defines CERs, their governance principles and the national enabling framework

Figure 9: Conceptual scheme of a community solar subscription (Author's illustration)

The figure illustrates households pay into a shared PV project, the plant delivers electricity to the grid, and part of the economic value is returned to participants as bill credits or payments. The red arrows show the circular flow of money and energy between members, the shared plant and the grid.

2.4.1 REC Concept

Conceptually, RECs represent a shift from centralized, top-down energy systems to distributed, participatory arrangements where citizens, local authorities and small enterprises co-own and co-govern renewable assets. Under RED II, three core design principles define RECs (European Parliament and Council of the European Union, 2018):

1. *Open and voluntary participation*

   Membership must be open to all eligible local actors (citizens, local authorities, SMEs) without unjustified discrimination. Participation is voluntary, and members may normally leave under fair conditions. This prevents RECs from becoming closed clubs that capture benefits for a narrow group.

2. *Effective local control and proximity*

   RECs must be effectively controlled by members or shareholders that are in proximity of the renewable projects. Proximity is not rigidly defined at EU level, but it is meant to ensure a genuine link between the community and the assets—avoiding purely financial or speculative arrangements detached from place.

3. *Primary purpose: community benefit, not profit*

   Unlike conventional energy companies, RECs must have a primary purpose of delivering environmental, economic or social benefits to their members or local area.

Profits may exist but cannot be the main goal; statutes must reflect this orientation. In practice, this means that surpluses are often reinvested in community projects, used to lower members' bills, or targeted at vulnerable groups.

RECs are thus hybrid institutions: they are at once market actors, participating in electricity markets and grids, and community organizations, embodying social goals and democratic governance. This dual nature aligns closely with the Sustainable Development Goals (SDGs) framework discussed in Section 2.1, in particular SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) (United Nations, 2015)

Figure 10:n

RECs are also distinct from Citizen Energy Communities (CECs). While RECs are renewables-focused and proximity-based, CECs (under the Internal Electricity Market Directive (IEMD) allow broader participation and technologies but may not have the same tight geographic link or renewable-only mission (European Parliament and Council of the European Union, 2019) . Italy chose to focus first on RECs/CERs and autoconsumo configurations as the primary instruments for community energy in electricity.

From a system perspective, RECs contribute to:

- Flexibility – by coordinating distributed PV, storage and demand across many small actors.
- Grid optimization – by increasing local self-consumption and reducing peak imports at certain hours.
- Social innovation – by reshaping how communities collectively manage infrastructure, risk and benefits (Joint Research Centre, 2020)

In island contexts such as Ischia, where space is limited and seasonal tourism dominates, the REC concept is especially powerful: it allows rooftop PV, residential loads, tourist-related loads and EV corridors to be organized in a single coherent framework

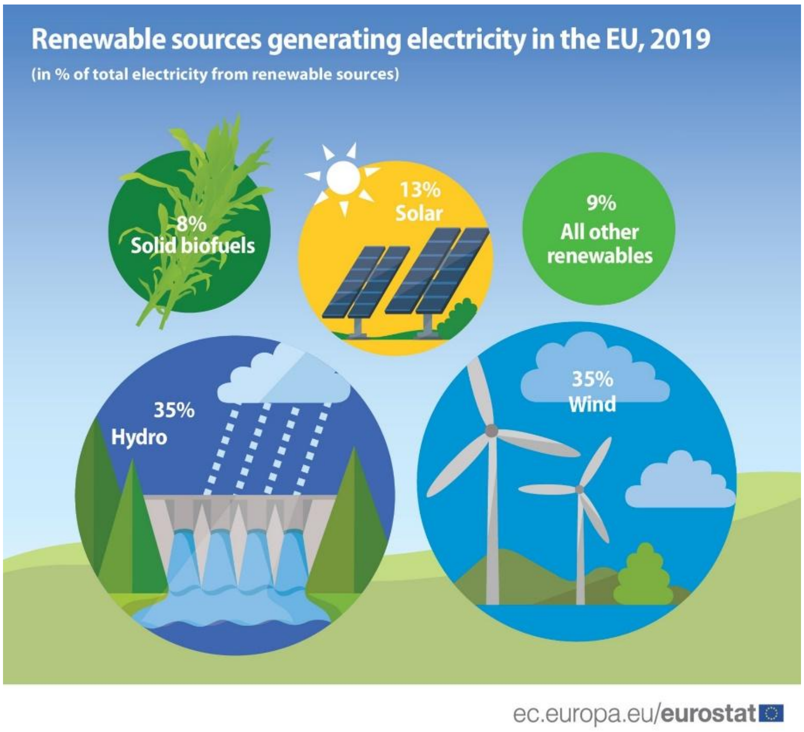


Figure 11: Distribution of electricity generation from renewable sources in the EU, 2019: hydropower 35%, wind 35%, solar 13%, solid biofuels 8%, and other renewables 9% (Eurostat, 2021).

As a **legal concept**, RECs "formed" in the EU on 11 December 2018 (RED II). Member-state roll-outs followed. In Italy, the pathway included ARERA's Resolution 318/2020/R/eel (rules for shared electricity and pilot configurations) and full transposition via Legislative Decree No. 199/2021. Under this transitional phase, Italy's **first REC** was established in Magliano Alpi (Piedmont) in December 2020, often cited as the country's pioneer case. These early steps demonstrated how small-scale PV with local sharing behind the same MV/LV substation could operationalize the EU's community-energy vision.

2.4.2 History of RECs

While the REC label is recent, the underlying practice of community-based energy has deep roots in Europe and Italy. Historical trajectories help explain why RECs were formally recognized and how they might evolve.

Early community energy traditions.

In the early 20th century, many rural areas in Europe were electrified not by national utilities but by local cooperatives and municipal utilities. In Alpine regions of Italy, for instance, small hydropower plants were built and operated by community or municipal entities, offering an early model of collective ownership and governance of energy infrastructure (Caramizaru, 2020). These entities often provided not just electricity but also a sense of local autonomy and identity.

Renewables boom and cooperatives.

From the 1980s onward, the rise of wind power and solar PV under feed-in-tariff regimes led to the proliferation of citizen-owned wind and solar cooperatives, particularly in Denmark and Germany. Here, residents bought shares in projects, reducing opposition and ensuring that economic benefits remained in the community (Roberts, Frieden, & d'Herbemont, 2019). These initiatives were mostly framed as cooperatives rather than as legally distinct "energy communities", but they contributed to the political momentum behind the EU's later recognition of energy communities as a specific category.

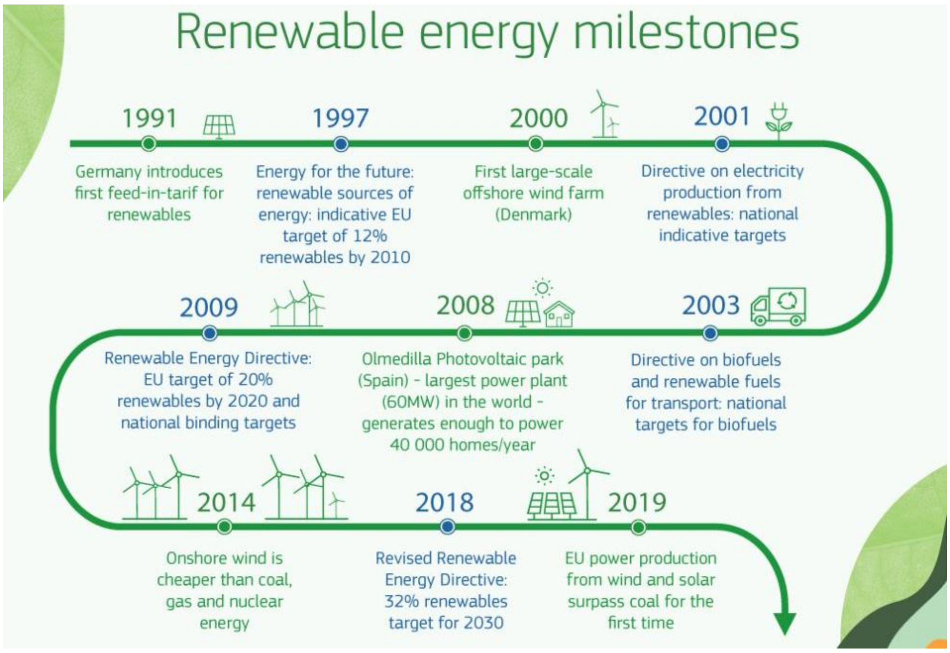


Figure12: Renewable energy progress over time

Italian context and pilot phase.

In Italy, community ownership of energy remained more limited, with utilities and independent power producers dominating. However, the combination of Conto Energia (PV feed-in tariffs) and local initiatives led to scattered examples of municipal PV roofs, school projects and cooperative plants. The real institutional turning point came with the Clean Energy for All Europeans Package[24] and its transposition.

Before full transposition, Italy created a pilot phase through Article 42-bis of Decree-Law 162/2019 (converted into Law 8/2020) and the Decree of 16 September 2020, which allowed early collective self-consumption and RECs within limited boundaries (low-voltage networks downstream of the same secondary substation) and with a transitional incentive (MIMIT/MiSE, 2020)

This pilot enabled the formation of Italy's first REC in Magliano Alpi (Piedmont) and other pioneering projects, which tested:

- How to apply hourly settlement to shared energy.
- How to organize governance and member participation.
- How to communicate benefits to citizens and municipalities.

[24] The Clean Energy for All Europeans Package is a set of eight legislative acts adopted between 2018–2019 that reform EU energy markets and renewables policy, including RED II and the IEMD

Figure13: Italy's first REC- Magliano Apli

These early pilots provided empirical evidence that informed the design of the stable regime under D.Lgs. 199/2021, the Testo Integrato Autoconsumo Diffuso (TIAD) and the Decreto CER/CACER (DM 7/12/2023 n. 414). The progression from cooperatives and pilots to formal REC frameworks reflects a broader trend: community energy has evolved from being exceptional and experimental to being treated as a mainstream policy instrument.

2.4.3 What is REC compromised of?

Under Italian law, RECs (Comunità Energetiche Rinnovabili) are classified within Configurazioni di Autoconsumo per la Condivisione di Energia Rinnovabile (CACER). A typical REC configuration includes:

- One or more renewable generation plants (mostly rooftop PV in urban and island contexts).
- A set of member loads (Points of Delivery – PODs) such as households, municipal buildings, SMEs and public lighting.

- A grid perimeter defined by the primary substation (cabina primaria) downstream of which all plants and PODs must be connected.
- A legal entity with statutes reflecting the REC requirements.
- A Referente who interfaces with the Gestore dei Servizi Energetici (GSE) and coordinates relations with the Distribution System Operator.

The regulator ARERA defines the core measurement rule in the Testo Integrato Autoconsumo Diffuso (TIAD): in each hour *h*, the shared energy of a REC is the minimum of (a) aggregated renewable injections and (b) aggregated withdrawals by member loads, all within the same primary substation (ARERA, 2022).

This hourly minimum rule is the backbone of the production–consumption analysis in this thesis: rooftop PV generation and residential/tourist demand are calculated at hourly resolution, and shared energy is derived using the same logic that GSE applies in real incentive settlement.

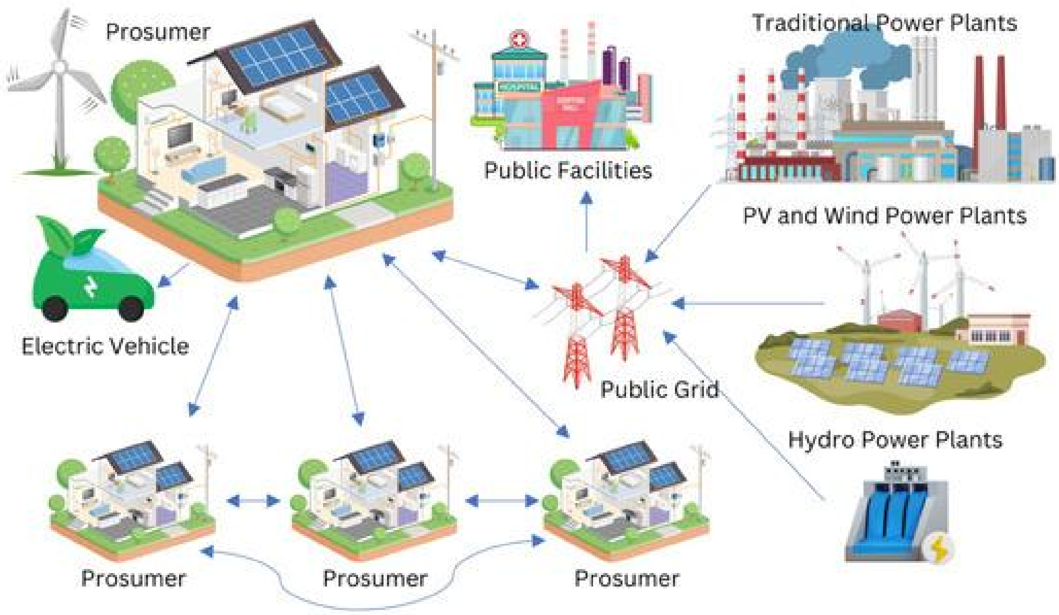


Figure 12: Components in a REC

2.4.4 Members of the REC

The question "who can be a member of a REC?" is crucial, because it defines both who benefits and who participates in decision-making. RED II and D.Lgs. 199/2021 stipulates that membership is open to:

- Natural persons – residents or other individuals in the area.
- Local authorities – municipalities, provinces, other public bodies.
- Small and medium-sized enterprises (SMEs) – local businesses, hotels, shops, artisans.
- Non-profit organizations – associations, cooperatives, social enterprises, religious institutions.

Large energy companies and purely financial investors can participate but must not exercise controlling influence; effective control must remain with local members whose primary purpose is community benefit (Italy, 2021) (European Parliament and Council, 2018).

Within a REC, members may play different roles:

- Anchor members – typically municipalities or public entities, which provide roofs (schools, town halls, sports facilities) and institutional support.
- Residential members – households that seek bill reductions and more control over their energy supply.
- Commercial and hospitality members – hotels, restaurants, shops, which often have significant daytime and evening loads, especially in tourist areas like Ischia.
- Social and vulnerable members – households in energy poverty, social housing, community centers, which may be granted favorable benefit allocation rules to support equity goals.

Governance arrangements must ensure that all categories are fairly represented and that vulnerable consumers are not marginalized. Some RECs use innovative allocation rules, such as:

- Reduced membership fees for low-income households.
- Priority inclusion of public housing and social services.
- Allocation of a percentage of REC revenues to a "solidarity fund" for energy-poor members (Joint Research Centre, 2020).

In island contexts like Ischia, hospitality and tourism actors are structurally important members because they:

- Have substantial summer demand, often aligned with PV generation hours.
- Can co-finance larger PV systems (e.g. hotel roofs, car park canopies).
- Benefit from branding and marketing associated with participation in a "green energy community".

At the same time, REC designers must ensure that permanent residents are not overshadowed by seasonal businesses, especially where the latter may have more financial resources and bargaining power.

RED II requires open, voluntary participation and effective local control (citizens, local authorities, SMEs), orienting governance to community benefit rather than profit. IEMD ensures non-discriminatory market access for community entities while limiting control by large commercial players, aligning inclusive governance with fair participation in markets (European Parliament and Council of the European Union, 2018)

Under TIAD/CACER, Italian RECs typically include households, municipalities, SMEs, third-sector bodies, and other local actors within the same “area convenzionale.” The Referente represents the REC to GSE, handles metering datasets and settlement, and distributes incentives; DSOs/Terna provide metering and grid services; aggregators may enable flexibility revenues. GSE guidance sets out admissible actors/roles and the procedural steps for constituting a REC (ARERA, 2022).

Figure 13:Essential phases for constituting a Renewable Energy Community (CER)—planning, programming, implementation and operational management (authors illustration)

2.4.5 Limitations of a REC

Despite their potential, RECs face a series of limitations and risks that must be acknowledged in design and analysis.

- Regulatory and grid boundaries.

  The requirement that all plants and members lie downstream of the same primary substation can be both a strength (ensuring physical consistency) and a constraint (excluding nearby consumers or producers that happen to fall under a different substation). In complex urban or island grids, this may lead to fragmented REC perimeters or to situations where optimal clusters from a socio-economic standpoint do not coincide with technical eligibility (ARERA, 2022). For Ischia, this implies that REC configurations must follow the actual cabina primaria layout rather than intuitive municipal boundaries.
- Administrative and legal complexity.

  Establishing and running a REC requires legal, accounting, technical and organizational competences that many communities do not have in-house. Small municipalities may lack staff time; citizen groups often need support from external facilitators or consultants. Without adequate guidance, the transaction costs of starting a REC can be significant, especially relative to small project sizes (Caramizaru, 2020).
- Financing barriers.

  Although RECs can access incentive tariffs and PNRR grants, they still need upfront capital. Challenges include:

- Access to credit for new entities without established credit history.
- Complexity of combining multiple funding sources (municipal budgets, grants, bank loans, citizen equity).
- Ensuring that financing structures do not undermine community control (e.g., overreliance on a single external investor).
- Equity and representation risks.
  If not carefully designed, RECs can end up benefitting primarily better-off households who can shoulder upfront costs and navigate administrative processes, while lower-income residents participate less or not at all. This can exacerbate inequalities and undermine political legitimacy (Joint Research Centre, 2020).
  In tourist islands, there is additional risk that large hospitality businesses dominate decision-making at the expense of permanent residents.
- Technical and operational constraints.
  On islands, high penetrations of PV may raise voltage and frequency stability concerns, leading DSOs to:
    - Impose connection limits or curtailment.
    - Require more sophisticated inverters and grid-support functions.
    - Delay or condition interconnections on grid-reinforcement investments (MASE)

This means that technical feasibility and grid-capacity assessments are as important as economic and social analysis for REC planning.

These limitations matter for Ischia, where municipal capacity is finite and social heterogeneity between residents and seasonal tourism workers is significant.

2.4.6 Benefits of REC

Balanced against these limitations, RECs offer substantial benefits documented in both research and practice.

1. Environmental and climate benefits.

   By increasing local renewable generation, RECs:

- Reduce CO_2 emissions relative to fossil-based generation.
- Lower local air pollutants such as NO_x and particulate matter, especially when combined with electric mobility.
- Contribute directly to national renewable targets as counted under PNIEC trajectories (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

In islands with high tourist traffic and limited air circulation, these benefits can be particularly visible.

2. Economic benefits and resilience.

   For members, RECs can:

- Lower electricity bills via self-consumption, shared energy incentives and avoided network charges.
- Reduce exposure to volatile fossil-fuel prices by substituting locally produced renewables for imported fuels.
- Keep a larger share of energy expenditure within the local economy, supporting jobs among installers, maintenance firms and local technical service providers (Caramizaru, 2020).

For municipalities, RECs can become long-term revenue or savings instruments, freeing up resources for other public services.

3. Social and governance benefits.

   RECs foster energy citizenship: members learn about energy flows, tariffs, and technologies, and participate actively in decisions about their local energy system.

This can:

- Increase public acceptance of renewable projects.
- Strengthening community bonds and trust.
- Provide new arenas for participatory governance, especially when municipalities and citizens share ownership and decision-making.

4. Innovation and policy learning.

   Because RECs operate at the frontier of regulation, they often act as laboratories for new solutions: local flexibility markets, peer-to-peer trading, EV integration, demand response. Their experiences feed back into national regulatory reforms and European policy debates (Roberts, Frieden, & d'Herbemont, 2019).

5. Specific benefits for islands like Ischia.

   In the Ischia context, well-designed RECs can:

- Reduce dependence on imported fossil-generated electricity.
- Power electric buses, shuttles and charging infrastructure for tourism, improving the island's environmental image.
- Channel part of the economic benefits into coastal protection, public transport subsidies or social programs, thereby linking energy transitions to broader territorial resilience.

Overall, RECs provide institutional and technical architecture through which rooftop PV, residential and tourist loads, and the proposed EV corridor can be coordinated. For this thesis, they are not just a regulatory box to tick but the central organizing concept that connects building-level PV potential, hourly demand profiles and electric mobility into a coherent, community-oriented energy transition pathway for Ischia.

Figure 14: Benefits of Energy communities

2.5 Types of Renewable energy

Renewable energy comprises technologies that harness continuously replenished natural flows—sunlight, wind, water cycles, biomass growth and geothermal heat—rather than finite fossil fuel stocks. The International Energy Agency broadly groups renewable electricity sources into hydropower, wind, solar, bioenergy and geothermal (International Energy Agency, 2023).

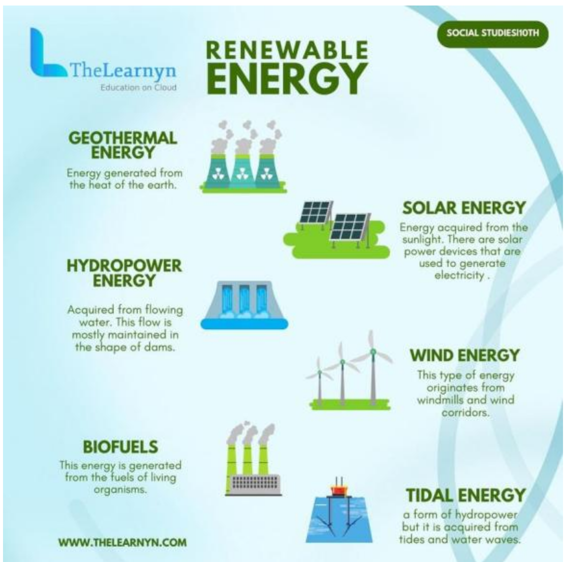


Figure 15:Types of Renewable Energy (Authors illustration)

In Italy, and particularly for the island of Ischia, these technologies differ significantly in terms of technical feasibility, spatial footprint, regulatory context and social acceptance. Hydropower and geothermal are important in the national mix but have limited local potential on a small island. Wind faces landscape and tourism constraints. Bioenergy is constrained by resource availability and air quality concerns. By contrast, rooftop photovoltaic (PV) can be widely deployed in built-up areas and aligns closely with the design of Renewable Energy Communities (RECs). This section briefly characterize each major renewable source and explains why rooftop PV is the focus of this thesis.

2.5.1 Hydropower

Hydropower converts the potential and kinetic energy of water into electricity via turbines and generators. It is one of the oldest and most mature renewable technologies and historically has provided a large share of Italy's electricity, especially through large plants in the Alpine and pre-Alpine regions (Terna S.p.A, 2023). Reservoir and run-of-river plants together form a key part of the Italian power system, supplying low-carbon electricity and providing flexibility.

Hydropower exhibits several system-level advantages:

- It can be dispatched relatively quickly, offering balancing and ancillary services.
- Storage reservoirs can buffer daily and seasonal variability in other renewables.
- Once built, hydropower plants typically have low operating costs and long lifetimes.

However, hydropower also has important limitations:

- Most economically attractive large sites in Italy have already been developed.

- New dams and diversions can cause significant environmental and social impacts, including disruption of river ecosystems and landscape changes.
- Climate change, through altered precipitation and increased drought frequency, may reduce hydropower output and increase planning uncertainty (Terna S.p.A, 2023).

For Ischia, a small volcanic island with no large river systems or suitable elevation differences, hydropower is not a realistic local option. In this thesis, hydropower is relevant only as part of the national context and is not modelled as a potential REC resource for the island.

Figure 16: Hydropower energy

2.5.2 Wind power

Wind power converts the kinetic energy of wind into electricity using turbines. Large onshore and offshore wind farms now play a substantial role in renewable generation in several EU countries. In Italy, onshore wind is concentrated mainly in southern regions and larger islands such as Sardinia and Sicily, where wind resources and planning conditions are favorable (International Energy Agency, 2023).

Wind has notable strengths:

- Production often shows complementarity with solar, with stronger generation in winter or at night in some areas, which helps balance the system.

- Technological improvements and economies of scale have reduced costs, making wind power cost-competitive in good sites.
- Onshore wind can be integrated into rural landscapes when carefully sited and designed.

However, wind development is often constrained by:

- Visual and landscape impacts, which are particularly sensitive in scenic and heritage-rich areas.
- Concerns about noise, shadow flicker and biodiversity, especially for birds and bats.
- Land availability and local opposition, especially in densely populated or touristic regions.

On a compact, highly touristic island such as Ischia, where the landscape and coastal views are central to the local economy, large onshore turbines would likely face substantial planning and social barriers. There is limited open land suitable for turbines, and the risk of conflicts with heritage and tourism objectives is high. As a result, wind power is not considered a core technology in the REC scenarios developed in this thesis. The analysis instead concentrates on technologies more compatible with the built environment, primarily rooftop PV.

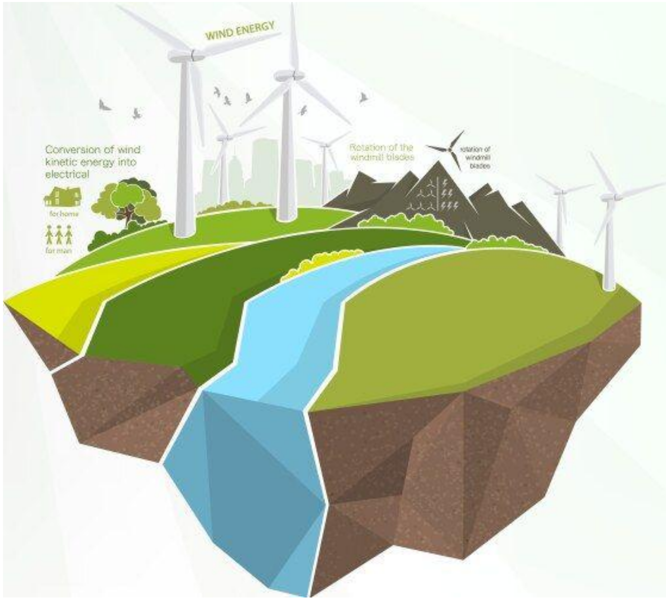


Figure 17: Wind energy

2.5.3 Solar photovoltaic (PV)

Solar photovoltaic (PV) technology converts sunlight directly into electricity using semiconductor materials. It is currently the fastest-growing renewable technology worldwide and has undergone dramatic cost reductions over the past decade (International Energy Agency, 2024).

From the perspective of communities and RECs, PV has distinctive advantages:

- It is highly modular, with system sizes ranging from small residential rooftops to utility-scale plants.
- It can be installed on existing surfaces such as roofs, façades and carpark canopies, minimizing land-use conflicts.
- It generates electricity during daylight hours, which aligns with many building and commercial loads and can be complemented with storage or demand shifting.
- In Mediterranean climates, including Campania and Ischia, solar resources are strong and relatively stable across years.

The European Commission's Joint Research Centre highlights rooftop PV as a key technology for energy communities, especially in urban and peri-urban contexts, because it can be deployed close to consumers, supports citizen participation and fits well with REC governance models (European Commission Joint Research Centre, 2024).

In Italy, PV uptake has been driven by feed-in tariffs, net-metering schemes, tax incentives and, more recently, REC-focused incentives and PNRR support (Ministero dell'Ambiente e della Sicurezza Energetica, 2023). Rooftop PV is particularly suitable for:

- Public buildings (schools, municipal offices, health centers, sports facilities), which can act as anchor sites for RECs.
- Residential buildings, including both single-family houses and multifamily blocks.
- Hotels, guesthouses and restaurants, which are very important on Ischia and often have substantial roof surfaces and strong daytime electricity demand.
- Transport-related infrastructure, such as bus depots and carpark canopies, where PV can be directly coupled with electric vehicle charging.

In this thesis, rooftop PV is therefore the primary renewable technology considered. Detailed modelling is based on:

- Estimating roof area, orientation and slope from geospatial data.
- Using PVGIS and similar tools to generate hourly production profiles for representative planes.
- Aggregating these at building and REC-perimeter level to evaluate self-sufficiency, self-consumption and shared energy.

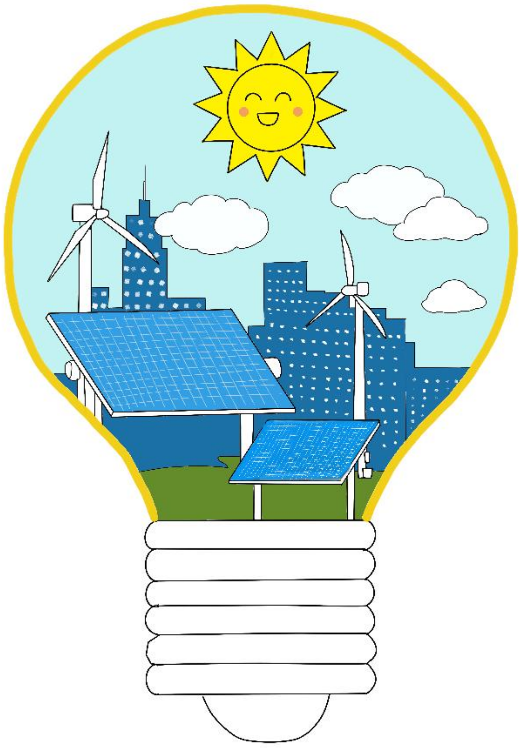


Figure 18: Solar Photovoltaic Energy (Author's illustration)

2.5.4 Bioenergy

Bioenergy relies on organic materials—wood, agricultural residues, biogas, biofuels—to produce electricity and/or heat. In Italy, bioenergy contributes a significant share of renewable energy, particularly through solid biomass heating and biogas plants tied to agricultural and agro-industrial activities (Terna S.p.A, 2023).

Bioenergy can offer several advantages:

- It is storable and dispatchable: fuel can be stored and used when needed, providing firm power and flexibility.
- It can support waste valorization, using residues that might otherwise be landfilled or burned without energy recovery.
- It can contribute to rural development where feedstocks are locally sourced.

At the same time, bioenergy raises issues that are increasingly debated:

- It can create land-use competition with food production and biodiversity when dedicated energy crops are used.
- Small-scale biomass combustion can have negative air-quality impacts, especially in densely populated or topographically complex areas.
- Lifecycle greenhouse-gas balances depend heavily on feedstock type, supply chains and forest management practices.

On Ischia, local biomass resources—forests, agricultural residues, organic waste—are limited, and large imports of biomass would undermine some of the environmental and logistical benefits. Additional combustion-based generation is also hard to reconcile with air-quality and tourism objectives. For these reasons, bioenergy is not modelled as a principal electricity source in the island's REC scenarios. It remains part of the wider Italian renewable mix, but it is not a central lever in this thesis.

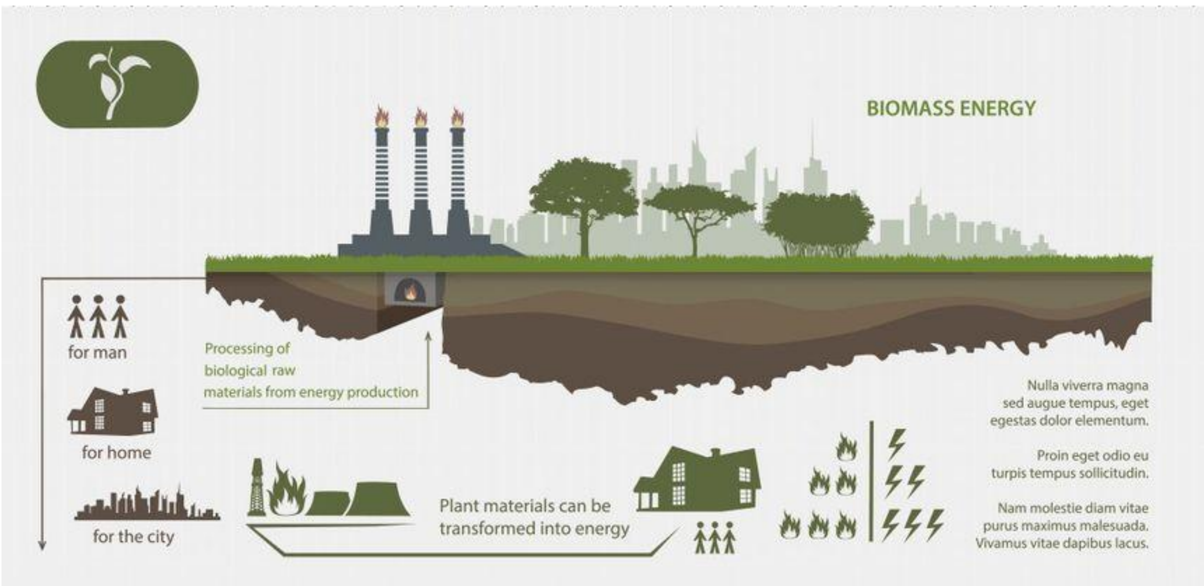


Figure 19: Biomass Energy

2.5.5 Geothermal energy

Geothermal energy harnesses heat from the earth's crust to supply electricity and/or heat. Italy is a historic pioneer in geothermal power, especially in Tuscany (e.g., Larderello), where high-temperature resources have been exploited for over a century (International Energy Agency, 2023).

Geothermal systems can be categorized into:

- High-temperature resources, used for electricity generation.
- Medium/low-temperature resources and ground-source heat pumps, used for heating and cooling buildings.

Geothermal energy offers clear benefits:

- It can provide baseload, low-carbon electricity and heat with high-capacity factors.
- It has relatively small surface footprints compared to some renewables.
- Ground-source heat pumps can deliver very efficient heating and cooling, reducing final energy demand.

However, geothermal electricity projects require suitable subsurface conditions and involve high upfront investment and technical complexity. Environmental concerns such as induced seismicity, subsidence and emissions of certain gases must also be considered. Although Ischia is a volcanic island, exploiting high-temperature geothermal resources for power generation would demand extensive geological studies and would likely raise environmental and social questions that lie beyond the scope of this thesis.

Given current national planning priorities and the scale of the present study, geothermal energy is not treated as a near-term local electricity option for Ischia. It may have long-term potential for heating and cooling, but this is not included in the REC modelling, which focuses on electricity from rooftop PV.

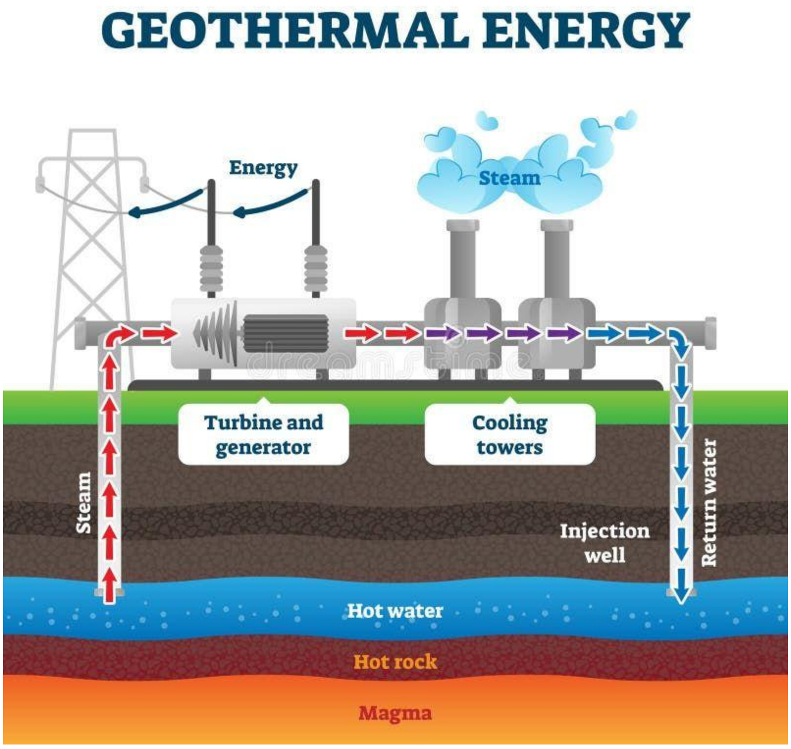


Figure 20: Geothermal Energy

2.5.6 Other renewables and hybrid systems

In addition to the main categories above, other options include:

- Solar thermal collectors for domestic hot water and low-temperature heating.
- Ocean energy (wave and tidal), which is still largely at the demonstration stage, with limited commercial deployment in the Mediterranean.
- Hybrid systems, combining several technologies (e.g., PV + wind + storage), designed to exploit complementary resource profiles and improve reliability.

At community scale, hybrid configurations can reduce variability and increase self-sufficiency. However, in the specific context of Ischia—with limited land, strong tourism, and a regulatory framework tailored to small and medium PV plants—the most realistic and impactful design axis is rooftop PV combined with battery storage and flexible loads, rather than multi-technology deployments.

2.5.7 Why this thesis focuses on rooftop PV for Ischia

Considering the technical, spatial and regulatory factors discussed above, this thesis uses rooftop PV as the core renewable resource for Ischia's REC feasibility study. The decision rests on several arguments:

1. *Technical suitability*

   Ischia has high solar irradiation, typical of Mediterranean islands. PV output can be modelled reliably at hourly resolution using tools such as PVGIS, which is crucial for aligning the analysis with REC settlement rules based on hourly shared energy (European Commission Joint Research Centre, 2024)

2. *Spatial and heritage compatibility*

   Rooftop PV makes use of existing buildings, limiting land-use conflicts and preserving open landscapes. Design choices (e.g., low-profile mounting, color integration) can reduce visual intrusion in heritage areas, making PV more compatible with tourism and cultural values than large wind or ground-mounted installations.

3. *Policy and regulatory alignment*

   Italian REC rules and incentives—set out in Legislative Decree 199/2021, ARERA's TIAD and the CER/CACER ministerial decree—have been designed primarily around small and medium rooftop PV plants within primary-substation perimeters (Ministero dell'Ambiente e della Sicurezza Energetica, 2023). Focusing on rooftop PV ensures that this thesis remains fully consistent with the actual regulatory framework under which REC projects will operate.

4. *Synergy with electric mobility*

   PV generation peaks during daytime, which is when electric buses and shuttles can be charged during layovers or off-peak periods. PV installed on depots, parking areas and other transport-related infrastructures can directly supply electric mobility, creating a tight link between REC-based generation and decarbonized transport.

5. *Replicability for other islands and municipalities*

   Rooftop PV-based REC designs are highly replicable in other Italian islands and mainland municipalities. By focusing on a technology that is widely applicable, the methods and conclusions of the Ischia case study can inform broader policy and planning discussions beyond the island itself.

For these reasons, while recognizing the importance of hydropower, wind, bioenergy and geothermal in Italy's overall energy transition, this thesis centers its quantitative analysis on rooftop solar PV, residential and tourist demand, and the integration of electric mobility within REC-compliant frameworks on the island of Ischia.

2.6 Eligibility requirement of REC

Eligibility requirements define which projects and actors can legally form a Renewable Energy Community (REC) and under what conditions they can access support schemes. They translate the general principles of EU law into concrete criteria tied to legal form, territorial scope, technology type and metering arrangements. For a case study like Ischia, these requirements are not just a legal backdrop; they directly influence how buildings can be grouped, which plants can receive incentives, and how residential, tourist and mobility loads can be connected within the same community.

At European level, the Renewable Energy Directive (RED II) defines RECs as legal entities based on voluntary participation, local control and a primary purpose of delivering community benefits, and it asks Member States to create enabling frameworks that respect these principles (European Parliament and Council of the European Union, 2018). Italy has implemented this through Legislative Decree 199/2021 and subsequent regulatory decisions, which specify detailed eligibility criteria for Comunità Energetiche Rinnovabili and related autoconsumo configurations (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

In practice, eligibility can be grouped into four main dimensions: legal and governance criteria, territorial and grid criteria, technical and plant criteria, and participant and procedural criteria.

2.6.1 Legal and governance criteria

First, a REC must be a recognizable legal entity under national law. In Italy this typically means establishing an association, cooperative, consortium or similar form with its own statute and governance bodies (Italy, 2021). The legal form itself is not prescribed, but it must support the core principles defined in RED II and transposed into Italian law:

- open and voluntary participation for eligible local actors
- effective control by members or shareholders located near the community's projects
- a primary purpose of delivering environmental, economic or social community benefits rather than financial profit.

To satisfy these requirements, the founding documents must:

- clearly state that the main objective is community benefit, for example by committing to reinvest surpluses or to use them for reducing members' energy costs or funding local projects
- define decision-making rules that prevent control by large energy companies or purely financial investors

- describe transparent membership rules, including how new members can join, how members may leave, and how voting rights are allocated

In most Italian examples, municipalities, citizens and small businesses share control, often on a one-member–one-vote basis or with weighted rules that still protect local actors (Caramizaru, 2020). For Ischia, this implies that any REC created to manage rooftop PV and potential EV charging would need clear statutes that reflect the island's mix of municipal, residential and tourist/hospitality stakeholders and ensure that local community interest, not just commercial interest, guides decisions.

2.6.2 Territorial and grid criteria

The second key dimension is territorial and grid eligibility. Under the Italian framework, energy is recognized as shared only if the generation plants and consumer points of delivery (PODs) are connected downstream of the same primary substation, the so-called cabina primaria (ARERA, 2022). This technical perimeter defines the maximum geographic extent of a REC or other eligible configuration for the purposes of incentive calculation.

This requirement serves multiple purposes:

- it ensures that shared energy has a physically meaningful relationship on the distribution grid
- it avoids configurations that would effectively use the REC framework for long-distance virtual trading without local network relevance
- it provides a clear, verifiable boundary for distribution system operators and GSE, which must identify eligible PODs and plants in their data systems

In practice, this means that a municipality may host more than one potential REC, if its territory is served by multiple primary substations, or that a single REC may cover parts of more than one municipal area if they share a cabina primaria. On small islands with a single primary substation, the effective REC perimeter may be close to the whole island; on more complex systems, the REC perimeter is smaller and less intuitive from an administrative point of view (ARERA, 2022).

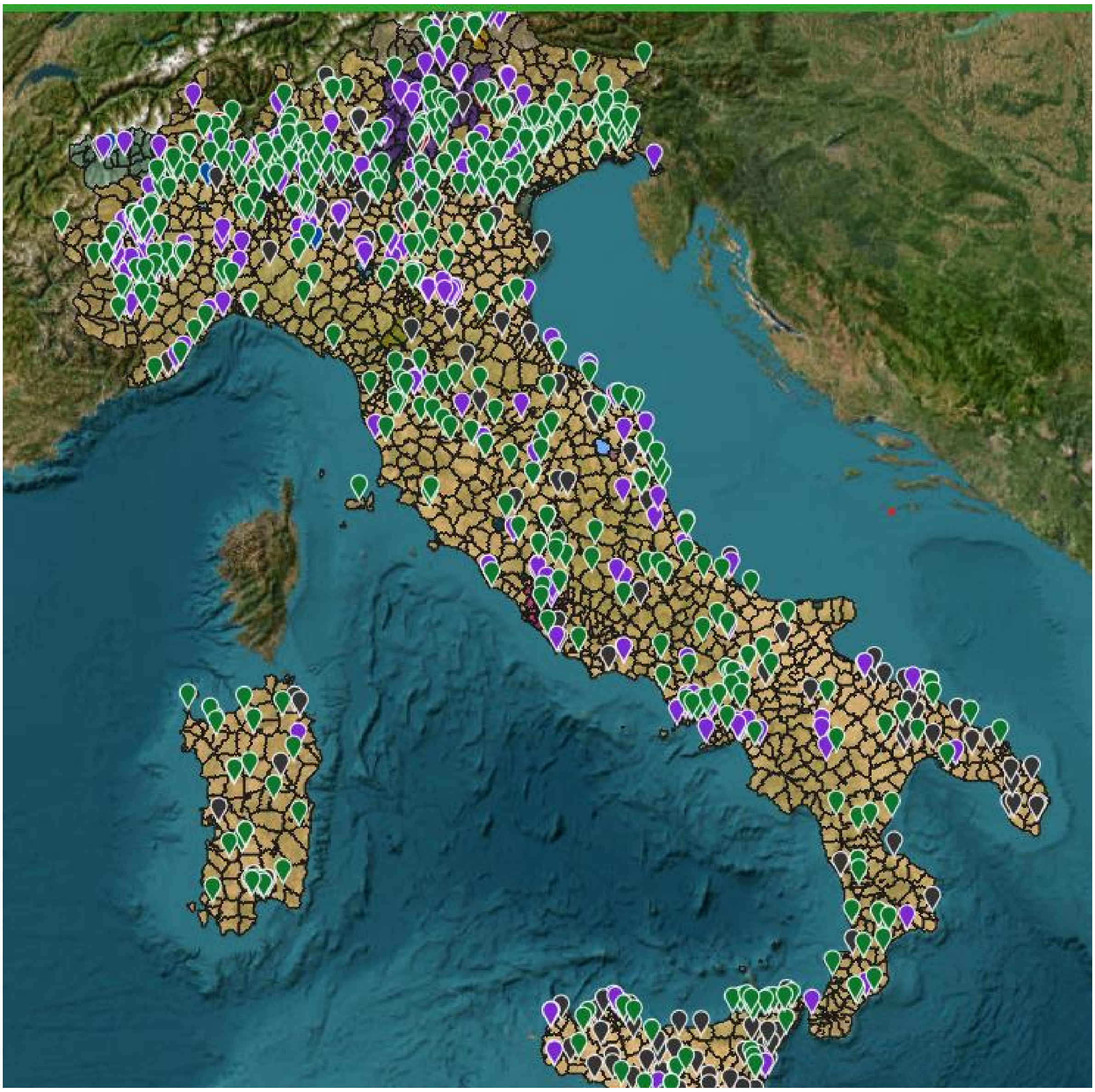


Figure 21: Primary Cabins in Italy (GSE)

For Ischia, eligibility therefore depends on the actual configuration of primary substations and their downstream networks. In this thesis, candidate REC clusters are formed in a way that respects these perimeters: only buildings and loads within the same primary-substation area are grouped together when evaluating self-sufficiency, self-consumption and shared energy. This ensures that the modelling corresponds to configurations that could genuinely be recognized and incentivized under the current rules.

2.6.3 Technical and plant criteria

Eligibility is also tied to the characteristics of the generation plants that will participate in the REC. The Italian framework specifies that:

- Plants must use renewable energy sources (e.g., photovoltaic, wind, hydro, biomass).
- To receive the operating incentive on shared energy established by the CER/CACER decree, the plants must generally be new or repowered and must have been commissioned after a certain date (16 December 2021 in the initial framework).
- The rated capacity of each eligible plant is subject to a size cap (for the current national tariff, typically up to 1 MW per unit for full incentive access, with some nuances for larger installations).

These criteria reflect the policy aim of driving new or upgraded renewable capacity rather than retroactively rewarding existing installations, and of favoring distributed plants that are consistent with local network conditions (Ministero dell’Ambiente e della Sicurezza Energetica, 2023).

From a metering standpoint, plants must be connected with appropriate meters capable of providing hourly or quarter-hourly data, which are then used to compute shared energy as the hourly minimum of aggregated generation and aggregated load. Storage systems, such as battery energy storage, can also be integrated, but their treatment in incentive schemes is more complex and depends on how they are configured relative to the plant and the grid (ARERA, 2022).

In the Ischia case, this thesis focuses on small and medium rooftop PV plants on residential, municipal and tourist buildings that can realistically be installed or repowered in line with current eligibility rules. Plant sizes in the modelling are kept within ranges compatible with these national caps, so that simulated performance and potential incentives correspond to what could be recognized by GSE.

2.6.4 Participant criteria

A fourth set of eligibility conditions relates to the types of actors who can participate as members or beneficiaries. RED II defines RECs as entities that may include citizens, local authorities and small and medium-sized enterprises (European Parliament and Council, 2018). Italian law follows this line by allowing a broad range of local actors to join CERs:

- individual citizens and households
- municipalities and other local public bodies
- small and medium enterprises
- third-sector organizations such as associations and cooperatives

Larger companies and energy utilities may participate but must not exercise controlling influence. This condition is designed to prevent the REC concept from being captured by large commercial actors and to maintain the emphasis on local value and community benefit (ARERA, 2022).

In practice, this implies that a REC on Ischia could include:

- municipal buildings and services (schools, town halls, public lighting, depots)
- residential consumers across different income levels
- hotels, guesthouses and restaurants that operate within the REC perimeter
- civil-society organizations active on the island

At the same time, governance arrangements must ensure that small actors and vulnerable consumers are not sidelined by larger economic players. While this thesis does not model governance in detail, it assumes that any REC compatible with the legal framework would be structured to avoid domination by a single large entity, even if that entity (for example, a public transport operator) plays a key role in investments or loads such as the proposed electric shuttle corridor.

2.6.5 Procedural and documentation criteria

Finally, eligibility has a procedural dimension. To be formally recognized by GSE as a REC and to access incentives, a configuration must complete a number of administrative steps, including:

- registration of the legal entity and approval of its statute
- definition of the list of plants and PODs that will form part of the configuration
- submission of an application via the dedicated GSE portal, with technical, legal and financial documentation
- Conclusion of necessary agreements with the distribution system operator concerning metering arrangements and data flows
- provision of consents and documentation from individual members, including authorizations to use their metering data for shared-energy calculations

Failure to complete these steps correctly can delay or prevent access to incentives, even if the underlying technical configuration would otherwise be eligible. For communities and municipalities with limited administrative capacity, these procedural requirements can be a barrier and often require support from regional agencies, consultants or facilitators (Caramizaru, 2020).

While this thesis does not reproduce the full procedural detail, it proceeds under the assumption that any REC configuration proposed for Ischia would have to comply with these administrative conditions, alongside the legal, territorial, technical and participant eligibility criteria summarized above. The modelling therefore focuses on configurations that could realistically satisfy these requirements, ensuring that the energy balances and self-sufficiency indicators calculated in subsequent chapters correspond to communities that could actually be recognized and incentivized within the current Italian regulatory framework.

2.7 Steps to create a REC

The creation of a Renewable Energy Community is best understood as a structured process rather than a single legal or technical act. A REC is simultaneously a legal entity, an energy configuration on the grid, a governance system and a social project. For this reason, Italian and European guidance increasingly present REC development as a sequence of stages: exploration, pre-feasibility, participatory design, detailed technical–economic design, legal constitution, implementation, and monitoring and expansion (Caramizaru, 2020) (Gestore dei Servizi Energetici, 2024).

In the context of Ischia, this process must integrate three additional complexities:

- the strong seasonal influence of tourism on demand.
- the presence of multiple municipalities on a single island.
- the potential coupling of RECs with an electric shuttle corridor and other EV loads.

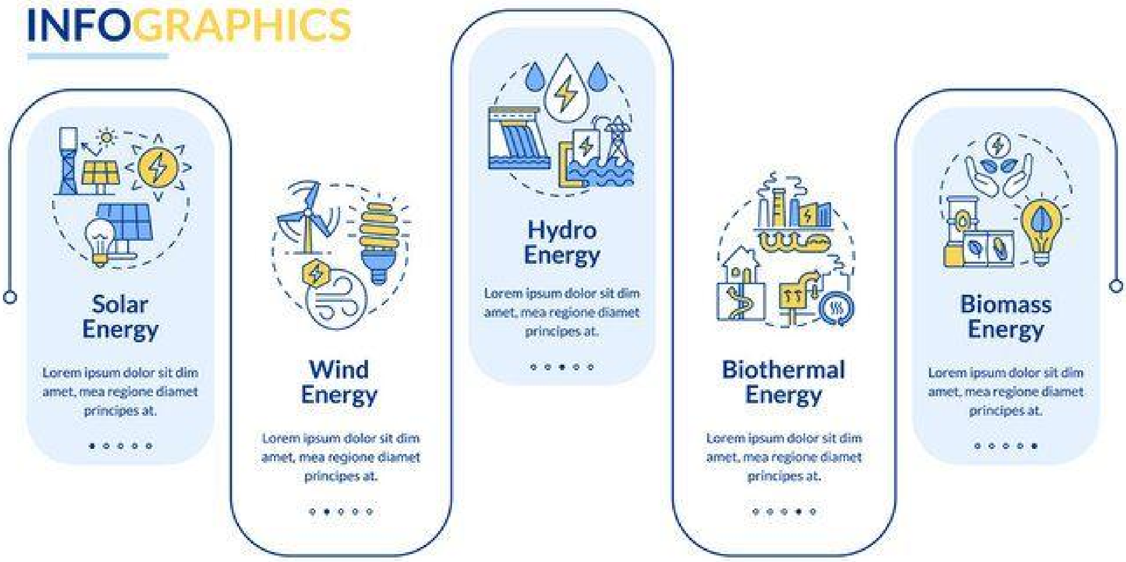


Figure 22: Process for establishing a Renewable Energy Community (REC) (Author's illustration)

2.7.1 Exploration and initial scoping

The first step is exploration. One or more local actors, municipal administrations, citizen groups, environmental associations, or even a transport company planning electrification—recognize RECs as a potentially useful tool. At this point, the tasks are qualitative and diagnostic rather than quantitative:

- understanding what RECs are in legal and practical terms (ARERA, 2022).
- reviewing existing Italian experiences and guidance, for example through GSE and regional energy agencies (Gestore dei Servizi Energetici, 2024).
- mapping obvious anchor buildings such as municipal offices, schools, sports facilities, depots and larger residential blocks.
- identifying key problems RECs might help address: high electricity bills, dependence on imported fossil-based electricity, visual constraints for large renewables, air quality, or tourist-sector expectations for “green” services.

On Ischia, initial scoping might involve a joint initiative by the municipalities and the transport operator to explore whether rooftop PV combined with an electric shuttle line could be organised within a REC framework rather than as isolated projects.

2.7.2 Pre-feasibility: quick technical and economic screening

Once there is a sense that RECs might be useful, a pre-feasibility study provides a first indication of whether the idea is technically and economically viable. This usually involves:

- a basic GIS-based estimate of rooftop PV potential, using building footprints, simple assumptions on usable roof fraction and standard PV performance (European Commission Joint Research Centre, 2024).
- rough annual consumption estimates for different classes of users (residential, hospitality, municipal), based on billing data, benchmarks or national statistics ((Terna S.p.A, 2023).
- identification of primary-substation perimeters to understand how potential members are grouped on the grid and whether the natural "social community" overlaps with the technical REC perimeter (ARERA, 2022).
- preliminary economic calculations: order-of-magnitude investment costs, expected annual generation, likely ranges for REC incentives and TIAD valuation, approximate payback times (Ministero dell'Ambiente e della Sicurezza Energetica, 2023)

The goal is not to optimize yet, but to answer basic questions such as:

- Is there enough roof area within an eligible perimeter to make a REC meaningful?
- Are possible savings and incentives large enough to justify the administrative effort?

– Are there obvious showstoppers (e.g., extremely constrained grid, negligible demand, or conflicting land-use rules)?

If pre-feasibility suggests very poor economics or insurmountable grid constraints, the project may be abandoned or scaled down. If results are promising, the process moves into more participatory and detailed phases.

2.7.3 Stakeholder engagement, vision and governance options

RECs are not purely technical constructs. Their performance and stability depend heavily on member buy-ins and on clear, legitimate governance arrangements. Early stakeholder engagement therefore plays a crucial role. Typical activities include:

- public information sessions and workshops explaining REC basics and early findings from pre-feasibility
- bilateral meetings with key factors such as hotels, resident associations, social housing entities, and the transport operator
- discussions within municipal councils about the role of municipalities (e.g., as anchor members, coordinators or simple participants)

The objective is to co-develop a shared vision that answers questions like:

– Is the REC primarily for residents, or is it explicitly a mixed resident–tourism community?

– Should the REC prioritize bill reductions, climate objectives, social inclusion, or mobility decarbonization

– What role should the municipality play: promoter, majority member, or neutral facilitator?

Possible governance models can also be discussed at this stage: small association led by citizens; cooperative with municipal participation; municipal-led consortium; or a hybrid arrangement (Caramizaru, 2020).

For Ischia, it may be appropriate to consider a model where municipal institutions and the public transport operators act as anchor members, with residents and hospitality businesses as voluntary members sharing benefits.

2.7.4 Detailed technical and economic design

Based on a clearer vision and stakeholder commitments, technical–economic design becomes more granular. This is the stage that aligns most directly with the modelling carried out in this thesis. It typically involves:

- refined rooftop analysis, distinguishing flat and pitched roofs, tilt and aspect, shading and structural suitability
- calculation of installable PV capacity per roof segment and aggregation into building-level potentials
- generation of hourly PV profiles using tools such as PVGIS for representative roof types and system configurations (European Commission Joint Research Centre, 2024).
- development of hourly demand profiles for residents, tourists and municipal buildings, calibrated to match annual and seasonal consumption data for the island (Terna S.p.A, 2023).
- inclusion of specific loads such as the electric shuttle corridor: deriving energy demand per trip, per day, and distributing charging over hours of operation and depot layovers.

- clustering of buildings and loads into REC candidates that respect primary-substation boundaries and test different inclusion choices (e.g., with or without certain hotels; with or without the shuttle depot).
- simulation of energy balances per hour, per day, per season, estimating shared energy, self-consumption, self-sufficiency, imports and exports for each configuration.

Financial design uses these energy sources to explore different investment and benefit-sharing models:

- centralized investment by the REC entity versus distributed investments by individual prosumers.
- possible use of PNRR capital support and its interaction with operating tariffs (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).
- allocation rules for incentives and savings across members, before and after accounting for administrative and O&M costs.

The outcome is a set of technically and economically coherent REC options that can be presented to stakeholders and decision-makers.

2.7.5 Legal constitution, internal rules and agreements

When a preferred option is selected, the REC must be constituted as a legal entity. This involves:

- choosing the legal form (association, cooperative, consortium or other) in line with national law and REC principles (Italy, 2021).
- drafting statutes that include membership rules; decision-making processes; distribution of surpluses; treatment of vulnerable consumers; conditions for joining and leaving; provisions for the inclusion of new plants or loads.

- formally creating governance bodies (assemblies, boards, technical committees) and appointing a representative (referente) for dealings with GSE and the distribution system operator.
- negotiating and signing engineering, procurement and construction contracts; O&M contracts; financing agreements if external loans are involved

At the same time, the REC must prepare documentation for the GSE application, obtain explicit consent from members for the use of their metering data, and coordinate with the distribution system operator on the tagging of plants and PODs in their systems (ARERA, 2022).

2.7.6 Implementation, commissioning and start of operation

Physical implementation covers the installation of PV systems and any associated infrastructure (storage, control systems, communication equipment). Key tasks include:

- detailed rooftop surveys and structural checks.
- permitting and compliance with building codes and heritage constraints, particularly important on Ischia.
- installation, testing and commissioning of PV systems and inverters.
- integration of monitoring systems that provide high-frequency data for performance and REC accounting

Once systems are commissioned and the REC configuration is validated by GSE, normal operation begins. The REC's representative receives monthly statements from GSE showing shared energy and incentive amounts; the REC then applies its internal rules for distributing benefits to members.

2.7.7 Monitoring, adaptation and expansion

REC development is not static. Over time, communities may:

- add new members or buildings, particularly as more residents or businesses become aware of the benefits.
- expand PV capacity when additional roof space or canopies become available.
- integrate new loads, such as extra EV chargers, heat pumps or municipal facilities.
- refine governance rules in response to member feedback or changes in regulation

Monitoring is essential for detecting underperformance (due to shading, faults or behavioral issues), verifying expected savings and equity outcomes, and informing future expansions. In the Ischia context, ongoing monitoring should also assess how the REC interacts with tourism seasonality and whether the integration of the electric shuttle corridor is effectively increasing shared energy without causing new local network problems.

2.8 Laws of REC

The legal framework of Renewable Energy Communities is a multi-level structure that combines EU law, national legislation, regulatory decisions and operational rules. From a practical perspective, this framework defines what counts as a REC, what rights and obligations it has, how energy sharing is measured and remunerated, and which protections exist for consumers and small actors. For a case study like Ischia, understanding this framework is crucial to ensure that any proposed configuration is not only technically and economically sound but also legally recognisable and eligible for support.

2.8.1 European legal foundations

At the European level, the key legal foundations are the recast Renewable Energy Directive (RED II), its update RED III, and the Internal Electricity Market Directive (IEMD).

RED II formally defines Renewable Energy Communities as legal entities that:

- are based on voluntary and open participation
- are effectively controlled by shareholders or members located in proximity of the projects
- have a primary purpose of providing environmental, economic or social community benefits, rather than financial profits
- may produce, consume, store and sell renewable energy, including through energy sharing (European Parliament and Council of the European Union, 2018)

RED III raises the EU's renewable targets and streamlines aspects of permitting, but it leaves the basic REC definition intact while strengthening the requirement for Member States to remove barriers to community energy (European Parliament and Council of the European Union, 2023).

The IEMD complements this by defining Citizen Energy Communities and setting broader rules for consumer rights, access to markets, and non-discriminatory treatment of community entities in grid access and tariffs (European Parliament and Council of the European Union, 2019). Together, these directives:

- obliges Member States to create enabling frameworks for RECs and related entities.
- stipulate that regulatory and administrative barriers must be proportionate and non-discriminatory.
- recognize the right of communities to engage in energy-sharing arrangements within a limited geographical area defined at national level

These principles underpin national frameworks, including Italy's, and ensure a certain degree of harmonization across the EU, even as implementation details vary.

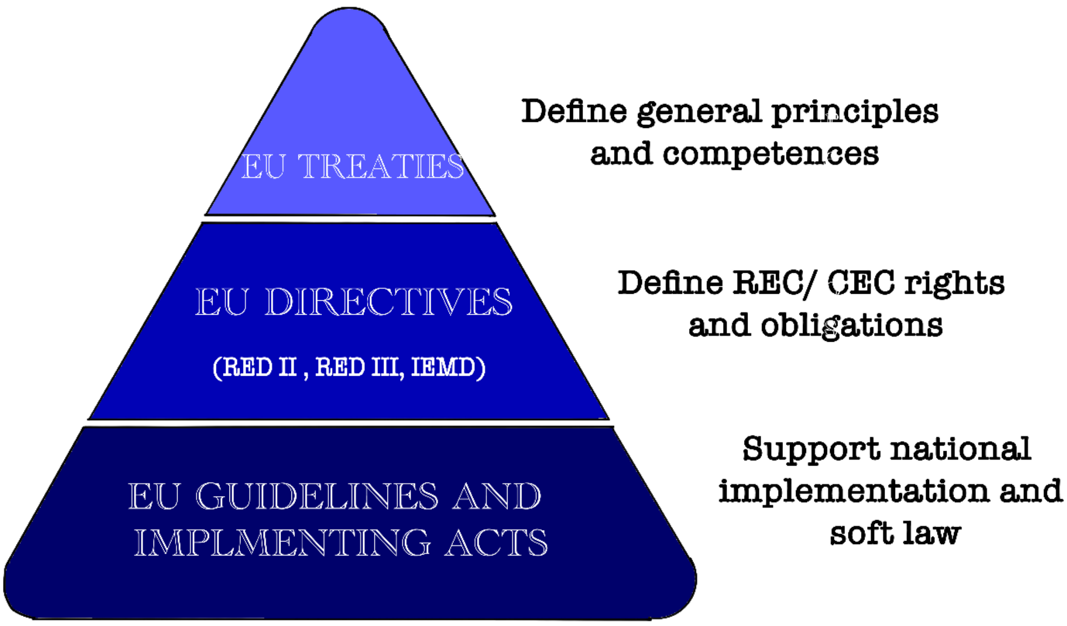


Figure 23:Hierarchy of EU legal instruments relevant to Renewable Energy Communities (Author's illustration)

2.8.2 Italian transposition: legislative layer

Italy's primary transposition of RED II in the field of renewable energy is Legislative Decree 199/2021. This decree:

- defines Comunità Energetiche Rinnovabili as national counterparts of RECs.
- sets general conditions for their establishment and operation.
- mandates the creation of support schemes and enabling measures for community energy (Italy, 2021).

The decree confirms the core EU principles of open participation, local control and community benefit, and authorizes the regulator (ARERA) and the competent ministry to define detailed rules on metering, settlement and incentives. It also clarifies that RECs can involve a range of actors, including citizens, SMEs and local authorities, and that they may own or contract renewable energy installations.

Additional legislative acts, including the National Recovery and Resilience Plan (PNRR), reference RECs as eligible beneficiaries for certain grants, particularly aimed at smaller municipalities and vulnerable territories. This integrates RECs into broader national strategies for decarbonization and socio-economic recovery (Presidenza del Consiglio dei Ministri, 2021).

2.8.3 Regulatory layer: ARERA and TIAD

The regulatory layer is largely handled by ARERA, the Italian authority for energy networks. ARERA's Testo Integrato Autoconsumo Diffuso (TIAD) is a central document in the REC legal architecture. It:

- defines the categories of configurations (collective self-consumption, RECs, other autoconsumo schemes).
- sets out how self-consumed and shared electricity is measured.
- specifies how shared energy is valued in terms of avoided network charges and other components (ARERA, 2022).

The TIAD defines shared energy as the minimum, in each hour, between aggregated electricity injected by eligible plants and aggregated electricity withdrawn by members within the same primary-substation perimeter. It also clarifies the treatment of storage, multiple PODs per member, and interactions with other market arrangements.

For REC projects, this regulatory layer has very concrete implications:

- it sets the technical perimeter (primary substation) that defines who can share energy.
- it determines the metering and data requirements.

- it shapes the economic value of shared energy beyond market prices, through TIAD valuation

This thesis explicitly uses the TIAD definition of shared energy as the basis for computing self-consumption, self-sufficiency and shared-energy quantities.

2.8.4 Ministerial decrees: incentives and support

Ministerial decrees provide detailed rules for financial incentives. The key act for RECs is the decree on incentives for Comunità Energetiche Rinnovabili and other configurations of distributed self-consumption, often referred to as the CER/CACER[25] decree. It specifies:

- the incentive tariff for each kilowatt-hour of shared renewable energy
- eligibility conditions, including commissioning dates and capacity caps per plant
- the duration of the incentive period
- how the tariff interacts with other supports, particularly PNRR grants (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

This decree operationalizes the mandate in D.Lgs. 199/2021 to create financial support for community energy. For REC designers, including those working on Ischia, it is a key reference for understanding which plants can be included, how large they can be, and what revenue streams shared energy will generate.

[25] CACER – "Configurazioni di autoconsumo per la condivisione dell'energia rinnovabile", the Italian umbrella category that includes Renewable Energy Communities (CER), groups of collective self-consumers and remote self-consumers operating under the same primary substation.

2.8.5 Operational rules: GSE procedures and portals

GSE translates legislative and regulatory texts into operational procedures. Its rules and guidelines:

- Describe the process for applying for REC recognition and incentives
- List the documentation needed (legal, technical and financial)
- explain how plants and PODs must be identified and associated with each configuration
- clarify the timetable and format of data exchanges between GSE, DSOs and REC representatives
- provide templates and tools to support municipalities and communities (Gestore dei Servizi Energetici, 2024).

From a legal perspective, these documents are not laws in the strict sense, but they are binding operational references. In practice, failure to comply with GSE procedures can prevent a technically compliant REC from receiving incentives.

2.8.6 Interaction with other legal domains

REC law does not exist in isolation. Projects must also comply with:

- building and planning regulations, including heritage and landscape protection.
- grid connection rules and technical codes for distribution and transmission networks.
- Consumer protection law and data-protection law, particularly regarding metering data and contractual fairness.
- public procurement law when municipalities or public companies are involved in investments

This means that rooftop PV projects and EV charging infrastructure associated with a REC may face the same permitting and design constraints as any other infrastructure, even if their energy-sharing and incentive aspects are governed by REC-specific rules. For a place like Ischia, with strong heritage and landscape constraints, these interactions can be decisive in determining which roofs or sites are usable.

2.8.7 Implications for the Ischia case study

For this thesis, the key implication of the REC legal framework is that not every "nice" energy cluster on the island can be called a REC and supported as such. Only configurations that:

- are composed of renewable plants and PODs within the same primary-substation perimeter.
- are structured as a legal entity with REC-compliant statutes.
- meet commissioning and capacity conditions for plants.
- follow the GSE application and data procedures

will be fully eligible for the incentive regime.

The energy modelling in this thesis therefore focuses on configurations that could plausibly be structured as real RECs under current Italian law. By respecting the TIAD definition of shared energy and the primary-substation perimeter, and by concentrating on rooftop PV plants of realistic size, the analysis produces results that are not only technically interesting but also relevant to regulators, municipalities and potential REC promoters on Ischia.

2.9 European Framework

The European framework for Renewable Energy Communities emerges from a broader agenda to transform the EU energy system into one that is climate-neutral, consumer-centred and resilient. RECs are one of several instruments, alongside prosumers, aggregators, demand response, smart metering and flexibility markets, that are meant to turn final consumers into active participants in the energy transition. The idea is that decentralized, citizen-led initiatives can complement large-scale renewable projects, accelerate deployment and increase social acceptance by visibly linking benefits to local communities (European Commission JRC, 2020).

From a legal perspective, three directives are central: the recast Renewable Energy Directive (RED II), its revision (RED III) and the Internal Electricity Market Directive (IEMD). These texts are interdependent: RED II and RED III set the renewable and governance framework, while IEMD defines electricity market rules and consumer rights. Together, they create the “space” within which Member States can design their own REC regimes.

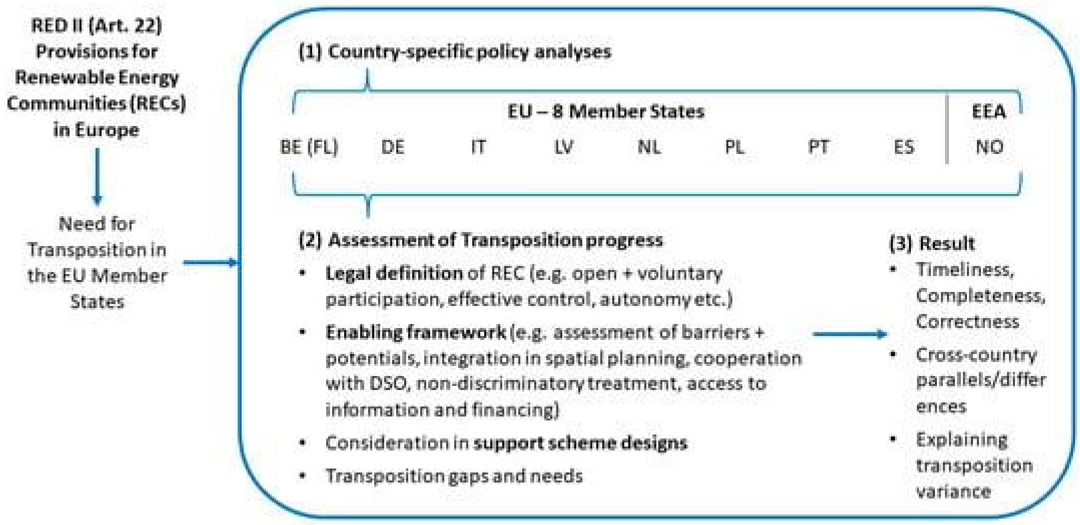


Figure 24: European Framework

2.9.1 RED II: legal definition and enabling framework

RED II is the starting point for RECs as a recognized legal category. It gives the first EU-wide definition of a Renewable Energy Community, insisting on three core elements:

- Participation must be voluntary and open.
- control must rest with local members or shareholders.
- The primary purpose must be environmental, economic or social community benefit, rather than profit maximization (European Parliament and Council, 2018).

These three pillars distinguish RECs from conventional energy companies. A private developer that happens to build solar farms in a town is not automatically a REC; to qualify, it must be governed in a way that puts community benefit and member control at the center.

RED II also introduces the idea of an “enabling framework” for RECs. Member States are asked not just to allow RECs to exist in theory, but to actively remove barriers and provide support. This includes:

(i) assessing and addressing regulatory and grid barriers that disproportionately affect community projects.

(ii) simplifying administrative procedures, particularly for small renewable plants.

(iii) facilitating access to finance, information and technical assistance.

(iv) ensuring that households, including low-income consumers, can participate on fair terms (European Parliament and Council of the European Union, 2018)

In other words, RECs are not supposed to compete under exactly the same conditions as large energy companies. The directive acknowledges that community initiatives face different challenges – fragmented capital, limited technical capacity – and therefore require tailored support.

Finally, RED II gives Member States flexibility in defining the "proximity" condition for RECs, including how close members must be to the installations. This is important because it opens the door for different national choices: some countries might tie locality to municipal boundaries, others to parts of the distribution grid, and others to specific maps of "accessible" regions. Italy, as discussed later, opted for the primary-substation perimeter.

2.9.2 RED III: higher ambition, permitting and system integration

RED III amends RED II mainly to increase ambition and improve implementation. It raises the EU's collective targets for renewable energy in gross final energy consumption and specifies sectoral contributions, including in heating, cooling and transport (European Parliament and Council of the European Union, 2023).

For RECs, higher renewable targets mean more pressure on Member States to find socially acceptable ways to accelerate deployment – precisely where community energy can be useful.

RED III also places considerable emphasis on:

- simplifying and speeding up permitting procedures for renewables.
- identifying "go-to areas" where environmental impacts are pre-assessed and procedures are faster.
- strengthening the grid integration of variable renewables.

Although RECs are not singled out in every provision, they stand to benefit from a more supportive environment for small and medium renewable projects. For instance, faster rooftop PV permitting eases one of the practical bottlenecks that can slow down REC development.

The directive also reinforces requirements for public participation and stakeholder engagement in planning processes, which align well with community-led initiatives. RECs can be seen as institutionalised forms of the kind of participation RED III expects in planning and siting decisions.

	RED II (2018)	RED III (2023)
RENEWABLE ENERGY TARGET	32% by 2030	42.5% by 2030 (45% aspirational target)
TRANSPORT SECTOR TARGET	14% renewable energy	29% renewable energy, 14.5% GHG intensity reduction in transport
GHG SAVINGS THRESHOLD FOR BIOFUELS	50–65% depending on installation date	70% (existing), 80% (new installations)
MASS BALANCE TRACEABILITY	Encouraged	Mandatory
ENFORCEABILITY	Partially voluntary or indicative	Legally binding and auditable
CHAIN OF CUSTODY SYSTEMS	Not required	Required across the entire value chain
ALIGNMENT WITH OTHER EU LEGISLATION	Limited	Integrated with ETS, CBAM, and EUDR frameworks

CIRCULARISE

Figure 25: Comparison between the differences between RED II and RED III on targets, enforceability, and alignment with other EU regulations, amongst others.

2.9.3 IEMD: market rules, consumer rights and Citizen Energy Communities

The Internal Electricity Market Directive (IEMD) focuses on how electricity markets are organised and how consumers are protected. Within this text, the concept of Citizen Energy Communities (CECs) appears. CECs are like RECs in that they are citizen- and community-based entities, but they differ in three main ways:

(i) They are technologically neutral (they can include non-renewable technologies, for instance in flexibility services);

(ii) They are not necessarily geographically constrained in the same way as RECs.

(iii) They emphasize roles such as supply, aggregation and demand-side flexibility (European Parliament and Council of the European Union, 2019).

IEMD also strengthens several consumer rights that are relevant for RECs:

- rights to self-generate and self-consume electricity without undue charges.
- rights to participate in aggregation and demand-response schemes.
- protections against unfair contract terms and complex switching processes.

These provisions ensure that when RECs sell electricity to their members, manage flexibility or aggregate demand, they do so in a framework that recognizes community actors as legitimate market participants.

For the Ischia case, the REC framework (from RED II/III) is more immediately relevant than CECs, because Italy's main national instruments focus on renewable-based communities tied to grid perimeters. However, the IEMD ideas around aggregation and flexibility are directly relevant for thinking about the potential future role of electric vehicle fleets and demand response within RECs, especially if vehicle-to-grid or smart charging becomes more widespread.

2.9.4 EU initiatives, funding and knowledge-sharing on RECs

The European framework is not just legal and regulatory; it also includes a growing ecosystem of support initiatives:

The Joint Research Centre and other Commission services publish studies, case collections and technical reports on community energy, PV modelling, storage, and governance structures (European Commission JRC, 2020)

Programmes like Horizon Europe and LIFE fund pilot projects that explore new REC models, including those combining renewables with electric mobility or energy efficiency.

Interreg and other cohesion-policy instruments support cross-border networks and capacity-building for municipalities and communities.

The Clean Energy for EU Islands initiative targets islands specifically, providing technical assistance, roadmaps and networking opportunities to integrate renewables and storage in island systems.

These initiatives have led to dozens of pilot RECs across Europe, in both rural and urban areas, mountain regions and islands. For Ischia, this body of experience provides a “library” of design options, governance choices and technical configurations that can inform local decisions, even though each case must be adapted to Italian law and the island’s specific grid and tourism context.

2.10 Italian Framework

The Italian framework for Renewable Energy Communities translates the European principles into concrete rules that are specific to Italy’s energy system, institutions and administrative culture. It is relatively comprehensive: there is a legal definition of Comunità Energetiche Rinnovabili (CER), a clear grid perimeter, metering and settlement rules, a national incentive, and operational procedures for applying and receiving payments.

At the same time, the framework is still maturing in practice. Many municipalities and communities are experiencing it for the first time, and some aspects—such as grid hosting capacity, administrative complexity, and long-term interactions with changing electricity prices—are being worked out through real projects rather than in abstract.

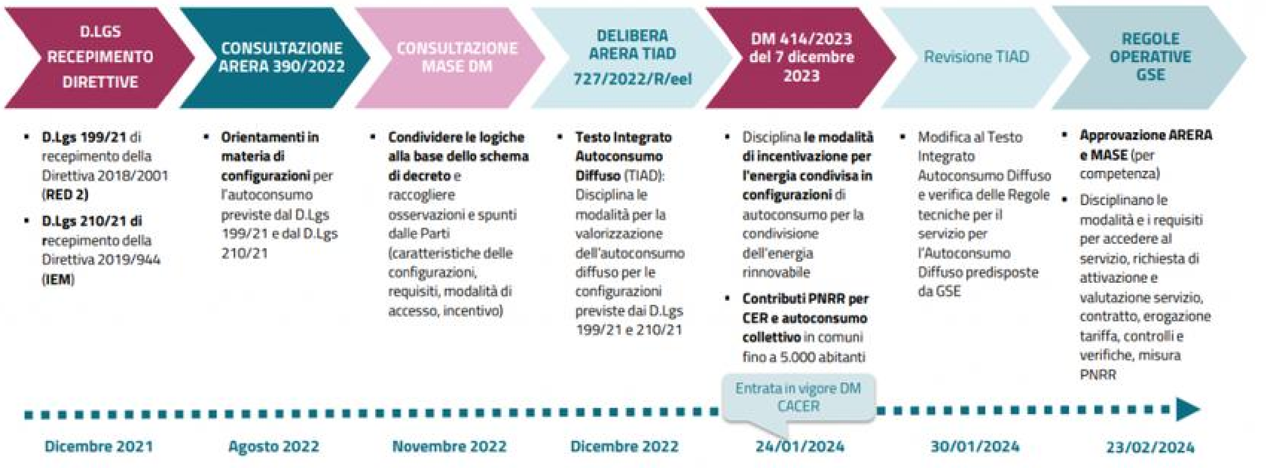


Figure 26: Describes the regulatory process developed by GSE

2.10.1 Legislative foundations and strategic framing

Legislative Decree 199/2021 is the backbone of the Italian REC regime. It transposes RED II and establishes CERs as distinct legal entities. It restates the European principles of open participation, local control and community benefit, and it frames RECs as instruments to:

- promote renewable energy deployment.
- empower consumers and local actors.
- reduce energy poverty.

- contribute to climate and energy targets (Italy, 2021).

The decree also explicitly mandates that a support scheme be defined for energy produced and shared within RECs, and that barriers to their development be removed or reduced. In this sense, RECs are not a marginal add-on; they are embedded in Italy's broader transition strategy.

This legal foundation sits alongside the National Integrated Energy and Climate Plan (PNIEC), which emphasizes the role of distributed generation and demand-side participation, and the National Recovery and Resilience Plan (PNRR), which allocates substantial funds to support green investments, including those involving community energy (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).

For an island like Ischia, this means that RECs are not experimental or legally fragile; they are recognized instruments in official planning documents and recovery strategies, giving local authorities a stable basis for planning.

2.10.2 From pilot configurations to full-scale REC regime

Italy's pathway to RECs went through a pilot phase before the full regime. In the pilot phase, launched around 2020, collective self-consumption groups and early CERs were allowed in a limited set of configurations: typically small renewable plants on low-voltage networks, with perimeters defined by secondary substations and transitional incentives (ARERA, 2022).

This phase served as a sandbox to test:

- whether metering data from distribution system operators and GSE could be integrated accurately.
- How to operationalize the concept of shared energy at hourly resolution.

- how communities reacted to the idea of joint projects and how governance structures emerged.
- which parts of the process were too complex or unclear.

Lessons from this phase informed the design of the stable regime. For instance, the decision to use the primary substation as the REC perimeter in the new framework reflects the desire to broaden membership and simplify certain aspects of grid mapping, while still preserving a physical link between generation and consumption (ARERA, 2022).

In the full-scale regime, relevant for the Ischia thesis, the framework includes:

- a formal legislative basis (D. Lgs. 199/2021).
- detailed metering and valuation rules through TIAD (ARERA, 2022)
- a national incentive for shared renewable energy (Ministero dell'Ambiente e della Sicurezza Energetica, 2023)
- operational guidance and portals managed by GSE (Gestore dei Servizi Energetici, 2024).

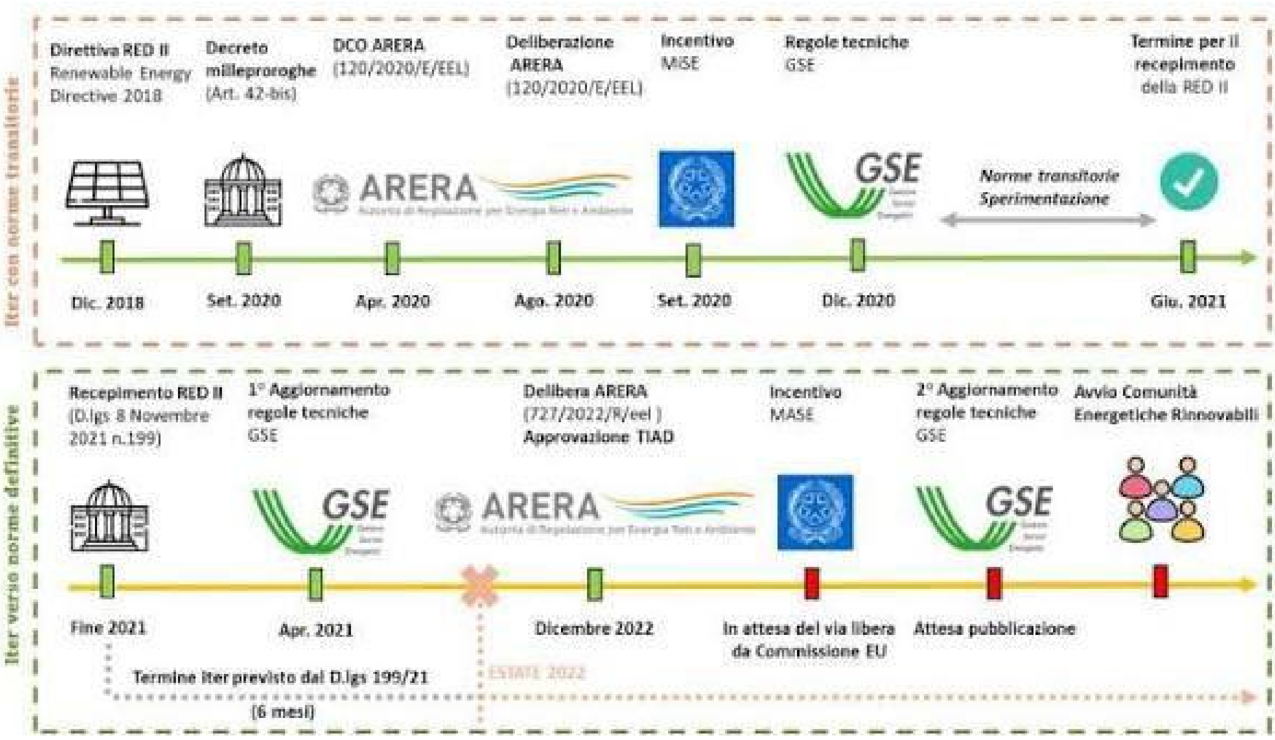


Figure 27: Legislative foundations

2.10.3 Roles of national and local institutions

Italy's REC framework distributes responsibilities between several institutions:

- ARERA focuses on network-related regulation: definition of configuration types, metering and settlement rules, TIAD valuation and interaction with tariffs (ARERA, 2022)
- MASE sets policy direction and the incentive framework, including plant eligibility, tariff levels and the relationship with PNRR grants (Ministero dell'Ambiente e della Sicurezza Energetica, 2023).
- GSE serves as the operational hub, managing applications, metering data, incentive calculation and payments (Gestore dei Servizi Energetici, 2024).

Regions and municipalities have more indirect, but crucial roles. Regions can set up technical assistance programmes, public calls and simplified procedures for PV on public buildings. Municipalities control local planning rules, have access to public roofs and can drive REC formation by convening stakeholders and acting as anchor members.

For Ischia, this means any REC that integrates rooftop PV and an electric shuttle corridor must be aligned across these levels: national rules for eligibility and incentives, regional frameworks for planning and support, and local political decisions on how strongly municipalities want to push the REC agenda.

2.10.4 Practical challenges and emerging practice

Despite the coherent formal framework, several challenges are commonly reported in early Italian REC experiences:

- Administrative complexity: small municipalities often lack in-house legal and technical capacity to navigate REC statutes, GSE procedures, and procurement rules.
- Coordination between actors: aligning the interests of municipalities, citizens, SMEs, energy companies and potential financiers is hard and time-consuming.
- Grid constraints: in some regions, especially where PV has already expanded rapidly, DSOs report limited hosting capacity and the need for network reinforcement before new projects can be connected.
- Timing and uncertainty: long lead times between planning and commissioning can make financial projections tricky, especially as electricity prices fluctuate.

Nonetheless, dozens of CERs have been formed across Italy, especially in the North and Centre, providing a growing base of practical experience. Some involve simple configurations (a handful of citizens and a municipal building), others involve more complex mixes of households, public buildings and SMEs. Lessons from these cases, although not all documented in academic literature yet, suggest that careful preparation of statutes, realistic expectation management and early engagement with DSOs are important for success.

For Ischia, the implication is that the formal framework is enabling but not sufficient. The municipality or group of municipalities must invest in institutional capacity or seek external support to handle the complexity of combining PV deployment, REC governance and electric mobility integration.

2.11 Comparison of RECs on mountain and island

The design of a REC cannot be separated from the territory in which it is embedded. Climate, morphology, existing energy infrastructure, socio-economic structures and tourism patterns all influence how a community can best use renewables and how easily members can be mobilized. Comparing typical mountain and island settings in Italy helps clarify which features of the Ischia case are generic and which are specific to islands.

2.11.1 Resource and climate contrasts

Mountain regions, especially the Alpine and high Apennine areas, combine:

- high winter heating demand due to low temperatures;
- snow cover, which both reflects sunlight and burdens structures;
- specific hydrological conditions that may support small or large hydropower.

PV in these areas can benefit from clean, cold air and snow-reflection but suffers from shorter winter days and potentially heavy snow accumulation. Design strategies often emphasise high tilt angles (45–60 degrees) to maximize winter output and encourage snow shedding (Kahl et al., 2019; von Frischholz et al., 2024). Hydropower, where available, can complement PV with dispatchable generation, smoothing seasonal variability.

Islands such as Ischia, by contrast, are characterized by:

- mild winters and hot summers, with lower heating needs but substantial cooling demand;
- strong, relatively stable solar resource, with pronounced summer irradiance;
- limited or non-existent hydropower options and challenging conditions for large wind turbines.

This naturally pushes island REC designs toward PV and storage centred strategies. Climate also shapes behaviour: on hot summer days, both residents and tourists use air conditioning, refrigeration and other services, creating strong afternoon and evening peaks that interact with PV production profiles.

2.11.2 Demand seasonality and structure

Demand seasonality is one of the dominant differences. In many mountain communities, the most energy-intensive period is winter, when heating loads, lighting and sometimes winter tourism drive demand. Summer can be comparatively quiet, except in specific resorts.

For islands and coastal regions, Eurostat data show strong summer peaks in tourist nights and associated electricity use, particularly in July and August (Eurostat, 2025). Base residential demand is present year-round, but seasonal visitors significantly amplify loads for:

- cooling and ventilation;
- food storage and preparation;
- hospitality services;
- transport and recreation.

This pattern is central for designing RECs on Ischia. In summer, PV output is high at the same time that cooling and hospitality loads are strong, which is favourable for self-consumption. In winter and shoulder seasons, PV production is still significant, but tourism-related demand collapses, which can lead to higher exports unless storage or flexible loads (such as electric vehicle charging or smart appliances) are used.

2.11.3 Grid characteristics and system strength

Mountain regions are typically connected to the national grid via long transmission lines and radial distribution feeders. While overall system strength is high, local conditions can be constrained: long low-voltage lines, phase imbalance and voltage rise issues can limit how much PV can be accommodated on specific feeders without reinforcement (ARERA, 2022).

Islands present different challenges. Non-interconnected or weakly interconnected islands have:

- lower short-circuit power;
- limited generation diversity;
- tighter operational limits for frequency and voltage.

Even for islands that are connected to the mainland, cable capacity may be limited, and outages or constraints on interconnection can occur. As PV penetration increases, managing ramp rates, cloud-induced fluctuations and midday export peaks becomes more complex, particularly when combined with large, inflexible loads.

For RECs, this means:

- in mountain areas, grid constraints may limit the amount of PV on certain feeders, but the backbone of the national transmission system is robust;
- in island systems, grid constraints may be more systemic, and DSOs may impose stricter technical conditions or limit new connections until reinforcements are made (ARERA, 2022).

In the Ischia context, careful dialogue with the DSO is needed to ensure that rooftop PV deployments under REC schemes and EV charging infrastructure do not exceed local hosting capacity. Staged deployment and possible incorporation of small storage can help mitigate risks.

2.11.4 Morphology, built form and heritage

Morphology affects both PV potential and visual impact. Mountain villages often have compact, traditional centres with steep roofs and narrow streets, sometimes facing heritage restrictions. Surrounding slopes may offer some open areas for ground-mounted PV, but these can conflict with landscape protection and agricultural uses. Snow loads and access issues add complexity.

On islands like Ischia, the built environment is a mix of historic centres, modern residential zones, tourist accommodations and public infrastructure. Common characteristics include:

- flat or low-slope roofs in some coastal and touristic areas;
- irregular, dense fabric in historic towns;
- strong coastal landscape values;
- salt-laden air and wind exposure that affect material durability.

Heritage and landscape protection can limit the use of visible roofs in historic cores, pushing PV toward less visible surfaces, newer buildings, industrial areas and public facilities. At the same time, the prevalence of flat or gently sloped roofs in some areas simplifies mounting and can allow optimal tilt and orientation. Hotels, resorts and municipal buildings often offer large, structurally robust roof surfaces that are attractive for PV installations.

2.11.5 Socio-economic structure and governance

Socio-economic structures also matter. Mountain communities may be characterized by ageing populations, lower incomes and limited institutional capacity, but also strong social ties and local cooperatives. Tourism may be important in some valleys, but not uniformly.

On Ischia, tourism is a primary economic sector. These shapes:

- the distribution of electricity demand (significant in hotels, restaurants and services);
- the distribution of economic power (hospitality businesses may be major players);
- the municipal agenda (pressure to maintain environmental quality and attractiveness to visitors).

RECs in mountain contexts may revolve around municipalities and citizen cooperatives, with SMEs playing a secondary role.

On Ischia, a REC that excludes tourism would ignore a major part of the load and the economic system. Yet, including large hospitality actors raises questions about governance and equity: who sets priorities, and how are benefits shared between permanent residents and seasonal businesses?

This thesis does not solve these governance questions but recognizes that the REC design for Ischia must at least conceptually accommodate both residents and tourism-related loads, including the electric shuttle corridor, while respecting REC principles of community benefit and local control.

2.12 Energy transition models for minor islands

The minor islands are already viewed as a laboratory to implement the energy transition since they are characterised by well-defined limits, high reliance on foreign fossil energy, and significant renewable (frequently solar and wind) resources (Ochoa-Correa, 2025). As a result, an increasing body of literature emerges in energy transition models of small islands, starting with techno-economic optimisation and simulating of the hybrid system, to multi-criteria-indicator frameworks and roadmap studies.

The Italian minor islands are perfectly placed in this dilemma, and some of their contributions explicitly modelled decarbonisation of islands, including Favignana, Pantelleria and the Egadi archipelago.

Figure 28:Minor Islands around Sicily

Methodologically, it is possible to distinguish three general families of models.

1. *The models of techno-economic optimisation*

Such models characterize minimal-cost technology mixed collections and operation plans within technical constraint and citizen goals. In the case of the tourist island of Favignana, Groppi et al. (2023) construct an hourly OSeMOSYS[26] model to plan the energy and water systems on a long-term basis. (Groppi, 2023).

The model covers PV, diesel generators, water desalination and water storage, and illustrates that it is possible to achieve high percentages of renewables when desalination and

[26] Open-Source Energy Modelling System used for long-term cost-optimised energy transition scenarios, including islands.

storage are considered a flexible component, as opposed to a fixed exogenous load. The same group has used these tools earlier to test combinations of PV, wind, biomass and diesel, but has found they are technically feasible with renewable penetrations of over 70-80 % but need large storage and reserve capacity to keep the grid reliably operating on renewable sources alone (Groppi et al., 2019).

2. Simulation and scenario models of hybrid power-systems

Some of the contributions dwell on non-interconnected islands in the Mediterranean that are presently dependent on local diesel production. The Kougias et al. (2019) study a big sample of such islands and indicate that the power infrastructure of these islands is almost always-controlled by oil-leavy thermal power stations, with renewable energy being less than 20 % of the total annual power generation despite great solar and wind resources. (Kougias, 2019).

Techno-economic models of PV, wind and storage reveal that at both present and estimated cost curves, the weight of renewable of more than 60-70% is cost-competitive when maintaining a diesel-dependent scenario, significantly when fuel price volatility is borne in mind. In the case of remote islands of Sicily, Ciriminna and Meneguzzo (2016) report on the gradual transition away of diesel by PV and batteries and believe that even a small establishment of PV can significantly decrease the use of fuel and emissions, and that complete coverage of the day with solar and storage is technically and economically achievable on small islands. (Ciriminna, 2016)

3. Multi-criterion and indicator-based transition models

In addition to pure power-system modelling, other works have a multi-sector and indicator-based viewpoint. Battistelli et al. (2023) create a composite evaluation of energy, mobility, waste management, and water management on Italian small islands as the merger of statistical data and performance indicators that classify the islands in terms of the level of their readiness to transition and determine priority interventions. (Battistelli F. M.-Y., 2023).

Their findings reveal that even though there were pilot projects and policy focus, a large portion of the Italian minor islands continue to have low renewable penetration, high diesel generation dependency and poor energy, transport and water planning integration. Equally, Peñalvo-Lopez et al. (2024) suggest a multi-criteria tool to evaluate the environmental performance of energy transitions in the Mediterranean islands in terms of life-cycle indicators and sensitivity to climate extremes and the necessity of customising decarbonisation transition to local resource endowments, demand and institutional capacities. (Peñalvo-López, 2024).

On the larger level, roadmap and best-practises projects make comparisons between islands that have already been close or near-ports to extremely high renewable shares, e.g., El Hierro, Samsø or Tilos. Legambiente report on the status of major city 100% renewable electricity, entitled Isole 100% rinnovabili, summarises various examples of so-called smart islands, which have achieved 100 percent of renewable electricity or have explicit objectives to do so, and may also include wind, PV and storage, and demand management (Legambiente, 2016).

Recent studies and documentation of EU awards show that the wind-pumped-hydro system of El Hierro is currently providing approximately fifty percent of the power on the island each year and is experiencing up to 100 percent of renewable operation use and over 10000 total hours of full autonomy since commissioning (European Commission, 2021).

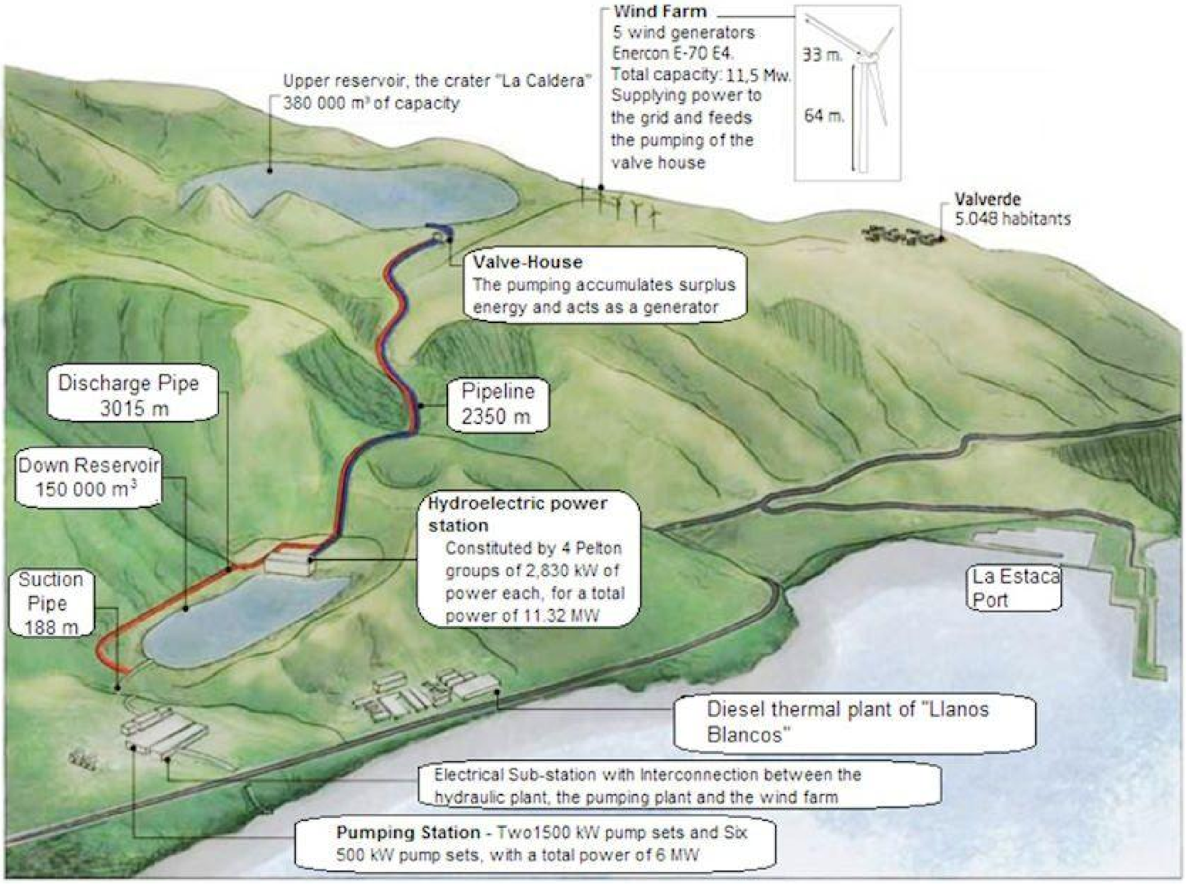


Figure 29: Wind-pumped-hydro system of El Hierro

As the systematic synthesis suggests by Ochoa-Correa et al. (2025), combinations of renewable generation and hydrogen or pumped- hydro storage coverage bring considerable renewable shares and frequency stability in several island configurations; an observation that justifies the place of storage as a core design component in high-renewable island models. Particularly in case of islands of Italian minorities, transition models are becoming more and more a multi-energy view. Groppi et. al. (2023) explicitly optimises the electricity and desalinated water on Favignana where desalination is viewed as an essential service, but as the adaptable load capable of absorbing the excess solar energy and serving as the energy storage in the form of water tanks.

Battistelli et al. (2023) associate energy with mobility and waste management, noting, among other things, that the maritime connexions are to be decarbonised, as well as the local transport fleets, and that power generation is needed. At the project scale, similar initiatives include the Islands programme of the MOREnergy Lab, the ISLET[27] project (Innovative Supporting schemes for community-Led Energy Transition) that develops decarbonisation routes of small Mediterranean islands expressly by proposing the establishment of energy communities as the governance and investment vehicle to such transitions.

Some of the cross-cutting findings that become evident as a result of this literature that can be directly applied in the case of Ischia are:

- High reliance on diesel and high energy prices, and, in particular, non-interconnected islands; transition models always indicate that PV- and wind-based hybrid systems with storage can decrease fuel consumption and total costs over time, even including investment requirement (Ciriminna, 2016).
- Tourism has a direct impact on demand profiles due to seasonal tourism. Island models, like in Favignana, indicate that peaks caused by tourism, desalination demands and cooling loads have a significant effect on optimal technology combinations and operation policies, which further supports the necessity to resolve the needs in demand and supply models hourly or sub-hourly (Groppi, 2023).
- High renewable shares cannot take place without storage and flexibility. Stored is systematically visible in situations where more than 60-70% renewable is penetrated (e.g., desalination), either with batteries, pumped hydro, hydrogen or flexible process (e.g. desalination), storage seems to be there (Ochoa-Correa, 2025).

[27] The LIFE ISLET project develops and tests support schemes and business models that help citizen-led energy communities drive the decarbonisation of EU islands.

- The concept of multi-sector integration (energy-water-mobility) is currently realised as a pre-requisite, but comparatively few of them clarify all three areas; a significant number of models thus consider transport and water as external pressures and not objects of focus within the optimisation (Battistelli F. M.-Y., 2023).

Meanwhile, some significant gaps can be noted in the comparison of these models with the REC-oriented vision of this thesis. The most common model of island transitions takes the form of the island being a unique aggregated system, and not a network of building level prosumers clustered inside a legal area like Italian primarie di cabine. They do not officially include the REC-specific regulatory framework, including the hour-by-hour definition of shared energy and primary-substation limits in the Italian TIAD, and only partially include the energy communities as institutional players, more so the portfolios and cost-optimal mixes of technologies than community ownership, community participation and energy-sharing practises.

The modelling framework derived within this thesis thus completes the available island transition frameworks with a building-scale layer based on the REC requirement. It makes use of hourly PV and demand data at building level, sums them within primary substation perimeters and enforces the Italian definitions of shared energy and self-consumption. By so doing, it fills the existing gap between the high-level island energy consummation cases and the real-life operational and regulatory considerations of an Italian island populated, with tourism-calibre high density, like Ischia.

2.13 Incentives

Incentive mechanisms form the financial backbone of most REC projects in Italy. A community may be motivated by climate concerns and social goals, but the decision to invest in rooftop PV systems and the infrastructure needed for energy sharing is still constrained by capital availability, payback times and perceptions of risk. Incentives act on these constraints in three main ways: they provide predictable revenue streams per kilowatt-hour of shared energy, they recognize the system value of local consumption, and they reduce upfront investment costs.

The current Italian regime combines:

- an operating incentive tariff on shared renewable electricity, managed by GSE;
- valuation of self-consuming and shared energy through TIAD;
- capital grants from the PNRR.

For an island like Ischia, these instruments are crucial in making rooftop PV-based RECs attractive for municipalities, residents and tourism operators, and in enabling more ambitious integration of electric mobility.

2.13.1 GSE operating tariff: structure and logic

The GSE operating tariff, established by the CER/CACER ministerial decree, remunerates each kilowatt-hour of shared renewable energy within a recognized REC. Shared energy is defined, in each hour, as the minimum between total generation from eligible plants and total consumption by member loads within the primary-substation perimeter (ARERA, 2022).

This definition embeds a strong design signal:

- installing very large PV capacity that mostly exports to the grid is not rewarded beyond normal market revenues;
- aligning generation and demand within the REC perimeter is rewarded with additional income;
- adding flexible loads that can absorb PV output when it would otherwise be exported increases shared energy and therefore incentive revenue.

The tariff itself typically consists of:

- a fixed component, differentiated by system size and designed to favor smaller plants.
- a variable component that tracks wholesale electricity prices, so that total support remains compatible with market conditions.

Eligibility conditions ensure that the scheme supports new or repowered installations, rather than retroactively rewarding old plants. Projects must be based on renewable sources, commissioned after specific dates and fall within defined capacity limits.

In the Ischia modelling, the key quantity is not the euro value itself, but the underlying shared energy curve. By simulating how shared energy changes when PV is added on different buildings and when EV corridor loads are included or excluded, this thesis can identify configurations that would, in principle, maximize the GSE incentive and thus be easier to finance.

$$E_{\text{shared hourly}} = \min\left(E_{\text{injected hourly}}, E_{\text{withdrawal hourly}}\right)$$

Equation 1: Shared energy in a Renewable Energy Community

$E_{\text{shared hourly}}$ – The shared energy in hour (kWh)
$E_{\text{injected hourly}}$ – The energy injected into the grid from the member plants
$E_{\text{withdrawal hourly}}$ – The energy withdrawn from the grid by the member loads

$$R_{\text{premio monthly}} = \sum_h \left(TIP_{\text{hourly}} \times E_{\text{shared hourly}} \right)$$

Equation 2: Monthly operated tariff revenue

$R_{\text{premio monthly}}$ – Monthly operated tariff revenue credited by GSE
TIP_{hourly} – Hourly operated tariff (€/ kWh)

System power	Incentive tariff
Power < 200kW	€80/MWh + (0-40 €/MWh)
200kW < Power< 600 kW	€70/MWh + (0-40 €/MWh)
Power > 600 kW	€70/MWh + (0-40 €/MWh)

Table 1: Incentive tariff by GSE

According to the CACER Decree, the configuration types eligible for the incentive tariff are the following (GSE):

- remote self-consumer
- group of self-consumers
- CER

The fixed portion of the incentive tariff decreased as the power of the systems increases, while the variable portion fluctuates between 0 to 40 €/MWh depending on the price of the energy.

In order to take into account, the lower production capacity of the photovoltaic systems installed in central- northern regions, the following tariff increases are envisaged:

- + 4€/MWh, for the regions of central Italy (Lazio, Marche, Tuscany, Umbria, Abruzzo)
- +10 €/MWh, for the regions of northern Italy (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piedmont, Trentino-Alto Adige, Valle d'Aosta, and Veneto).

Incentive tariff = Fixed component + Variable component. The fixed component varied based on size of the system, the variable component based on the market price of energy.

2.12.2 TIAD contributions: recognising network value

The TIAD framework provides additional economic recognition for self-consumed and shared energy, beyond the GSE incentive. It reflects the fact that locally consumed electricity reduces flows over the transmission and distribution networks, thus avoiding some infrastructure and loss costs (ARERA, 2022).

TIAD contributions are not identical for all users; they depend on:

- tariff structures applicable to different user categories;
- time-of-use bands (F1, F2, F3);
- the relative level of network charges in each zone and period.

From the REC perspective, TIAD has several implications:

- energy consumed locally in high-tariff periods (for example, daytime F1) can yield greater value than consumption in low-tariff periods;
- designing PV orientation and system configuration to better match F1 or F2 loads can improve overall economics;
- adding flexible loads like EV charging in midday F1 periods can materially increase both self-consumption and TIAD benefits.

Although this thesis does not calculate TIAD in monetary terms, its presence reinforces the strategic importance of synchronizing PV output with local demand. It also suggests that REC designs that significantly increase midday local consumption – for example, by charging electric shuttles during depot layovers – can have disproportionate economic advantages compared with designs that let midday surpluses flow to the grid.

TIAD uses hourly metering (aligned with settlement) and standard tariff components that reflect avoided network charges and where, applicable avoided losses.

In member-level analysis, bill savings depends on time-of-use bands defined by ARERA :

Band F1: Monday to Friday, from 8:00 am to 7:00 pm, excluding national holidays.

Band F2: Monday to Friday, from 7:00 am to 8:00 am and from 7:00 pm to 11:00 pm, excluding national holidays; Saturday, from 7:00 am to 11:00 pm, excluding national holidays.

Band F3: Monday to Saturday, from 12:00 am to 7:00 am and from 11:00 pm to 12:00 am; Sundays and holidays, all hours of the day.

For residential customers, for homes served under the protected regime, consumption is divided into Band F1, as defined above, and Band F23, which includes all hours included in Bands F2 and F3 (i.e., from 7:00 pm to 8:00 am on all weekdays, Saturdays, Sundays, and holidays).

GIORNO \ ORE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Lunedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Martedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Mercoledì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Giovedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Venerdì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Sabato	F3	F3	F3	F3	F3	F3	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F3	F3
Dom e Fest.	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3

Figure 30: TIAD Bands (F1-F2-F3)

2.12.3 PNRR capital grants: lowering the investment barrier

The PNRR adds a different type of support: capital grants that cover part of the costs of installing renewable plants in REC and autoconsumo configurations, with specific ceilings per kilowatt and eligibility rules that often prioritize small municipalities or specific territories (MASE, 2023).

Capital grants influence REC design in several ways:

- they reduce the amount of capital that communities or municipalities must raise upfront.

- they improve indicators such as net present value and internal rate of return;
- they can make projects viable in places where the operating tariff alone might be insufficient, for instance due to lower load density or higher installation costs.

However, because grants and tariffs are both forms of state aid, the framework includes interaction rules to prevent overcompensation. Typically, receiving PNRR support leads to some reduction in the per-kWh operating tariff ((Ministero dell'Ambiente e della Sicurezza Energetica, 2023).This makes financial modelling more complex, but the basic logic is simple: projects in disadvantaged or small municipalities can get more upfront help, but must accept somewhat lower ongoing support per kilowatt-hour.

For Ischia, capital grants can be particularly important for:

- PV systems in municipal buildings and public transport depots.
- canopy PV installations over park-and-ride areas.
- initial deployment of charging infrastructure for the electric shuttle corridor, especially if integrated into REC schemes.

Grants help ensure that the benefits of REC projects are not limited to large, well-capitalized hotel groups or private investors, but also accrue to public services and residents.

The PNRR's capital contribution is equal to 40% of the costs incurred for the construction of RES plants, within the limits of eligible expenses and the following maximum investment costs based on the power size (GSE) :

Power [kW]	PNRR maximum incentive [€/kW]
Power < 20 kW	1.500 €/kW
20 kW < power< 200 kW	1.200 €/kW
200 kW < power< 600 kW	1.100 €/kW
600 kW< power< 1000 kW	1.050 €/kW

Table 2: PNRR capital contribution

2.12.4 Combined effects: design and policy implications for Ischia

The combined effect of the GSE tariff, TIAD contributions and PNRR grants is to create a layered set of incentives that reward:

- high levels of self-consumption and shared energy.
- distributed generation within REC perimeters.
- investment in new renewable capacity rather than legacy assets.
- participation by smaller municipalities and communities.

From the design point of view, this means that the most attractive REC configurations on Ischia are likely to be those that:

- maximize alignment between PV output and local demand (residential, tourist and municipal).
- include flexible loads such as the electric shuttle corridor and possibly other EV charging infrastructure.
- make good use of municipal buildings and public spaces as anchor PV sites.
- remain within the capacity and eligibility thresholds of the national scheme.

From a policy perspective, the incentive framework motivates local authorities to look at integrated solutions. Instead of planning rooftop PV, RECs and electric mobility separately, they are encouraged to think of them as a single system: PV on roofs and depots, shared through REC structures, powering both buildings and electric shuttles, with incentives structured around shared energy and local network value.

The modelling in this thesis is therefore not simply an academic exercise in PV and load matching. It is a way of testing how different spatial and temporal patterns of production and consumption on Ischia interact with the actual incentive framework available to REC projects. The intention is that the scenarios developed here can help municipalities and stakeholders identify those combinations of rooftop PV, households, tourist structures and EV infrastructure that are not only technically feasible and environmentally beneficial, but also financially credible under Italy's current REC support regime.

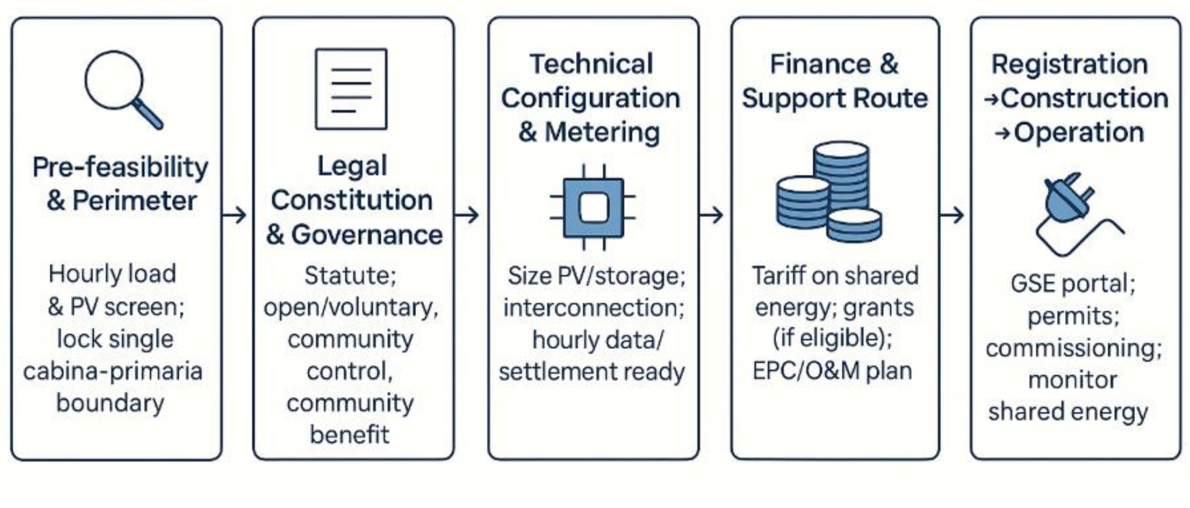


Figure 31: Design and Policy Implementation

2.13 Production and Consumption analysis with energy sharing

Production–consumption analysis is the core analytical task in any REC study, because it links the physical behavior of the system (when and where electricity is produced and used) to the regulatory and economic definitions of shared energy, self-consumption and self-sufficiency. In this thesis, production and demand are simulated at hourly resolution, and energy sharing is evaluated using the same logic that GSE and ARERA apply in practice: shared energy in each hour is the minimum between total local generation and total local demand within the REC perimeter (ARERA, 2022).

On Ischia, this analysis must capture several specificities: the distinction between resident and tourist demand; different building types (residential, hospitality, municipal); and, in later stages, the additional loads associated with electric mobility. The island context also makes seasonal variation particularly important, since summer tourism heavily distorts load patterns compared with yearly averages (Eurostat, 2025).

2.13.1 Analytical objectives

The production–consumption–sharing analysis in this thesis is designed to answer practical questions:

- How much of the residential and tourist demand can be met directly by rooftop PV in different parts of the island?
- How does this change across seasons, especially in months of peak tourism versus low season?
- What is the potential for RECs to increase local use of PV through energy sharing, compared with isolated self-consumption at the individual building level?
- How would the inclusion of new loads, such as an electric shuttle corridor, change self-consumption and the shared energy metric?

These questions are not purely academic. They correspond quite directly to the decisions a municipality or REC promoter must take when prioritizing rooftops for PV, selecting candidate REC perimeters and deciding whether and how to integrate EV infrastructure into community energy planning.

2.13.2 Data and temporal resolution

Hourly resolution is chosen because it aligns with:

- the granularity of PV output data provided by tools such as PVGIS.
- the settlement interval used in TIAD and GSE’s incentive calculations.

- the time-of-use tariff structure, which differentiates costs and values across periods F1–F2–F3 (ARERA, 2022).

Working with hourly data allows the model to reflect realistic intra-day variations in both production and demand. It also avoids the distortions that arise when daily or monthly averages are used to approximate inherently dynamic processes. For example, a daily balance might show that PV and demand are equal in a given day, masking the fact that there was a surplus at noon and a deficit in the evening. Only an hourly view reveals how much of that demand can actually be met by PV in the same hour and how much must be imported from the grid.

2.13.3 Modelling production

On the production side, this thesis models rooftop PV generation using:

- geospatial assessment of rooftop suitability (area, tilt, orientation, shading)
- allocation of PV capacity to each suitable roof segment;
- hourly output profiles for representative tilt–orientation combinations derived from PVGIS or similar models (European Commission Joint Research Centre, 2024).

These profiles are scaled by installed capacity and aggregated at building, municipal and REC-perimeter levels. Seasonal variation is captured by the underlying irradiance data, while inter-hour variations follow solar geometry and local weather patterns embedded in the PVGIS dataset.

2.13.4 Modelling consumption

On the consumption side, different demand profiles are built for:

- residential buildings: typical Italian daily patterns with morning and evening peaks, adjusted for local conditions.
- tourist accommodation: profiles with higher daytime and evening use, especially in summer, reflecting air conditioning, hot water and services;
- municipal loads: schools, offices, public lighting and other facilities, with characteristic operating hours.

Where detailed metering data are unavailable, generic load shapes from literature and national sources are calibrated with local annual or monthly energy data, including tourist presence statistics and, when possible, utility data aggregated at municipal or island level (Terna S.p.A, 2023).

For each building, an annual or monthly demand estimate is distributed across the year using these hourly profiles, scaled appropriately for high and low seasons. This yields a synthetic but internally consistent representation of demand that can be combined with the PV generation profiles.

2.13.5 Computing shared energy and key indicators

For each REC candidate configuration and for each hour h, the model computes:

- total PV generation Gh (kWh) from all participating rooftops;
- total electricity demand Dh (kWh) from all participating loads;
- shared energy Sh = min(Gh, Dh);
- PV self-consumption ratio (sum of Sh over the year divided by total PV generation);
- self-sufficiency (autarky) ratio (sum of Sh over the year divided by total demand);
- imports from the grid (Dh − Sh, when Dh > Gh);
- exports to the grid (Gh − Sh, when Gh > Dh).

These definitions are consistent with TIAD and GSE rules and allow direct interpretation in terms of REC performance (ARERA, 2022).

2.13.6 Seasonal and spatial disaggregation

To capture Ischia's specific dynamics, results are disaggregated:

- by season: peak summer, shoulder seasons, low winter;
- by time-of-use bands (F1, F2, F3), to understand when shared energy is most valuable;
- by REC perimeter and within-perimeter clusters, to identify sub-areas with particularly high or low self-sufficiency.

This disaggregation makes it possible to answer questions such as:

- In which months do tourist demand significantly increase shared energy and reduce exports?
- Do some REC perimeters reach very high self-sufficiency in summer but low values in winter?
- Where would additional flexible loads (e.g., EV charging) be most effective in absorbing midday PV peaks without creating new evening deficits?

2.13.7 Scenario analysis with and without EV integration

A final dimension of the production–consumption analysis concerns scenario comparison. This thesis contrasts, for example:

- a baseline scenario with rooftop PV and residential + tourist + municipal loads;
- a scenario where the electric shuttle corridor loads are added as REC members;

- potentially, variants where EV charging is concentrated at night versus aligned with midday PV.

By comparing shared energy, self-consumption, self-sufficiency and import/export patterns across these scenarios, the analysis reveals how much additional value the EV corridor can bring as a flexible load in REC design and where trade-offs appear.

2.14 Rooftop modelling PV potential and hourly

Rooftop PV potential assessment is a key step in translating high-level solar resource into concrete, building-level capacities. For RECs, which are typically built around rooftops rather than large ground-mounted plants, this is arguably the most important spatial input to the entire analysis. On Ischia, rooftop modelling must be sensitive to the island's morphology, building typologies, heritage constraints and the distribution of residential vs tourist structures.

2.14.1 Geospatial data and roof segmentation

The first step is to obtain and harmonize geospatial data: building footprints, a Digital Surface Model (DSM) or digital elevation data, orthophotos, and any available information on building height and use. Using GIS tools, roofs are segmented into planar surfaces. Where LiDAR is not available, segmentation relies on DSM analysis and image processing to approximate roof planes (GRASS Development Team, 2025).

For each roof segment, the following attributes are derived:

- horizontal area;
- tilt (slope angle);
- aspect (orientation in degrees, grouped into bins: N, NE, E, SE, S, SW, W, NW);

- shading indicators using hillshade or horizon analyses to capture topographic and near-object shading.

This step distinguishes flat roofs, which allow free choice of panel tilt and orientation, from pitched roofs, where panel orientation is essentially fixed by the plane.

2.14.2 Estimating installable PV capacity

Once segments are identified, an "effective usable area" is calculated by applying factors that exclude:

- areas occupied by chimneys, skylights, HVAC units;
- access paths and required safety distances;
- portions that are heavily shaded or structurally unsuitable.

A typical net-to-gross factor might range from 40% to 70% depending on roof type and density of obstacles. A conversion factor (kWp per square metre) is then applied to estimate the maximum PV capacity on each segment. The result is a building-level dataset listing one or more roof segments with associated potential PV capacities and geometries.

In Ischia's case, this process also considers heritage-sensitive areas where visible PV may be restricted. In such zones, potential may be limited or shifted to less visible surfaces (back slopes, inner courtyards, canopies over parking).

2.14.3 Hourly PV yield modelling

To convert capacity into time-resolved energy, hourly PV yield is modelled. For each representative tilt–orientation combination present on the island, PVGIS or similar tools are used to generate:

- hourly plane-of-array irradiance.

- expected PV output per kWp for a reference system, accounting for typical losses (temperature, inverter, wiring, soiling) (European Commission Joint Research Centre, 2024).

These profiles are then scaled by the capacity on each segment and aggregated:

- to building level.
- to cluster or REC-perimeter level.
- and by technology mix, if different module types or system configurations are considered.

This approach balances computational efficiency (by using representative profiles) with sufficient granularity to capture orientation effects—important on an island where east–west vs south-facing roofs can significantly change the timing of generation.

2.14.4 Validation and sensitivity

Where possible, the model can be qualitatively validated against:

- available metered data from existing PV installations on the island or in similar Mediterranean climates.
- published PV yield benchmarks for Italian regions.
- overall solar production statistics from national sources (Terna S.p.A, 2023).

Sensitivity analyses may explore variations in:

- system losses (e.g., ±5–10%);
- roof usability factors.
- PV capacity density (e.g., different assumptions on panel spacing or future higher-efficiency modules).

This ensures that uncertainty in PV modelling is recognised and that main conclusions are robust across plausible ranges.

2.14.5 Demand profiling and context databases

In parallel with PV potential, demand profiling uses context databases to build realistic hourly load curves. For residential demand, typical Italian household profiles are taken from national studies and adjusted for climate, building typology and household size (ARERA, 2022).For tourist demand, hotel and accommo dation consumption studies, combined with tourist-night statistics, inform the shape and magnitude of loads (Eurostat, 2025).

Monthly or seasonal tourist presence data are used to scale hotel and hospitality profiles up and down across the year, producing a strong summer peak and lower shoulder/off-season loads. Municipal loads are modelled through typical schedules (school hours, office hours, evening lighting) and scaled to match known or estimated annual consumption figures.

In some contexts, anonymized smart-meter datasets or system-level load curves can be used as benchmarks. For Italy, Terna's system reports and load curves help ensure that the aggregated profiles do not contradict observed national and regional patterns (Terna S.p.A, 2023).

2.14.6 Integrating PV and demand: spatially explicit hourly balance

With hourly PV and demand for each building or group of buildings, a spatially explicit hourly energy balance can be built for each REC candidate perimeter. This integration is what turns rooftop PV potential maps into actionable REC scenarios:

- each building is assigned one or more roof segments and a demand profile;

- buildings are grouped into REC clusters that comply with primary-substation perimeters;
- PV production and demand are aggregated at the cluster level to compute shared energy, self-consumption and self-sufficiency.

For Ischia, this means that each part of the island can be characterised by:

- its rooftop PV potential;
- the mix and seasonality of residential, tourist and municipal loads;
- its position relative to REC-eligible perimeters.

This integrated perspective is then used in the subsequent analysis of REC design and EV integration.

CHAPTER 3

ELECTRIC MOBILITY

CHAPTER 3: ELECTRIC MOBILITY AND RENEWABLE ENEGRY COMMUNITIES IN ISLANDS CONTEXT

The transport sector has gone to a greater scrutiny especially after climate change and environmental degradation. The transport of people through roads is a major cause of the greenhouse gases and city air pollution. This means that many governments are supporting electric vehicles (EVs) as a necessary part of sustainable mobility especially when paired with the rapid adoption of renewable energy resources. Islands are particularly satisfactory laboratories of nature with this transition. (International Energy Agency, 2024)

They often have an excessive dependence on imported fossil fuels, limited and weak infrastructures, and, at the same time, have significant potential of renewable energy. Therefore, a number of the European and Mediterranean islands are currently exploring options to deal with sustainable mobility as well as energy self-sufficiency simultaneously. Achieving three main goals is the aim of the chapter in a broader context:

- to present the electric vehicles and investigate their environmental, infrastructural, and economic impact.
- to examine how EVs might be integrated within Renewable Energy Communities (RECs), with a specific focus on island settings.
- to describe and evaluate a planned outdoor light rail/electric shuttle project on the island of Ischia, viewing it as an EV-based sustainable transportation intervention that might be connected to a nearby REC.

The chapter is structured in the following way. In section 3.2, the methodological framework used in the study is stated. Section 3.3 takes a look at electric vehicles (EVs) and its environmental, economic, and social impacts. In Section 3.4, renewable energy certificates (RECs) are introduced, and the possible synergistic interactions between EV deployment and community-scale renewable energy efforts are critically evaluated. In sections 3.5 and 3.6, the context of the project of the light rail/electric shuttle in Ischia is established and the project introduced. Section 3.7 is a comparative analysis of the proposal of Ischia regarding similar initiatives in other islands and coastal areas. Section 3.8 covers feasibility, integration with RECs and long-term sustainability. Lastly, Section 3.9 will conclude the findings and provide tentative conclusions.

3.1 Methodological Approach of the Chapter

The chapter takes a conceptual/case-study approach that incorporates three main elements. To begin with, both the academic and grey literature on electric vehicles (EVs), sustainable mobility, island settings, and renewable energy communities has been provided in the form of a narrative literature review. The sources included in the review are reports created globally policy documents that concern EU, articles created by scholars who discuss EV integration, transportation of islands, and community energy (IPCC, 2023).

Second, a document analysis was carried out on materials related to the Ischia "metropolitana leggera a cielo aperto" proposal, local mobility policies, and regional planning documents; this analysis facilitated a detailed description of the Ischia case and the reconstruction of the rationale underlying the proposed light-rail/shuttle system.

3.2 Electric Vehicles and Sustainable Mobility

3.2.1 Environmental impacts of EVs

Electric vehicles generally refer to road or rail vehicles, which are powered fully or partly by electricity, which can be battery powered (battery-electric vehicles), overhead lines (trams, trolleybuses), or both (hybrids). What is relative to an internal combustion engine vehicle (ICEV), there are a number of salient environmental benefits that electric vehicles are expected to have.

To begin with, electric vehicles have zero tailpipe CO_2 and domestic air pollutants including nitrogen oxides (NO_2) and particulate matter. This short-term gain will improve urban air conditions and reduce the contact of the residents and tourists with toxic pollutants (IPCC, 2023). The reduction of emissions in the form of localised actions, in particular, can be especially significant in urban areas or tourist locations that have a high population density.

Second, electric cars are more energy efficient. The ratio of the fraction of input energy that is translated into motion by electric drive systems is commonly very high compared with the case of combustion engines. In addition, the well-to-wheel analysis has shown that the electric vehicle uses less energy to drive a single kilometre than the ICEV, including the consideration of the upstream electricity production (International Energy Agency, 2024).

Third, electric vehicles ensure that noise pollution is reducing particularly in low driving speeds where engine noise prevails. The lower noise levels in the upper centres, coastal promontories, and natural environments that are coming with the reduced traffic enhance the quality of life and presence of the tourist sites (Miedema, 2001). There are two major issues that should be considered in relation to these benefits. The former is related to the lifecycle emission: even electric cars, not mentioning their batteries, require manufacturing energy and heavy resources use.

However, it is stated that through life-cycle assessment, electric vehicles are typically compensated with their initially high manufacturing pollutants in the first couple of years of operation, after which their overall emission over the course of the lifecycle is significantly lower compared to ICEVs (ICCT, 2021).

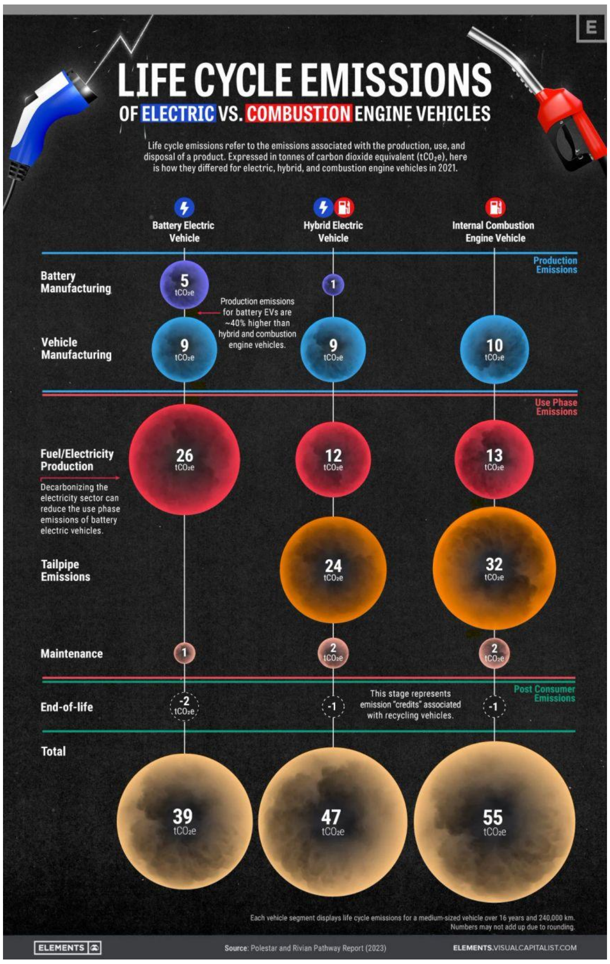


Figure 32: Life cycle emissions of EV vs Combustion vehicles

The second concern concerns resource extraction and end-of-life management: the mining of battery minerals such as lithium, cobalt, and nickel may entail environmental and social ramifications, underscoring the necessity for stricter environmental regulations, enhanced recycling protocols, and the promotion of second-life applications (Harper, 2019).

The overall picture suggests that, in the event of powering them by an increasingly decarbonizing grid, electric vehicles can offer tremendous benefits of greenhouse gas and local emissions in comparison with conventional vehicles (IPCC, 2023).

3.2.2 Infrastructural implications of EV adoption

The vehicle fleet electrification has great implications on the infrastructure planning. The shift requires creation of the network of dense and reachable charging infrastructures which include the facilities at domestic buildings and at workplaces, at car parks, transport stations, and at main routes. There should be integration of a diversity of charging speeds, which are slow AC, fast DC and ultra-fast, business models, which are public and private provision as well as pay per use and subscription, to meet heterogeneous demand (International Energy Agency, 2024).

At the same time, used by a large number of electric cars, the load profile of the electric power grid changes. Local distribution networks and transformers will be overloaded when a massive group of EVs is charged simultaneously and at both the peak periods, such as, in the early evening. Electric vehicles have the potential of overloading the available infrastructure, thereby increasing peak demand without proactive planning, which is a compounding factor of the problem (Menyah, 2012). The measures to reduce these risks include smart charging approaches where grid operators and policymakers recommend that charging should occur during off-peak hours or during the hours or times when renewable energy generation is heavy, especially solar energy (Hledik, 2019).

Smart charging programmes and dynamic tariff systems are proper to flatten the load curves and lessen the need to introduce expensive reinforcements to the grids (Sovacool, 2018). In addition vehicle-to-grid (V2G) technologies allow electric vehicles to act as both consumers and sources of electricity (under certain conditions) of the grid, which means that they also serve as a source of distributed storage (Kempton, 2005).

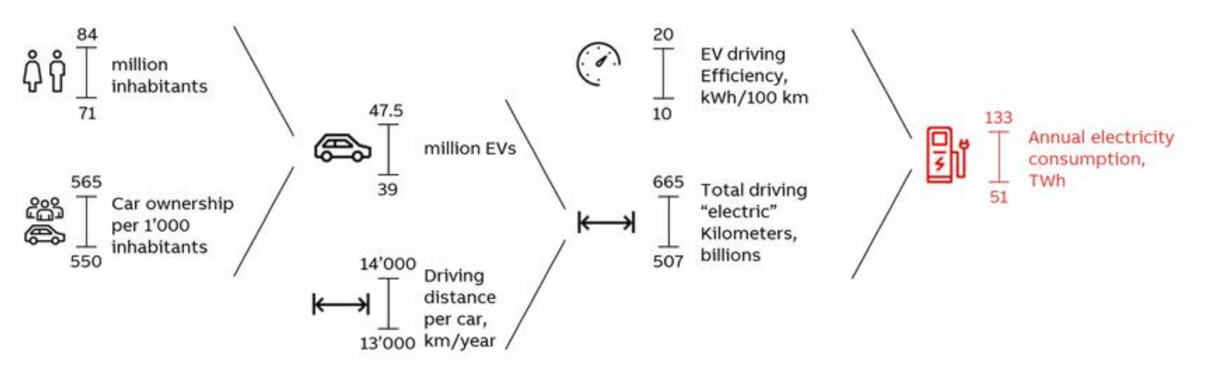


Figure 33: The change in assumptions of demographic, cars, and utilisation

The context of an island is highly infrastructural. The remote islands have disconnected or loosely connected grids and still depend partly on the diesel generators to provide electricity (Soomauroo, 2023). Already unpredictable seasonal peaks are characterized by tourism activity and residential air conditioning that put additional pressure on the system. EV charging should not be implemented without an overall plan as it may increase these risks.

However, the smaller distances, and smaller settlement patterns of the islands, can support the delivery of charging infrastructure as more efficient than over the continent. By combining EV charging with the use of locally accessible solar photovoltaic energy sources, e.g., installing solar carports in ports, in park-and-ride facilities, or bus depots, the load on the central grid can be reduced, and a process of aligning charging demand and the locally generated renewable energy can be achieved (CIVITAS, 2013).

3.2.3 Economic implications of EVs

The EV transition is multi-dimensional in terms of economics. EVs generally cost less to operate in the case of individual users compared to internal combustion engine vehicles (ICEVs). The cost per kilometre is lower with electricity than it is fuels and due to fewer moving parts, EVs cost less to maintain (International Energy Agency, 2024).

The initial cost of buying a vehicle is higher, but the cost benefit increases during the life of the vehicle, especially in the situations when the high fuel prices are observed, including the islands that are dependent on import of diesel and gasoline (Soomauroo, 2023). On a national and regional level, EV will reduce reliance on imported fossil fuels and the lack of energy security. Funds previously directed toward oil imports could be reallocated toward domestic electricity generation and infrastructure, including renewable energy sources and grid upgrades (IPCC, 2023).

Small island developing states (SIDS), or another group that often devotes a significant part of their GDP to imported fuel, will have a lot to gain through EVs that will be powered using local sources of renewable energy, enhancing the balance of trade and supporting economic resilience (Soomauroo, 2023). Industrial and the labour markets are also changed by the EV transition. The automotive industry is most actively involved in battery and EV production, which has led to the production of new jobs in the battery industry, e-mobility service, and charging networks, and the traditional engine and fuel supply chains can shrink (Sierzchula, 2014).

This structural change requires proper policy levels which include retraining programmes and regional development strategies. There is also interference with the public funds. Fuel taxes are another major source of revenue to many governments that may decrease as the EV uptake increases, leading to other forms of tax such as road-use charges being considered (OECD/ITF, 2021). Meanwhile, concomitantly, health savings in terms of better air quality, reduction of noise, and expansion of benefits in relation to climate can be significant (Shindell, 2012).

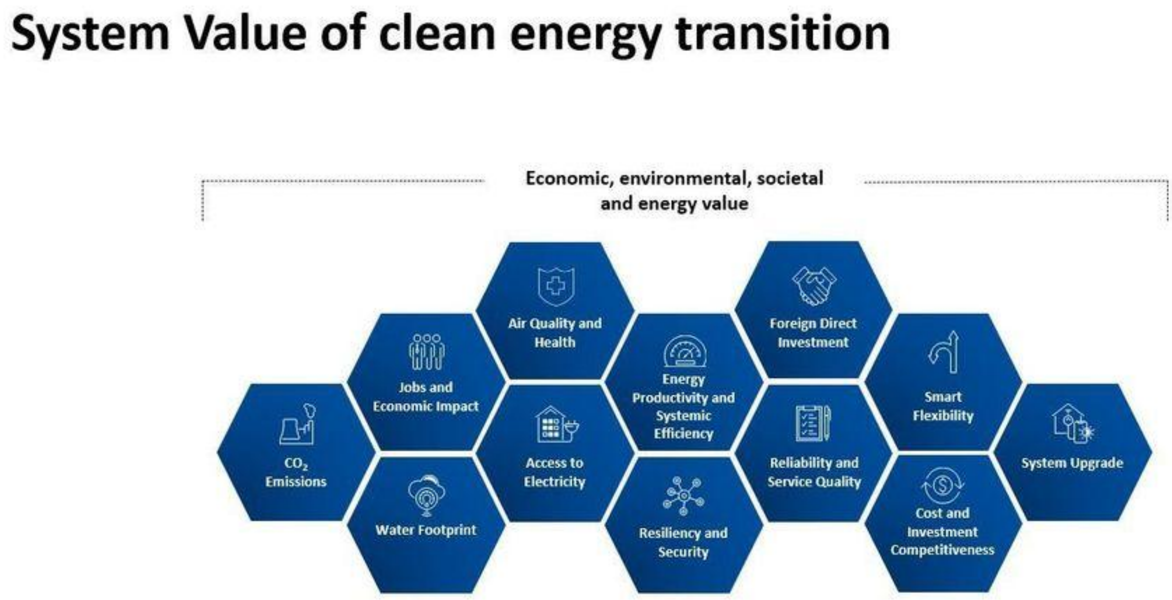


Figure 34: Economic and energy value

Although the cost-benefit analysis shows that the advantages of EV deployment to society are higher than the public funding in the long run in cases where the environmental externalities are sufficiently considered (International Energy Agency, 2024). In the case of island economies that are heavily reliant on tourism, the EV-based solutions can be introduced as an addition to the value: cleaner air, less noise, and a unique image associated with being green can be offered to the brand of the island and help it rise in terms of attracting environment-conscious tourists (Maltese, 2021).

3.3 Integrating EVs and Renewable Energy Communities

3.3.1 Concept and role of Renewable Energy Communities

Renewable Energy Communities (RECs) are organizations in which residents, local authorities, small firms, or other actors collaboratively create, share, and manage renewable energy. Under the European legal framework – in particular Directive (EU) 2018/2001 (RED II) – RECs are characterised by open and voluntary participation; effective control by local members; a primary purpose of delivering environmental, economic, or social benefits rather than profit maximisation; and the capacity to generate, consume, store, and sell renewable energy (European Parliament and Council, 2018).

RECs frequently rely on shared solar PV systems on public buildings, residential roofs, or community-owned facilities, along with local consumption by members (Roberts, Frieden, & d'Herbemont, 2019). This may help lower electricity costs, keep money flowing in local economies, build up social capital and increase tolerance toward renewable projects (Gui, 2018).

According to recent analysis, RECs are multifunctional local energy organizations that may solve energy poverty, support local development, and facilitate citizen engagement in the energy transition. (Caramizaru, 2020).

3.3.2 EVs as flexible loads and storage in RECs

There are a number of roles EVs can assume in a REC.

First, since it is a flexible demand, EV charging may be timed to match times of high local renewable generation (e.g. midday solar peaks). This enhances self-consumption of the community produced electricity and decreases external grid importation (Ullah, 2022). Either straightforward time-of-use tariffs or novel smart-charging programmes can harmonise the charging behaviour with renewables (Hledik, 2019).

Second, by using bi-directional chargers (vehicle-to-grid or vehicle-to-building) EV batteries can be used as distributed storage. Under the conditions when the community has an excess of renewable energy, EVs would take extra charge, when there is a deficit or a peak in demand, they would re-feed electricity into the system. This increases the ability of the REC to deal with variability and reduces the need to have stationary batteries (Kempton, 2005).

Third, the combination of energy and mobility assets helps RECs to realize economies of scope. A community can co-fund photovoltaic systems and charging infrastructure to serve their cars and a community or shared car fleet of EVs. Sources of revenues may include electricity sales, grid services and in some cases transport fare or service contract (Gui, 2018).

Lastly, EV programmes in REC, i.e. shared electric vehicles, e-bikes, or e-shuttles can be very visible and raise awareness and interest in people, which makes the energy community more real in daily life (Roberts, Frieden, & d'Herbemont, 2019).

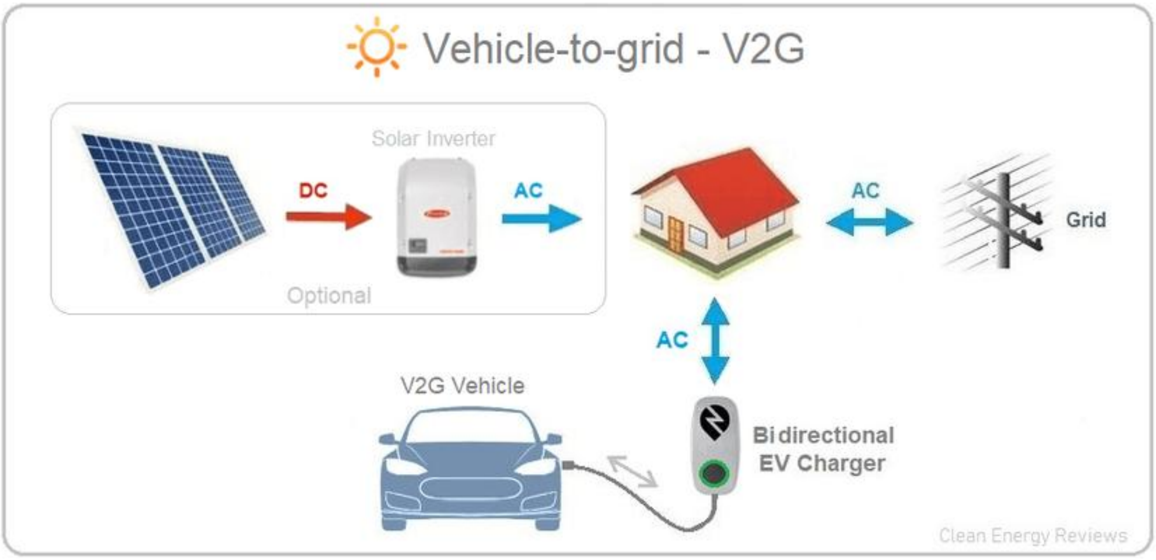


Figure 35: Vehicle to Grid (V2G) energy flow diagram

3.3.3 RECs and EVs in island context

The combination of electric vehicles (EVs) with renewable energy certificates (RECs) is especially appealing in island settings due to the following reasons: most islands have massive potential of renewable resources, whether in the form of solar power or wind power; they often have small, isolated electric grids where flexibility gains significant importance;

they are highly reliant on imported fuel sources of both electricity and transport; tourism increases seasonal changes in the energy demand and mobility (CIVITAS, 2013).

EV and hybrids - EVs, car rentals, buses, or shuttles can be used to absorb renewable peaks when supply and demand of electricity do not match. Meanwhile, charging EVs using local renewables would do as much as possible to maximise the climate benefit of transport electrification and facilitate the discourse of a green island (Martínez, 2023).

The development of RECs on Italian islands, such as recent efforts in Ischia, is a tangible institutional avenue through which EV-based projects in the area of public transport can be institutionalised in a wider decarbonisation policy (Caramizaru, 2020).

3.4 Case Study Context: The Island of Ischia

3.4.1 Socio-economic and spatial characteristics

The volcanic island of Ischia is located in the gulf of Naples, occupying an area of about 46 km^2 and the permanent population of nearly 62,000 people. The Body of administration is further subdivided into 6 municipalities that include Ischia, Casamicciola Terme, Lacco Ameno, Forio, Serrara Fontana, and Barano d Ischia. The region is mostly fueled by economic activity based on tourism such as thermal spas, beaches, and culture plus services, small-scale commerce, and agriculture (Maltese, 2021).

Figure 36: Road map of Ischia

Population in the area is high, and the built environment is typified by a mosaic of small towns centers, linear development of the coast and small scattered dwellings in the interior hilly areas. The geomorphological limitation of the island and the steep nature of the slopes and small nature of the valleys cause limitations in the potential large-scale infrastructural development. Roads have developed out of ancient lanes, and they tend to be narrow and meandering, especially in older settlements.

3.4.2 Mobility challenges on Ischia

The recent mobility crisis on Ischia has a number of severe problems as reported by local news and scholarly studies (Maltese, 2021).

- *High motorization rate*: The island has about 1 motor vehicle per person that includes cars as well as two-wheelers. The ownership of cars only shows 63 cars per 100 people, which is highly above the national figures, a sign that people are highly dependent on cars.

- *Tourism-induced congestion*: The effective population can also increase four times during the peak tourist season thus crowding the major road corridors. The ports of Ischia, especially Porto and Casamicciola, are especially impacted as well since motor movements have been overloaded with ferry disembarkation. It is a characteristic of the main coastal road to have long queues and slow traffic flows.
- *Network constraints*: The road system is provided with one major coastal ring road and with a system of small interior streets. Many of the settlements and hotels and tourist sites are located through narrow roads which cannot accommodate large buses, thus restricting the effectiveness of traditional forms of public transportation in condensing all places in an efficient way.
- *Transport restrictions in the area of the village zones*: The regional company has bus routes that serve the major routes, but have long had issues with regularity, overcapacity, and mismatch in the size of the buses. Financial problems every now and then have also deteriorated the quality of the services and many residents and tourists tend to prefer riding scooters or renting cars.
- *Regulatory paradox*: Temporary restrictions on the arrival of vehicles of non-residents to eliminate congestion are implemented seasonally. The prevalence of scooter and car rentals in the island nullifies these bans. It is often costly and inconvenient to have tourists carry their vehicles into the country and renting locally allows tourists to save money and preserve traffic, at the same time.
- *Environmental impacts*: Combination of large volumes of traffic, high percentage of older vehicles, and overcrowded flows lead to high air and noise pollution especially along the coastal road and in the centres of history. All these effects to the environment do not align with the idea of a wellness and nature destination that Ischia is.

These demands prove the need to reconsider the concept of mobility in Ischia adopting a more systemic and sustainable perspective (Maltese, 2021).

3.5 Comparative Experiences in Island and Coastal Regions

3.5.1 Astypalea (Greece)

The small island of Astypalea, located in the Aegean Sea became a pilot project to test a smart and sustainable island project. The project aims to replace a substantial share of typical motor vehicles with electrically powered vehicles, vans, e-scooters, and e-bikes, introduce app-based on-demand shuttle services, and to develop a solar park and battery storage, thus to provide renewable electricity to the electric vehicle (EV) fleet (Volkswagen AG, 2022).

Figure 37: Electrified Greek Island

Astypalea shows the feasibility of a combined strategy, which simultaneously implements the transport electrification, new mobility services, and renewable generation. The major lessons to Ischia are the need to match EV implementation and the need to utilise renewable energy at home, need to offer collective transport options reducing the demand to own personal vehicles, and need to have incentives that would encourage locals to switch to electric vehicles.

3.5.2 Capri (Italy)

Another island that belongs to the Gulf of Naples is Capri which can be taken as an example of how strict accessibility is regulated concerning individual vehicles. Most of the year, non-resident vehicles are forbidden, and movement is fostered by:

(a) funicular railway connecting the marina to the main town

b) minibuses and taxis, some of which are electrically propelled; and

(c) extensive pedestrian walks with little use of small vehicles across pedestrian-friendly streets (Maltese, 2021).

Figure 38: Main bus station in Capri

Capri demonstrates that strong policies that reduce access to cars can succeed socially and economically with the help of the strong alternatives. Although Ischia is not able to fully imitate the regime of Capri because of its larger size and population, the comparison implies that decisive actions regarding the traffic control, combined with high-quality transportation can be tolerated, and they will be able to keep the spirit of the island.

3.5.3 Gran Canaria (Spain)

Gran Canaria has developed plans of electric light-rail line between the capital Las Palmas and tourist sites in the southern coast. The scheme is aimed at giving a replacement to high capacity of cars in a busy route and to operate using renewable energy mainly generated by Island wind and solar power (Martínez, 2023).

Figure 39: Electric light-rail line

Modelling studies show that there could be considerable car traffic and energy reduction as well as CO two emissions in case the rail line is developed and combined with buses and park-and-ride centres (Martínez, 2023). The experience of Gran Canaria, Ischia highlights the importance of the design of electric rail or bus rapid (OR) transit systems as elements of a larger intermodal network and of actively scheduling the renewable energy supply to traction.

3.5.4 Other relevant examples

Other examples, including: Zion National Park (USA), where a light bus (now full-electric) provides millions of tourists with transportation a year; Mauritius, which is working toward electrification of light-rail and buses across metropolitan areas; and numerous other coastal cities (e.g., Nice, Santa Barbara), which use electric trams or buses when they need to handle a waterfront, all testify to the fact that specially dedicated electric public transport can effectively substitute in terms of cars in environmentally sensitive areas or high-traffic routes (CIVITAS, 2013).

3.6 The Open-Air Light Rail / Electric Shuttle Proposal

3.6.1 Design principles and description of the project.

To remedy the issues mentioned above a new project has been suggested and that is the following: the “metropolitana leggera a cielo aperto” translated to mean the light metro in the sky. This is operational as an idea of high frequency dedicated shuttle corridor on the main coastal road, with traffic controls and cycling facilities.

The initial section proposed would be between the Ischia town on the eastern side (Ischia Ponte) and Ischia Porto and Casamicciola, and finally in the municipality of Lacco Ameno; Capitello. This is the longest line on the ring road on the island and links great population hubs, port terminal and tourist spots.

Key design elements include:

- Dedicated right-of-way

This corridor would have the coastal road reconfigured so that the priority was given to shuttle vehicles which travel in both directions at a high frequency. Either private cars and scooters would prohibit this area, or they would be severely restricted with some types of vehicles (taxi, emergency vehicles, delivery vans) permitted to enter this area under certain conditions

Figure 40: Proposed open-air light air

- Vehicle typology

The initial house idea was to have minibuses with a length of about 8 metres and around 60 seats, with the models having the ability of significantly cutting down the emissions as opposed to the normal buses that use diesel. In the context of the current thesis, these vehicles are also developed as battery-electric minibuses or light tram-bus vehicles, so that they can be completely decarbonised in case of being driven by renewable electricity.

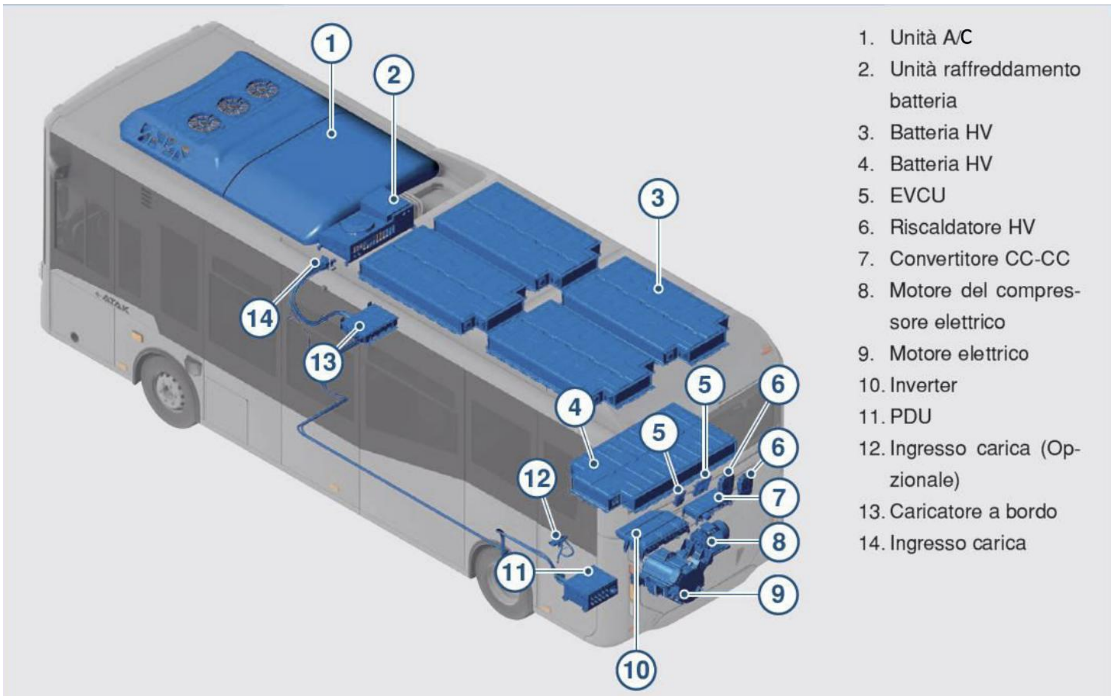


Figure 41: KARSAN e-ATAK minibus

- Service characteristics

    The ridings are configured to run in short headways (high frequency), long operating hours daily and straightforward and clear routes. The main factor to be considered is reliability and convenience to attract residents and visiting tourists to avoid personal vehicles.

- Urban integration

    The line is open air, which means it is on the level of the street, so the urban design is also to be taken into account to incorporate stops, pedestrian crossings and approach to the waterfronts as well as town centres. Elimination of extensive, personal traffic and vehicles on the road creates space available to re-design the land to sidewalks, plants and other public avenues.

3.6.2 Cycling facilities and last mile solutions.

Cycling and micromobility are to be part of the project as a complement to the shuttle:

- It is suggested to have a pedal-assisted cycle path parallel to the shuttle path where space is not a constraint and where there will be complementary routes.
- An e-bike path across the pine forests (Pineta Mirtina and Pineta degli Atleti) is imagined between Piazzale delle Alghe and Piazza degli Eroi among numerous strategic destinations in Ischia Porto.
- More cycle lanes or shared low speed roads are planned along parts of the seafront and on secondary roads enhancing continuity to cyclists.

In localities that do not come directly on the main shuttle route (e.g. hill settlements, isolated houses), smaller scale, more adaptable solutions are envisaged:

- shared or rented quadricycles and e-scooters of last-mile connexion.
- community / cooperative models with vehicles like the Ape Calessino, which have long been on the island, to offer local bus services.

These steps are proposed to make sure of the accessibility of residents and visitors even in case of decreasing the usage of personal cars on the main corridor.

3.6.2 Costs to be expected and the issues of concern.

The light rail / electric shuttle system is an open-air mechanism that is aimed to accomplish several objectives that are interrelated:

- Environmental improvements

The project would have the side effect of reducing the emission of air pollutants and greenhouse gases along the corridor and lowering the level of noise produced by the great number of personal vehicles and the old-fashioned diesel buses.

- Less congestion and better travelling duration.

Getting the bulk of the cars off the main corridor and favouring shuttles would ease the traffic as well as enhance reliability and travel time using the means of transportation.

- Rationalised land use and parking.

When the number of cars travelling and parking cars in the corridor reduces, the pressure on parking spots in historic centres would drop. It might also repurpose some parking spaces and convert them to other purposes or replace them with park-and-ride terminals.

- Improved image and use of the transport that is available to the public.

With the help of a modern, electric shuttle network, the image and attractiveness of public transport can be greatly enhanced, which will promote the movement towards the modal shift of private cars and scooters.

- Tourism and branding

The project adds to a storey of Ischia as a green island, which is a strength to promote the project as a sustainable wellness destination.

Meanwhile, a few essential problems and risks should be taken into consideration:

- The limited space could make it difficult to have a completely separated lane throughout the route, and context-sensitive solutions will be needed.
- This may not be accepted and may be opposed by imposing traffic control to the vehicles owned privately without giving alternatives and gentle introduction.
- Funding and operation expenses have to be properly analysed and that capital expenditures of vegetation and infrastructure and life-cycle expenses of electric fleets.
- There is the need to have institutional coordination among the municipalities, transport operator, regional authorities, REC organisations and individual stake holders.

These dimensions are also expounded in Section 3.8.

3.7 Feasibility, REC Integration and Long-Term Sustainability

3.7.1 Technical and economic feasibility.

Technically, Ischia open-air light rail/shuttle system should be possible: the modern electric minibuses have adequate performance range even considering the rather short area and can be charged overnight or opportunity charging at endpoints (International Energy Agency, 2024). Priority and access restrictions can be enforced with traffic-management technologies as well as physical means, whereas the island already has a bus depot which could be modernised to use electric vehicles.

The economic side of the project requires initial capital investments in vehicles, road layouts and charging systems; however, these costs are offset by the cost of operating electric buses per kilometre is expected to be lower compared to diesel-powered vehicles (energy and maintenance) (International Energy Agency, 2024), external benefits such as decreased health spending due to pollution, time savings due to a reduction in congestion, and increased tourist attraction (Maltese, 2021), and possible funding by schemes offered by national, EU programmes aimed at encouraging sustainable mobility and energy conversions A clear cost-benefit analysis is needed in later chapters, but conceptually the estimated balance indicates that the project would be justifiable in case co-benefits are included.

A renewable community aims to integrate with communities powered by renewable energy sources using renewable materials.

3.7.2 Interaction with Renewable Energy Communities Renewable community

Interaction with Renewable Energy Communities Renewable community is to interact with the community powered by a renewable energy source using a renewable material.

- Coupling the shuttle system to a local renewable energy community (REC) can also significantly upgrade the sustainability: the traction energy used in the electric shuttles can be partially provided by community-owned photoelectric arrays (e.g., on the municipal buildings, depots, at the park-and-ride spaces).
- Instead of having external utilities, the transport operator would buy electricity at the REC, hence keeping values on the island and benefiting its members (Gui and MacGill, 2018; Roberts et al., 2019).
- The REC can further maximize self-consumption and minimise the imports to the grid as well as alleviating the peaks due to the maximisation of how often the shuttle is charged by the PV generation (Ullah, 2022).

Its practical implementation would involve:

- making the transport operator a member of the REC.
- developing tariff and sharing policies to capture the consumption of the shuttle
- investing in smart charging technology which is responsive to REC signals.

The next stage, the buses might in future be experimented with more sophisticated features like vehicle-to-grid capabilities used by the shuttle fleet, and this could turn the buses into community mobile stores (Kempton, 2005).

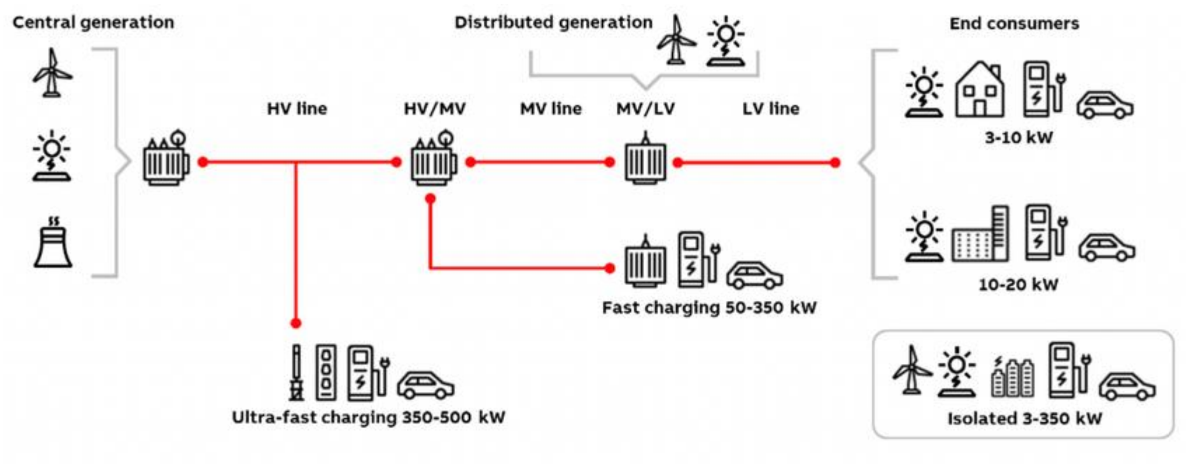


Figure 42: Schematic representation of how central and distributed electricity generation connect through high-, medium- and low-voltage lines to end consumers

3.7.3 Instruments of governance, behaviour and policy.

Success of the Ischia project rests not alone on the basis of technology and finance, but also governance and behavioural change:

- institutional coordination should be made by the municipalities and the region to the transport operator, REC organisations to the private stakeholders (Caramizaru, 2020).
- Access control, parking control, speed regulation, and pricing policies are policy tools that should be formulated and strictly implemented (CIVITAS, 2013).
- It requires public communication and involvement; the citizens and companies must feel that the new system is beneficial and does not interfere with their everyday routine and financial opportunities (Maltese, 2021).
- Implementing transition management should be gradual and flexible; this could be by starting with pilot segments or implementation during specific seasons, which can be expanded upwards as the implementation is accepted.

As practise on other islands shows, as soon as the citizens see the positive effects of the reduced traffic congestion and better use of public areas, the resistance to the ban on cars is likely to fade away (Maltese, 2021).

3.8 Synthesis

This chapter has explored the interplay among electric vehicle, community-based renewable energy, and sustainable mobility into closed settings with an open-air light rail/electric shuttle project in Ischia taking centre stage. The analysis explains the synergistic nature through which these aspects could be used to solve special transportation and energy problems inherent with any island setting.

The main conclusions of this study can be outlined as follows:

- EVs present explicit environmental advantages compared to traditional vehicles, such as low emissions and sounds, as well as have the economic one, like low operating prices and less fuel imports.
- their implementation requires careful planning of charging systems and grid connection (IPCC, 2023). Renewable energy communities (RECs) represent an excellent institutional model of localised renewable energy implementation in a community.
- EVs may serve as a source of flexible loads/assets of storage, which will be especially useful to small grids or isolated ones (Ullah, 2022).

Ischia is facing strong barriers of mobility, which are high motorisation rates, seasonal congestion, infrastructural constraints, as well as environmental pressures. Conventional fixing strategies are not sufficient to harmonise business interests of tourism and the quality of life enjoyed by residents (Maltese, 2021).

The suggested metropolitana leggera a cielo aperto is a reaction to these problems in sense of a holistic vision: a special shuttle lane on the major coastal highway, traffic congestion, cycling roadway and supplementary last-mile services. This suggestion modifies transportation and energy transitions into a consistent system, when understood as an electric system, which would be coupled with a REC.

The existence of analogous initiatives in different contextual settings with some varying constraints and opportunities confirms the viability and efficiency of specific efforts in other locations and islands (Soomauroo, 2023) (Roberts, Frieden, & d'Herbemont, 2019). Ischia project depends on technical engineering, economic support, integration of REC, governance networks, and acceptance of the project by the citizens. However, the potential benefits such as reduction of emissions, elimination of congestion, improvement in public spaces and strong positioning of tourism are significant.

Overall, the case of Ischia can serve as the example of how the interventions of localized mobility can be integrated into the wider practices of energy democracy and decarbonisation. The potential of the electric public transport powered by the own renewable energy community-based has the ability to be a salient and a strategic part of a fair and sustainable transition in small islands. The analytical framework as expressed herein, that is, connecting EVs, RECs, and island mobility, forms the conceptual basis of the more comprehensive quantitative analyses and scenario analysis that should be carried out in the following chapters.

CHAPTER 4

CASE STUDY

CHAPTER 4: CASE STUDY

The current chapter locates Isola d'Ischia as the empirical location of analysing the feasibility of the Renewable Energy Communities (RECs), dispersed rooftop photovoltaic (PV) plants and the incorporation of the electric, public transport under an island energy system. Its purpose is not just a description of the island, but rather to outline how the geographical, demographical, topographical features, environmental constraints, hazard profile, electrical infrastructure, and tourism dynamics restrict the design space of REC designs, and local energy sharing designs.

Section 4.1 gives the geographical and administrative background of the island. The second section, 4.2 examines the demographics and household setups and how they relate to energy needs. Section 4.3 is concerned with topography, geology and environmental designation and how they relate to the location of infrastructure. The constraints and natural hazards have been evaluated in Section 4.4 more particularly flooding, landslides, coastal erosion and seismic risk. Section 4.5 explains the electricity system with the highlighting of the primary substations and regulations perimeter that controls energy sharing. Section 4.6 studies demand in the season generated by the tourism and its interdependence with the availability of solar resources. Section 4.7 presents the conclusions and states the reasons why Ischia is particularly a suitable example in the context of community-based energy transitions and self-sufficiency of islands.

Figure 43: Ischia

4.1 Geographic Setting

Ischia is located on the island in the Northern Gulf of Naples, about the Tyrrhenian Sea, and about 30km south-west of the municipality of Naples. It belongs to Phlegraean Islands archipelago, and the others are Procida and the islet of Vivara. The island, though it has a relatively small size of about 46km^2, portrays outstanding landscapes and coastal morphology (Orsi, The Ischia volcanic field: Structural setting, eruptive history and hazard, 1999) which have also led the island to play a historic record in terms of being a strategic maritime route as well as a major tourist destination in the Campanian coastal tourism system.

Figure 44: Campania region

Its administrative municipality is the Metropolitan City of Naples (Regione Campania) and composed of six municipalities: Ischia, Forio, Barano di Ischia, Casamicciola Terme, Lacco Ameno and Serrara Fontana.

Figure 45: Municipalities of Isola di Ischia

The largest urban centres, port facilities, and a high density of tourism related activities are located in Ischia and Forio- these are the more rural locations of Serrara fontana that are thinly populated like Serrara fontana, located on the steep side. Such a multi-municipal structure not only brings about institutional complexity, but it also allows variousiated local planning approaches in terms of coherent island-wide approach.

Ischia has a morphologically pressed foot pattern, about trapezoid, with an inlet northward of the coastline with opposite sinks in the forms of pocket coastlines, tidy bays, rocky headlands, and precipitous truffle cliffs. Monte Epomeo occupies the interior and is a re-emerging block of volcano and it has an elevation of about 789m a.s.l (Nappi, 2021).

This gradient up of this block along with the fault systems around it create steep slopes along the interior with sudden topographical splits as hills become coastal plains and terraces. These geomorphological differences also find their reflection in settlement: high urbanization and tourism-based growth use low- slope coastal belts, but high slopes are filled with vineyards, chestnut depots and isolated hamlets. The seaside stretch that includes Ischia Porto, Casamicciola, Lacco Ameno and Forio makes up a quasi-continuous urban strip with very high building density, tight streets and mixed uses of land. Most of the economic functions of the island such as the hotels, restaurants, the retail outlets, small industries, and port facilities are taking place in this fringe. On the other hand, the municipalities of the interiors, Barano and Serrara Fontana, have more discontinuous built-up patterns, terrace agriculture and relatively restricted provision of service.

In the case of renewable-energy-capacity (REC) planning, this inland coastal distinction would mean that the densities of rooftop photovoltaic (PV) potential and loads are unevenly spread, which are concentrated on coastal nodes. Ischia belongs to the

Mediterranean type (**Csa** according to the Köppen 3 system) with mild winters, hot and arid summers and transition spring and fall seasons (Peel, 2007)

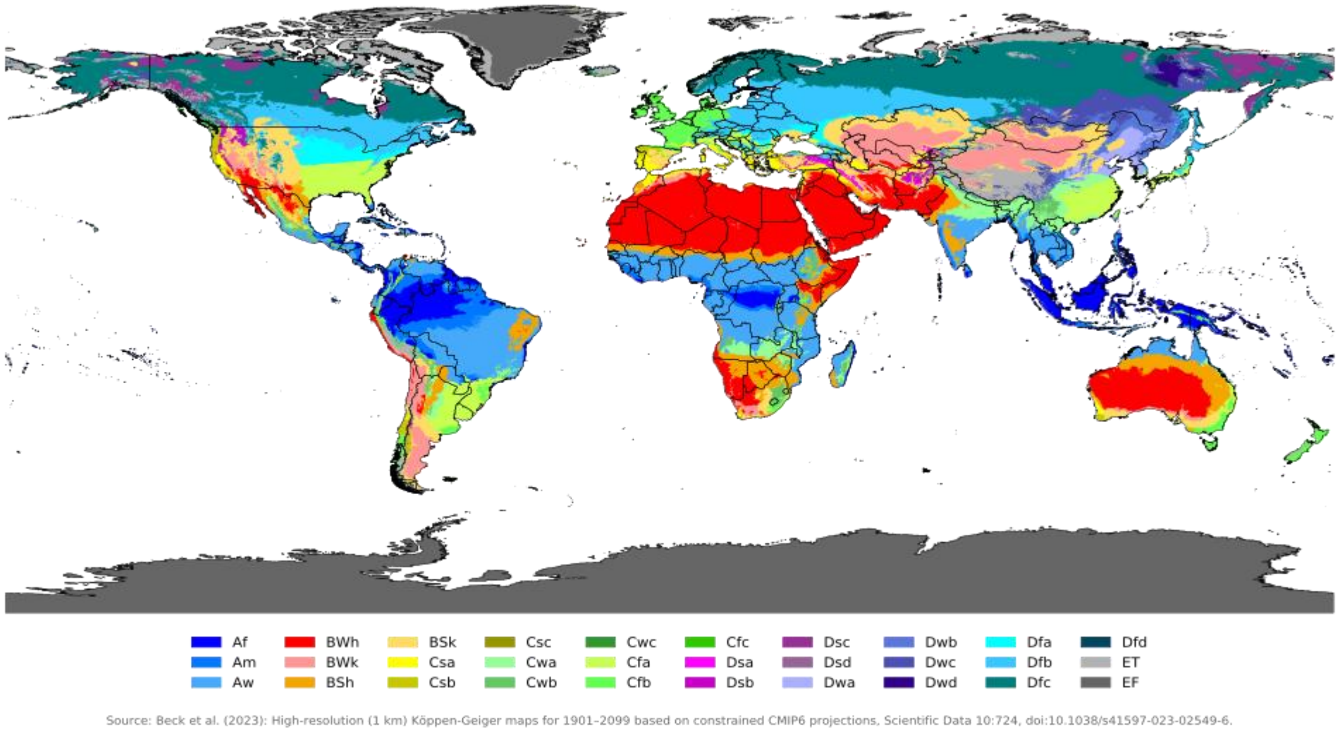


Figure 46: Köppen–Geiger climate classification map (1991-2020)

1ST	2ND	3RD
A (Tropical)	f (Rainforest) m (Monsoon) w (Savanna, dry winter) s (Savanna, dry summer)	
B (Dry)	W (Arid desert) S (Semi-arid steppe)	h (Hot) k (Cold)
C (Temperate)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer)
D (Continental)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer) d (Very cold winter)
E (Polar)	T (Tundra) F (Ice cap)	

Table 3:Köppen climate classification scheme symbols description table

It is due to high solar irradiation rates per annum, long summer photoperiods, and intermittent sea breezes that cool summer heat, and can circulate cool air over PV modules to advantage the islands. This climate is twice energy-wise, beneficial to produce solar energy, but, at the same time, it creates a strong impetus to find alternative cooling in high-rise buildings and transport centres in the summer season (Trull, 2019).

At the regional and landscape plan, the whole area of the six municipalities is covered under the Piano Territoriale pří Paesistico dell Frisito mp isculato su Ischia (Ischia Landscape Plan). Implemented on the basis of the national landscape acts, this plan creates the rational system of protecting and transforming the territory of the island as a unity, but not on the basis of the municipalities. Its Norme di Attuazione (implementing rules) give specific prescriptions on the detail of the building forms, material, roofscape, and transformations. Such a coherent scaffold of planning is important to REC implementation: rooftop PV[28] systems, energy additions and high-profile technical installations need to be examined in relation to one set of island-wide morphological and scenic requirements, not a regalice of local mandates.

[28] Solar panels installed on building roofs that convert sunlight directly into electricity, typically connected behind the meter of the building or within a local distribution grid.

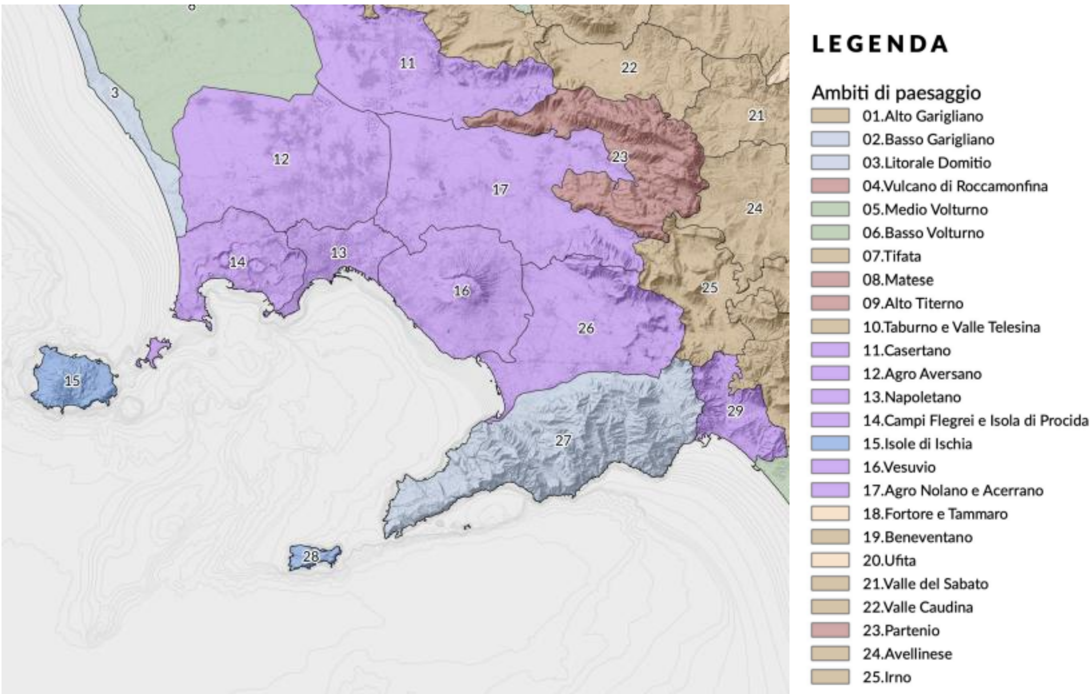


Figure 47:Landscape ambits of the Campania region

In the marine environment, Ischia, Procida, and Vivara waters are the Area Mariniana Protetta (AMP) called Regno di Nettuno by the ministerial decree to protect marine biodiversity, submerged habitat, and coastal ecosystem. The AMP is further divided into zones (A, B, C) with variated limitations to anchoring, fishing and navigation. Even though rooftop PV is terrestrial, any submarine cables, pier retrofits, and coastal depot upgrades relating to RECs or electric public transport should be subject to AMP regulations and cumulative effects on marine ecosystems should be appropriately taken into account (Piantadosi, 2018).

The geographic location of Ischia has its opportunities and limitations concerning the energy planning process. The definite physical boundary of an island system creates opportunities related to the accounting of imports, exports, local generation, and other aspects and consequently enables assessments of self-sufficiency. Topographic steepness, paucity of land, and high levels of coastal and landscape protection are the factors that lead to constraints, in favour of PV on rooftops and facade of buildings rather than on large parcels. Therefore, geographic profile of Ischia is favourable to exploration of distributed energy solutions built into the current settlements (which is a key priority of REC practises).

i) Demographic Profile

The tourism economic background makes up the demographic profile of Ischia as a medium one-town island community. High permanent population density is present in conjunction with great seasonal tourist inflows, which creates very high variability in the samples of population-equivalent and the resultant energy demand to the calendar year (Battistelli F. M., 2023).

4.i.1 Resident population and density

It has a permanent population of about 60,000 people and the urban centre of the city, Ischia-Forio alone found about 60,400 people according to recent statistical releases. Some of its coastal regions have over 1,200 residents per km 2, placing Ischia among the more densely populated Mediterranean islands of similar proportions (Pleijel, 2015).

In this regard, the municipality of Ischia, which is the largest demographic pole, has around one-third of the demographics on the island, with the next largest being Forio. The smaller (in absolute terms) populations of Casamicciola Terme and Lacco Ameno are built up and receive concentrated tourism and spa services. Barano d'Ischia and Serrara Fontana, both with smaller population, nonetheless, create sufficiently high demand by residential use, agritourism, and local services. This high density and small area mean that the vast majority of residents are in close proximity with each other and the local services, two implications which are direct.

To begin with, electricity delivery networks have the capability of servicing most people with a comparably small infrastructure footprint. Second, thousands of customers within relatively long distances can be covered by potential REC boundaries with the main substations of the primary origin, which is beneficial to the diversity of the loads in communities.

Variable	Municipality of Ischia	Municipality of Barano d'Ischia	Municipality of Forio	Municipality of Lacco Ameno	Municipality of Serrara Fontana
Demo					
Demographic density (N° inhabitants per Km²)	2,409	911	1,337	2,165	477
Demographic size (N° of inhabitants)	19,600	10,002	17,477	4,505	3,077
Average members of the family (N°)	2.13	2.29	2.09	2.02	2.35
Foreigners Incidence (%)	5.8	5,2	9.5	6.5	5.4

Table 4: Comparative analysis of all the municipalities

4.i.2 Type of households and types of dwellings

The trends in household structures in Ischia are characteristic of the national tendencies in Italy: average households sizes have become smaller, the population has become older, and the proportion of foreign residents has increased, although still insignificant (ISTAT, 2023). Older couples and single elderly people often live in many households especially in the inland villages compared to the coastal municipalities where mixed age structures face families and seasonal workers.

Types of dwellings include historic masonry structures in the centres of old towns, post-war multi-family blocks, individual scattered single-family houses and small apartment blocks in peri-urban outskirts. A large percentage of houses are second homes or vacation apartments belonging to non-residents and used on a part-time basis. This creates a vast amount of unused built area during winter and can create potentially high intensity, but short duration uses during summer in terms of energy-modelling.

In the case of rooftop PV, that means that numerous roofs can be physically large enough to instal PV but not produce much at the location during winter that in other words may not result in as much self-consumption annually unless the roofs are incorporated into REC schemes that can serve local consumers.

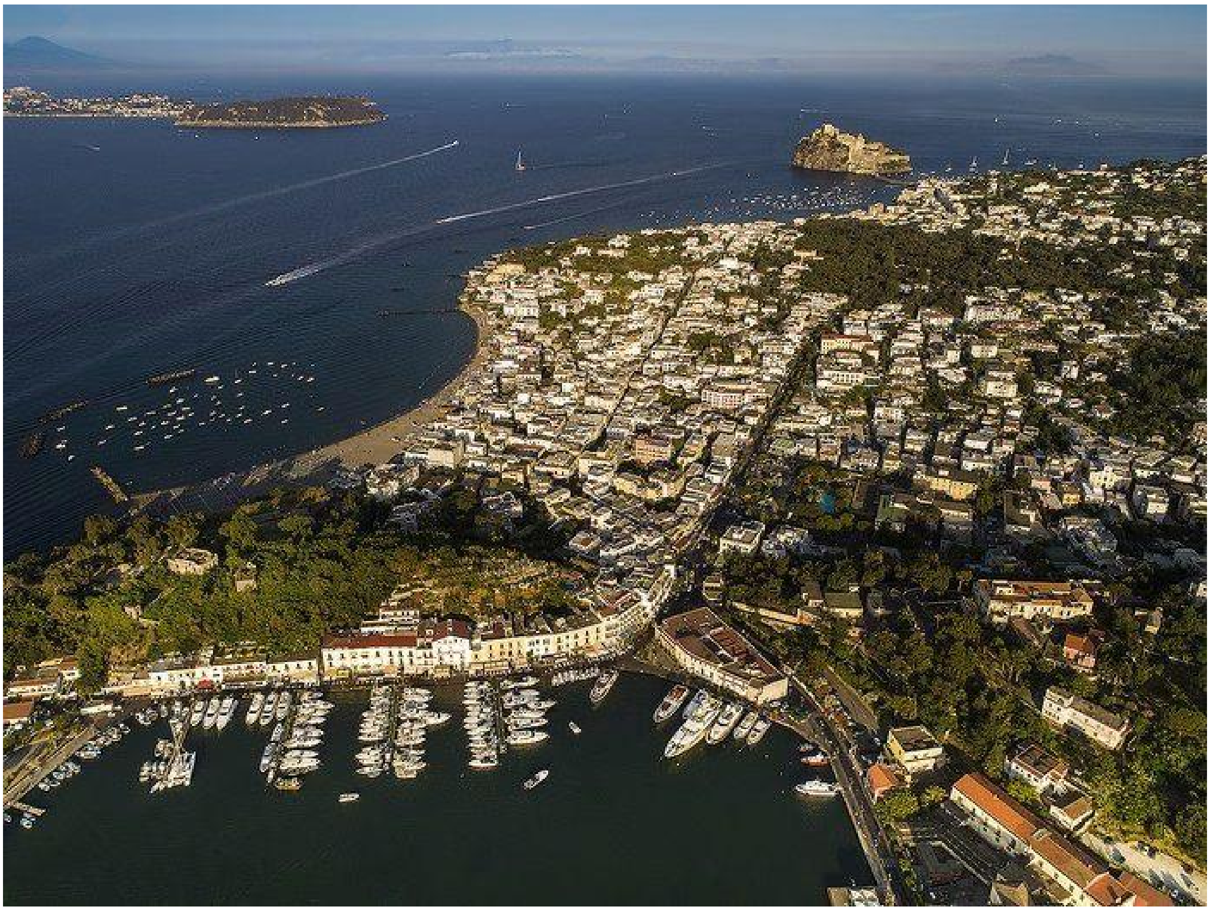


Figure 48: Houses and dwellings in Ischia

4.i.3 Tourism dependency and economic structure

Ischia is very specialised economically and the hospitality, thermal spas, restaurants, retail and transport business are the main pillars of the local jobs. There are agricultural activities (vineyards, horticulture) and small-scale fishing that have a secondary place in the entire economy (Busignani, 2022). The economic structure is completed by the public services (schools, hospital, municipal offices), as well as small commercial enterprises. The prevalence of tourism brings with it a high level of seasonality.

During the popular months, the visitors might be three to five times more than the local residents (Pileri, 2017). Hotels, guesthouses, wellness centres, and holiday rentals are almost at full capacity, and other services beneficial to the resort stay, like laundries, restaurants, entertainment centres, and such, operate on longer hours. This causes furniture utilisation of electricity particularly in air conditioning, hot water, food preservation and lightening.

In REC perspective, this means that non-residential members (e.g. hotel, spa, store) can be significantly used as flexible loads being active at the time where most important solar production is made, thus increasing shared energy volumes.

4.i.4 Social aspects and participation by REC

The social implications to the acceptance and governance of RECs also present the demographic profile. The relatively high permanent population around the coastal towns has a relatively large potential base of REC members, both households and small and medium-sized enterprises (SMEs). The ageing population can also create more interest in measures that stabilise or lower the energy bills, especially when the energy prices are volatile and the risk of energy poverty of older, low-income households (Bouzarovski, 2018).

At the same time, co-existence between the permanent residents and seasonal occupants brings up equity and representation in the RECs. There are cost distribution and benefits division decisions that must reflect the presence of households occupying homes on the island throughout the year and households who own their second homes but may not contribute much to the winter load. The designing of statutes and engagement approaches are, thus, essential so that legitimacy would be guaranteed and that no one would perceive that only a few better-off members of society are gaining.

4.2.5 Construction of demand profile and sources of data

On the methodological level, quantitative foundation of developing composite demand profiles is based on demographic and tourism statistics of ISTAT and regional tourism observatories along with the municipal records. The permanent Census and municipal time series are used to come up with the baseline resident population and household numbers per municipality.

In order to factor in tourism, the arrivals and presences (nights spent) are multiplied by the population equivalents per season which is then summed with the per-capita estimates of electricity consumption across the various accommodations (hotel, apartment, campsite) (Gössling S. P.-P., 2012). The combination process enables developing of monthly or even daily population-equivalent curves which can be converted into hourly load profiles with the help of conventional Italian domestic and tertiary consumption profiles and corrected to cooling degree days. These profiles play an essential role in the analysis of matching of PV-load to power, as well as in the study of the configuration of REC later in the chapters.

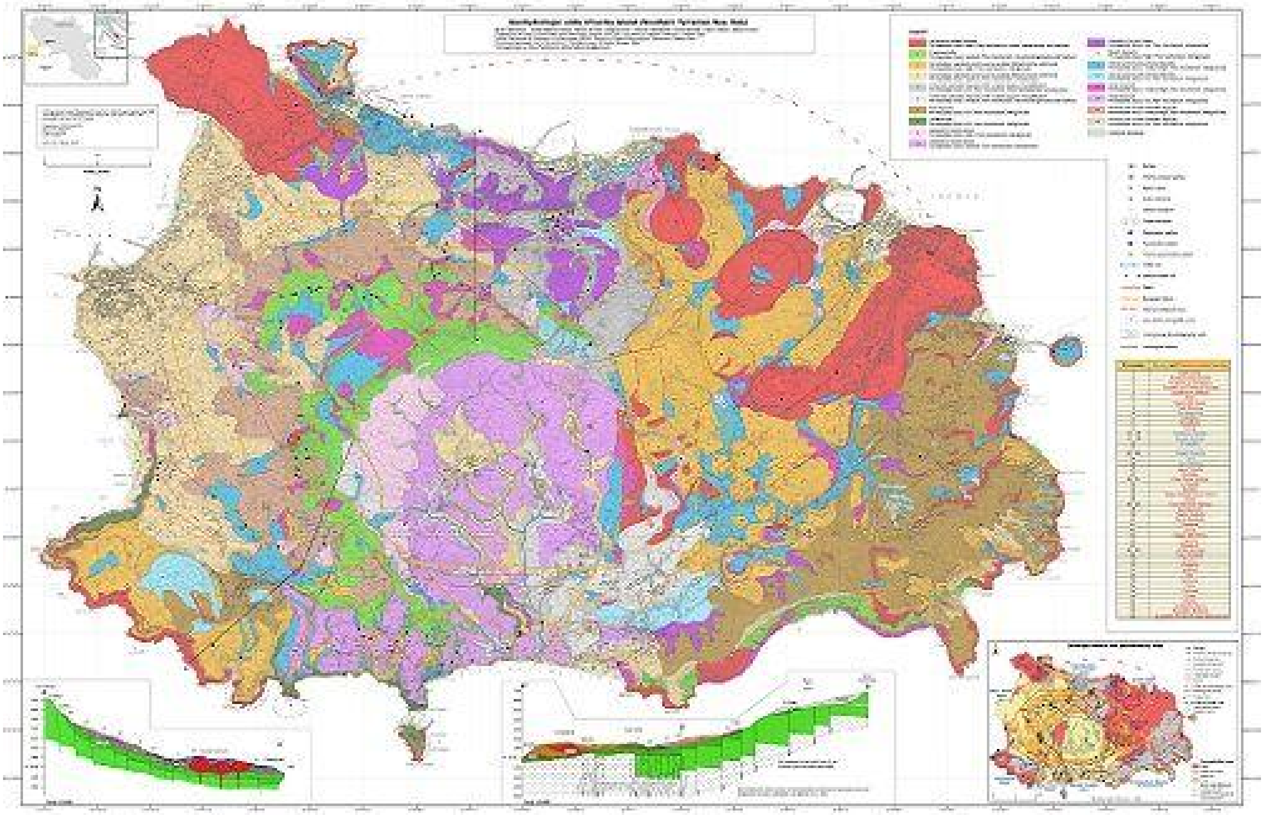


Figure 49: Schematic map of main settlement areas and density gradients, highlighting the concentration of residents along coastal belts.

ii) Topography, Geology, and Environmental Setting

Ischia topography and geology are both crucial prerequisites to the understanding of environmental susceptibilities of the island as well as technical limitations in the arrangement of energy infrastructure.

4.ii.1 Volcanic origin and resurgent block

The town of Ischia is located in the Campanian volcanic arc and is within the larger area of Campi Flegrei-Ischia volcanic district. Its most prevalent morphological feature, Monte Engages, is a resurgent block which is lifted up due to magmatic and tectonic activity along a caldera structure (Orsi, The Ischia volcanic field: Structural setting, eruptive history and hazard, 1999). The uplift since the Late Pleistocene has been many hundred metres in extent, which forms a plateau-like topography between steep side slopes which slope toward the adjacent coast.

Underlying material is mainly volcanic tuffs, lava domes, pyroclastic fall sediments and ignimbrites, on top of which have freshly reworked epiclastic and colluvial materials. Very often these deposits are extremely weathered and uncompacted, and this makes a good part of the slopes vulnerable to landslides in the seasons when strong rains occur. The island is cut by faults and fractures, and these provide a supply of hydrothermal fluids, in addition to affecting slope stability.

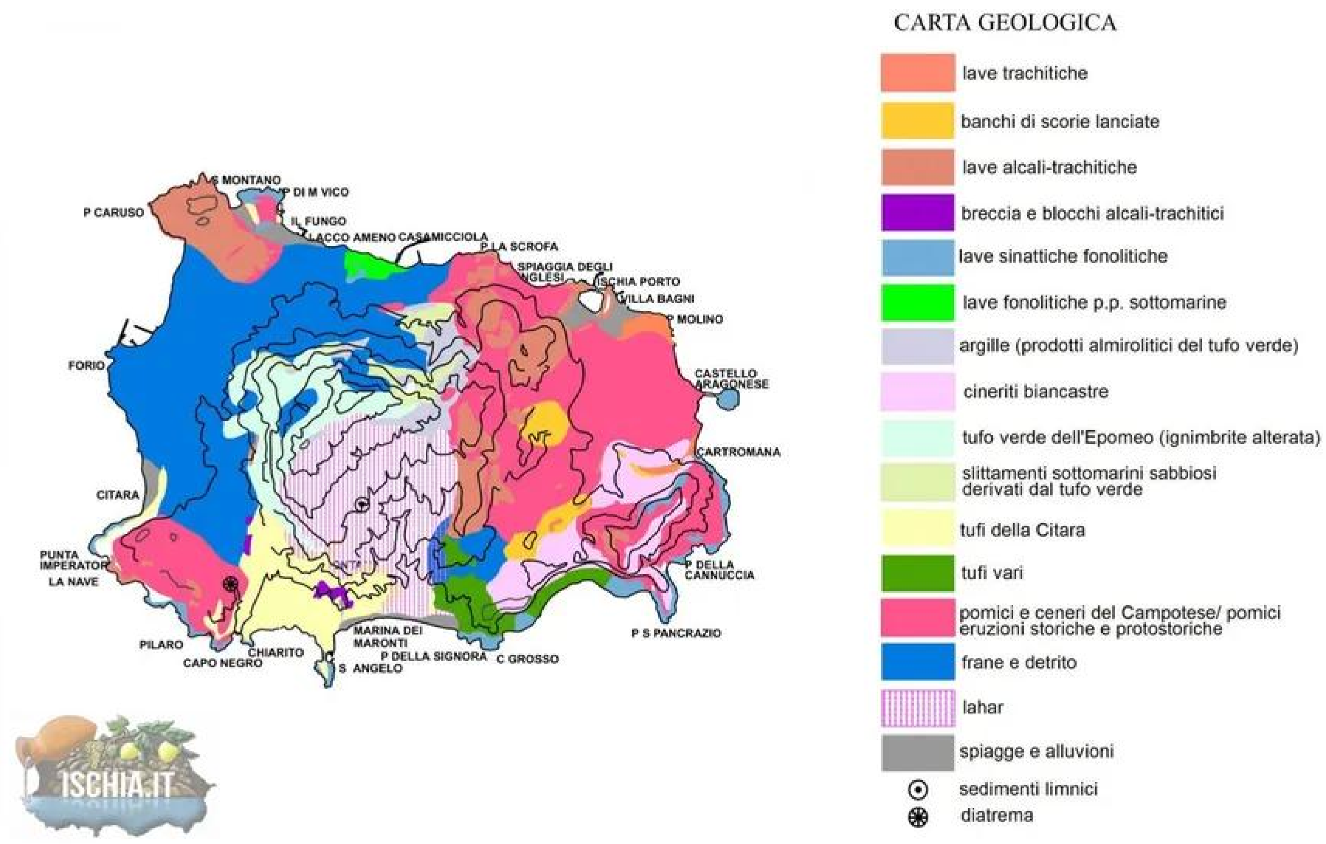


Figure 50: distribution of volcanic formations and sediments across Ischia

4.ii.2 Lithology, slopes, and land use

Due to their interplay, lithology and uplift have resulted in a complicated pattern of slope units. The most unprecedented and the most unstable slopes are on the north and north-western side of Monte Epomeo and within blatantly cut-out valleys near Casamicciola and Forio (Matano, 2023). On the other hand, softer slopes and minor coastal plains have formed where the lava flows or pyroclastics are not that steep or the coastal depositions have formed lowlands. These geomorphic conditions are represented by land use patterns. The area on the plains and low slope terrace encourages high-density urbanisation, transport routes, and farms (vineyards, orchards). Mid-slopes areas are mainly fed by terraced agriculture and woodlands, but the highest altitudes are relatively natural with woodland and scrublands. This arrangement has the planning implication that most acceptable rooftop surface area is located in the lower-slope urban areas, whereas steep slopes prone to landslides are less favourable to the heavy technical installations.

4.ii.3 Hydrothermal resources and geothermal potential

Ischia is famous with its rich sources of thermal springs and fumaroles, the temperatures of which in some cases are more than 80° C. These are resources based on the fact that the geothermal gradient in the island is very high and the magmatic heat that is available at a depth (Caliro, 2012).

Most spa and wellness centres are also watered with thermal waters that are not only considered as large tourist resources but also direct uses of underground heat. Even though generation of electricity using geothermal is not presently done in Ischia, low-temperature geothermal would, theoretically, be utilised in space heating, domestic hot water, or absorption cooling in larger complexes (Lund, 2016).

This offers a possible future opportunity to develop renewable energy systems further: the combination of low-carbon heat and cooling with geothermal resources with photovoltaic electricity in the hybrid community energy systems.

Figure 51: Hydrothermal resources

4.ii.4 Environmental designations and biodiversity

There are also a number of protected areas in Ischia across the terrestrial domain, such as Natura 2000 sites, which preserve a variety of pine forests, coastal cliffs, and a home to the communities of interest. These include the locations; Pinete dell Isola d Ischia, and Rupi costiere dell Isola d Ischia. The marine Natura n. 2000 location Fondali marini di Ischia, Procida e Vivara (offshore) is located in the marine environment where the seagrass meadows

(Posidonia oceania), corals, and other vulnerable marine ecosystems are safeguarded (European Environment Agency,2011).

Such coinciding names put a limit on the location of infrastructure. An example is the having of hundreds of new ground-mounted photovoltaic technologies on slopes or coastal bluffs that have not been developed is not preferred or allowed generally. Any thermal, electrical or charging facilities poised in or in the vicinity of these sites should be properly assessed to be able to ascertain that no substantial adverse effects on habitats and species will take place.

4.ii.5 Climate and microclimates

Although the macro-climate of this island is generally Mediterranean, there are micro-climates due to the differences in altitude, exposure to the slope and exposure to sea winds. Slopes that face south get more solar irradiance and generally have warmer microclimates in comparison with the north-facing slopes.

Temperatures in the coastal regions are relatively lower, and humidity is higher as compared to those in the slopes. These microclimate differences can cause small impact on photovoltaic production (i.e. temperature and wind cooling effects) and building energy requirements (i.e. high cooling requirements in low-wind, urban canyons).

Photovoltaic potential mapping in a photovoltaic potential mapping viewpoint, such microclimatic subtleties are tertiary to rooftop geometry (slope, aspect, shading) but can be taken into account in the estimation of annual yields and performance ratios.

4.ii.6 Rooftops PV and EV implications.

The overall topography of Ischia, its geology, and environmental context, are highly supportive of a distributed system of rooftop photovoltaics generation as opposed to large ground-based systems. There is a lack of flat non-urbanised land, high landscape value, and geohazard vulnerability that gives low opportunities to large-scale photovoltaic farms. On the other hand, the construction of roofs in urban and peri-urban regions suggests a universal, un-exploited area to mount the solar.

These types of installations may be integrated with existing building shapes, this being subject to restrictions brought about by the landscape planning rules. In the case of electric vehicle (EV) infrastructure, such as depots and fast-charging hubs, Geological maps should be avoided in slope areas that are likely to be susceptible to storms, as well as in natural reserves that are preserved. The benefit of a coastal location is that it might be convenient, but there should be a keen eye on the coast erosion and storm surge.

Interior sites adjacent to those of the existing substations and major road junctions might be better, in the context of risk mitigation and grid integration.

iii) Constraints and Natural Hazards

Energy infrastructure in Ischia needs to operate within a complex risk environment, which is regulated by landscape conservation policy, and designated areas, a continuum of natural hazards which may include landslides, inundations, coastal erosion, and earthquakes.

4.iii.1 The constraint on landscape and cultural-heritage

Detailed zoning and normative prescriptions of building forms, material, and modifications are codified in the Piano Territoriale Paesistico dell'Isola d'Ischia, on the entire island. In high scenic and cultural importance localities, e.g., historic town centres, panoramic views, and coastal views, the plan controls visible changes in the roofspace geometry and colouring, and also to the placement of technical apparatus concerning photovoltaic (PV) modules, IT antennas and heating ventilation air conditioning (HVAC).

These rules are meant to maintain the beauty and cultural character of the island in order to support its tourism value (Busignani, 2022). Therefore, to use a deployment of REC, there should be a visual integration of a roof-top PV installation: it should be able to match current roof slopes, use non-glare modules, or be located on in-place roof planes less visible. PV can be limited or require special permits in some of the designated historically significant buildings or other areas of extreme sensitivity.

The landscape plan will not deny PV therefore but will create conditions that will require architectural sensitivity to design.

4.iii.2 Marine conservation area and coastal restrictions.

The AMP Regno di Nettuno[29] has put in place the scheme of zoning where the protection around Ischia, Procida and Vivara is graded. At travelling and general reserves are Zones A and B (zone of integral protection) and B (general reserves), restricting anchoring, fishing, and underwater activities, and other areas have regulated uses (Piantadosi, 2018). Though rooftop PV is earth-based, a number of other elements of an island energy transition (such as developing submarine cables, shipping shore-power, or building coastal depots of electric-vehicles) may overlap with the AMP.

Projects that involve laying new cables or other major works in the coastal-marine ecosystem should undergo environmental assessment in order to make them fit in line with the objectives of AMP. This highlights the significance of focusing on in-island generation

[29] A marine protected area around Ischia, Procida and Vivara that regulates fishing, anchoring and other uses to safeguard marine ecosystems and coastal landscapes

and efficiency as an effort to reduce the demand on other or heavier submarine systems, which would further impact on marine ecosystems.

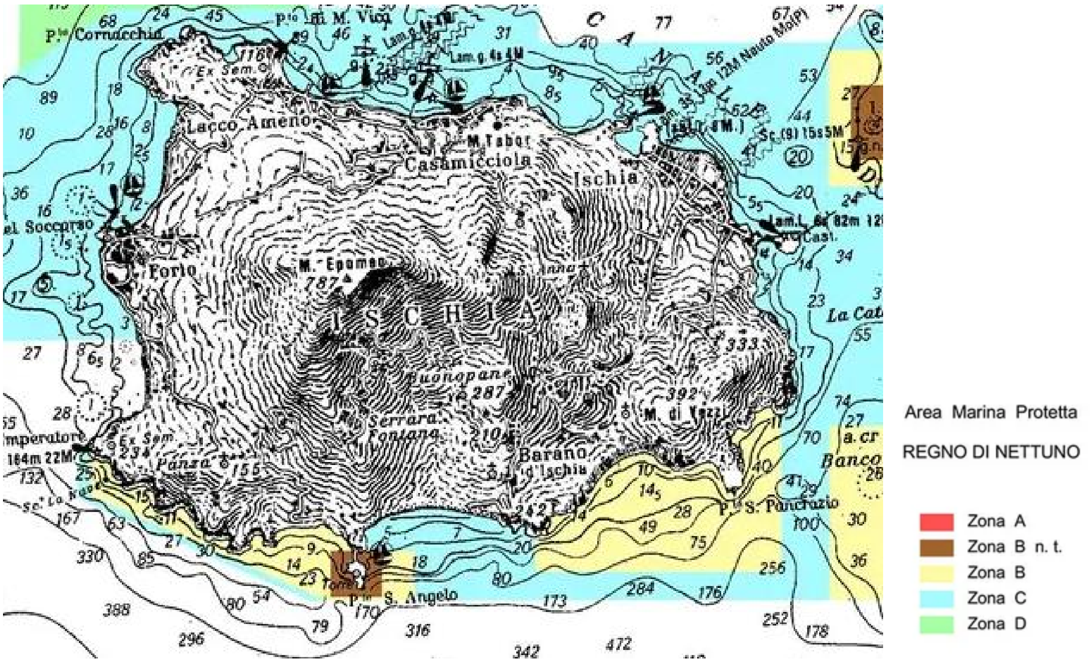


Figure 52: Marine protected area of Isola di Ischia

4.iii.3 Natura 2000 and constraints to biodiversity

Natura 2000 Ischia sites and environs are managed by standard data forms that set conservation goals and priority habitats and species. Any proposed interventions which may affect these sites, like ground-mounted PV systems in natural locations, large slopes-stabilisation works, or large transport depots, should be regulated by Habitats Directive. In the case of RECs, it mainly impacts the centralised, greenfield PV plants and EV hubs in large scales located in natural or semi-natural environments, which are typically discouraged. Therefore, REC needs to be developed in already urbanised or highly adapted areas: in already rooftops, car parks (PV canopies), brownfields, and industrial locations.

This resonates with the movements in the conceptualisation of the REC policy to having citizen-led and neighbourhood-based projects fitted within local built environments instead of the distance utility-scale generation plants.

Figure 53: Landscape structure of Ischia (natural and semi-natural landscape types)

4.iii.4 Hydro-geomorphological risk

Ischia is generally known as a landslide-prone area, and the number of disastrous events that occurred in the last century is enormous (Matano, 2023). Combination of slopes, pyroclastic soils, high incidence of rain-descent and high density of human settlement on the sensitive slopes leads to repeat landslides and gush flows.

An example is that the 1910 episode caused mudflows and flash floods in Casamicciola, Lacco Ameno, and Forio; the event of 2006 in Monte Vezzi led to flashy water flows that demolished houses; and that of 2022 in Casamicciola left behind 12 dead people, collapses of structures, and massive destruction of infrastructure. They often happen during the times of unusually large rainfalls and may also become more frequent in the conditions of climate change (Crosta, 2013).

The requirements of this risk in energy planning are as follows:

- PV roof-tops that are located in high-hazards areas should have strong mounting and anchoring mechanisms.
- Equipment of significance (e.g. main REC switchboards, inverters, batteries) must be moved off mapped debris-flow paths.
- The lines of overhead distribution can also require undergrounding or reinforcement in an open valley.

Therefore, landslide hazard maps and civil protection planning, when applied to the sights of REC, is unavoidable.

4.iii.5 Flood and coastal-erosion

On top of landslides, there are some low-lying coastlines and river outlets which are vulnerable to flooding and coastal erosion, especially during winter storms. Buildings directly on the beachfront and on the harbour may undergo periodic flooding or overtopping of waves. The danger of rockfalls in tourist destinations has been highlighted by the 1978 incident in Maronti beach that claimed the life of a cliff at that specific location (Santo, 2012).

Energy infrastructure within these areas including low-lying substations, electric-vehicle chargers on the coast, or electrical equipment in the basement should be designed or redesigned to resist the effects of floods and waves or moved where possible. On the part of REC, slightly higher slightly inland locations with centralised equipment will improve resilience.

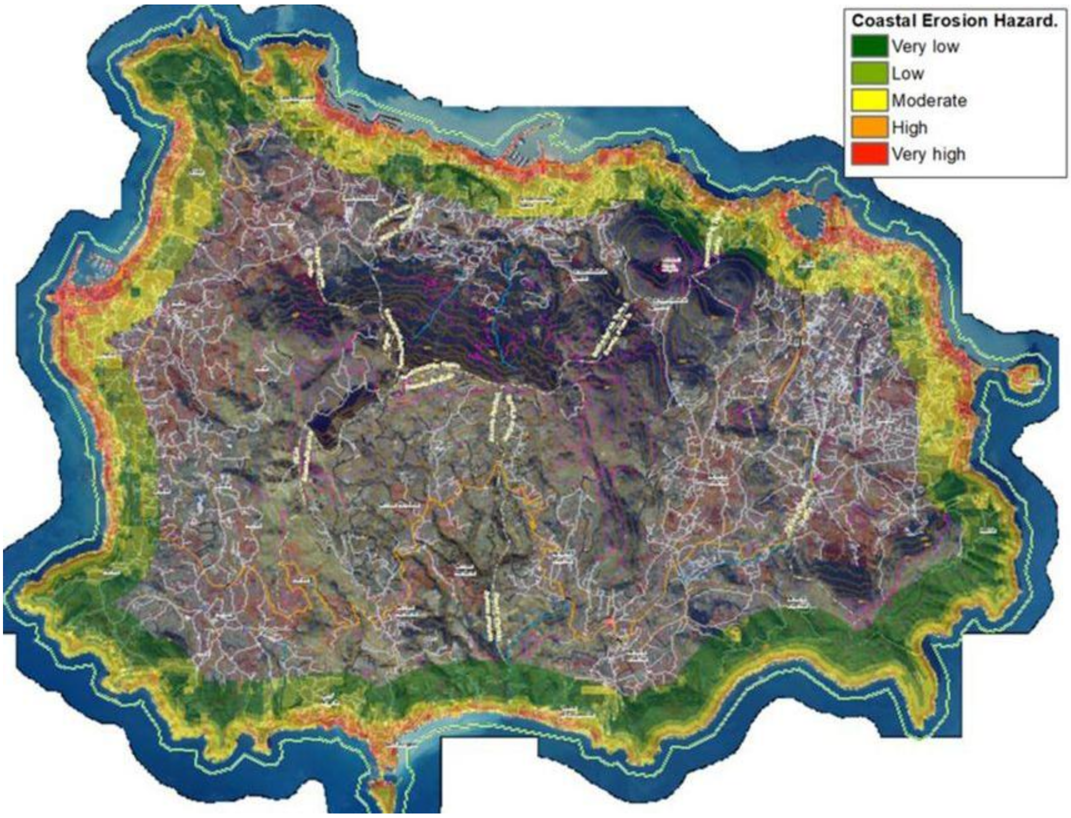


Figure 54:Coastal erosion in Isola di Ischia

4.iii.6 Seismic hazard

Ischia is not a very active seismically active tectonic area, but it has suffered a number of destructive seismic tremors, such as the 1883 Casamicciola earthquake and the 2017 Mw ≈ 4.0 one. However, local amplification effects and shallow focal depths caused devastating local effects by these quakes with moderate magnitudes (Nappi, 2021).

Unreinforced buildings that were constructed traditionally are especially susceptible. PV systems on these types of buildings would thus have to consider seismic loads which would mean that the mounting structures of these installations are firmly installed and that they do not increase the risks of collapse. In the case of essential REC infrastructure (i.e. community batteries, control rooms) it is recommended that they be placed in structurally sound and seismically retrofitted buildings.

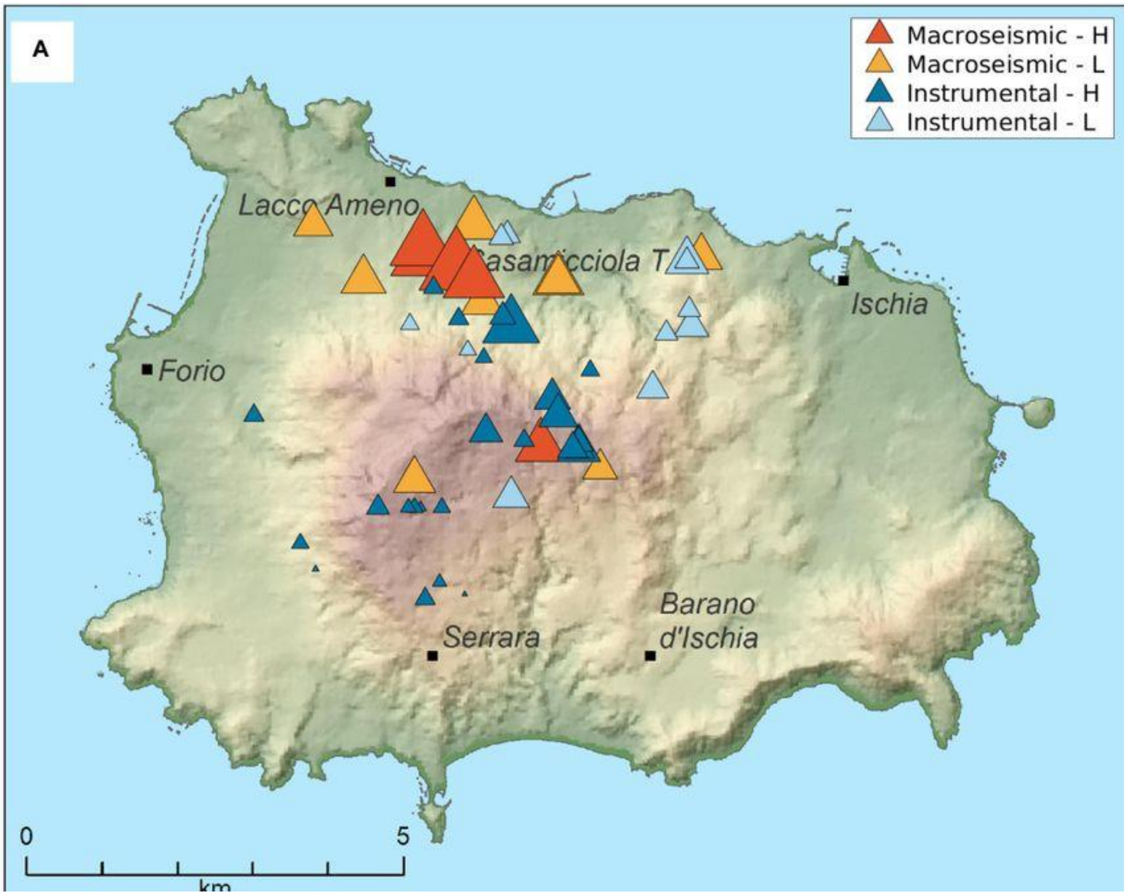


Figure 55: Seismicity of Isola di Ischia

4.iii.7 Multi-hazard perspective and REC resilience

Because Ischia is exposed to various hazards landslides, floods, coastal erosion and earthquakes, the overall planning of the town should be oriented on multi-hazard approach. Instead of drawing a parallel between decarbonisation and safety, energy communities on the island may be a conceptualised as resilience-enhancing infrastructures: distributed generation and storage which provides backup power during an emergency, microgrids which may island critical loads in case of main-grid failure, and demand-management measures that help reduce stress on weak links in the network.

According to this approach, the REC configuration, and investment decision making must be work shared with civil protection authorities and incorporation of hazard map, evacuation routes, and emergency shelter zones. The first obvious choice of prioritised rooftop PV and storage locations is the public buildings that are used as shelters.

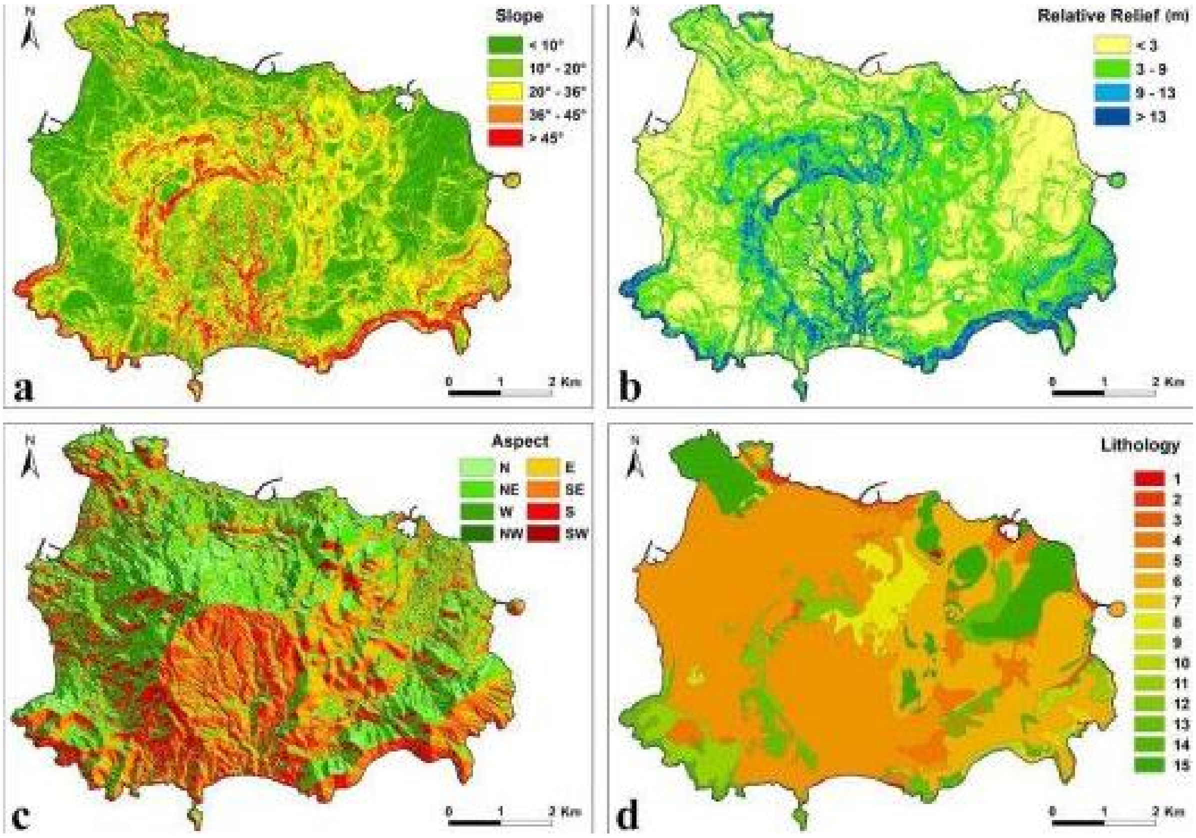


Figure 56: Map of major natural hazards on Ischia (landslide susceptibility, flood-prone zones, seismic epicentres 2017 and landslide 2022), overlain with main settlements.

iv) Electricity System Environment and the Primary substation Perimeter

The structure of the electricity system of Ischia is the core in evaluating the viability of Renewable Energy Communities (RECs) as it helps in defining the physical limits as well as the regulatory limits which determines the state of energy sharing.

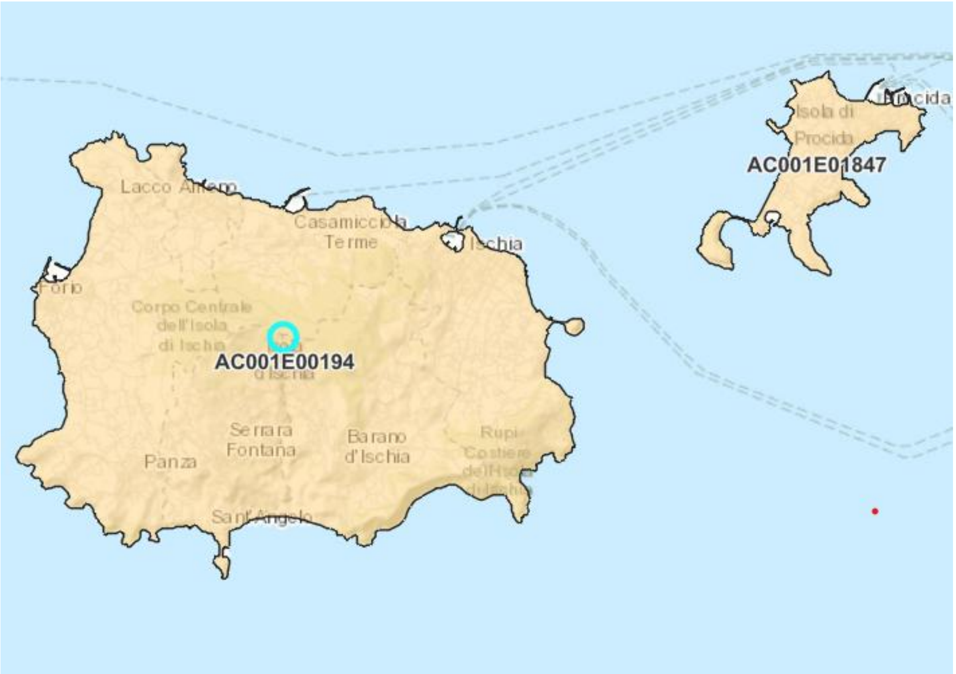


Figure 57: Primary substation

4.iv.1 Interconnection and supply

Ischia is not isolated like many other smaller Italian islands, requiring local diesel generation, but made part of the mainland grid by several submarine cables working at medium voltage. These interconnection lines usually run at the 30 kV, and they create a loop, starting in a substation on the mainland coast (Foce Vecchia), moving on to Procida, and finally to Ischia.

Redundancy is offered by a number of parallel cables (Battistelli F. M.-Y., 2023) Ischia, therefore, acts as a hub of the Italian power system, and flows of electricity are dictated on the basis of the regional generation and demand. With a normal functioning system, the importation of electricity is the primary source of power on the island, with local generation of photovoltaic (PV) generation playing a minor role.

4.iv.2 Distribution system and main substations

The distribution network inside the island is maintained at medium and low voltage (usually 10 kV and 400/230 V) from which a high number of low-voltage customers (36,000) are fed on a fine network of secondary substations (transformer cabins). Ischia has three major substations (cabine primarie,IPS) that normalise high or medium voltages of supply to MV distribution level.

Spatially speaking, every primary substation serves a specific number of feeders and customers, thereby forming three large supply areas. These areas are not necessarily congruent with municipalities, e.g. one CP area[30] may be the area of two or more municipalities and vice versa.

4.iv.3 Smart meter and digital infrastructure

Italy has also introduced a countrywide system of installing smart metres (second-generation metres in the recent years) and Ischia is not an exception. High-resolution (at least 15 minutes) consumption data are provided by smart metering, needed to compute shared energy in RECs, to design demand-response programmes, or to confirm the performance of PV -load matching.

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[30] The conventional geographical area served by a primary substation; in Italian REC rules, all members of a REC must be connected within the same area convenzionale.

New tools of monitoring network constraints, voltages and congestion are based on digitalisation as well. This applies to RECs since massive deployment of rooftop PV can cause changes in power flows, and the occurrence of reverse flows on local feeders and necessitate active network management.

4.iv.4 Regulatory framework TIAD and the CP perimeter

In Italy, the Testo Integrato Autoconsumo Diffuso (TIAD) regulates energy sharing within RECs according to the EU Renewable Energy Directive in its transgaby statute, and ARERA. TIAD provides that members of a REC (consumers and generators) are to be linked within the area of the same primary substation (cabina primaria); shared energy is computed at hourly as the least of the sum total of renewable injections and renewable withdrawals of the members of the REC in that CP area (ARERA, 2022).

This same CP rule is an effective definition of the regulatory perimeter of a REC that is operationalised by a dynamic map of primary substations issued by the GSE. Users will be able to cheque whether certain PODs (metering points) will be located in the same CP area and thus be combined in a REC.

In the case of Ischia, three CPs exist, which would mean that there are three possible macro-perimeters in which REC can be designed. Any REC legally recognised must pick its membership within either one of these areas though a number of RECs may be operating under the same CP.

4.iv.5 Implication to REC design on Ischia

Several implications derive out of the CP -based perimeter:

- *Non-coincidence to municipal boundaries*: REC membership will not just reflect on a municipal boundary. As an example, two groups of households in Forio and Lacco

Ameno can have a common CP and therefore become members of the same REC, but two different groups of households in the same municipality can be required to belong to different RECs in case they are served by different CPs.

- *Scale and diversity minimum*: CP areas serve thousands of customers and different applications (residential, business and government buildings). This will improve the possibility of internal balancing and high shared energy.
- *Spatial analysis is needed*: RECs have to be designed by overlaying building, demand, and rooftop potential information with CP boundaries in order to find clusters that can be supported.

  Effectively, the approach to Ischia will have to need to define CP areas first, conduct PV-loads analyses in each area, and subsequently investigate various grouping strategies (e.g., residential-only RECs, residential-tourism RECs, RECs with a focus on public buildings and EV depots).

4.iv.6 EV and depot siting relevance

Of particular interest is the location of large charging stations and depots of EV among the boundaries of CP. Such a depot within a CP area which also has high roof-top PV potential, e.g., a group of municipal buildings, and nearby residential blocks can be incorporated into a REC in which its charging load is utilised to take up midday PV generation, augment both share-energy and REC economies. In the case of a depot spanning a couple of CP areas, however, different configurations or metering arrangements would be needed, which could make the design of REC more complex.

System resiliency and local generation continue to be a concept presented within the so-called activity content model.

4.iv.7 System resilience and local generation

Even though Ischia is typically served very well by submarine cables, its past history (e.g. cable faults, disturbances on the mainland) has proven that its supply is not completely beyond attack. The locality of generation by rooftop PV (especially with storage and ability to run a microgrid) can, therefore, increase resilience of the system, making it less reliant on a small set of submarine connexions in general, and providing reserve supply in the unfortunate event of system events.

Overall, the electricity system of Ischia provides not only a regulatory framework in which RECs can be implemented (through CP-based perimeters) but also a technical infrastructure (smart metres, modern distillate grid) that will facilitate distributed energy sharing.

v) Tourism on the Island and Seasonal Demand

Tourism is the core of the Ischia economy and the main factor in determining the seasonality in the demand of electricity. Therefore a thorough comprehension of the tourism dynamics is invaluable in the analysis of the PV performance of PV-load matching and REC performance.

4.v.1 Tourism profile and seasonality

Ischia is internationally famous in terms of thermal spas, seaside resorts, botanical gardens, and cultural events, which is why it is one of the locations that welcomes domestic tourists and international visitors during most of the year (Busignani, 2022). The data of the national statistics show that over half of the annual tourist arrivals in Italy are concentrated in the period between June and September, whereas coastal holidays and insular locations like Ischia have even stronger seasonality even in a more pronounced form (ISTAT, 2023). Common features are:

- an acute increase in the tourist numbers after the late spring.
- maximum demand in July and August.
- shoulder seasons in May- June and September- October.
- less, though not insignificant, spa and wellness tourism during winter.

4.v.2 Tourism types and energy-use patterns

The energy consumption patterns of the differentiated tourism segments are different:

- Wellness tourism (wellness hotels, spa) will involve hot-water manufacture and in-room climate regulation that can be used on a year-round basis.
- Summer Beach tourism contributes to cooling loads, water pumping and intensive use of restaurant and nightlife facilities.
- The mainland may produce the effect of concentrated weekend peaks in demand through short city-break bookings.

  Hotels and accommodation facilities are normally characterised by:

  - high occupancy in summer.
  - strong energy consumption per guest (air conditioning, laundry, catering, pools);
  - high surface areas, most of which have large roof sizes which can support PV.

Towards this end, accommodation facilities are therefore not only significant load centres, but also good candidates of PV hosting in RECs.

4.v.3 PV alignment and the seasonal demand curve.

The daily load profile changes regularly on an island with a tourism basis like Ischia during winter and summer periods (Trull, 2019) :

- Winter day: morning and evening residential peaks, moderate daytime commercial activity Workday balance Light cooling.
- Summer day: high level of flatter load profile between late morning and late evening; high-afternoon cooling peak that is also parallel to the maximum solar production. The characteristics of Mediterranean solar-resource conditions enhance this correspondence: during the summer long and sunny days and a large amount of sunshine are the most harmful months of the cooling demand.

This synergistic timing maximises the self-consumption potential of PV, especially in summer when RECs have a mix of tourism related members in combination with residential members

4.v.4 Approach to modelling tourism in demands.

This thesis uses the tourism statistics by the following steps in order to measure the demand that is related to tourism:

- Gather monthly tourist presences (nights) in each of the six municipalities.
- Divide the number of presences, by 30, and add to the amount of the resident population.
- Deterministic per-capita coefficients of electricity-consumption allocated by the type of accommodation (hotel, apartments, campsite) estimated by literature values and local standards (Gössling S. P.-P., 2012).
- BREAK growth Break down monthly non-aggregate demand (using standard Italian residential and tertiary load profiles) by hour using standard temperature-dependent and day-of-the-week load modulation.

The process results in a synthetic hourly demand picture of resulted demand per municipality and the CP area, which combines the resident and tourism demand. The contact with rooftop PV and RECs will be avoided since they are distinct issues.

4.v.5 The contact with rooftop PV and RECs

The contact with rooftop PV and RECs will not be considered as they are independent issues. The strong seasonal change in demand combines with PV production in a number of ways:

- When the day demand is high in summer due to faculties of tourism, rooftop PV in hotels and spas and in municipal buildings results in extremely high self-consumptions rates; shared energy in RECs peaks in those months, and according to that the economic value of the participation in the REC is high.
- When it is not peak season, PV generation is high, but the number of tourists is lower; this could result in a bulk of unused PV that would have to be sold at the market or in resources to refill batteries.

Less PV in winter can contribute to the satisfaction of the demand bespoke PV; RECs can be more heavily dependent on imported power and yet gain advantages due to PVs on sunny days and hope energy in common between residential and public buildings (ex: schools, municipal offices).

4.6.6 EV demand and seasonal demand of transport.

Another dimension is brought by the integration of the electric forms of public transport: electric buses or electric shuttles to transfer the tourist flows between ports, beaches, thermal parks and town centres. Tourism increases pressure in the demand of public transport particularly during summer and subsequently increases the load in EV charging.

Isolated charging of EVs can be done during the day and by scheduling, the following can be achieved:

- absorb midday PV surplus,

- flatten peak loads,
- further improve volumes of shared energy in RECs.

Therefore, the seasonality of tourism in Ischia turns out to be not an issue but a potential lever that can be applied to better incorporate PV and EV into a coherent energy system.

vi) Constraints

4.vi.1 Italy's Cultural Heritage and Landscape Code – D.Lgs. 42/2004 (Codice dei Beni Culturali e del Paesaggio)

D.Lgs. 42/2004 regulates the protection of cultural heritage and "beni paesaggistici," which include natural landscapes, built heritage, historic settlements, coasts, and scenic viewpoints. Under Articles **136–142**, several categories of land automatically fall under protection, including:

- coastlines within 300 meters from the shore,
- areas with significant geomorphological or environmental value,
- historic centers and traditional settlements,
- natural areas of scenic interest.

Ischia, due to its volcanic morphology, panoramic coastline, thermal springs, historic centers (Ischia Ponte, Forio, Lacco Ameno), and unique cultural landscape, is classified almost entirely as a **protected landscape area**.

- **Implications for Renewable Energy and Rooftop PV**

A critical takeaway from this constraint is that landscape protection does NOT prohibit PV installation, but it regulates how and where PV systems may be installed, especially to avoid visual impacts on the landscape.

According to D.Lgs. 42/2004:

- New constructions or installations must respect the landscape character (Art. 167–181).
- Any intervention visible from public spaces may require authorization (Autorizzazione Paesaggistica).

  However, rooftop-integrated solar panels (impianti FV integrati nelle coperture esistenti) are generally permitted, particularly when:

  - they follow the slope of the roof
  - they are non-intrusive and not visible from street level,
  - they do not alter the architectural profile of the building.

Recent Italian national guidelines and regional landscape plans increasingly promote **"low-visibility PV solutions"**, which include:

- solar tiles
- roof-integrated modules,
- dark-colored or anti-glare PV units,
- installations hidden behind parapets.

This is highly relevant to the REC feasibility on Ischia: the cultural-heritage constraint does not hinder PV deployment but instead shapes the type of rooftop PV systems that can be proposed, favoring integrated, non-impactful, visually unobtrusive designs.

4.7.2 Historic Centre Constraint (Decree n. 1089/1939 – "Tutela delle Cose di Interesse Artistico e Storico")

Decree 1089/1939 ("Tutela delle cose di interesse artistico e storico") is one of Italy's earliest national frameworks for safeguarding:

- historic buildings
- culturally relevant urban fabrics

- monuments and architectural ensembles

Under this law:

- Any modification to a protected building or its visible surfaces is subject to **mandatory authorization** from the cultural heritage authority (Soprintendenza).
- The aim is to preserve the visual integrity, materials, and architectural coherence of historic areas.

Although this decree was later incorporated into D.Lgs. 42/2004, it still defines the historic value categories and the obligation to protect "immovable cultural property."

Interpretation of the map in the context of the thesis

The resulting spatial analysis confirms that:

- The historic centre constraint is concentrated mainly on the northeastern part of the island, where most of Ischia's oldest settlements are located,
- These areas contain a high density of buildings but are subject to stricter architectural regulations,
- Therefore, PV installation feasibility is not excluded but must follow specific heritage protection rules.

Implications for Rooftop PV Installation

Importantly, even within areas protected under Decree 1089/1939:

– PV systems can still be installed, provided they

- are non-visible from public viewpoints,
- are integrated into the existing roofing surface,
- do not alter the building's historic appearance.

– National heritage guidelines (Soprintendenze, MiC) increasingly allow:

- roof-integrated modules,

- solar tiles (tegole fotovoltaiche),
- anti-glare and colour-blended PV solutions,

especially where they do not interrupt the visual continuity of traditional terracotta roofs.

This means that, despite the strong cultural-heritage protection, the constraint does not eliminate PV potential within historic centres—rather, it requires a more architecturally sensitive approach, which is consistent with the broader Italian landscape-compatibility guidelines for renewable energy installations.

4.7.3 Protected Areas (Natura 2000)

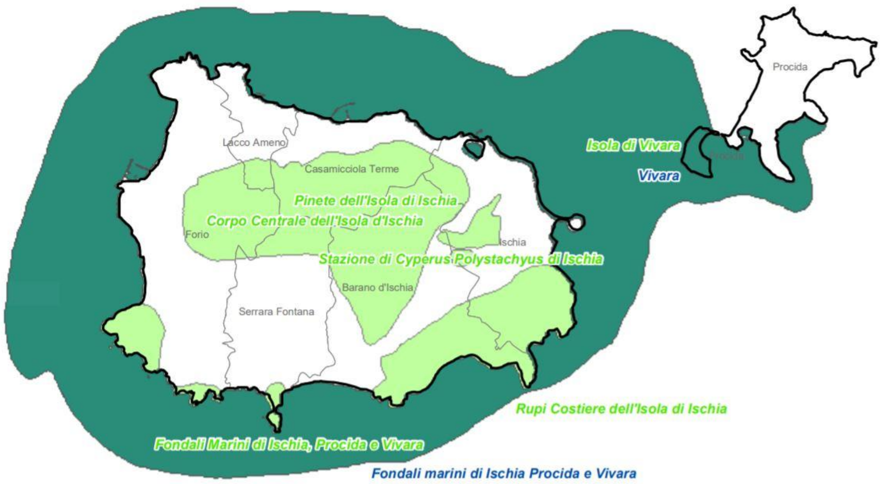


Figure 58: Protected areas

The map illustrates the **Natura 2000 environmental constraints** on the island of Ischia, defined under the EU Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC). The pink areas represent Zona Speciale di Conservazione (ZSC)—Special Areas of Conservation established to protect habitats and species of European importance—while the light blue area indicates the Zona di Protezione Speciale (ZPS)—Special Protection Zones designated for bird conservation.

- Interpretation of the Constraint on Ischia

The results show that a large portion of Ischia's interior and southern coastline falls within the ZSC, reflecting the island's volcanic landscape, endemic vegetation, forested slopes, and ecologically sensitive habitats. Surrounding marine waters are designated as ZPS, emphasizing the presence of migratory bird routes and coastal ecosystems of high ecological value.

Key observations:

- The central volcanic plateau, dense with natural vegetation and geothermal environments, is almost entirely protected as ZSC.
- Coastal cliffs and promontories in the south and southwest (e.g., Serrara Fontana, Forio) also fall within conservation zones.
- Urbanized areas along the coast remain outside Natura 2000 boundaries, which aligns with their suitability for rooftop photovoltaic installations.
- Regulatory Implications for PV Deployment

Natura 2000 regulations do not prohibit renewable energy, but they strictly regulate activities that may affect protected habitats, requiring environmental assessments (Valutazione di Incidenza Ambientale – VINCA) for interventions that alter land cover, landscape continuity or ecological conditions.

However:

- Rooftop PV installations within settlements are normally compatible, as they do not involve land transformation or habitat disturbance.
- The constraint primarily affects ground-mounted PV, infrastructure expansion, or activities in natural and forested zones.

- Since this thesis focuses on rooftop photovoltaic potential, Natura 2000 limitations have minimal direct impact on the solar feasibility results, reaffirming the strategic choice to prioritize existing buildings.

4.7.4 Cultural Heritage Buildings

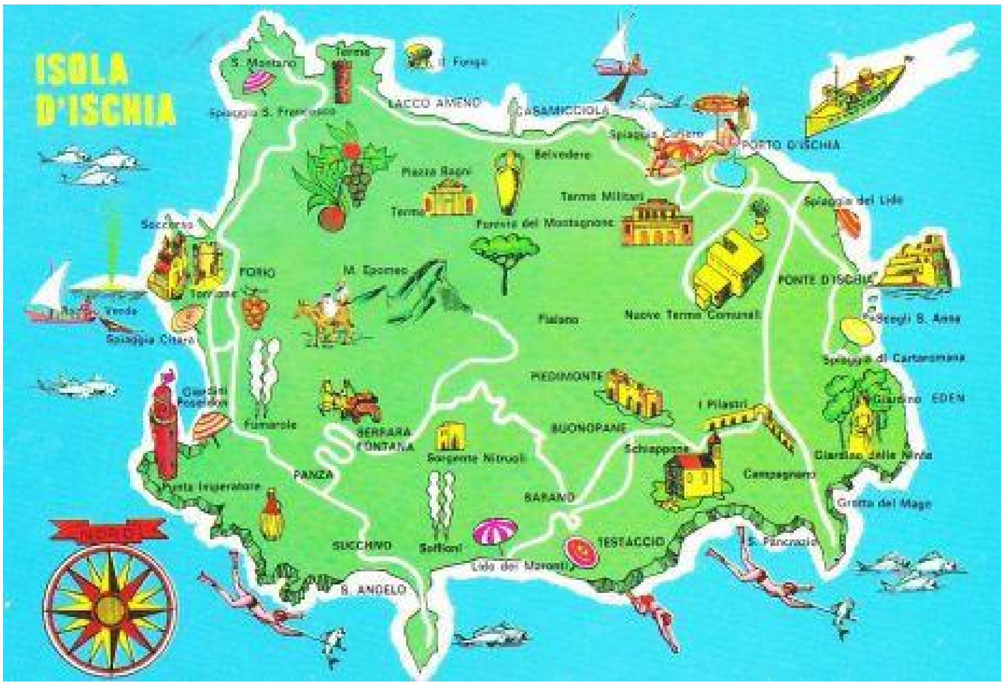


Figure 59: Cultural heritage buildings

The map identifies individual cultural heritage buildings on the island, highlighted in red, representing structures protected under Italian cultural-property legislation (Decree n. 1089/1939 and later incorporated **into D.Lgs. 42/2004 – Codice dei Beni Culturali**). These buildings are classified as “beni culturali vincolati”, meaning they possess historical, architectural, or artistic value, and are therefore subject to strict preservation and authorization procedures for any modification.

- Interpretation of the Map

The spatial pattern shows that protected buildings are not uniformly distributed across the island; instead, they are concentrated in historically significant areas, particularly:

- Ischia Ponte, including the buildings surrounding the access to the Castello Aragonese,
- the historic waterfront of Ischia Porto,
- scattered heritage nuclei in the interior settlement fabric.

These areas represent the oldest urban cores, where architectural heritage has national and regional significance. The red-marked buildings include churches, convent structures, coastal fortifications, historic residences, and other culturally relevant assets.

- Implications for PV Installation

  For buildings under heritage protection:

- Interventions on the roof require mandatory authorization from the Soprintendenza.
- Visible modifications—such as traditional PV panels placed on pitched roofs—are usually not permitted if they alter the historic appearance.
- However, the Italian Ministry of Culture (MiC) allows PV only when the intervention is non-visible, such as:
  - roof-integrated photovoltaic tiles (tegole fotovoltaiche),
  - panels placed behind parapets or concealed surfaces,
  - installations on secondary volumes not facing public viewpoints.
- Relevance for REC Feasibility

Although these cultural buildings form a small subset of the total building stock, their presence is relevant for understanding:

- locations where PV installation is heavily constrained,
- areas where the REC may need to rely on PV production from nearby non-protected buildings,
- the limited role of heritage buildings as producers within the energy community.

Importantly, because the number of architecturally protected buildings is relatively low and geographically concentrated, the overall PV potential for the island remains largely unaffected. The constraint is localized, not widespread, and therefore does not significantly compromise the total rooftop availability for REC development.

vii) Why Ischia Is an Appropriate Case Study for Renewable Energy Communities

When compiling the above-discussed discourses, Ischia is a better model of Renewable Energy Communities (RECs), rooftop photovoltaic (PV) applications and the adoption of electric communications of the public transport system.

To begin with, Ischia has definite boundaries of the system. Being an island, it is a physically and electrically delimited territory where the local production can be improved by imports and exports, the latter and the former can be measured with accuracy, and therefore the performance indices, including the self-sufficiency and self-consumption, become particularly visible.

However, its relation with mainland softens the extremes of complete isolation, so that there are realistic alternatives where the local generation significantly, without being a replacement of imports.

Secondly, the island shows a very sharp seasonal dynamics between PV resources and demand. Tourism led to the summer peak in electricity use which also coincides with highest solar irradiance on time scale. This synchronisation opens structural benefits of high PV self-consumption and collectivized energy throughout the summer seasons and, therefore, offers an environment where RECs can conclusively augment system value through matching nearby generation with nearby consumption, reducing the peak imports, and reducing network pressure.

Thirdly, there is favourable regulatory environment. The Italian implemented framework of European Union directives, in the form of the Legislative Decree on the subject 199/2021, the TIAD, and the Ministerial Decree on the same3414/ 2023, represents a consistent set of regulations and incentives concerning the creation of RECs. Despite the constraints implied by the primary-substation perimeter, it can be used analytically: it divides the island into three macro-REC-serviceable zones which are marked by different combinations of loads and roof-scapes. The segmentation will enable the comparative evaluation of the different REC set-ups within the island.

Fourthly, Ischia can also be described as a high-quality data environment. National and regional agencies do have geospatial data of buildings, land cover, and of protected areas and hazard areas, as well as statistical series of population, tourism, and energy consumption. These data allow bringing analysis of geospatial PV potential, hourly load profile and REC mapping on the perimeter of perimeter to one unified process, which is repeatable. The access to comprehensive hazard data also enables engineering planning to be as like-minded in its associated goals as it is to risk-minimization and civil-protection.

Fifthly, the socio-economic landscape of Ischia, which is a combination of permanent residents, tourism operators, SMEs, and government actors, is similar to the stakeholder mix in the concept of the EU definition of energy communities (European Commission, 2019). Such heterogeneity allows the investigation of the governance structures, the benefit sharing schemes, and the member structures, which are applicable to a wide spectrum of European settings, not just those limited to insular explanations.

Lastly, the lesson learned in Ischia is the difficulty in balancing conservation and transition. The island has to protect its landscape and biodiversity, control natural hazards, save its touristic attractiveness, and at the same time work on decarbonisation and improvement of its resilience.

It is on the basis of these reasons that Ischia, as a case study, can be considered more than a mere convenience to the explanation that a regulatory, technical, environmental and social nexus takes shape in the application of the Renewable Energy Communities in the Mediterranean Island settings. The approach and findings that are crafted to the Ischia in this thesis are expected to be deployable, with reasonable modifications, to similar insular and coastal jurisdictions that face similar issues.

CHAPTER 5

METHODOLOGY

CHAPTER 5: METHODOLOGY

5.1 Digital Surface Modelling and Solar Energy Introduction.

Solar energy systems transform the incident solar radiation to the usable energy, which can be thermal or electrical. Specifically, Photovoltaic (PV) systems harness the solar energy and convert solar rays directly into electricity. As Peretti (2019) notes, solar technologies are premised on the fact that they can convert solar radiation into thermal and electrical products. The system design including panel orientation and panel tilt determines the conversion efficiency. The three-dimensional depiction of the environment is thus necessary in order to examine the rooftop solar potential with accuracy.

Digital Surface Model (DSM) is a representation of that kind, including the representation of both the terrain and man-made structures- buildings and vegetation. In most cases a DSM can be acquired by augmenting a prior base Digital Terrain Model (DTM) with building heights. The DSM (1 and 5) is high-resolution (1 and 0.1 and 0.1) in order to record the geometry of the buildings and their shaded effects.

5.2 Data Sources and Preparation

The DSM and helps in calculating the solar irradiation on the roof taking into consideration slope, aspect, and shadowing of the immediate obstacles. The study is based on the following data sources and preparation. It utilises a variety of reliable data sets that include demographic, building, climatic and solar fields in the methodology.

The number of inhabitants and housing statistics were obtained with the help of ISTAT, the Italian statistical institute, namely census data of families and residents and the number of buildings (ISTAT, 2021). These data points were plotted over building footprints, and each structure was given a household value.

The height of the building was obtained using the Global Human Settlement (GHS-OBAT) database, which is able to provide height data in a worldwide manner. The combination of these height values together with a base DTM resulted in creating a 1-metre DSM of the study area. Hourly load profiles that were used were provided by ARERA, the Italian energy regulator which released patterns of normative consumption across F1, F2, F3 time periods for different categories of consumers.

ARERA profiles that have been utilised in the study to disaggregate annual energy consumption into hourly value of every building type. The local solar data was taken through the PVGIS database (JRC, 2023) that gave most common gene meteorological parameters, such as the solar irradiation, clearness index, and other parameters at reduced spatial resolutions available at each location.

Also, the Linke turbidity factor (TL) and the ratio of diffusion to global radiation (D/G) of the target location was provided through the Meteonorm 8.0 (Meteotest, 2023). These are parameters that define weather conditions that affect the insolation. TL and D/G, which were to be used in further solar simulations (see Section 5.4), were twelve monthly rasters, with their annual averages. The calculation of irradiation also involved an adequate surface albedo value which is the proportion of skyward radiations the surfaces on roofs of urban areas (0.2025) would reflect.

All spatial data such as the DSM, building footprints and administrative boundaries were projected and clipped in QGIS. Census statistics, ARERA profiles, and other tabular data were prepared and configured as CSV files and joined with the equivalent units spatially. The result of this pre-workflow pre-preparation provided a coherent geodatabase of input data which included:

- Demographic data (ISTAT): figures on the population and the number of families that can be admitted in a municipality or building.

- Building identifiers - (GHS -OBAT): polygons and height features of the footprint.
- DSM (1m): high resolution digital surface model with terrain and buildings.
- Solar information (PVGIS/Meteonorm): monthly rasters of D/G and TL of the solar irradiation modelling.
- Albedo: supposed value of surfaces in the city. - F1, F2 and F3 band ad hoc
- Load profile with F1, F2, and F3 loads hourly format of demand

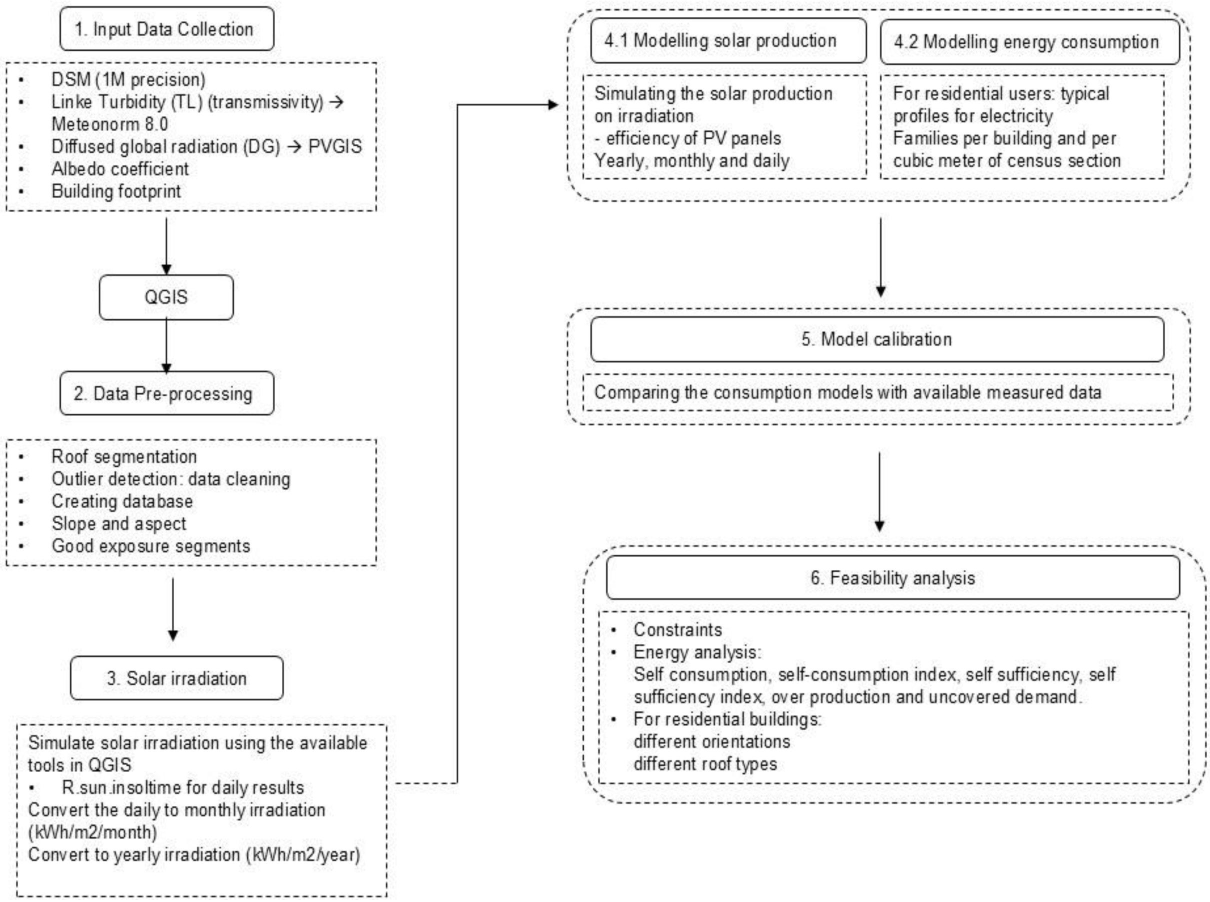


Figure 60: General flowchart of the feasibility analysis

5.3 GIS and Analysis Tools

Open-source GIS software was used to perform all the spatial analyses. The main tool that was used would be QGIS (version 3.x) with complements of GRASS GIS modules. QGIS was taken as the workflow manager: it supported both import/export of data, reprojections between coordinate reference systems and offered the Processing Toolbox that contained all the analytical algorithms.

Solar irradiation calculation was done with the

- GRASS GIS module r. sun. insoltime (through QGIS GRASS controlle). This algorithm computes the simulation of beam, diffuse and reflected radiations on a non-horizontal surface during certain days or during an average of a month of the computer simulation through the supply of sky parameters by the user.

The analysis entailed executing otherwise normal days (twelve days) of each month to capture seasonality with the use of the r.sun.insoltime. The digital surface model (DSM) representing the elevation data were taken as the input to the module, together with monthly diffuse/ground -based (D/G), and terrain-luminosity (TL) raster, and optional horizon data (discussed below). The result included monthly radiation maps (Wh/m^2) of horizontal and tilted surfaces.

- GRASS GIS module r.horizon was used to calculate the skylines (horizon) angle of each pixel of roof. To derive the azimuthal profile of the horizon heights, the DSM is then utilised, and the result is applied by the r.sun to reconstruct the shading created by nearby terrain and buildings. r.horizon was run at QGIS per location of the roof at coarcer intervals and its output was included in the computation of irradiation.

- GRASS GIS module r. slope. aspect (available in the QGIS Processing Toolbox) was applied to get slope and aspect rasters out of the DSM. A model of tilted solar radiation requires slope (degrees), and aspect (0-360); the slopes with low tilt factors that only face south in the northern hemispheres get high insolation. These rasters were then utilised in the calculation of the irradiation and to avoid ineligible roof areas.

- GRASS GIS module i. segment was utilised to segment raster or vector layers. In the current paper, the segmentation was used to determine homogeneous segments of the rooftop of using either high-resolution orthophotos or the DSM.

The segmentation is a process whereby the adjacent areas of the roof that share the same orientation and a slope are grouped to create individual photovoltaic installation areas. What this means is that the result is a series of polygonal roof segments that approximate discrete roof planes.

The Secondary source of verification of the irradiation and production estimates was a web interface of PVGIS (JRC, 2023). In the case of some selected buildings, the panel parameters were keyed in PVGIS to get max energy output estimates yearly. The products of these PVGIS were further utilised to provide crosscheck of the QGIS-based irradiance simulations (see Section 5.5).

Accordingly, QGIS (including GRASS) was the key ecosystem of the spatial model with the transformation of DEM/DSM, solar simulation, and tabular joins. Python codes may be used either optionally as an external script to QGIS- such as to extract building characteristics in batch mode or may be used to interface with PVGIS via its API- but the techniques outlined below were run mostly within the QGIS/GRASS environment.

5.4 Solar Radiation Modelling

To simulate solar resource in rooftops, we have undertaken a logical series of GIS processing steps including slope and aspect derivation, creation of a solar path map, and calculation of horizon shading, productivity of irradiation and subsequent filtering of outputs to rooftops.

5.4.1 Slope and Aspect

The soil slope and surface aspect were derived based on the 1m Digital Surface Model (DSM) of the slope and aspect of the terrain both by using QGIS Slope and Aspect in combination with GRASS r. slope. aspect.

Each roof surface is depicted as a slope or aspect, which is denoted in degrees, and the direction goes as North (0°degree), East (90°degrees), West (180°degrees), and South (270 °degrees). To conduct photovoltaic (PV) siting analysis, only roof areas whose aspect is within the flat ranges of approximately due south were kept because these are the regions found to be the best in the deployment of PV.

5.4.2 Sun Path (Sun Map)

A sun-path map (sun map) was created which showed the azimuth and the elevation of the solar disc at every hour of the calendar year. This map makes it possible to view the temporal and spatial occurrences of shadows.

Custom solar angle computation or Sun Path plugin in the QGIS was used to create the map. The resultant sun chart educates the choice of pertinent hours in which to measure solar gain and also simplifies the reading of following irradiation outcomes.

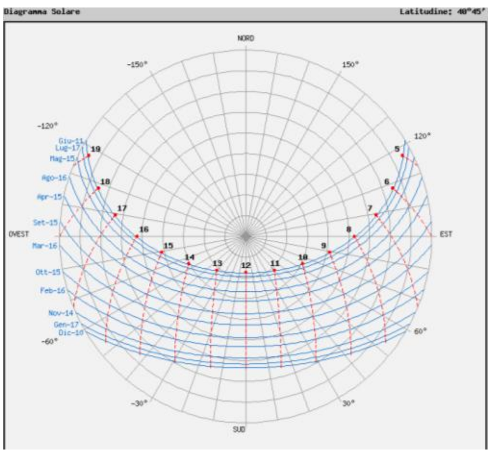


Figure 61: Sun Map

5.4.3 Horizon/Shading:

With the DSM we obtained the skyline (horizon) of every azimuth direction of all roof points with the router, r.horizon of GRASS. This step forms, at each 10 o AZ interval, the greatest elevation angle of obstructions with respect to the horizon. These horizon heights were subtracted during the simulation of the irradiation (r.sun. insoltime) as the sky had shaded areas. This, in turn, causes pixels in the deep shadows, e.g. those under tall neighbouring buildings, to obtain hurting or no beam radiation.

5.4.4 Calculation of Irradiation:

Having determined slope, aspect and horizon, we ran GRASS r.sun.insoltime on one day per month (usually the 21st day) to be able to obtain the average irradiation of the sun on a given day.

The input parameters were the

- DSM raster (to calculate roll angles using slope/aspect),
- slope and aspect raster,
- horizon azimuth masks,
- the diffuse/global ratio (D/G) raster of the monthly period,
- the Linke turbidity (TL) raster of the monthly period
- constant albedo.

The data were beam, diffuse, and total irradiation output (Wh/m^2) on a flat plane and a tilted surface, ideally optimally, respectively. The tilted radiance was removed to the roof tilt (i.e. the slope raster) to reflect the genuine sunlight on each roof producing a dozen raster layers per customary day of sunshine energy per square metre. Addition of each of these layers, weighted by the number of days in months, yielded an estimate of monthly irradiation, according to the methodology specified by (Usta, 2024), and it can be seen that open-source tools are effective in reaching the required accuracy.

5.4.5 Temporal Aggregation:

Each of the twelve typical day rasters was aggregated to monthly and annual values of irradiation. In particular, the raster cell values (Wh/m² per day) were multiplied by the number of the days in the corresponding month which gave monthly total Wh/m² per day. The sum of all monthly sums gave the annual kWh/m².

Also, annual average profile, was built which is a distribution of the monthly daily values over the number of daylight hours in each month (By presupposing a trapezoidal or equal per-hour distribution). It was a process that provided an estimation of hourly global irradiance of each roof.

5.5.5 Segmentation and Rooftop Filtering:

With the segmented roof polygons of i. segment of the DSM/orthophoto, the irradiation rasters were masked to obtain only valid roof surfaces. Clearly non-roofed areas, vegetation, roads, and open ground were eliminated through intersection with building footprint masks.

Segments of the roof that were too small (e.g. less than 10m 2) or with very steep slope/aspect ratios (vertical walls or north southern orientations) were excluded too. Results will be rasters (and related polygons) showing the incident solar irradiation to each of the rooftops (per unit area) on each hour based on the typical-day rasters and on each month and year.

This is a map of space solar, which is used as the basis of calculating solar PV energy output.

5.5 Rooftop PV Potential Modelling.

The surface irradiance of the roof was used to determine the possible electricity production of PV panels on the roof of each roof based on the roof irradiance data. The research methodology to be used is as follows:

- *Usable Area Criterion*: The polygon footprint was used to obtain the flat-projected area (plan area) of each segment of the roof. It was divided by the cos of the slope to convert in this area to a tilted area. The gross PV area was only calculated as the fraction of this area covered by physically installed PV panels.

A correction factor, estimated as 0.82, was used to capture the inter-panel gaps, the space, and the non-photovoltaic areas on the roof. Therefore, net PV area was obtained as 0.82(gross projected area)/cos(slope) of area. All segments of the roof whose net PV area is less than 5 m^2 were extrapolated because these are too small to fit a typical panel.

Aspect (degrees)	0-22.5, 337.5-360	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5
Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**

- *Parameters of PV Systems*: PV modules of high efficiency were considered, where the module efficiency is 23% or the efficiency of a typical crystalline silicon modern day module. The performance ratio (PR) was taken as 0.75 that covers the system losses due to wiring, temperature, and inverters and other components.

The panels were considered as permanent tilt panels that were positioned based on the roofs pitch and facade but did not have any tracking devices. These are the parameters with conservative best-practice estimates of modern PV installations.

- *Energy Production*: The hourly production of each of the roof segments was calculated based on the expression.

$$E\_PV(h) = A\_net \times I(h) \times \eta \times PR$$

In which, the abbreviations used are, A net- The net PV area on that segment, and I, (h)- The Incident irradiation at that hour, based upon the irradiance model. Adding the hourly values would provide the energy output in terms of daily, monthly and annual output of energy per roof. Parallel PVGIS simulations were also implemented in representative roofs with the same inputs of panel area, tilt, orientation, and local irradiation, which yielded the same annual yields and the difference of the annual yields is 1015% as a consistency cheque.

- Community Aggregation: The overall PV power of all Regional Energy Communities (REC) was the sum of the hourly power output of all comprising roofs thus producing an hourly community power production profile. This can be compared directly to the hourly electrical demand in the community as explained in the next paragraph.

In sum, the rooftop PV model determines all the acceptable roof space- conclusion on the basis of slope, orientation, and sizes and calculates the theoretical hourly generation. Using the efficiency and performance ratio that has been adopted and the calculated irradiation maps, the model provides the anticipated PV output on each rooftop and the summed potential on the island.

5.5.1 Roof-Integrated PV Technologies for Renewables Communities

- *Integrated photovoltaic*: (formerly known as BIPV) modules take the place of or over conventional roofing materials in the form of PV shingles and tiles. These products normally use crystalline silicon cells attached to slate, shingle or tile-shaped substrates. An example is the Swiss SunStyle solar shingles, which use monocrystalline cells with

PERC and provide a power output of 84-115w/tile, or about 170-172wpm^2 without the sun.

The Tesla Solar Roof in America is made of black glass tiles with an approximate size of 15 x 45 in, with each tile producing approximately 71.7W (=15.4 W/ft^2). Dyaqua, Italy has the Invisible Solar system: polymer terracotta tiles with an embedded monocrystalline cell and Tegosolar: terracotta roof tiles with photovoltaic technology. The systems are also fitted directly into the roof deck thus offering both weatherproofing and power generation.

- *Glass modules*: In-roof glass modules will be frameless or low-profile modules that fit flat with roof planes. As an example, the Spanish manufacturer of Onyx Solar makes thin skylight and roof photovoltaic glass. This type of module can be provided in semi-transparent (2-6% efficiency) or opaque designs. Amorphous silicon BIPV skylights cost more than this, but with a higher wattage (236W / each) were installed on the Evora project in Portugal, which had an efficiency of 2.8-5.8 percent. These are usually used where there is a combination of daylighting and photovoltaic generation e.g. in glass roof or in skylights.
- Thin-film films are flexible ultra-thin photovoltaic laminates: (mostly CIGS-based or organic) which can be bonded to different roof substrates. An example representing a 2 millimetres thin film of organic photovoltaic is known as HeliaSol, which is a product of Heliatek in Germany, but which has an adhesive backing. A 0.436 mm x 2.00 mm HeliaSol module provides an output of about 50-55W (78-percent aperture efficiency) and its weight is only 1.6 kg, and it does not need any mechanical support or back-ventilation.

The thin-film modules may often have lower efficiencies (about 5-12 percent) than crystalline modules however, they are light with slenderness to weight as well as curved or fragile surfaces (heliatek.com).

- Glass-glass Photovoltaic Onyx Solar glass: glass photovoltaic products (e.g. Onyx Solar) may include glass-glass units, sometimes combined with a lot of windows, that can be shaped as balustrades, skylights or components of a facade, and through which some visible light can pass. Their efficiencies usually are in the low, or single, digit range, but they provide the ability to integrate photovoltaics into roofs with glass surfaces that can be discerned.

5.5.2 Technical Characteristics

- *Monocrystalline BIPV tiles*: can have an efficiency of 1520 percent per panel, and SunStyle offers about 172Wp/m^2, and Tesla has prices of 8-10 percent tile. The cell efficiency of the terracotta tiles made by Dyaqua is up to 22 percent at the cell level, but the opaque coating restricts the overall output to approximately 7.57W/tile giving a net efficacy of 7.8 percent to the end use.

The efficiencies of the thin-film technology of HeliaSol are approximated to be 7-8 percent. As a result, a product range of 50-170 W/m^2 rating is usually obtained with an integration of BIPV roofs, as opposed to 200 W/m ^{2} with a state-of-the-art flat-panel device.

- *Dimensional and wattage*: can bring about the realisation that roof tiles are smaller than the traditional panels. SunStyle shingles (745mm x 745mm) only produce 84Wp of power overall and Dyaqua tiles (38mm x 18mm) can only produce 7.1 W and would require installing about 141 of the tiles to cover one kilowatt.

A tile system of 71.7 W (integratesun.com) would be comparable to Tesla tiles (0.433 W, 0.519 W, 0.686 W) but the HeliaSol films have 5055 W (0.872 W, 0.872 W, 1.193 W) more. Such a misfit in the performance would mean that a larger roof would be needed to achieve such a similar kilowatt of output, generally needing between one and three times the surface area of regular framed panels, and yielding lower per-piece output.

- Mounting systems: consist of the safe attachment of modules to the roofing framework, either at deck level, or on the underside, and thus dodge the need to mount independent mounting equipment. Waterproofing systems Building mounting Systems via the attachment of modules safely and firmly to the roofing structure, either at deck level, or on the underside, and consequently eliminate the need to mount separate mounting equipment. The modules are to form a continuous weather-proofed layer. As an example, SunStyle tiles are an alternative to slate tiles, and HeliaSol can be attached directly to the roofs of metals or concrete.

The process of installation needs a professional team of roofing experts, as well as professionals involved in electrical tasks; the time of installation of the solar-shroud is five or ten days, whereas the installation of rack-based systems takes one to three days.

- The significance of ventilation and thermal control: is supported by the reality that the flush-mount cell modules limit the airflow behind the cells, which increases the temperature of the cells and is even worse at causing thermal losses. This can be alleviated by manufacturers by the choice of material, and design decisions. HeliaSol exhibits a low temperature coefficient ranging between 0.00 and 1.0 C minus of about 0.00 -1.00 at higher temperatures of up to 65 °C, and the device maintains operation at high temperatures.

The polymer composites of Dyaq have a thermal retardation value of -32 percent. However, integrated systems suffer a typical output loss of 0.3 to 0.5 percent/°C in a 25 C temperature increase which is equivalent to traditional photovoltaic modules, or even worse with poor ventilation. The installers can use edge gaps or reflective foils to minimise heat buildup.

- The data on the durability and degradation show that BIPV modules are made of strong materials. Both glass (e.g. Tesla) and ceramic tile (e.g. SunStyle) are very durable, and the Power and tile warranty is 25 years on Tesla. The polymers used like the ones used by Dyaqua do not react to acid, UV and solvents.

Despite the fact that organic films do not include extensive testing over the long term, they meet IEC 61215 and UL 61730; HeliaSol has a 20-year service warranty. A typical degradation of the crystalline photovoltaic is 0.5-0.7 percent/year in comparison to a thin film; it is more probable that this degradation is lower in a thin film system.

- Other controlling factors include the adherence to fire, hail and wind resistance requirements. Tesla Solar Roof either has an A Class fire test and a B3 hail test (integratesun.com). BIPV systems employ the same inverters and peak/maximum power point trackers as the typical photovoltaic systems.

In cases where photovoltaic modules are used on a roof covering, such attic ventilation should be taken into consideration; since the module forms the tile covering of the roof, no more mounting aluminium would be needed on top and the weight of the modules is similar to that of standard tile roofing, except the lighter films.

5.5.2 Example Products (Europe)

(i) SunStyle (CH/USA). The size of this pattern of slate- like photovoltaic shingles is 745 x 745 mm, or 870 x 870 mm and utilises PERC mono-crystalline cells. The tiles generate an average of 84 Wp which is equivalent to 172 Wp/m². Installed productivity of the product is more than 60 MW within a period of over fifteen years. The interlocking tiles combine to create an impervious layer which is apt to an alpine-style roof, and which appears like slates. The business has a distributive base in the European Union .

Figure 62: Sun Style PV panels

(ii) Dyaqua Invisible Solar (IT). These terracotta-coloured tiles are either flat or rounded over with embedded monocrystalline cells to appear like regular roof tiles (Tuscan/Roman shapes). In the ground point of view, the modules would look opaque.

The cell efficiency is 22 per cent, but end-use efficiency is only 7.8 per cent (7.57W/38x18cm tile). The tiles are biodegradable and self-cleaning. The Evora historic site was deployed in Portugal with 3350 tiles and yielded 25.36 kWp. Disadvantages are low per tile and expensive (~E7,000/kWp). In Italy, the products are sold through InvisibleSolar.it.

Figure 63:Dyaqua Invisible Solar (IT

(iii)Tesla Solar roof (US, option available EU). Tiles are made up of tempered glass instead of the conventional shingles. A solar module is about 380 x 1140mm and power output is about 71.7W (165 W/m². 8-10% efficiency). It has an integrated backup (Powerwall) and a 25 -year warranty. There are the features of aesthetic such as a smooth black glass surface and it can be used in modern architecture; in the heritage areas, it is possible, depending upon the local approvals.

Figure 64: Telsa solar roof

(iv) Heliatek HeliaSol (DE). It is a triple-junction organic photovoltaic film that has a supporting adhesive. Modules are around 0.436 × 2.00m and have 50-55W which yields 7-8 per cent area efficiency. The weight of the film is below 2kg per module, it is very flexible and is also capable of sticking to metal, glass or concrete without penetration.

There is no longer a need to heat the plate through heat-spots, since the temperature coefficient is zero. Elasticity: Tile roofing is ideal in prohibitively heavy roofs, or irregular shapes. The pricing information is not publicly available; integration of the adhesives minimizes the installation manpower. The sale of products occurs across the EU .

(v) Others are Wienerberger/Koramic (AT) with solar clay tiles, SolteQ (NL) with photovoltaic slates and Onyx Solar (ES) with bespoke BIPV glass covering facades and windows through distributors like R2M Solution (pvsites.eu).

Figure 65: Heliatek HeliaSol

5.5.3 Italian REC Incentives Compliance.

(i) Plant size. The maximum power of every community-based photovoltaic installation should not exceed 1MWp of the low-voltage grid and have the same primary substation. The law on Energy Communities of 2021 raised the 200 kW capacity limit to 1 Megawatt

New-build/repowering. To claim incentives, most of the installed PV capacity should be new (installed after December152021). Pursuant to which, the system mandates shared output must be commissioned after 2021; 30 percent maximum of a community capacity must be yielded by pre-2022 systems. Practically, installed PV at the roof has to be changed or been added in order to be eligible.

(ii) Smart metering and data. Every photovoltaic point (except the ones under 400 W) and consumption point will need second generation smart metres that can log data every hour. The Italian grid operator aggregates the consumption and production data of the GSE; the community does not require an independent monitoring device.

(iii) Registration and incentives. Registering of REC and application of incentives is done through GSE portal. The GSE is required by law to provide its response within three months.

The Gamma tariff offered to approved RECs is a 20-year tariff which is currently between 60-120 MWh, which varies by the shared capacity of kWh generated. Based on roof integrity and e-governance requirements, projects can also receive the Super bonus or other building incentives.

(iv) Additional rules. Energy community cannot be established by the private entities as their main enterprise. Timelines of installation are observed including a not more than two years to be installed after registration.

Summarising, PV systems that qualify as REC need to meet the same building and photovoltaic requirements as any new system, but the vast majority of its capacity must be conventional under REC decrees.

5.5.4 Heritage-Area Suitability

Sensitive historic historical areas, like the historic centre of Ischia, require inconspicuous photovoltaic systems in terms of aesthetics. BIPV that mimics conventional products are hence favourable. The tiles produced by Dyaqua imitate the classic terracotta (invisiblesolar.it) and it is stated that the product is not visible to the eye, which makes the photovoltaic devices able to be incorporated on the areas of conservation.

SunStyle insists on the maintenance of the historical roofscapes and townscapes by its slate-like tiles. A project of the EU (Pacityf) reported that BIPV products can be merged into the environment of the buildings that are post-registered by UNESCO.

The use of black glass tiles could be also used, although not all, as it is allowed to look like traditional shingles. In all heritage-based solutions, it is recommended that the finishes used should be non-reflective, flat finish and clay based colours. It is worth mentioning that heritage-grade BIPV compromises power (e.g. -7-8 W per tile of Dyaqua) and is more expensive, requiring more area on the roof or yield in the energy harvest acceptance.

5.5.5 Costs and Trade-offs

Photovoltaic systems integrated on the roof are very expensive with respect to capital expenditures compared to the conventional modules. According to Tesla, the Solar Roof is estimated to cost roughly €15 per watt (around 15000 dollars per kilowatt) with a roof replacement, compared to a price per watt of around 3 cents (commonly called euro) of traditional commercial modules. According to Evora project, the costs of invisible tiles (pv - magazine.com) were seen to be of access to 7,000 pennies in a single kW. Custom manufacturing and specialised labour, and aesthetic integration are reflected in premium pricing, and allows the implementation of RECs in the secured areas at the cost of 2 to 5 times higher capital cost and 1 to 3 times roof area per kilowatt.

The trad-offs are intense in terms of performance. In the same conditions with the roof area, the conventional monocrystalline panels (2022-percent) remain superior to the BIPV tiles (1018-percent) and thin-film films (about 78percent) (sunstyle.com; heliatek.com).

On the contrary, BIPV has a long service life and two-fold use, both as a roofing and power. The warranties resemble the familiar ones (e.g., Tesla tiles have 25 years of power warranty, HeliaSolar has 20 years of performance warranty). BIPV can also save labour expenses used in roofing in situations where the current roof has to be replaced (retrofit). Designers have to carefully strike the balance of these trade-offs so that the targets of REC are achieved at once by keeping visual compatibility through the punitive application of the use of BIPV in the heritage areas and conventional panels to less conspicuous parts of the roof.

5.6 Consumption Modelling

The current research takes a bottom-up approach to modeling the electricity demand, as it is based on census data. The first step was to allocate the consumers to separate buildings. The level of estimate of the number of families or business units living in each structure involved a combination of ISTAT census tables with that of building footprint.

In the case of residential units, the number of apartments was multiplied by average household use, as it was reported by ARERA or obtained based on the local measurements. In commercial, industrial and public buildings, such as hotels, shops and schools, the analysis was done using consumed data either on the utility bills available (where the data is directly measured) or as the nationally available per floor area consumption values.

Hourly load profiles were then introduced after the population assignment. ARERA provides 3-time bands, F1(peak hours, excluding weekends) and F2(peak hours, including weekends) are mainly weekday daytime and F3(peak hours, night) are mainly off-peak night.

The residential loads were modelled using the standardized ARERA shape with the household commonly used F1, F2 and F3 consumption fractions. The annual consumption of each family was divided into hourly portions dotted after these fractions, and a pattern was designed of a weekday standard chosen and repeated in the case of each type of day.

The non-domestic loads were attributed to relevant profiles such as increased weekend demand in hotels and weekdays only usage in educational institutions, based on the ARERA profile library.

The result of this procedure was an hourly demand time series, D (h), of each building and aggregate time series at the community level, Σ D (h). Addition of D(h) in all the hours generated the annual consumption by each building.

The profiles were set to make sure that the height of the hourly sum equated to the projected annual energy of the building based on census-based sums or real metered charges. Therefore, each building has an hourly demand curve which represents its category.

5.7 Energy Balance and REC Performance Indicators

The energy balance and the main renewable community indicators were calculated with the help of hourly photovoltaic generation P_PV(h), and community-scale demand D(h) (per building). For every hour h:

- Self-Consumption (SC): the ratio of PV generation used by the community itself, i.e.

$$SC(h) = \min(\text{Photovoltaic generation } (h), \text{ Demand } (h)).$$

- Overproduction (OP): the excess PV that is not locally utilized:

$$OP(h) = \max(0, \text{Photovoltaic generation}(h) - \text{Demand}(h)).$$

- Uncovered Demand (UD): the unmet demand:

$$UD(h) = \max(0, \text{Demand}(h) - \text{Photovoltaic generation}(h))$$

Such hourly values were summed up to a daily, monthly and annual total (e.g., total SC = Σh SC(h)).

Based on these aggregates standard indicators were obtained:

- Self-Consumption Index (SCI): the ratio of the amount of PV energy utilized in the community. Mathematically,

$$SCI = (\sum \text{self-consumption} / \sum \text{photovoltaic generation}(h)).$$

This is to gauge the extent of PV production utilization on the ground.

- Self-Sufficiency Index (SSI)- Self-sufficiency ratio (also known as Self-Sufficiency Index, or Self-Sufficiency Index): the ratio of local consumption satisfied by local PV.

$$SSI = (\sum \text{self-consumption} / (\sum \text{demand}(h)).$$

- Overproduction Index(OPI): This is the ratio of PV produced that was exported (or wasted).

$$OPI = (\sum over\ production(h)) / (\sum photovoltaic\ generation(h)).$$

- Unmet Demand (UD) Ratio: the portion of the demand that PV has failed to satisfy.

$$UD\ Ratio = (\sum Uncovered\ Demand\ (h)) / (\sum demand(h)).$$

By definition, SCI + OPI = 1, and SSI + (UD/D) = 1. The values of these indices were assessed on a community level and analyzed in terms of their changes through time. An example of this is hourly SC and UD, which represents the repetition rate of the community being export limited or supply limited. Also, monthly calculation of SCI and SSI was used to obtain the pattern of seasonality. Large values of SCI /SSI are an indicator of a properly sized community PV system (high self-use); large values of OPI or UD represent over- and under-sizing, respectively.

These indicators will combine the performance of Renewable Energy Community (REC) and compare it with policy objectives. The European system of renewable energy certificates (European REC), e.g., prioritizes the maximization of local consumptions of renewables (high SCI). In the current case, the most appropriate design had a score of 84% per year, meaning that most of the PV energy is allocated to the community (see Section 5.8).

5.8 Case Study: to Isola di Ischia.

The workflow stated above was implemented in the Island of Ischia. The spatial layers (DSM, building footprints) were cut to the boundary of the island. DEM (1m resolution) and the height of the buildings created a dense urban DSM of Ischia. The evaluation of solar irradiation on the buildings of the island was then adhered through the 12 typical-day simulations (Section 5.4). Figure 5.1 shows the assembled workflow that consists of data inputs, modelling processes and indicators that follow.

With the help of the data of Ischia, maps of rooftop irradiation and PV potential were drawn. As an example, south facing roofs in open places received an annual irradiation of around 1500-1600 kWh/m² compared to the shaded or northward roofs receiving less than 900 kWh/m². It was found that about 500 large roof sections (more than 10m^2) would be good as PV. Summing, their net PV areas produced approximately X m^2 of available area which is equal to Y kW with a nominal efficiency of 23%.

Demand As the energy use of chosen members of the REC (school, hotel, supermarket, public buildings, residences) was approximated at about Z MWh /year. Their hourly load pattern was constructed based on the ARERA residential and commercial patterns.

Achieving self-consumption of 84 per cent. annually using the community's optimal design, which was sized to match production to demand, gave a self-sufficiency of about 75 per cent. This finding can be explained by comparing the profile of generation and demand These sample indicators indicate that the methodology can be applied to the specified problem: all calculated indicators (SCI, SSI, OPI) are calculated hourly and summarised as mentioned earlier to allow a full evaluation of the performance of the REC during Ischia.

In short, the following sequence of steps was followed with the Ischia: input data was calculated in QGIS/GRASS; solar radiation was simulated on each roof; usable PV area and production were calculated; consumption was modelled by census data and ARERA profiles, and finally, the energy balance and REC indicators were calculated. As it is established in the case study, the GIS-based methodology can be used to approximate rooftop PV potential and community energy indicators to the case of a real-mediterranean island.

CHAPTER 6

RESULTS

6.1 Spatial Constraints on PV installations

6.1.1 Cultural Heritage

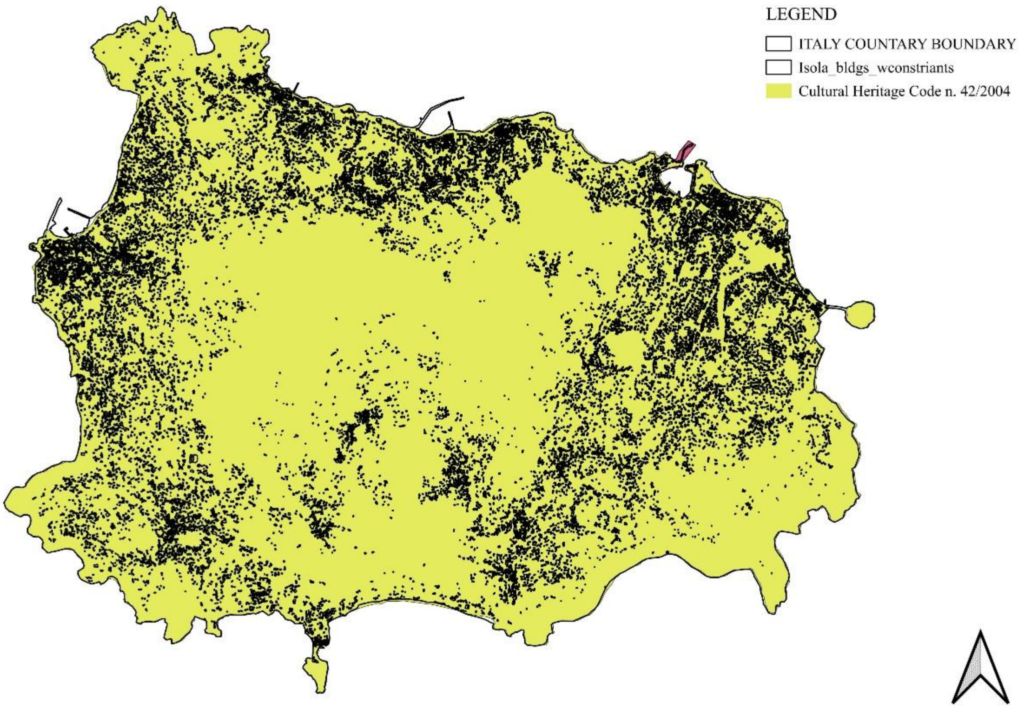


Figure 66: Cultural constraints

The map above illustrates the Cultural Heritage (Paesaggistico) constraint applied under **Italy's Cultural Heritage and Landscape Code – D.Lgs. 42/2004 (Codice dei Beni Culturali e del Paesaggio**). The shaded yellow area represents the portion of Ischia falling under this legislative protection. As the results indicate, this constraint covers almost the entire territorial surface of the island, leaving very minimal areas exempt. This outcome is consistent with the legal and territorial context: Ischia is widely recognized as a landscape of exceptional cultural, historical, and environmental value, and therefore subject to extensive heritage protections.

The cultural heritage constraint is comprehensive but compatible with rooftop PV deployment, provided that installations follow the landscape guidelines of D.Lgs. 42/2004. Therefore, for REC planning on Ischia, roof-integrated or low-visibility PV systems represent the technically and legally appropriate option, enabling renewable production while preserving the island's protected visual and cultural identity.

6.1.2 Historic centres

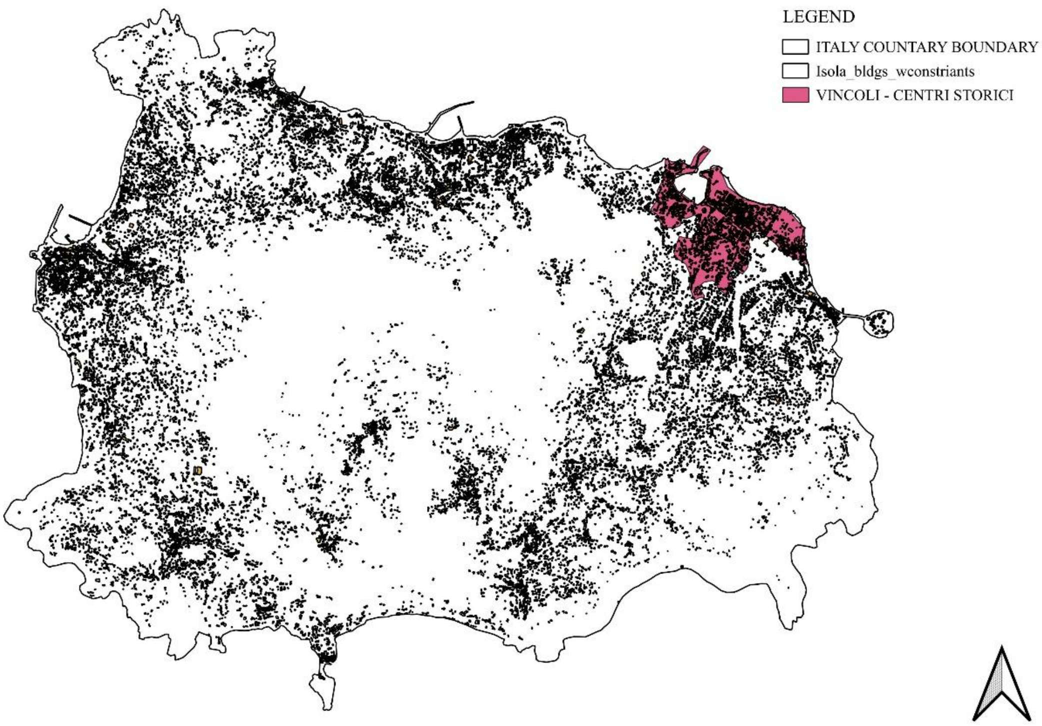


Figure 67: Historic centre

The map illustrates the spatial extent of the Historic Centre Protection Constraint (Vincoli – Centri Storici), regulated under Royal Decree n. 1089/1939, Italy's foundational law for the protection of cultural and historic assets. The highlighted areas (shown in pink) correspond to the historic nuclei of Ischia—particularly the dense traditional settlements in

Ischia Ponte, Ischia Porto, and parts of Casamicciola, where centuries-old architectural forms, narrow street networks and heritage buildings are concentrated.

The map demonstrates that the Historic Centre constraint under Decree 1089/1939 affects only specific high-value nuclei, not the entire island. While these areas require special visual and architectural considerations, rooftop PV installations remain feasible, supporting the overall PV potential assessment for the REC feasibility study.

6.1.3 Protected Areas

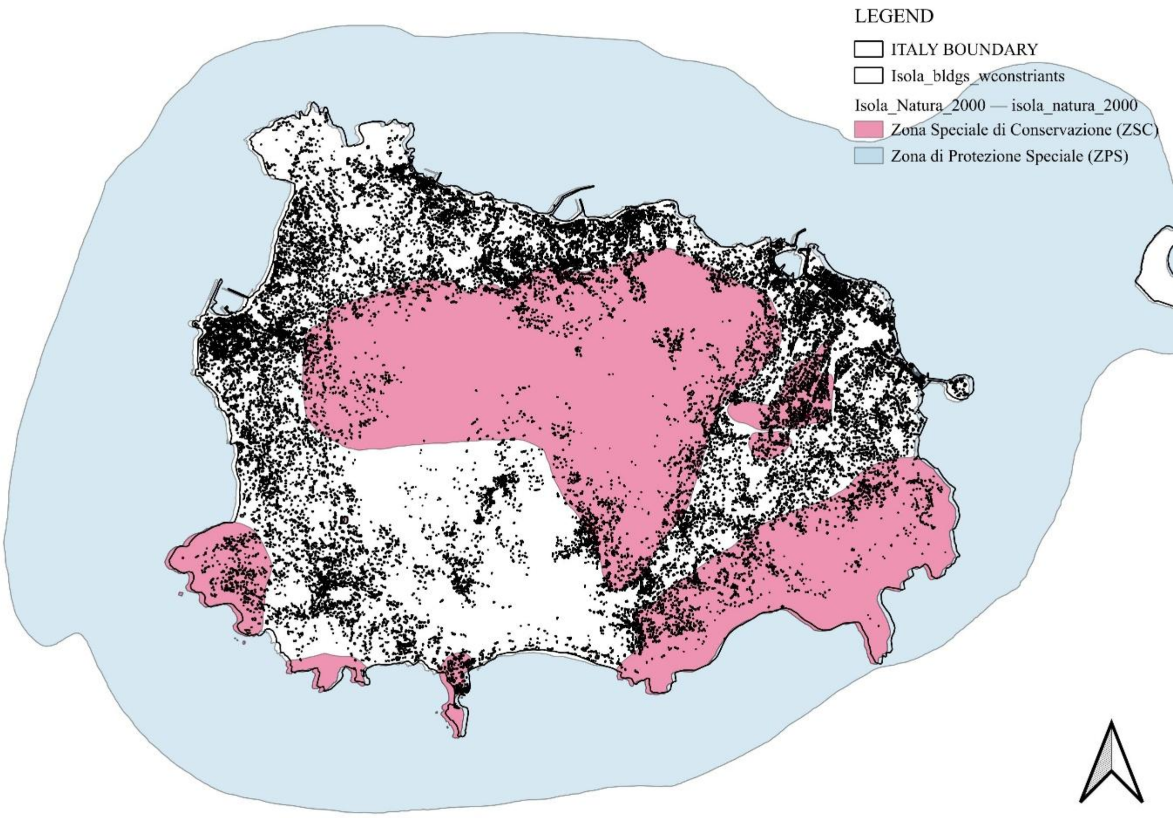


Figure 68: Natura 2000 protected areas

The map illustrates the Natura 2000 environmental constraints on the island of Ischia, defined under the EU Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC). The pink areas represent Zona Speciale di Conservazione (ZSC)—Special Areas of

Conservation established to protect habitats and species of European importance—while the light blue area indicates the Zona di Protezione Speciale (ZPS)—Special Protection Zones designated for bird conservation.

The Natura 2000 constraint confirms that while Ischia's natural environment is extensively protected, rooftop PV remains permissible and fully compatible with conservation objectives. Therefore, the island's protected ecological zones do not hinder its capacity to participate in REC development, provided that renewable energy installations remain confined to the anthropized (built) areas already identified in the rooftop analysis.

6.1.4 Cultural Heritage Buildings

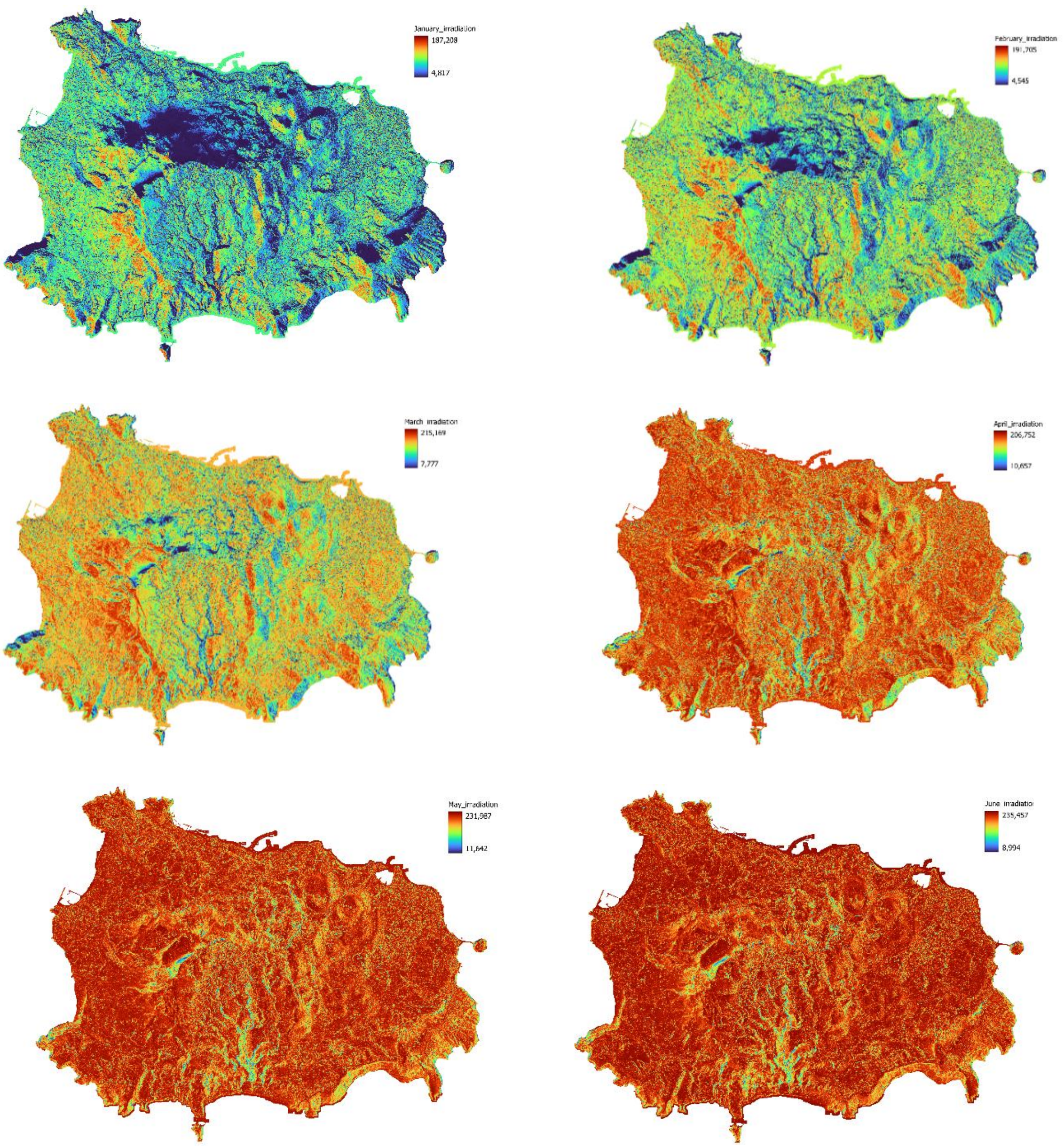
Figure 69: Cultural buildings

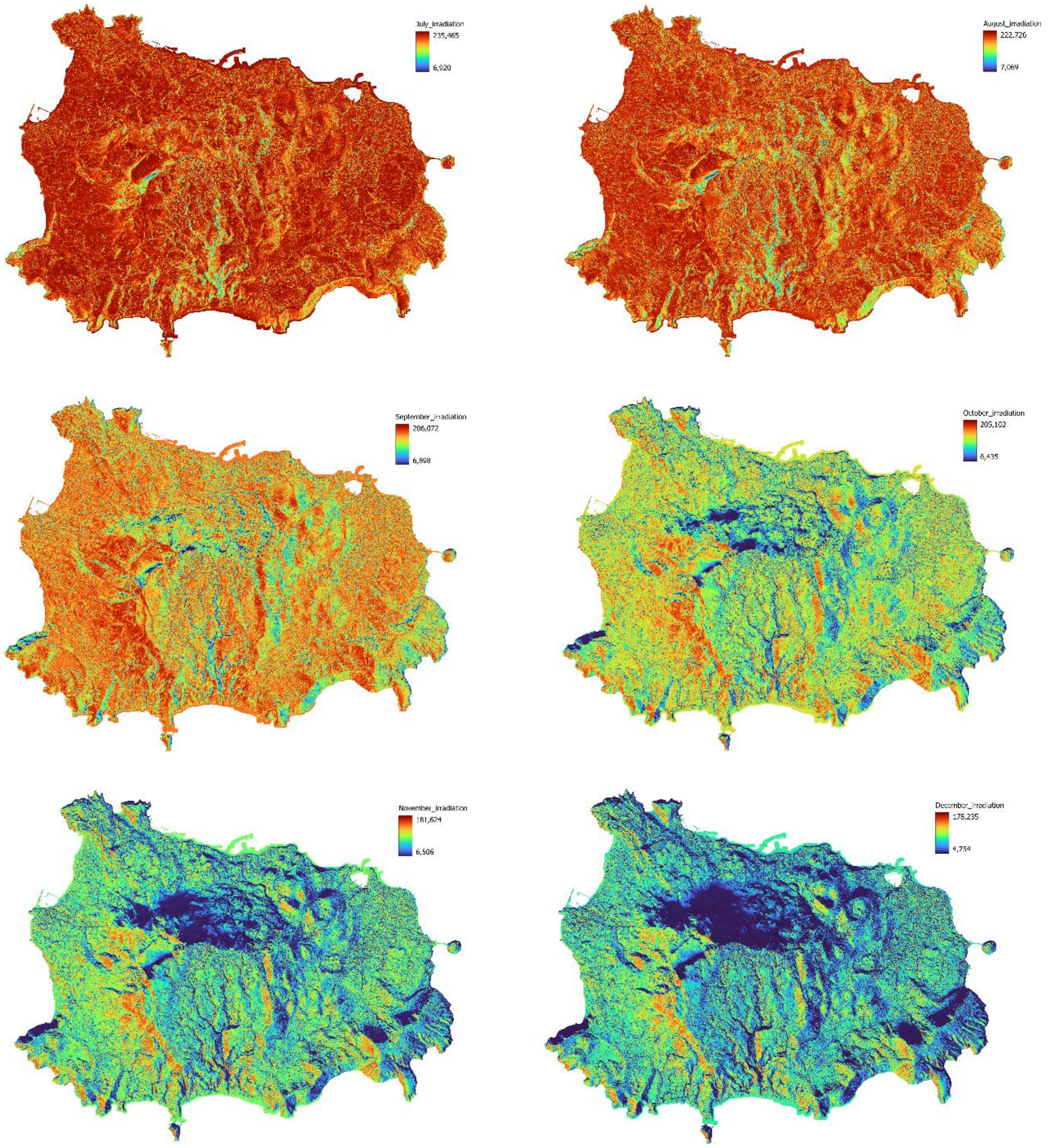
The spatial pattern shows that protected buildings are not uniformly distributed across the island; instead, they are concentrated in historically significant areas, particularly:

Ischia Ponte, including the buildings surrounding the access to the Castello Aragonese, the historic waterfront of Ischia Porto, scattered heritage nuclei in the interior settlement fabric.

These areas represent the oldest urban cores, where architectural heritage has national and regional significance. The red-marked buildings include churches, convent structures, coastal fortifications, historic residences, and other culturally relevant assets.

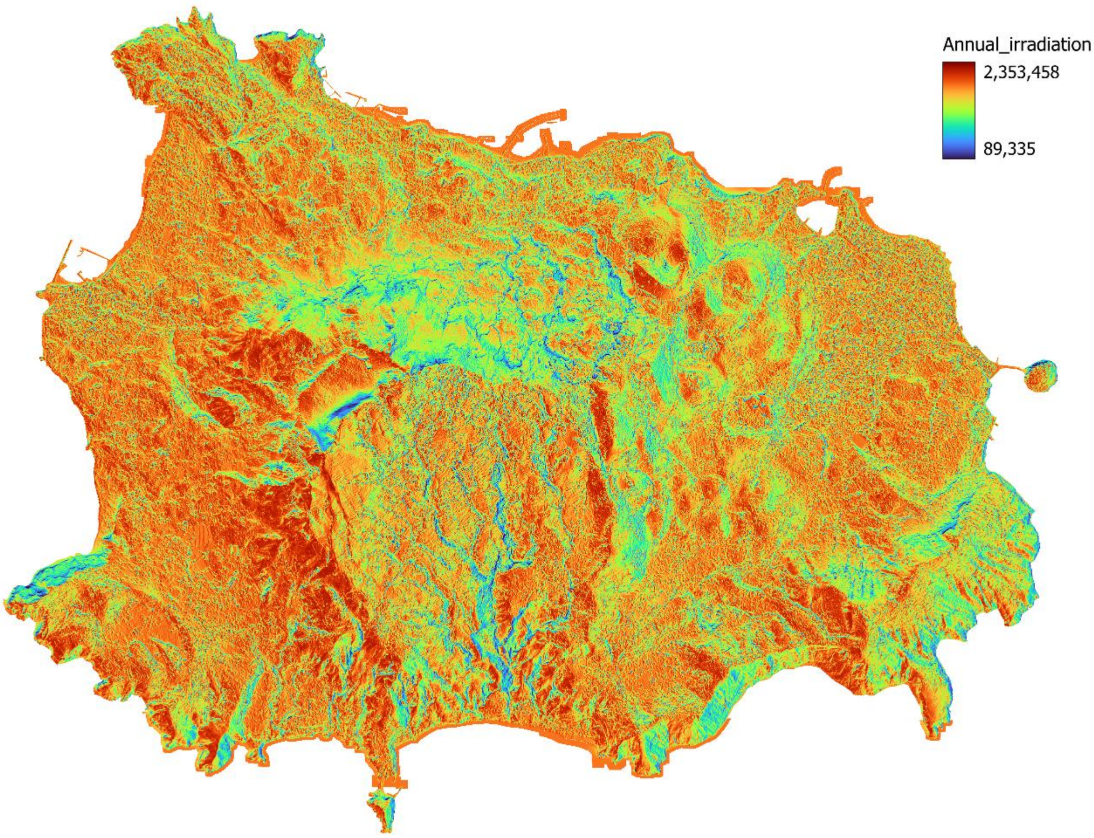
6.2 Monthly Irradiation Maps (Wh/m^2/month)





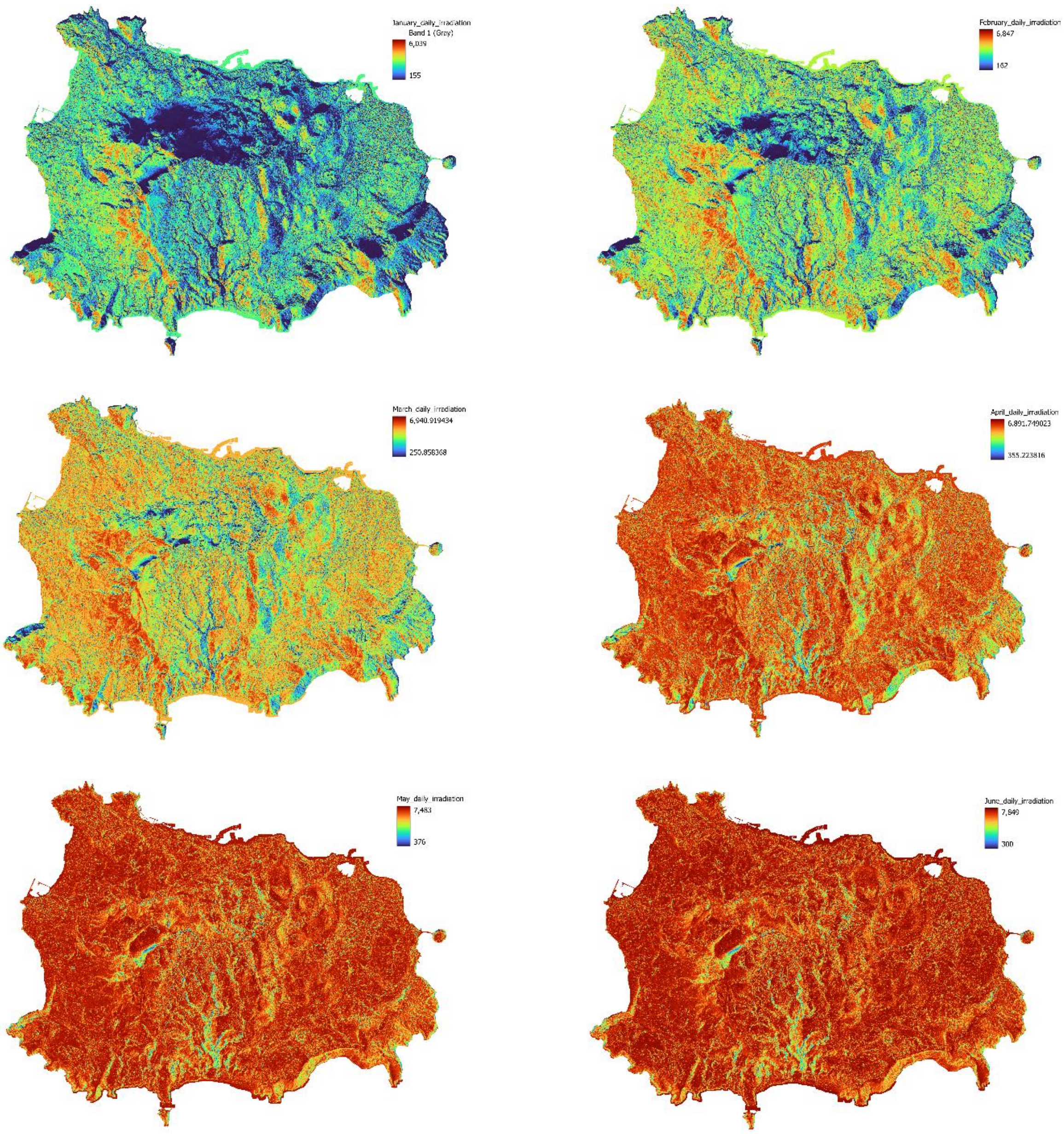
This map indicates the spatial distribution of average solar radiation in every month on Ischia. It relies on color gradients to show the intensity of sunlight delivered to each place at various seasons. Initial examination using the map shows that there is a strong seasonal difference: irradiation during summer months is significantly higher (bright colors) as compared to winter months. Some regions (like south facing hilly slopes and elevations) invariably get more sunlight in each month, and darker areas are found in deep valleys and shadowy places. This is a seasonal trend, which implies that the production of PV will be saturated during summer and low in winter. The implication to a REC is that it is easy to generate in summer more than what the local needs demand (but generating a surplus), but in winter there is little supply. These trends of seasonality were modelled in Chapter 4 of solar modelling and the outcome of this finding is related to the island context of Chapter 1, where it is necessary to fulfill peak tourist-season demand with summer solar.

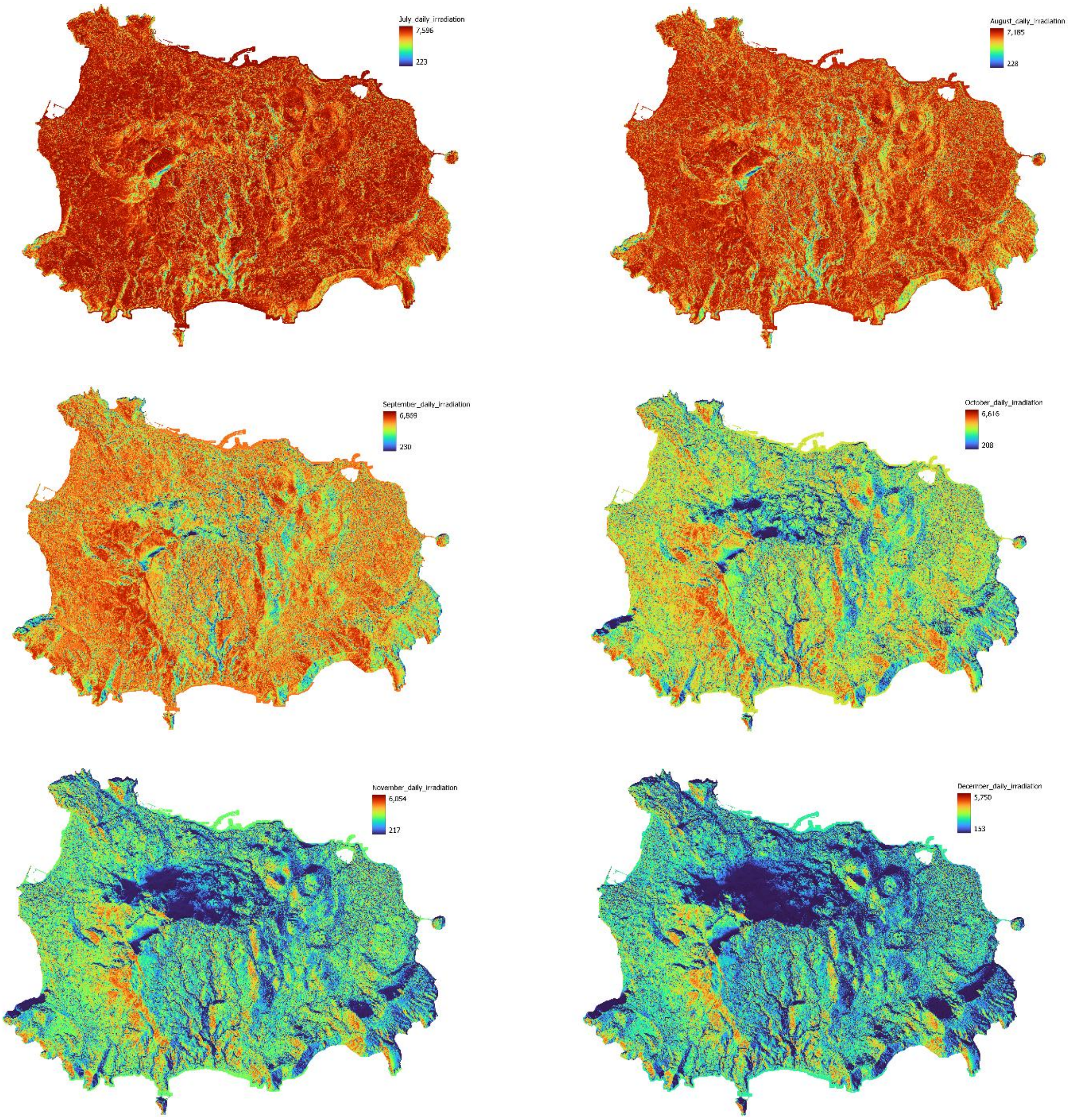
6.3 Annual Irradiation Map (Wh/m^2/year)



Each location in the island is here coloured by the annual solar irradiation on it. As it can be seen in the map, Ischia is usually very sunny all year long (light tones prevail everywhere), yet there is some fluctuation. The steep slopes and open spaces are exposed to the greatest amount of radiation and more of the island which is steep or north facing is a bit darker (has lower values). Sun is also likely to be high in the plateaus and ridges. This map shows the areas that are characterized by the most promising PV resource. Regions where the annual irradiation is the greatest are the best place to install solar panels since they yield the highest amount of energy. The chapter 4 radiation modelling was replicated in this map and forms the basis of the thesis aim (Chapter 1) of where the PV rooftop will be most effectively it will offset demand.

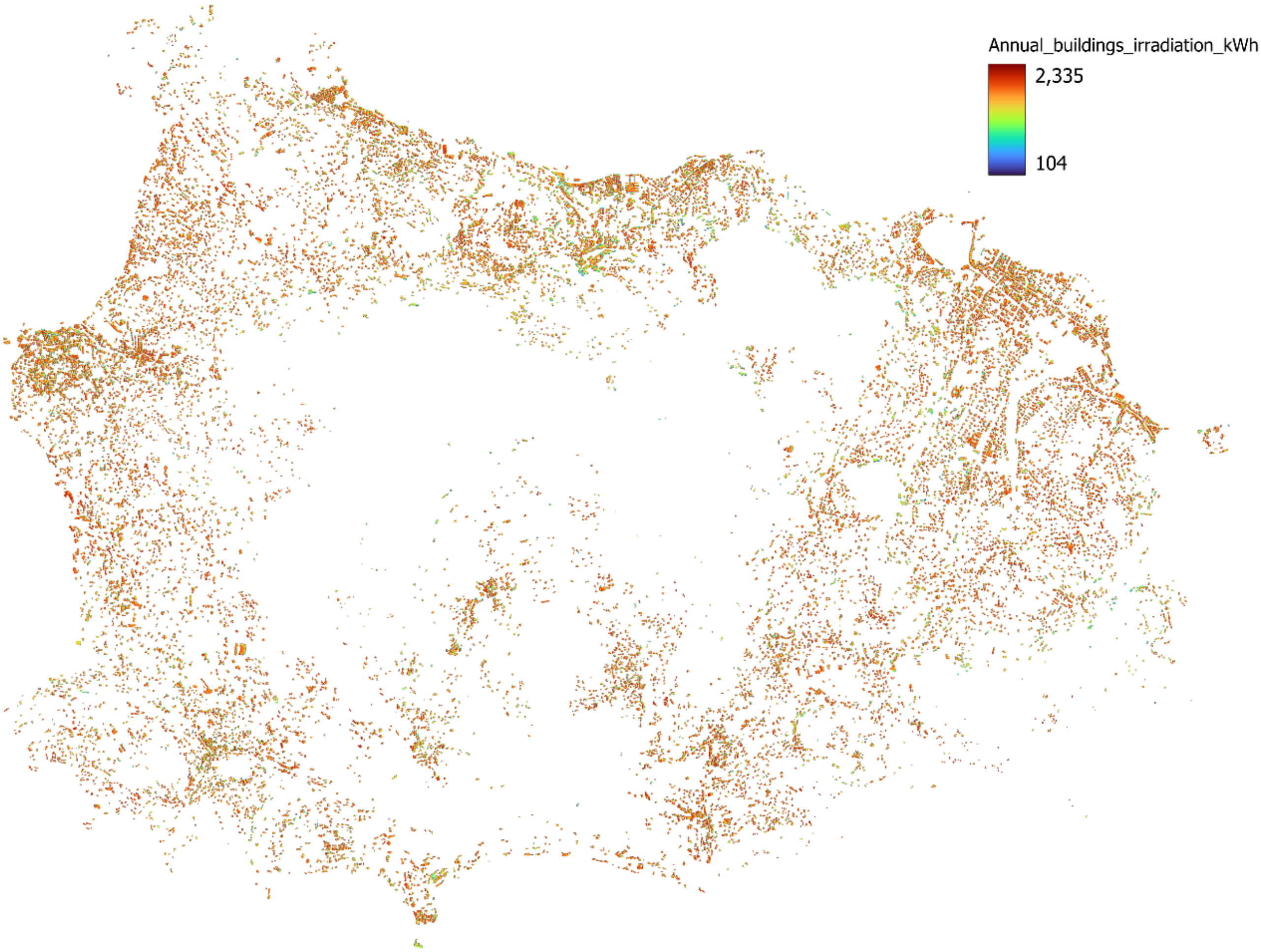
6.4 Daily Irradiaiton Maps





The twelve daily irradiation maps that occurred on different days throughout the year and which demonstrate the changing amount of solar radiation reaching the rooftop surfaces based on transient atmospheric conditions (cloud cover, solar elevation, humidity, shading, et cetera). Although the monthly and annual irradiation maps would provide a more climatological view of a region, these daily maps are essential when trying to explain the daily variation of photovoltaic production, which directly corresponds to the hourly simulations of energy balance used in revenue-credit feasibility studies.

6.5 Annual building irradiation (kWh)

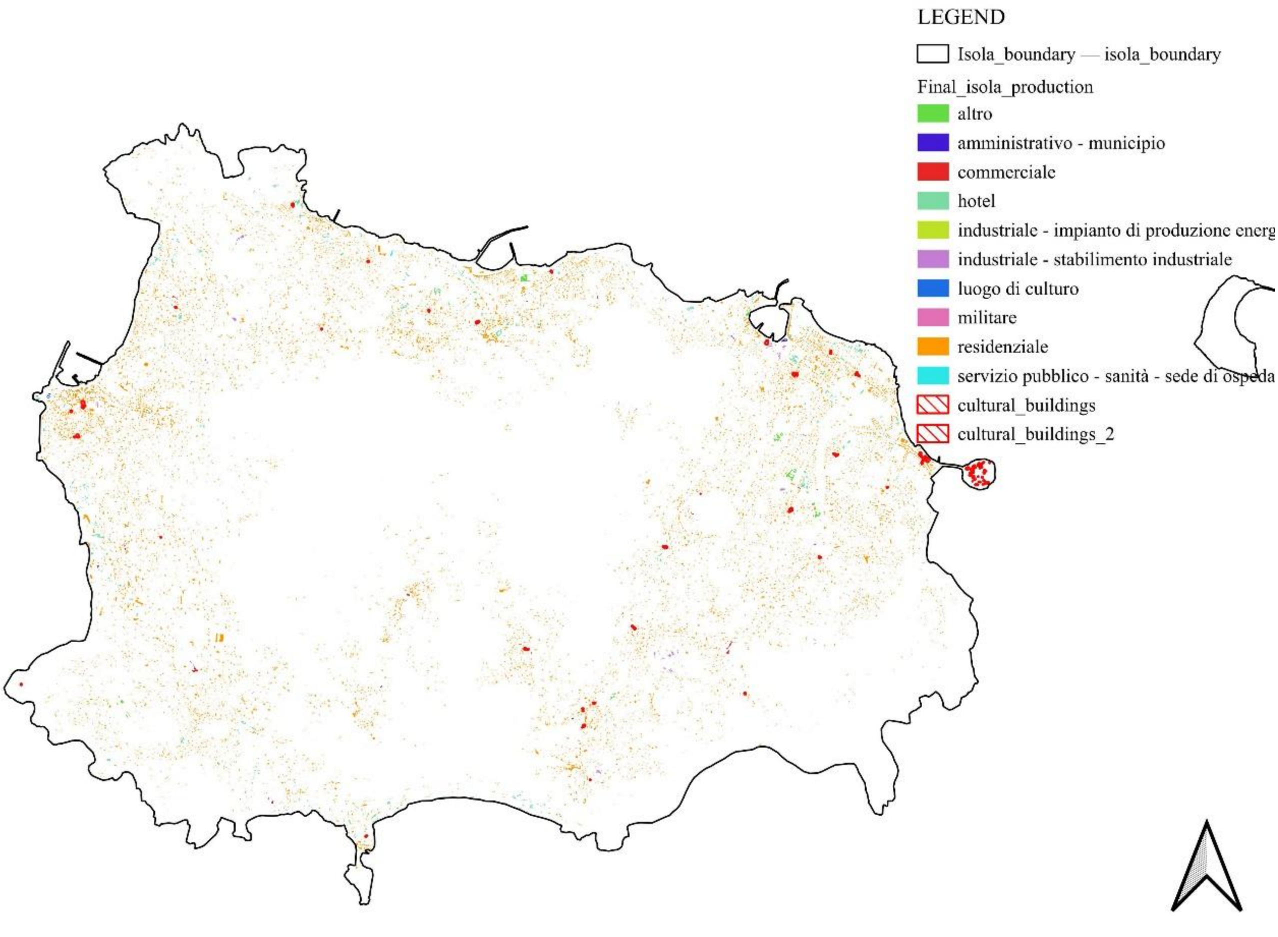


This map represents every building based on its yearly energy output of photovoltaics, including roof space, tilt, and insolation. Big flat roofed buildings (industrial or community buildings) are painted in very contrasting colour, which indicates large possible production. However, the residential houses smaller in size and covered with strong shades on the roofs are represented in darker colours, indicating their low yearly yields.

This means that the majority of the generation capacity within the island is concentrated in a few large buildings and thus, it is important to focus on these strategic buildings in order to have the maximum benefits of self-consumption. The concentration of potential also emphasised in the spatial patterns as the concentrations on urban centres with low yields on rugged lands. Technologically, map is obtained by combining the data of solar irradiance with GIS roof inventories, as explained in Chapter 4.

Through this method, tangible identification of the rooftops with the most significant contribution to local self-sufficiency in terms of energy is identified.

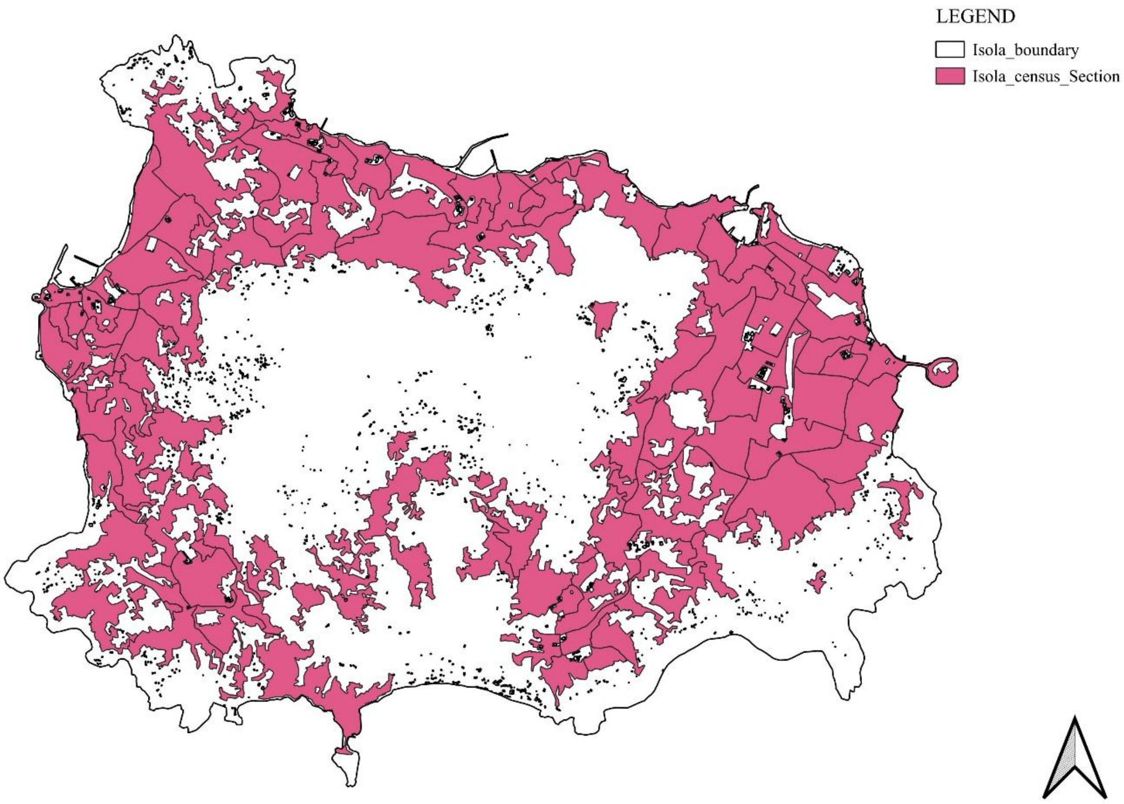
6.6 Building Typologies



The spatial distribution of all the buildings on the Island of Ischia as shown typed is systematically classified in functional designation. The colour schemes of the individual building footprint are related to the corresponding use: residential, commercial, industrial, administrative, hospitality, public service, cultural heritage, and miscellaneous. The basis of such classification is the analytical evaluation of energy demand sources and development of typologies of buildings with the strongest impact on the potential of rooftop photovoltaic production.

The overall pattern shows a dense and uniform distribution of buildings, especially in the central and coastal areas of the island.

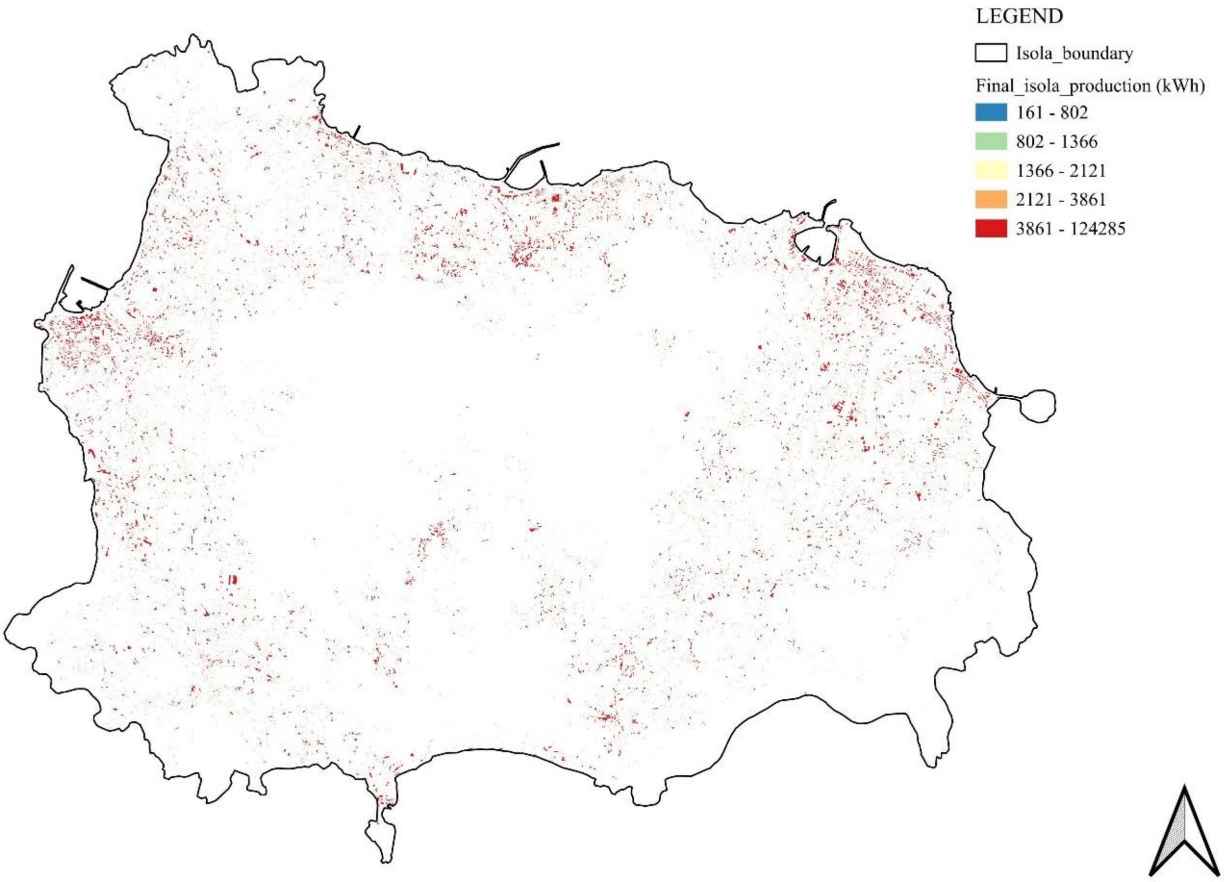
6.7 Census Section



This map clarifies the official ISTAT census blocks throughout the Island of Ischia indicated by pink and overlaid onto the boundary of the island. ISTAT uses census sections as the most narrow and important statistical grid to arrange the data on population, built environment, and socio-economic features. Their addition as indicators to the analysis cannot be more necessary since many of the indicators that support this thesis, such as annual consumption, self-sufficiency, population density, and renewable energy credit (REC) cluster of potential need to be computed and interpreted on this space level.

Graphically, the map can be seen to show the census section of nearly the entire coastal area and most inhabited zones of the island, and the mountainous core of the island is left unclassified due to absence of any urban or residential settlements. Such distribution is a precise reflection of the urban structure of Ischia where city building focuses on the coast, road systems and flat terrain. The map is therefore central in converting technical models of energy into policy-relevant models that are spatially explicit and thus direct to the overall intention of evaluating the feasibility of Renewable Energy Community on the Island of Ischia.

6.8 Production



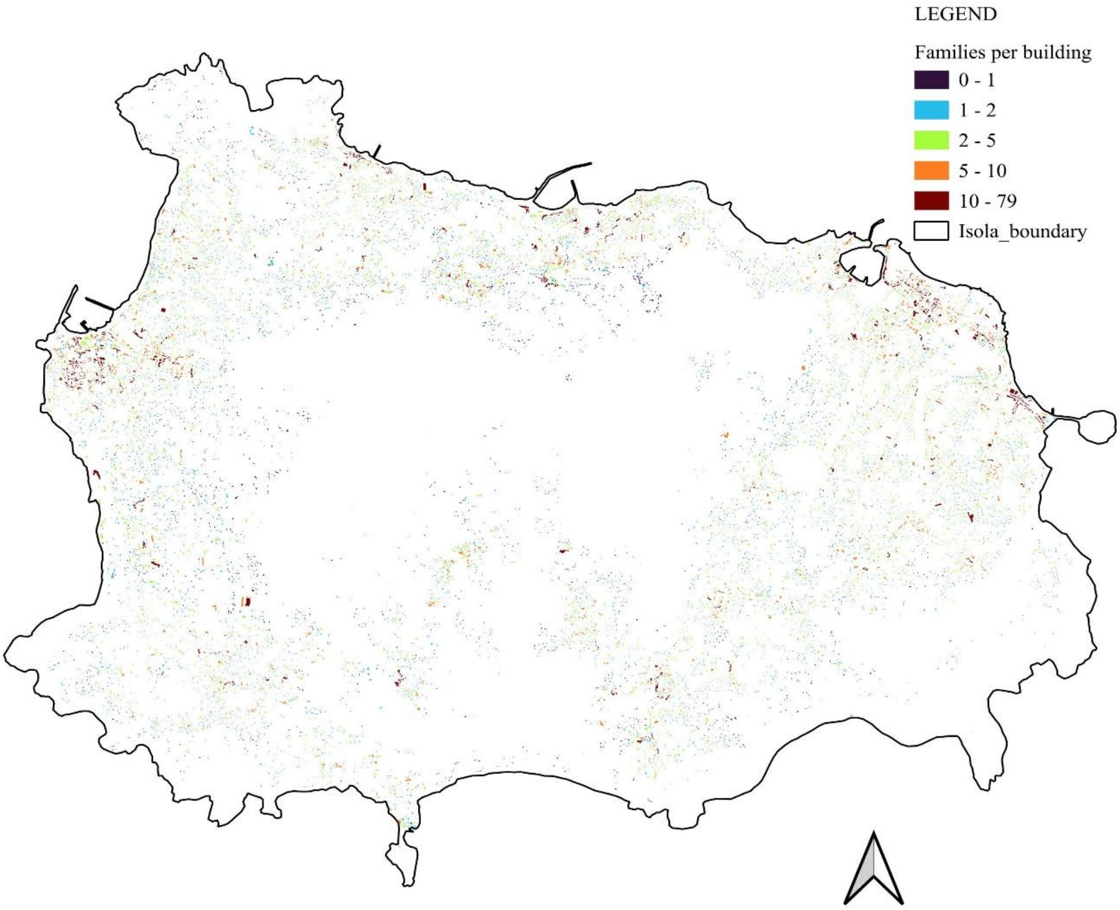
This map outlines the spatial distribution of the annual photovoltaic (PV) production potential of the Island of Ischia of all the buildings, and categorises the potential into five production groups, such as, very low (161-802 kWh/yr) to very high (up to 124285 kWh/y). As shown by the visualisation, the greatest portion of rooftops is classified under the highest production category, which is marked in red, which suggests that most of the buildings in the island have favourable exposure to the sun, are oriented to the best positions, and have minimal levels of shading, which are all traits that always combine to produce high PV yields. The greatest concentrations of high production buildings are located along the north, northwest, and east coastlines with buildings having a uniform orientation and are not obscured by topography.

Conversely, buildings with lower yields, which are marked by the blue and green colours are more common on the interior of the island where steep slopes, or tree cover, or uneven roof lines reduce access to the sun. These spatial differences highlight the role of micro-topography and cities form in determining PV viability, even in an environment of relatively high irradiance as at Ischia. It is important to note, however, that these local variations do not have an overall impact since within the larger pattern, the island has an unusually extensive pool of solar resource, and the few regions where the production potential remains low, are scattered about.

This result has a substantive point of view when considering a Renewable Energy Community (REC). The widely spread high-producing buildings have shown that generation of energy is not a handful activity in exclusivity of few locations; on the contrary, almost in every neighbourhood is contributing significantly to the total power production on the island. This space balance improves sustainability of efficient community energy sharing, so the excess power produced in large production sites could be used to sustain less productive buildings.

Additionally, the availability of outstanding high-yield rooftops, commonly gigantic residential homes, government structures or business buildings, offer strategic possibilities of placing major REC creation facilities in spots where they can have the greatest impact of their functionality. This map, in general, demonstrates that Ischia is suitably sited in order to realise high degrees of local PV generation, and the allotted potential throughout the area is sufficiently sufficient to constitute a robust and justifiable REC design.

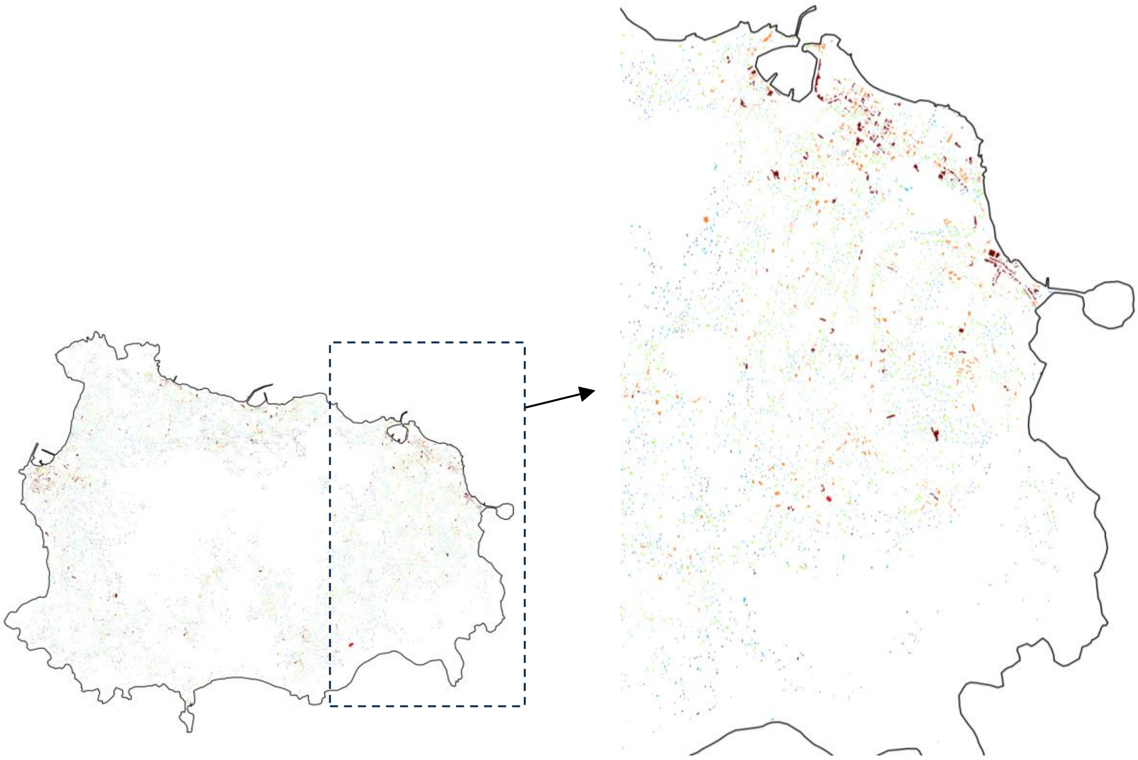
6.9 Families per buildings



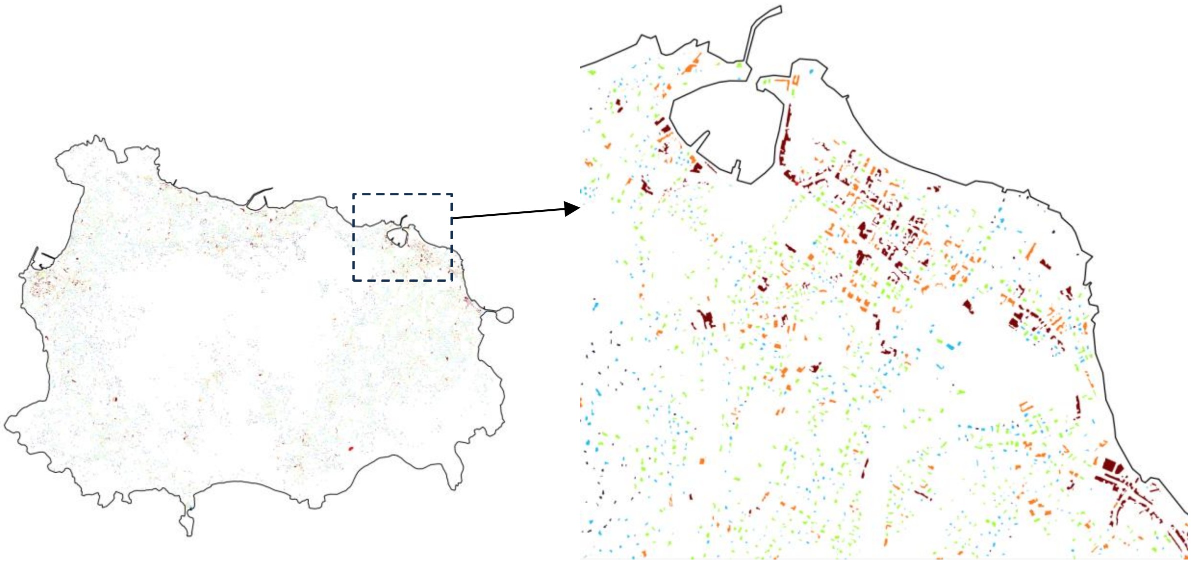
The current cartographical map shows the locations of the amount of families hosted in each building in the Island of Ischia. There are five categories, 0-1 family (dark blue), 10-79 families (dark red). Mapped by household density on a building-to-building basis, this number offers the indication of Ischia residential structure and population density, and possible patterns of electricity demand.

The demarcation of the borders of the island is provided to align the residential density impacting the terrain. All in all, the map shows that most of the structures in the island have between 1 and 5 families which is represented in the numerous light blue, green and yellow dots. This is in accordance with usual single-family houses and small multi-family buildings, which are the major part of the residential life in Ischia.

In general, such buildings have simple but regular patterns of electricity demand, which has a major impact on the baseline residential consumption used in the energy-balance modelling of this thesis. Their geographical distribution all over the island confirms that residential demand is not highly concentrated and hence the need to have a distributed photovoltaic generation as opposed to the need to have one central source of demand.



The map also points at high-density multi-family structures (10-79 families) that are drawn in dark red. These groups are mainly concentrated in more urban cities or coastal municipalities where there are multi-storey apartment buildings or hotels or very high residential complexes. As numerous houses have a single building footprint, these facilities constitute hotspots of demands.

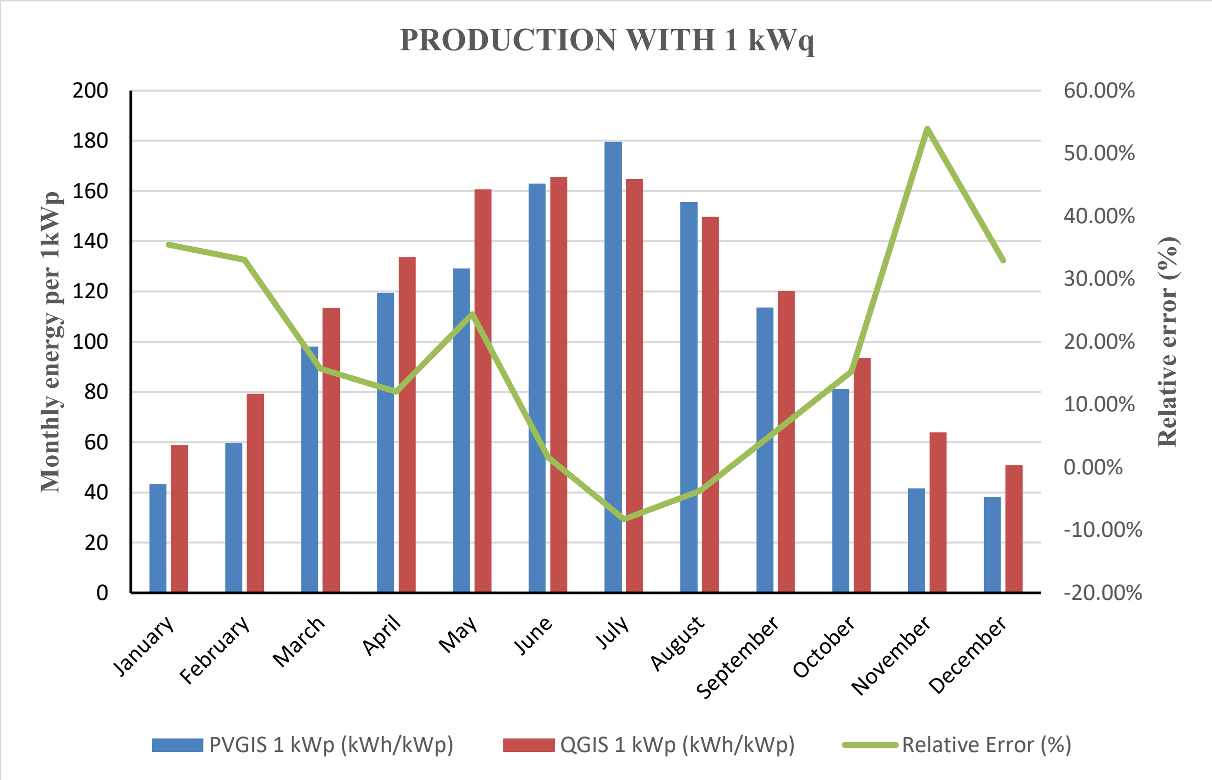


Energetically, these structures are of considerable significance since their rooftops are very small in terms of space compared to the number of households they should accommodate. This imbalance has clarification that even with the presence of photovoltaic systems, the impact of these buildings is that it would be a net consumer implying that it would essentially gain a lot in an event where a Renewable Energy Community where the surplus production of other zones are shared.

On the other hand, there are dark blue points, which depict zero or one family buildings, usually rural houses, agricultural buildings or poorly used second houses. These entities are defined as lower and more erratic users of electricity making them a perfect candidate in providing excess photovoltaic power to the community when their needs are at their lowest point. The fact that they are distributed over the southern and central sections of the island to imply generation-heavy but demand-light nodes within the REC gives a notion of local balancing between high-demand and high-generation localities.

The distribution of families over buildings can help the REC to be planned strategically in linking high-generation rooftops to high-demand households collectively improving the amount of energy shared and ensuring greater community self-sufficiency.

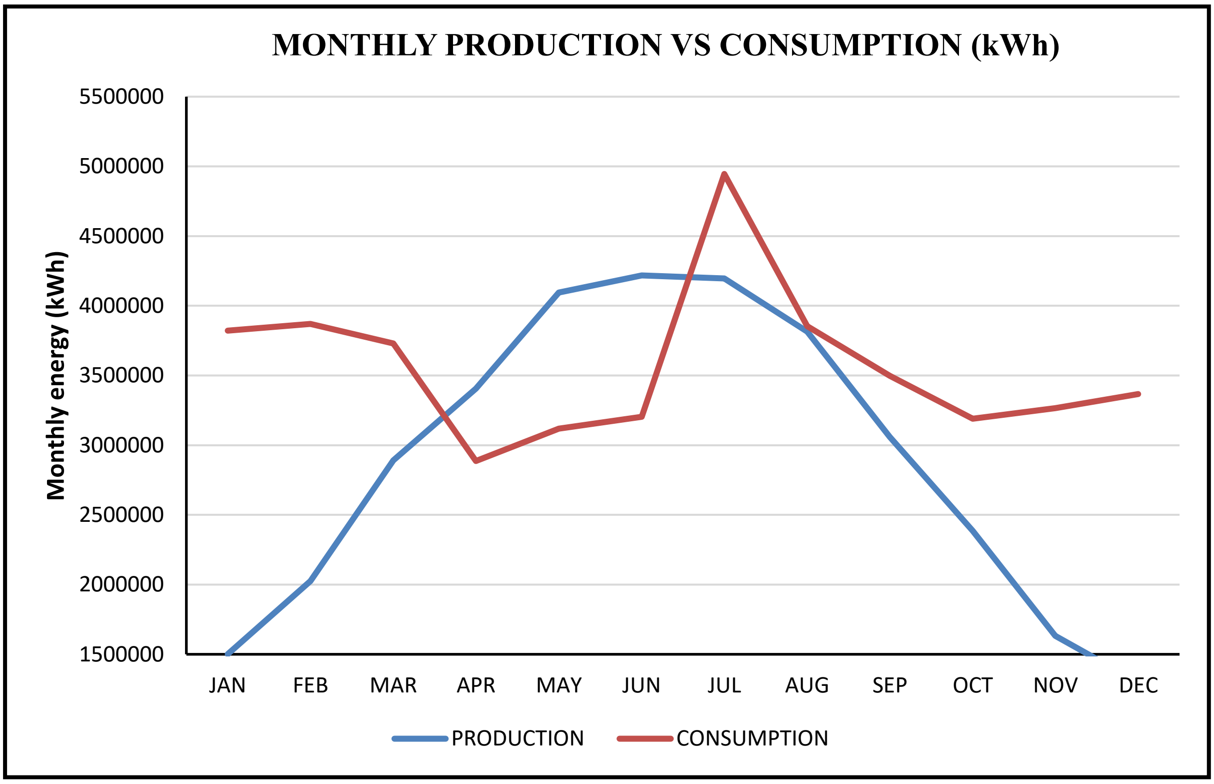
6.10 Production with 1 kWq



The graph compares the monthly photovoltaic energy production per 1 kWp obtained from two different methods—PVGIS (blue bars) and the QGIS-based radiation model (red bars)—alongside the relative error between the two (green line). This comparison is essential for validating the solar modelling methodology used in the thesis.

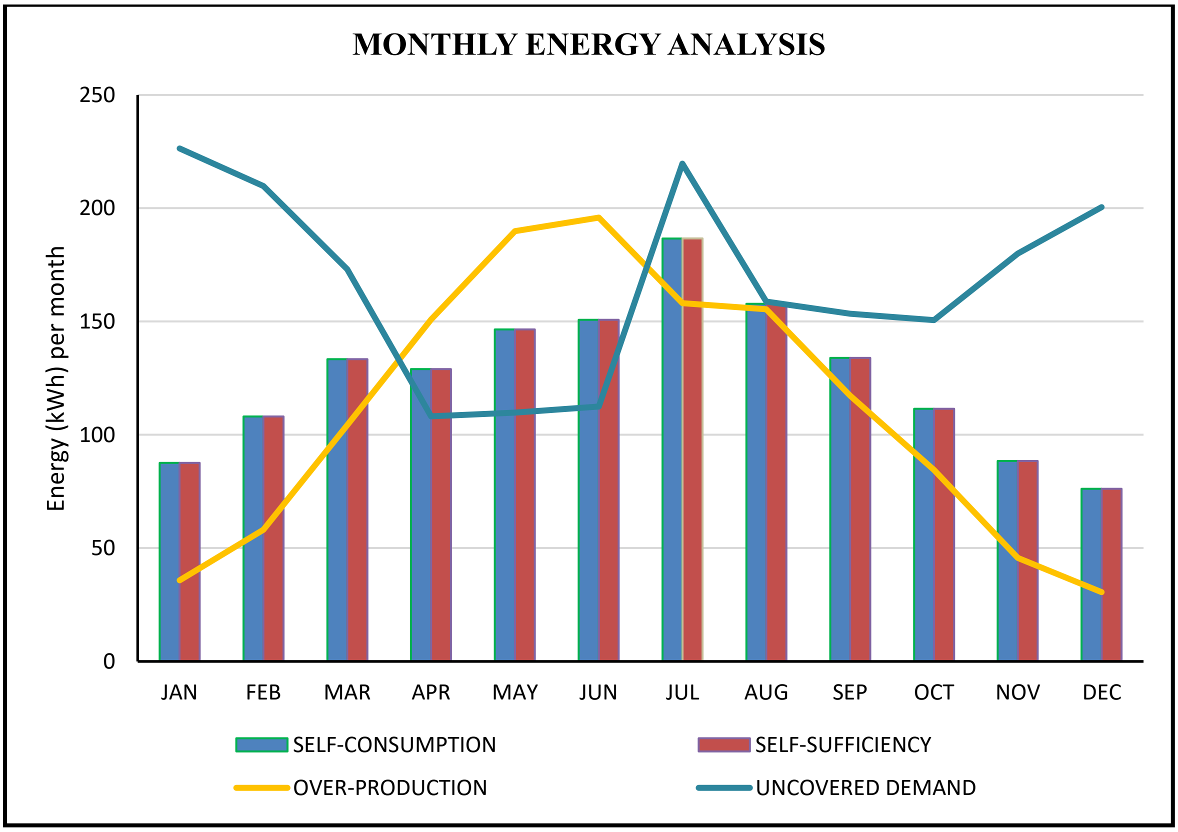
This comparison illustrates that the two radiation models of PVGIS and QGIS possess a regular seasonal trend of which the maximum amount of photovoltaic (PV) output is presented during summer and significantly low production during winter. The two data sets converge to the nearest in the times when the solar irradiance is in its peak- especially in June and July meaning that the QGIS model will be able to get its best precision during the times when PV production is the most influential in terms of the energy balance in the island. The error is also significantly larger in winter but still its impact on the overall performance is mild considering that winter makes only a small fraction of total PV production. As a result, the plotted data substantiate the fact that the QGIS-based rooftop modelling system that is used in this thesis entails a credible basis of estimating building-level PV production on Ischia and provides a sound foundation of estimating the feasibility of Renewable Energy Communities.

6.11 Monthly Data



This graph is with respect to comparing the total monthly photovoltaic (PV) generation and the total electricity that is consumed by the island where we see that there is a seasonal imbalance between the energy generation itself and the demand of the power. There is a sharp upward trend of the production curve during the period between January through June and reaching its pinnacle of approximately 4.2million kWh (4.2 GWh) in the middle of summer after which it decreases sharply to winter. By contrast yearly consumption differences are fairly constant, and lie between 3.2 and 3.8m kWh (3.2-3.8 GWh), with the exception of a sizable spike in July, where demand is more than 5m kWh, and both tourism and cooling demands are highest at a similar time.

Even though in June the output of PV was almost equal to the consumption, it was lower in July, since even at the maximum production rate it was lower than the peak demand of the island, which is still high. As the year advances to the autumn and winter seasons, the gap between production and consumption increases significantly and this leaves the grid reliant on imports. In general, this graph shows that even though Ischia has high potency of PV generation in summer months it is the lack of availability of storage, inflexible load control or energy-sharing concepts within a Renewable Energy Community that will ensure the energy availability all year round.

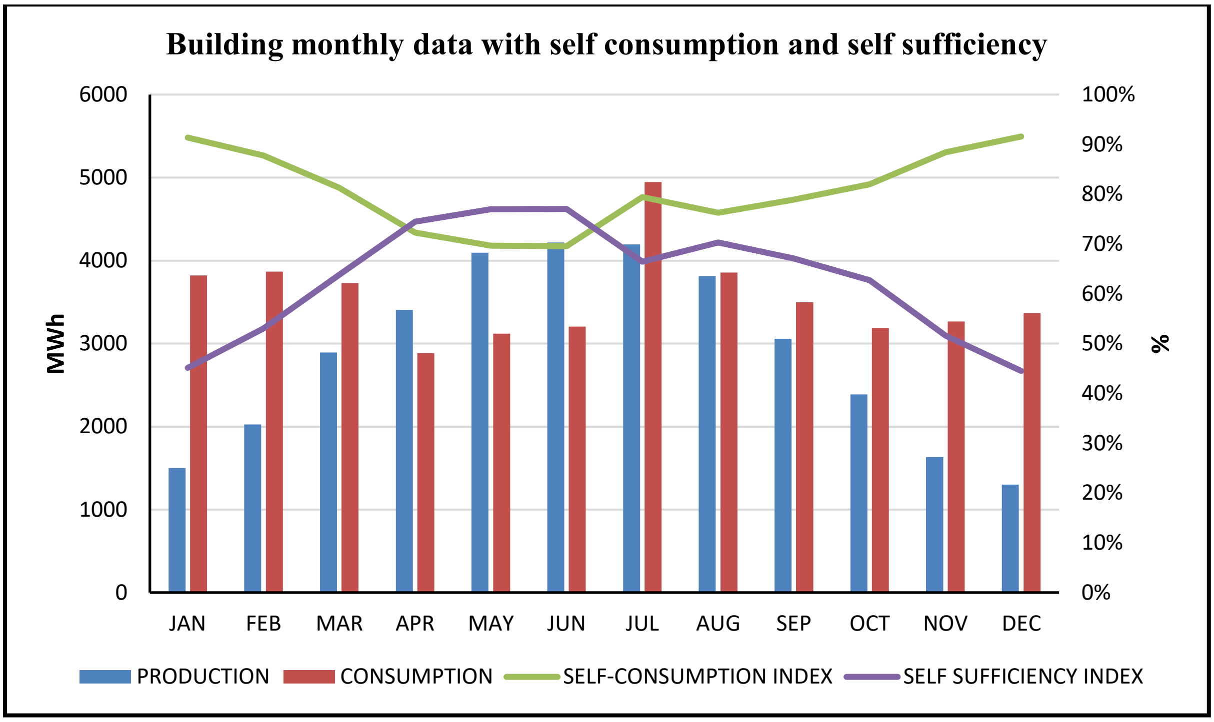


In the current graph, four key variables, namely self-consumption, self-sufficiency, over-production, and uncovered demand, are provided through a monthly breakdown. The bar elements self-consumption (green) and self-sufficiency (red) indicate that both the indicators increase throughout the period of January until they go to the highest point in the summer months when the sun is best positioned to be used. During the months of June and July, the buildings absorb much of the PV energy (made), and the self-sufficiency level is the highest, as production is highly matched by the total demand.

The yellow line shows how over-production rises high towards the spring and to early summer periods showing that PV production surpasses the production needs of the buildings. This phenomenon is reversed after August because solar output decreases.

The blue line depicts bare demand and in that case, it is most active during winter (January3) when the amount of PV production is minimal, then it decreases during the summer months and increases during the autumn because of the decreasing number of daylight hours.

The graph clarifies that the energy independence and excess generation are better in summer months and so the heavy use of the grid is required to compensate deficits in winter months. In general, the analysis has shown that storage should be combined with demand management or sharing of the mechanisms of REC to save the summer surpluses and balance the winter deficit.



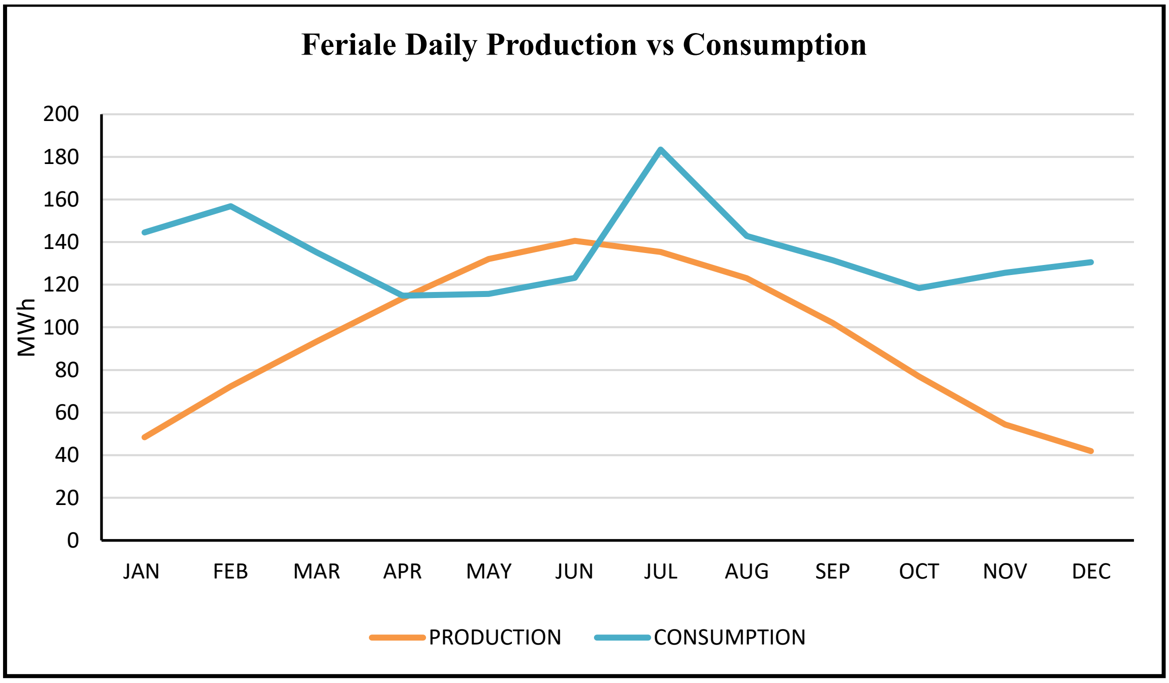
The graph figures out the monthly correlation of PV production, consumption of electricity, self-consumption index, and self-sufficiency index of all buildings in the study area. PV production (blue bars) has a regular seasonal pattern that rises in the winter to the summer period and peaked in June-July then descended towards the end of the year. Consumption (red bars), however, is not very volatile overall, only slightly dropped in the spring and significantly rises in July, which can be well explained by the effect of tourism-based variation of cooling loads and the level of commercial activity.

The green line indicates the index of self-consumption that is an index of the PV energy produced that is used within buildings directly. This index reaches a highest point in winter as the production is minimal and almost all the energy generated is used immediately and lowest point in summer when the PV generation is higher than the demand at a given time. Contrastingly, self-sufficiency index (purple-line) increases in summer months where a higher proportion of PV production contributes to overall consumption with maximum growth in the months of June through July.

It reduces significantly in winter when there is limited access to solar energy, and electricity on the grid is more needed. In general, the graph indicates a strong imbalance between the production and demand seasonality.

Although when the summer seasons come, it allows increased energy independence, winter seasons are those months that are defined by low self-sufficiency and minimal use of solar energy. This highlights that even more will be needed like energy storage, shifting of loads or a coordinated sharing of buildings to overcome such seasonal imbalances so as to make the Renewable Energy Community in the island stable.

6.12 Daily Data

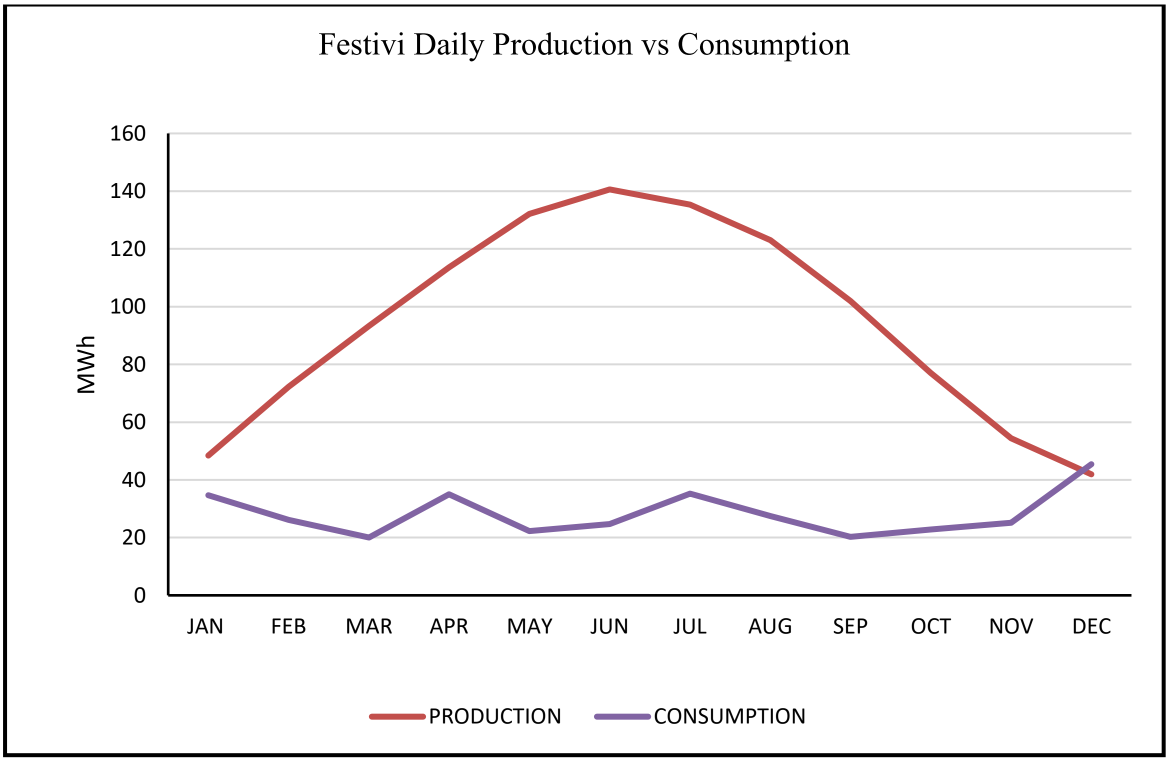


The graph below compares the phovoltaic output and electricity consumption statistics of the whole year on weekdays. The curve of production (orange) illustrates a consistent increase in production levels since January to a peak in June, to around 140

2MWh/day and decreases steadily in the second half of the year. Such a tendency can be explained by extended working hours and intense sun rays in spring and summer.

However, the consumption curve (blue) is relatively steady throughout the year with most values falling around 110-160 MWh/day, with a sharp peak in July, as it is typically hot and air-conditioners are turned on, and tourism activity is active. An obvious disastrous imbalance arises between the production and consumption: in June production reaches its maximum, and the peak of demand is reached a month later, in July, when photovoltaic output has already started to decrease.

In the winter season, the production becomes sharply low, and it is even lower than consumption and this leads to the constant demand of grid energy. On the whole, this graph underscores the seasonal inbalance between the daily renewable generation and the daily energy demand, as a manifestation of the significant role of storage, demand-shifting mechanisms, and energy-sharing processes in a renewable electricity energy system.



This chart compares the average photovoltaic (PV) generation and kilowatt-hrs (kWhs) used on weekends on an annual basis. The PV production (curve is plotted as red line) exhibits a clear seasonal cycle with a starting point of about 50 MWh/day in January which gradually grows through spring to reach a peak of about 140 MWh/day in June.

Later, the production would gradually decrease to winter with the level being approximated at 45 MWh/dayin December. However, when considering Sunday-Saturday (weekend consumption, portrayed by the purple line) is continually lower and reasonably stable and varies between 20 and 40MWh/day-on-day off.

The highest consumption is made on weekends in April and July; nonetheless, these are very low compared to the production level reached during the summer. The graph therefore shows that there is high excess of solar energy on weekends with May to August recording the highest production against demand.

The surplus reduces during winter months but PV output is still higher than weekend consumption in the majority of cases. This sharp imbalance suggests that the most desirable situations in energy exportation or storage charge or as a performance-based RE-certification sharing is on weekends because buildings produce a great amount of energy than they are using.

In general, the figure indicates that in most of the year, the solar production meets the demand of the weekends and thus gives considerable flexibility of operations and validates the potential benefits of a coordinated Renewable Energy Community.

6.13 Hourly Data

The two plots are a complete annual summary of hourly photovoltaic (PV) generation, hourly building consumption, and prototypically missing demand on a typical day of each month. The dynamics of the left panel (nonworking day) are shown on the weekend, and those of the right panel (working day) are weekdays. The dark area indicates an hourly PV production (purple) and unsatisfied demand (blue), overlaid on a black line that shows hourly consumption of each of the representative days of the month. Taken together, these visualisations allow conducting a study of how or how not daily solar production matches with consumption trends during the calendar year.

6.13.1 Weekday (Feriale) Hourly Behavior

Hourly consumption patterns on weekdays tend to have relatively large magnitudes and higher variability that imitate traditional activity patterns that include morning routines, business activities, and evening household peaks. The black curve describes this behaviour by introducing two separate diurnal maxima, one at the beginning of the day and the other stronger at the end of the day. The photovoltaic (PV) generation peaks in the middle of the day in all months, and, therefore, creates a time imbalance between the moment of energy generation and demand peak. Over the course of a summer year (May August), PV generation, marked in purple, has reached high values at midday to cover building consumption during the specific hours.

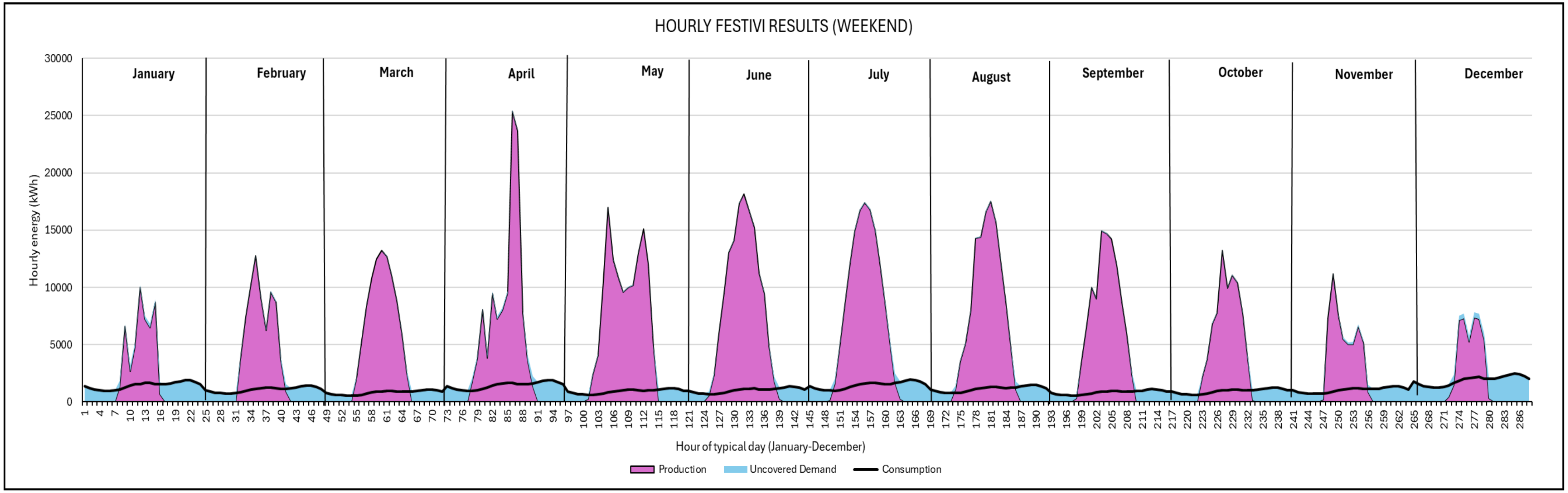
However, the dawn and evening periods continue to display large blue zones, or areas that were not covered by demand, and PV cannot fulfil even on the most favourable days. Conversely, the winter season (December-February) is generally characterised by significantly low PV generation (as indicated by the few purple wedges), and the consumption is comparatively constant. Thus, the blue zone of uncovered need is dominant in most of the 24-hour cycles, which highlights a high dependence on the external grid on weekdays in winter.

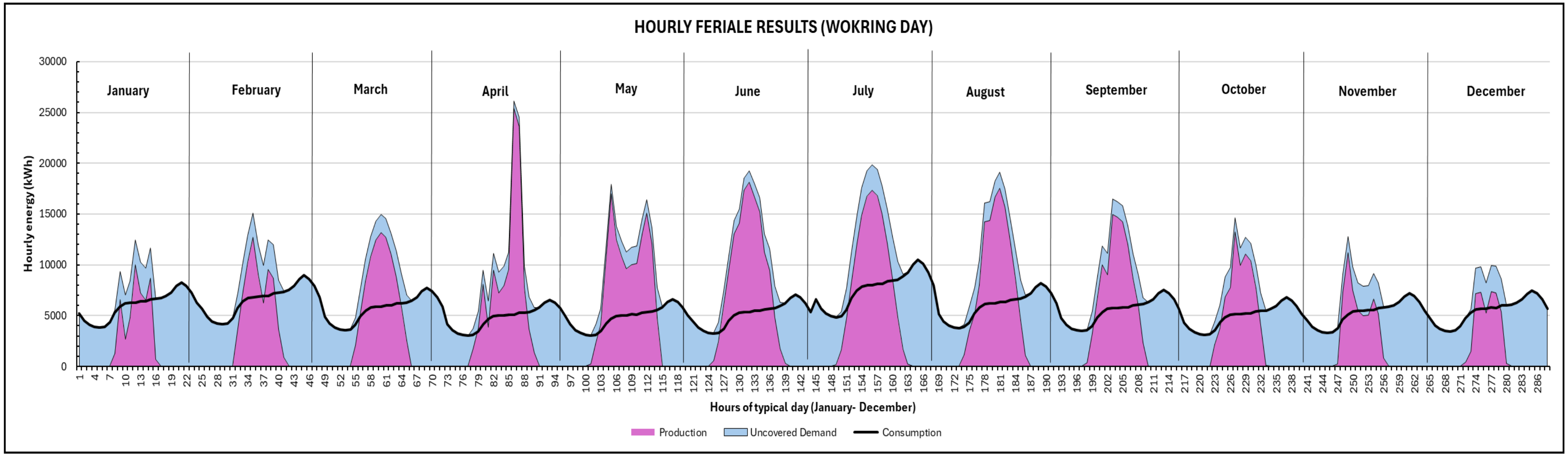
6.13.2 Weekend(Festivi) Hourly Behavior

The pattern of consumption on the weekends is somewhat different: it is relatively smaller and slower during the day and does not imply a lot of sudden spikes. This is as would be expected of a commercial and institutional activity to be virtually non-existent leading to a more balanced distribution of a residential demand profile.

In this regard, PV generation is more favourable to be aligned with the flatter consumption curve. Purple production area is significantly larger than the blue uncovered fraction in summer, therefore showing that PV is able to meet the midday and early afternoon demand totally on the weekend leaves deficits to the early morning and late evening.

On the other hand, the weekend in winter still show significant uncovered demand; but less consumption as compared to weekdays enables even a small amount of PV output to generate a larger share of the load. This difference proves that weekends enjoy more of the benefits of solar generation, and have significantly reduced importation on the grid in the summer season.


HOURLY FESTIVI RESULTS (WEEKEND)
Hourly energy (kWh)
January
February
March
April
May
June
July
August
September
October
November
December
Hour of typical day (January-December)
Production
Uncovered Demand
Consumption


HOURLY FERIALE RESULTS (WOKRING DAY)
Hourly energy (kWh)
January
February
March
April
May
June
July
August
September
October
November
December
Hours of typical day (January- December)
Production
Uncovered Demand
Consumption

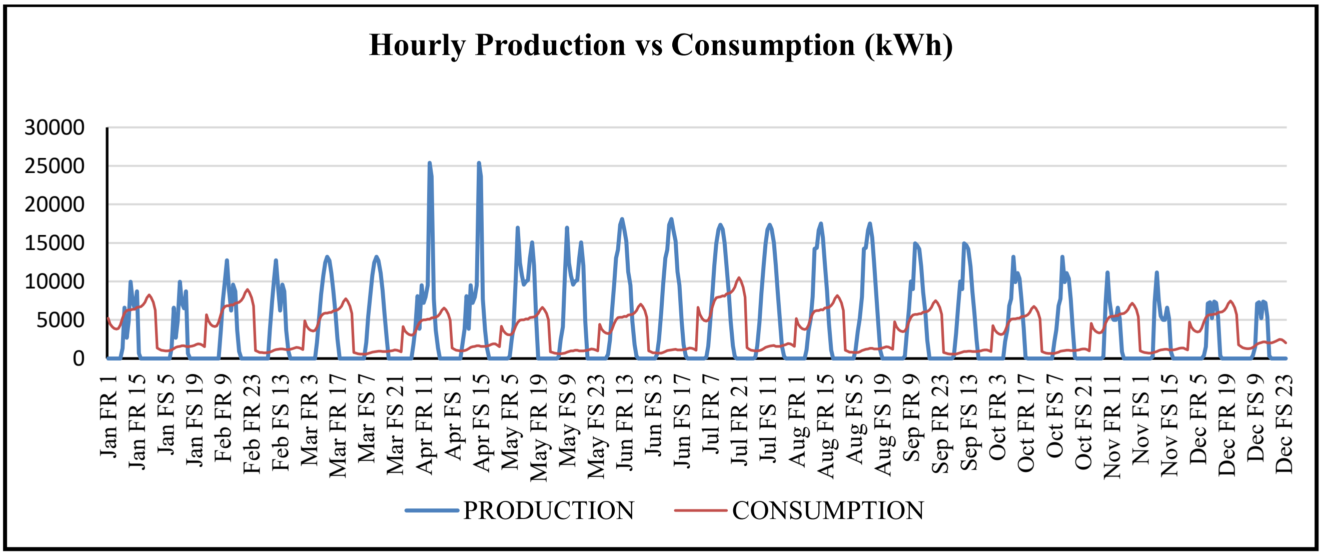
6.13.3 Combined interpretation

An analytical evaluation of both panels produces a few interesting conclusions:

- PV matching on the weekends is better; trough profile of demand closer to production peak of PV.
- Weekdays have a higher uncovered consumption with a particular concentration in the nascent morning and evening peaks which PV fails to address.
- During summer, weekdays and weekends have substantial amounts in the form of surpluses during midday periods, which adds to the sustainability of storage or intra-community energy sharing in a Renewable Energy Community.
- Winter months show little or no overlap between production and the demand, creating a structural reliance of that season on external supply to the grid which is less intense in warmer months.

Such aggregate data indicate how extremely valuable flexibility mechanisms, including storage facilities, developing demand, or charging electric vehicles are to utilize the large summer midday excess and alleviate winter and evening shortage.

6.13.4 Hourly Production vs Consumption



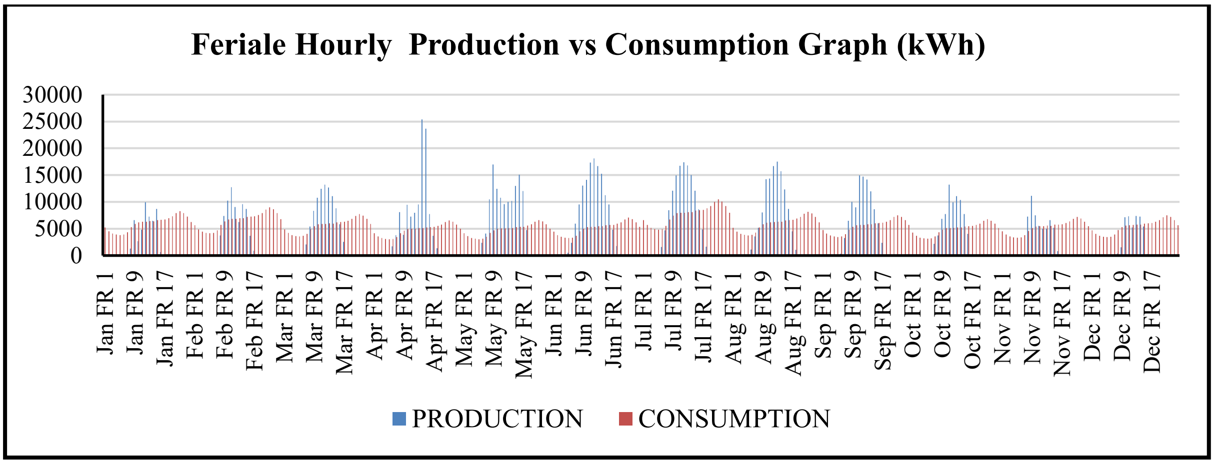
This graph shows the generation of photovoltaic and consumption of electricity per hour during the full year, which will help to study the correspondence of the solar generation and real demand in detail. The blue line that is a production clearly shows a strong diurnal pattern with a sharp rise around the mid day when the solar irradiance is highest and also when the curve moves to zero in the evening and at the night hours.

The seasonal change is also apparent: the highest production value can be seen in the late spring and summer months whereas the peaks produced in the midday can be clearly reduced in winter months. The red line, which shows consumption on the other hand, is quite stable and quite flat throughout the year with only slight diurnal and seasonal variations.

The production, in most of the hours, is lower than the consumption, giving rise to large periods of unsatisfied demand. The imbalance between the solar peak and the consumption profile is present even in summer, when the peaks of production are the highest.

This graph would emphasise the drawbacks of this approach to covering hourly demand based solely on relying on rooftop photovoltaic installations and would help justify the need to develop additional measures like energy storage, load shifting, or REC-based sharing. Such strong seasonal and hourly disequilibrium accentuates the structural reliance on external grid power both in winter seasons and in non-solar hours.

6.13.5 Feriale Hourly Production vs Consumption



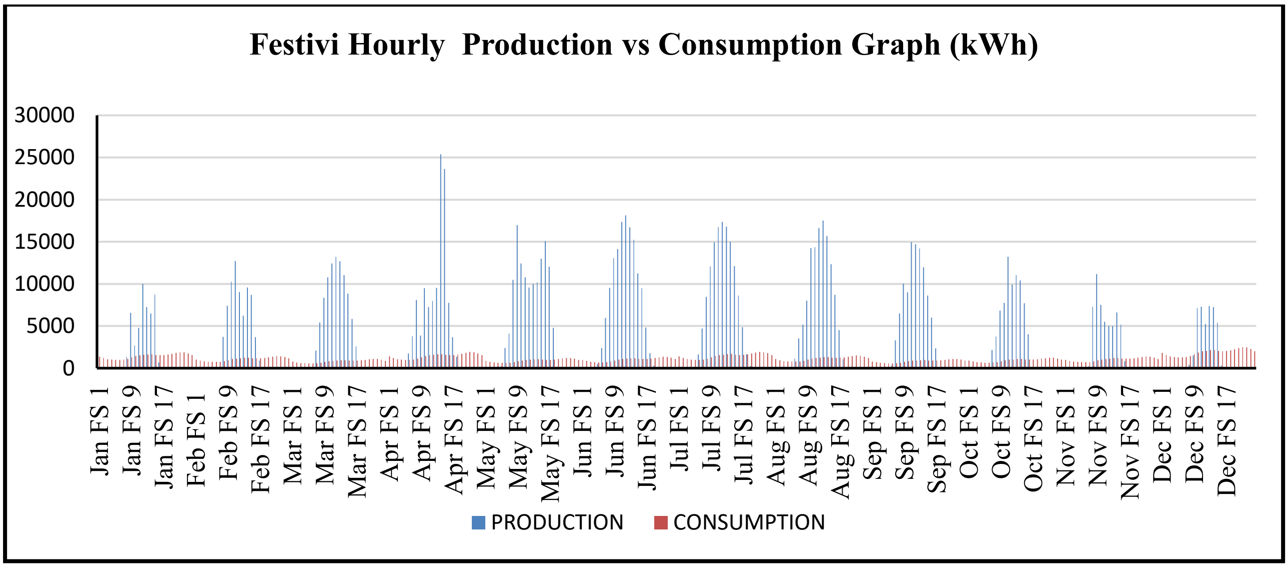
The graph shows the amount of photovoltaic (PV) output and electricity being consumed during working days (feriali) throughout the whole calendar year. The blue bars are the PV generation which has its daily maxima at midday and seasonal variations in that its amplitudes are higher in the late spring and summer season and the big amplitudes are experienced during the winter months.

These daily production cycles are similar to the sun irradiance pattern which is deterministic so that even to the very end the production is close to zero, at the nocturnal hours. The red bars depict consumptive patterns on an hourly basis which are quite stable all year round with slight seasonal fluctuations. Unlike the production curve, the consumption does not show sharp peaks daily but has a smoother appearance, indicating the presence of constant consumption of electricity during the daytime and evening because of the residential and commercial components.

During most months, especially between October and March, demand exceeds supply during most hours which creates a long term dependence on grid imports. The levels of PV generation also become much higher during the summer months and are at levels that surpass consumption during a number of hours in the midday. However, there are still severe shortage periods on early morning and evening, thus maintaining an unending disequilibrium among the occurrence of solar energy and demand by users.

The graph also shows clearly that despite the intervals of full PV cover of summer working days, the most extensive energy needs of the island are not feasible to meet only with the help of rooftop solar without any additional steps like energy storage, load shifting, or REC-based sharing. In general, this graphic illustrates the engineering issue of matching hourly production of renewable energy with real-time consumption during a standard weekday situation.

6.13.6 Festivi Hourly Production vs Consumption



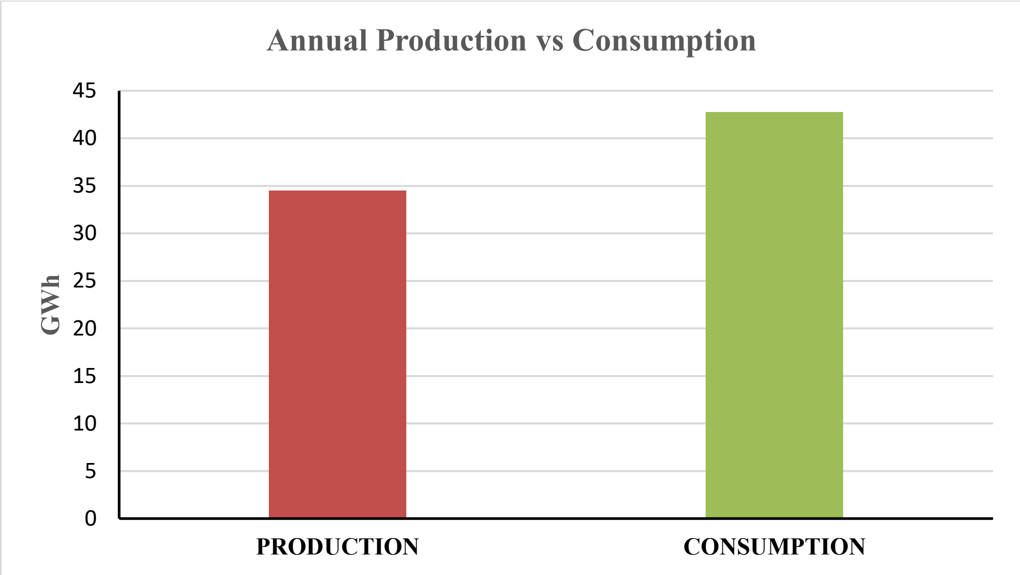
This is a plot of the hourly photovoltaic (PV) production and power consumption during festivals (weekend) days throughout the calendar year. PV generation is represented by the blue bars, where one can see specific sharp peaks around solar noon on both weekends. These extremes are significantly large in the spring and summer, and relatively low in winter, therefore indicating the common solar radiation cycle, and showing that weekends have a generation pattern that is similar to weekdays.

The consumption, represented by the red bars, is consistent, and low and constant the same across all months and is indicative of the lower activity levels in weekends where the commercial loads are low and residential demand is evenly distributed throughout the day. Another salient observation that aids in observation is that PV production on a weekend is consistently much higher than the consumption level, especially during the period between September and April. In this time frame the midday production levels are much higher than the fairly constant levels of consumption, which will create long periods of surplus energy.

During winter times, although the generation is reduced sharply, consumption remains low enough that the midday PV generation still supplies part of the demand. Due to the significantly low consumption at the weekends which is much lower than that of weekdays, there are only negligible bouts of uncovered demand in comparison to feriali days. Overall, as this graph clearly highlights, weekends represent the best source of natural concordance of PV production and the local demand, which has tremendous potential to integrate renewable energy.

The history of excessive production during the weekends implies that storage charging, electric vehicle charging policy, or energy exporting would be a viable solution to feed other sections of the Renewable Energy Community. It also strengthens the need to incorporate the time variation in the planning of REC since there is a high variation in performance between the weekdays and the weekend.

6.14 Annual Data



The figure shows the comparison of the annual photovoltaic (PV) generation and the annual electricity consumption that is taken into account in the current research. The bar which is produced signifying the PV production shows that rooftop PV systems modelled in the island would possibly accumulate a total of about 34-35 GWh per year thus showing the potential of the Island to harness his solar potential.

Conversely, the consumption bar is more at about 43 GWh/year, which results in an evident shortfall between the amount of electricity that the rooftop PV can be able to provide and the amount of electricity demanded per year. It is worth noting that the consumption used herein entails solely residential type of electricity demand only; commercial, industrial, hotel, and public-service demands were not part of the dataset.

As a result, the consumption value is lower than the total electricity consumption at Ischia. The chart alone even when just focusing on residential demand shows that the PV types of production is not enough to sustain the production by about 89 GWh per year, meaning that rooftop solar itself cannot fulfil the entire household amplitude of electricity needs with one year. The results indicate the structural downside of local PV and note the role of renewable energy certificate (REC) frameworks (i.e. energy sharing, energy storage, and demand flexibility) in decreasing the reliance on external grid and increasing the overall energy self-autonomy.

6.14.1 Annual PV energy use

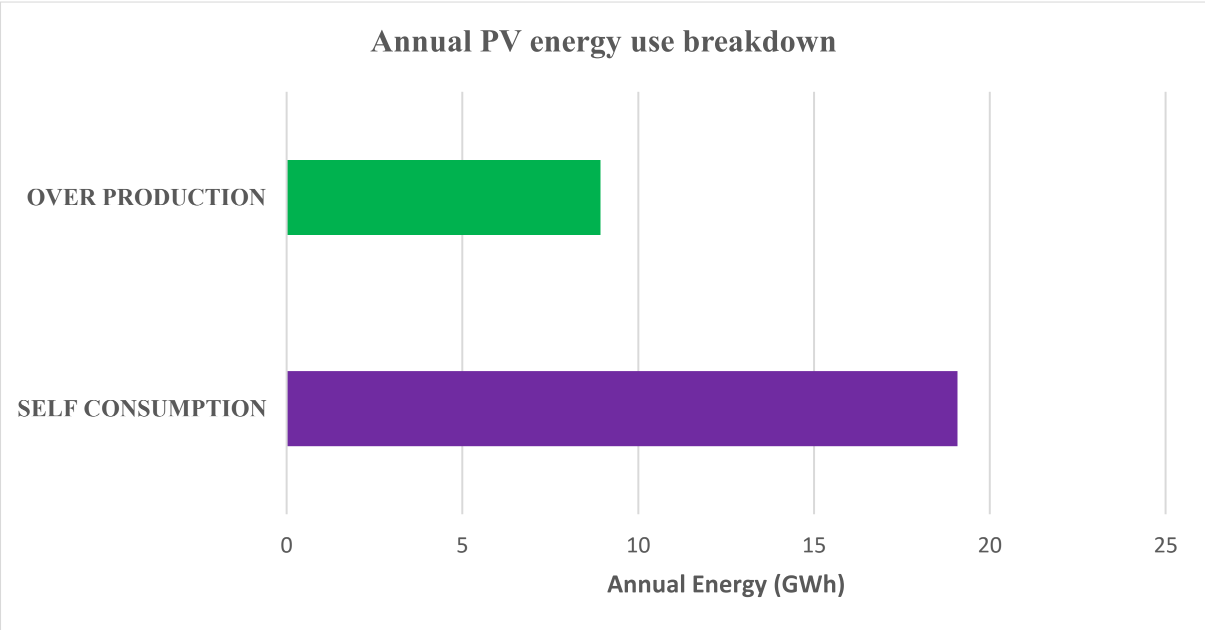


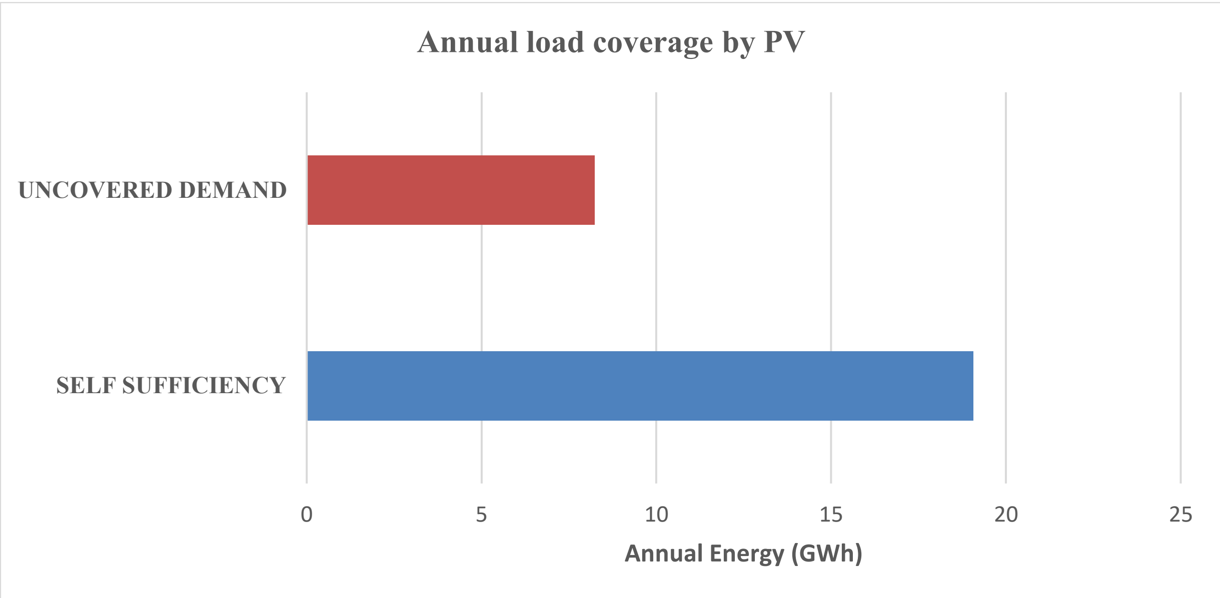
Figure shows the proportion between the total annual photovoltaic (PV) generation and self-consumed energy and over-production of residential buildings located on the island. The bar in magenta colour shows that about 1920 GW of solar electrons is used at the site, which offsets directly the household electricity needs.

The green bar shows over-production which equals approximately 9 GWh; which is more than what residential consumption can consume at different periods and would normally be sold to the grid. All these numbers represent a projected roof-top PV of approximately 2829 GWh/year of the residential sector. This decomposition is limited to residential consumption as any data related to commercial and tourism, as well as any building used by the population, was not included in the analysis.

The resulting over-production which was almost a third of the total production indicates significant solar power resource and proves that it is possible to set up Renewable Energy Communities (RECs) that would be able to share excess energy with adjacent buildings, store energy to use later or channel it to other facilities like the charging of the electric-vehicles and other community needs.

In this way, this visualisation shows the significance of balancing production to the larger local demand and opening up energy-sharing processes in order to make the most of PV use.

6.14.2 Annual load coverage



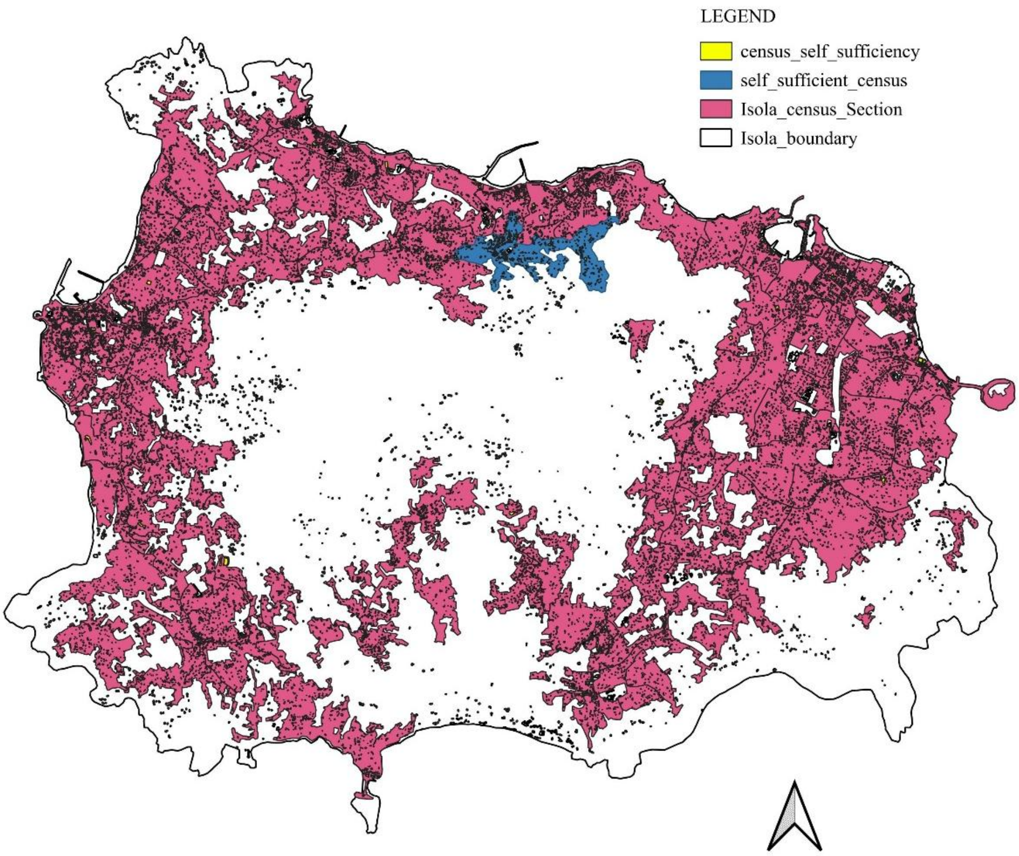
This graph shows the percentage of the yearly residential electricity usage met by a rooftop photovoltaic (PV) production differentiating between self-expressed energy demand and remaining demand.

The blue bar represents the fact that the main portion of residential power that is delivered directly through PV is about 19 20 GWh of the total residential power load, which is equal to the portion of annual power demand that can be met by installed rooftop systems in the specific area.

On the other hand, the red bar indicates approximately 8 9 GWh of demand that should not be met; meaning that during some time of the year, specifically during winter seasons and during the evening when the sun is not shining, the amount of residential consumption has to be imported by the grid since PV generation is not enough.

Again, it should be emphasised that this estimate is calculated only on residential demand since commercial, public and tourism buildings were not included in the consumption data. As a result, the presented unmet demand is only in the residential segment. Overall, the graph shows that rooftop PV is the significant part of the electricity use of households annually, although grid support remains significant to residential buildings in the UK, which supports the need to implement strategies, including renewable energy certificate (REC) sharing, energy storage, and demand-shifting to encourage the improvement of energy independence.

6.15 Census self-sufficiency



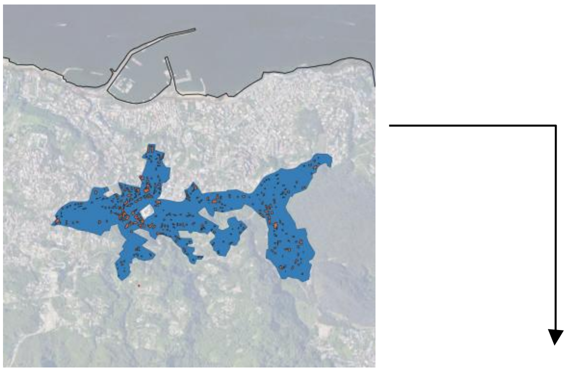
census_self_sufficiency — Features Total: 126, Filtered: 126, Selected: 1

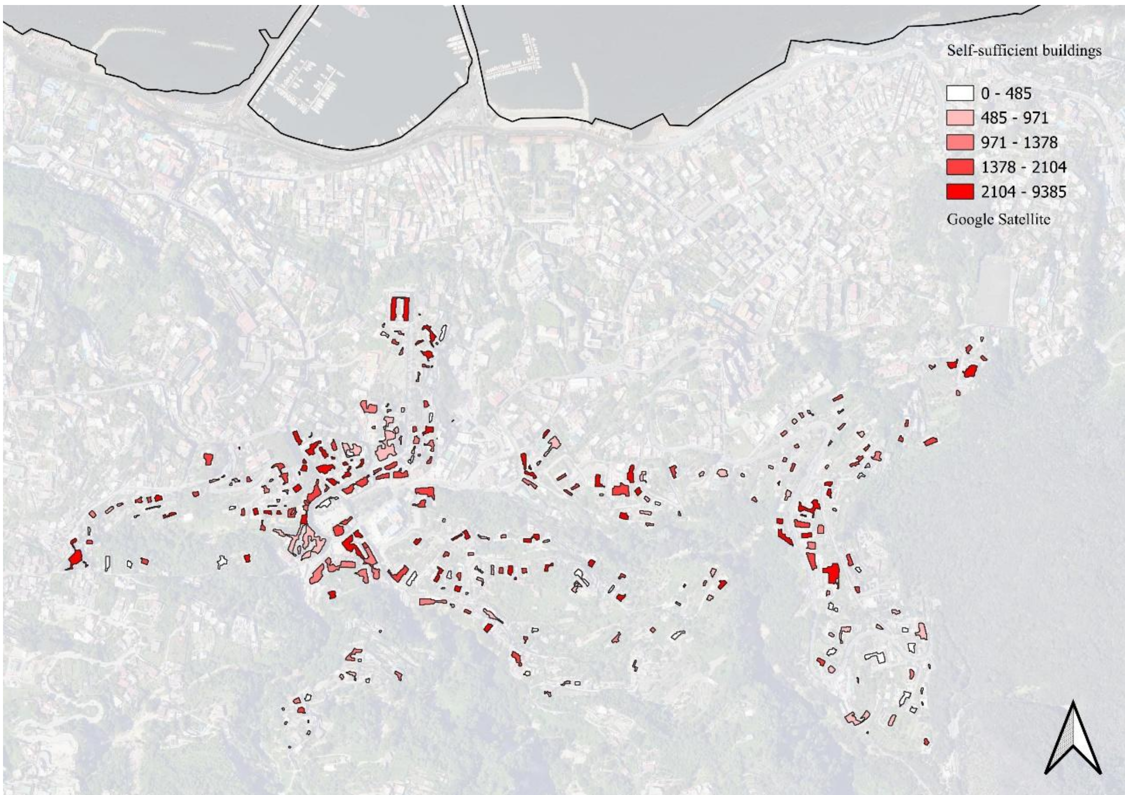
	fid	SEZ_CODE	PRODUCTION	CONSUMPTION	SELF CONSUMPTION	SELF CONSUMPTION INDEX	SELF SUFFICIENCY	SELF SUFFICIENCY INDEX	OVER PRODUCTION	OVER PRODUCTION INDEX	UNCOVERED DEMAND
1	32	630190000007	1619081.08	634803.86	374029.07	0.23	374029.07	0.59	1094554.72	0.68	260774.79
2	1	630070000001	302742.06	342726.05	181350.63	0.6	181350.63	0.53	26455.87	0.09	161375.42

The map presents the self-sufficiency performance of every ISTAT census section on the island, thus, highlighting the geographical area of locations where local photovoltaic (PV) production can meet a significant proportion of each year domestic electricity consumption. Most of these sections are written in pink, which is a visualisation that indicates low to medium levels of self-sufficiency with blue-highlighted area in Casamicciola being a census section that displayed very high levels of self-sufficiency.

This can be confirmed by the analysis of the attribute table: the specified section generates about 1.61 GWh of the PV energy per year in comparison with the residential demand of about 0.63 GWh, resulting in a self-sufficiency rate of 0.59 (i.e. 59%). This is a higher figure than most sections are as they usually fall in the range of 40-50%.

The better performance in Casamicciola can be explained by the fact that there are a number of buildings that have large, well-sized roof surfaces and receive good energy in form of irradiation because of the sun and such large surface allows energy to be collected on a large scale and consequently very large energy is produced which is above the amount of energy consumed.





This excess is also demonstrated in the fact that the over-production figure is more than 1.04GWh which means that the chosen section is able not only to meet its production needs, but also produce significantly more energy which can be redistributed in the context of a Renewable Energy Community. The additional unmet demand in this part is low, approximately 260†MWh, highlighting a high level of interrelation between local PV production and household demand.

This case, therefore, shows that even in the census-section level there are already neighbourhoods in the island that are already showing high potential of energy independence hence solidifying the viability of the REC based sharing schemes that are aimed at repacking excess electricity by high-performing neighbourhoods to the areas of the island that have relatively lower production power.

6.16 Electric Mobility Proposal

6.16.1 Energy Model Overview

GENERAL BUS & ROUTE INPUTS (Ischia Ponte - Lacco Ameno)	
One-way route length (km)	9
Departures in each direction	96
one way trips per day	192
Distance travelled per day (km)- each one way	1728
Number of buses on the line	10
Distance travlled per bus	172.8
Base round trips per bus per day (16h, 10-min headway)	9.6
Bus Energy Consumption	
1 full charge	6.5 hours
bus travel (km)	240
battery capacity (kWh)	220
Average energy consumption (kWh/km)	0.92
Auxiliary load factor (extra %) (HVAC,lighting)	1.20
Average consumption (kWh/km)	2.02
Summer service multiplier	1.5
Winter service multiplier	0.7

The EV fleet model was designed on the basis of the Ischia Ponte-Lacco Ameno line, a 9-kilometre unidirectional route, the schedule of which is 96 trips per way, which takes 192 trips per day and includes 10 buses. The individual vehicle travelled an average of 172.8 kilometres a day, and the daily travel distance in the fleet is 1,728 km. This number includes service multipliers which have a seasonal variation; because of winters or off-season summers, the multiplier is 0.7 and when it is in high season it is 1.5.

Using a mean of 2.02 kilowatt-hours per kilometre or an aggregate of this figure which forms the total energy demands of heating, ventilation, air conditioning (HVAC) and other auxiliary loads.

During summer, higher heating and cooling demand can push the consumption to the high limit (around 2.3-2.5/km) but colder climates can result in lower consumption. The model states that every bus is expected to take one to three full charges daily, which vary in relation to the month; that means that there would be at least one overnight charge per season, and at maximum two extra recharges on peak days.

An example is that in warm months (May to August) one of the buses would be needed to do approximately 3 rounds per day (1.7 midday fare), and when the weather is not hot one round would be enough to do 1.2 rounds (one at night and once in the morning). This in turn draws out the operational need of the fast charging issuance to operate mid-day to allow positive service to be offered on the busy routes.

6.16.2 Monthly Demand and PV Supply

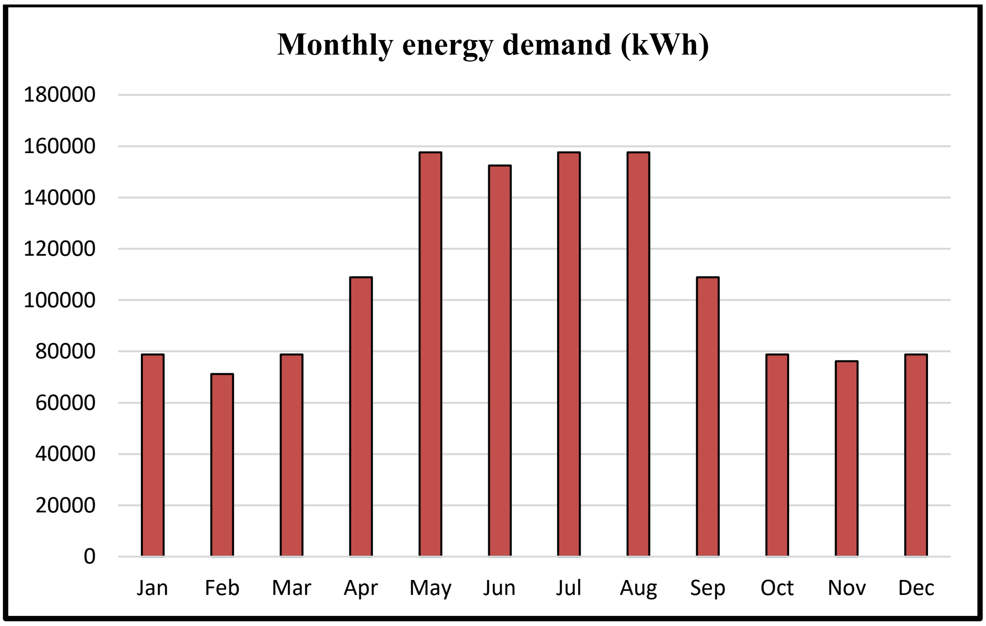
Month	Days	Service multiplier	Round trips per bus per day	Round-trip distance (km)	kWh/km	Aux factor	No of Buses	Daily energy per bus (kWh)	Total daily energy fleet (kWh)	Monthly energy fleet (kWh)	Battery cycle per day
Jan	31	0.7	7	18	0.92	1.2	10	254.10	2541	78771	1.16
Feb	28	0.7	7	18	0.92	1.2	10	254.10	2541	71148	1.16
Mar	31	0.7	7	18	0.92	1.2	10	254.10	2541	78771	1.16
Apr	30	1	10	18	0.92	1.2	10	363.00	3630	108900	1.65
May	31	1.5	14	18	0.92	1.2	10	508.20	5082	157542	2.31
Jun	30	1.5	14	18	0.92	1.2	10	508.20	5082	152460	2.31
Jul	31	1.5	14	18	0.92	1.2	10	508.20	5082	157542	2.31
Aug	31	1.5	14	18	0.92	1.2	10	508.20	5082	157542	2.31
Sep	30	1	10	18	0.92	1.2	10	363.00	3630	108900	1.65
Oct	31	0.7	7	18	0.92	1.2	10	254.10	2541	78771	1.16
Nov	30	0.7	7	18	0.92	1.2	10	254.10	2541	76230	1.16
Dec	31	0.7	7	18	0.92	1.2	10	254.10	2541	78771	1.16

Max daily fleet energy (kWh)	5082
Total annual fleet energy (kWh)	1305348
Total annual fleet energy (MWh)	**1305.35**

Base round trips per bus

Table presents a range of modelled monthly energy demand of the fleet in 71,148 - 157,542 kWh in February and July, respectively. Addition of all twelve months will amount to an annual demand of approximately 1,305,348 kWh/ 1,305 MWh.

By comparison, the current system of depot photovoltaic (PV) with capacity of 95.55 KWp power can produce approximately 106kWh/anno (kilo Watts per year), which is insignificant compared to the need.



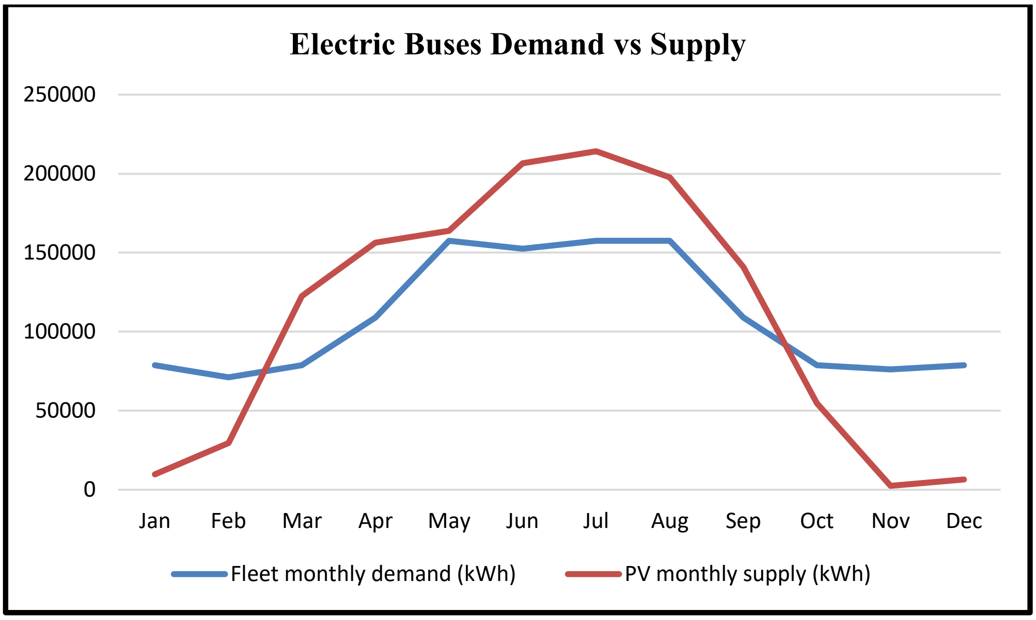
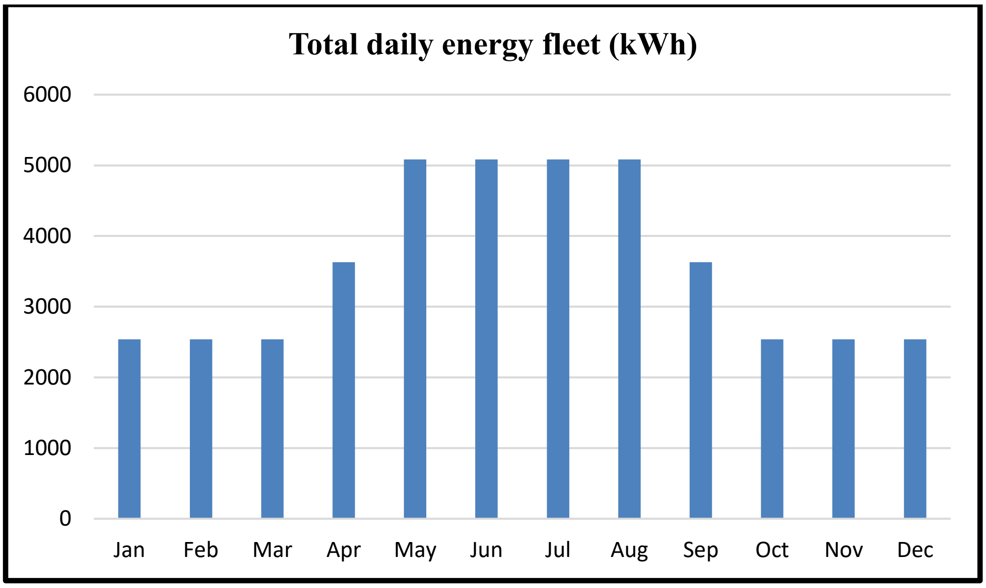


Figure compares the profile of the Fleet demand versus the PV supply: PV generation is low at the time of year (e.g. 214 MWh in November) and high (e.g. 214 in July).

This means that during winter (<10% by November/December), the resultant self-sufficiency ratio (PV/demand) is very low (less than 10 per cent) and during the majority of spring and summer months (up to 156 per cent in March and 135 per cent in July).

In practise, the depot would produce surplus solar energy in summer, and could potentially be exported, but will produce less in winter, requiring imports of the grid. The difficulties in the two seasons have intimable operational consequences. During the summer seasons the solar surplus means that PV can meet its full charging capacity during the mid-day period, perhaps surpassing demand, whilst during the winter only a small percentage (3-8 percent) of the low EV demand can be supplied by PV energy.



Based on this, the maximum deficits during the winter season will involve either grid-sourced power or the utilisation of stored power. This is supported by the monthly cycle.

Month	Fleet monthly demand (kWh)	PV monthly supply (kWh)	Net (PV - demand) (kWh)	Self-sufficiency (%)
Jan	78771	9790.11	-68980.89	0.12
Feb	71148	29631.40	-41516.60	0.42
Mar	78771	122572.18	43801.18	1.56
Apr	108900	156380.69	47480.69	1.44
May	157542	163821.17	6279.17	1.04
Jun	152460	206636.59	54176.59	1.36
Jul	157542	214207.61	56665.61	1.36
Aug	157542	197629.69	40087.69	1.25
Sep	108900	140977.58	32077.58	1.29
Oct	78771	54694.08	-24076.92	0.69
Nov	76230	2480.16	-73749.84	0.03
Dec	78771	6526.74	-72244.26	0.08
Annual totals	**1305348**	**1305348.00**	**0**	**100%**

PV would cover **100 %** of the bus energy for this line.

The self-sufficiency of 136 percent, July demand of 214 MWh compared to PV of 289 MWh is high, compared to November, with only 2.5 MWh PV and 76 MWh demand (3.3 percentage). In practise, it means that every bus in a summer will probably be able to charge once during a day with the help of plenty of solar and that in winter the majority of charging has to take place at night through the grid.

The presence of permanent chargers at mid-day further justified by the fact that buses need numerous cycles during the summer months (mentioned above) when the sun is out- the variable canopies conducted PV and depot chargers can be used directly to charge vehicles during sunny days. On the other hand, low output during winter would mean that any under-performance of PV would affect the consistency of schedules unless powered by the grid or even the storage.

6.16.3 Proposal to size PV to serve EV Fleets

The model suggests that much more PV is needed in order to cover the full-year (100 -percent) PV of the EV energy load. At a local Ischia solar yield of 1,109ʿWh/kWp-yr 1.305ʿWh/Yr would nominally require just under 1,177%Wp of PV. Since the current 95.55 kWp results in 95.55 kWp divided by actual consumption, which stands at 100 kWp, an extra1 thousand and 810.92 kWp would be needed to equal the actual consumption. In the case study, it is planned that about 542 000 Wp of new PV (on top of the existing 95.55 Wp, which exceeds these numbers), which is approximately 637.6 Wp in total, are to achieve a conservative desired goal of 100 000 self-sufficiency/year.

PV & STORAGE INPUTS	
Existing PV capacity (kWp) - Depot Ischia	95.55
Annual yield per kWp (kWh/kWp·yr) from depot data	1109.37
Existing depot PV (kWh/yr)	106000
Battery DoD (usable fraction, e.g. 0.8)	0.8
Battery backup days	1
Total annual fleet energy (kWh)	1305348
New PV capacity to size (kWp)	1081.11
Total PV capacity (KWp)	1176.66

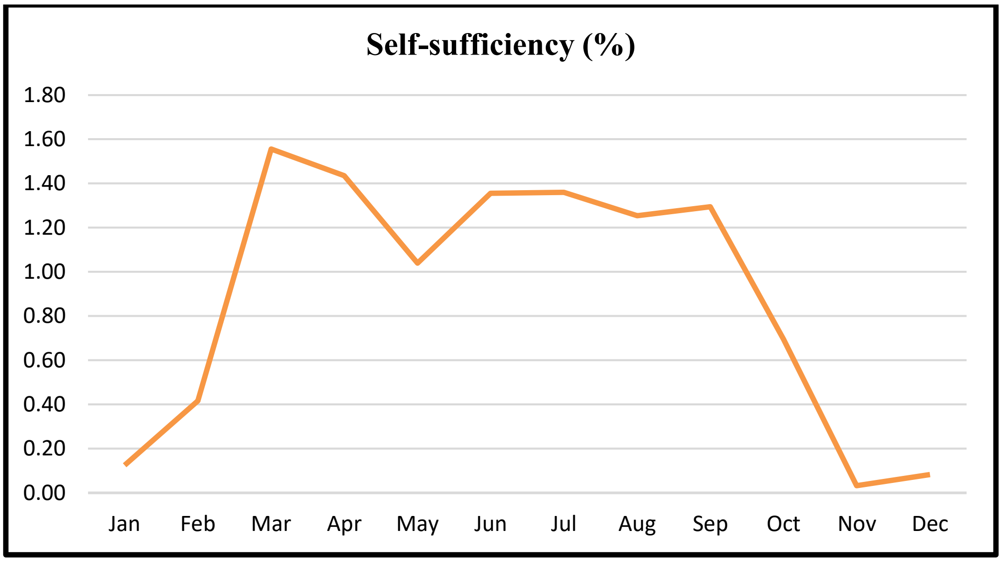
Month	Fraction of annual PV yield (from depot injected energy 2023)	Existing PV monthly (kWh)	New PV monthly (kWh)	Total PV monthly (kWh)
Jan	0.0075	795.00	8995.11	9790.11
Feb	0.0227	2406.21	27225.19	29631.40
Mar	0.0939	9953.43	112618.75	122572.18
Apr	0.1198	12698.84	143681.85	156380.69
May	0.1255	13303.04	150518.14	163821.17
Jun	0.1583	16779.85	189856.74	206636.59
Jul	0.1641	17394.65	196812.96	214207.61
Aug	0.1514	16048.45	181581.24	197629.69
Sep	0.108	11448.03	129529.55	140977.58
Oct	0.0419	4441.41	50252.67	54694.08
Nov	0.0019	201.40	2278.76	2480.16
Dec	0.005	530.00	5996.74	6526.74
		Total annual PV (existing + new) (kWh)		**1305348.00**
		Total annual PV (existing + new) (MWh)		1305.35

The above is given that the majority of the charging is planned to be done in the daytime, and the rest of the load will be handled by the shared grid of the REC or short-term storage. Considering these assumptions the PV production annually (existing and new) approximates closely to the 1.305 ~ 1.305GWh demand. This sizing is comparable to the normal installation results. The solar conditions in Italy offer a yearly output of 1,000-1,500 kWh /kWp, so the 637.6kwp at 1,109kwh /kWp would produce a power output of about 707MWh /year. (In reality, planners can either over-size or provide the storage to accommodate the nighttime requirements.)

However, the 637 kWp of PV power is approximated to a 20-25 m 2/kWp footprint (against design), shown to be capable of fitting into the offered sites below. Even the daily peak demand (approximately 5.08 MWh on the busiest day) would still be higher than PV output at a time, yet by planning the scheduling of daytime charging to match PV output it is possible to reduce the net imports to the lowest possible level. Demonstration of Charts: The demand versus PV charts are monthly charts, which highlight the system behaviour.

During winter months the self-sufficiency ratio is extremely low, which represents the famous seasonal loop of PV generation in the Mediterranean climate.

According to SolarTech, solar canopies are able to directly charge the charging stations throughout the day, which works well in summer when PV exceeds the demand, but and in winter without storage, when it is not effective.



The curvy outlines indicate that the Renewable Energy Community (REC) ought to map out energy trade or battery buffer: the surplus of solar power on summer days can be used to recharge sufficient batteries (or other power customers) to maintain energy shortages during winter. Even the modelling demonstrates that the self-sufficiency in spring and autumn (April, September) is approximately 130140%, which means the mild surplus, which is a positive outcome of the energy balance in the REC.

6.16.4 Proposed PV Siting and Distribution

The main suggestion regarding the description of a photovoltaic (PV)-based electric bus charger node is to locate it in the Lacco Ameno marina terminal. This location combines positive spatial parameters with a vigorous local renewable production environment.

The bus stop lies adjacent a large surface parking place along the water, providing a large capacity in the installation of a parking canopy equipped with PV modules, concomitant with the likelihood of adding the facility with the augmentation of PV panels on the roofs of similar buildings.

On a rough preliminary evaluation of the available surface, it is assessed that of the available space the terminal precinct would have the capability to support possibly 300-350 kWp of new PV capacity, located within the parking canopy and the adjoining rooftops. The canopy construction is more suitable in this context since it allows a placement of PVs modules over the parked vehicles and buses and at the same time provides the vehicles with coverage and protection against weather.

By placing the charging points directly under or adjacent to the canopy, a direct connexion between local PV generation and the electric bus chargers would be easier, especially at the time of daytime, when the vehicles are back in the terminal between trips. On the opposite side of the roadway to the terminal, there is a hotel structure, the roof of which has a surviving PV system, which produces about 20,000 kWh of power per year.

Since the consumption of the commercial building is not factored in the residential demand analysis carried out in the thesis, the building contributes to the generation of renewable energy availability in the same census tract. The concurrent presence of this pre-existing PV system and the 300 350 kWp of supplementary capacity in the proposed site consolidates Lacco Ameno as a place rich in production in the perimeter of the Renewable Energy Community (REC), hence, the rationale behind the location of a community charging site at this point.

Operationally, Lacco Ameno is one of the termini of the bus corridor Ischia Ponte-Lacco Ameno and is amongst the busiest termini of the route. Buses usually accrue some lay over time at the terminal and this offers them a chance to do opportunistic charging between trips. The positioning of a PV-fed charging node on this site, thus, is not only a conformity to spatial generation of renewable resources but also a practical solution to the needs of the fleet.

Overall, the Lacco Ameno marina terminal turns out to be the leading option of having a PV-electric vehicle charging station, where local solar energy (current and potential) can be utilised directly to power the electric buses circulating inside the Renewable Energy Community.

The electric-vehicle corridor needs about 1.3 GWh of electricity annually. The modelled fleet demand is the highest during the summer season (more than 157 MWh/month) and the lowest level is in winter (approaches 71 MWh/month). In spring and summer the monthly self-sports of the system are between approximately 135% and 155% suggesting that the output of the photovoltaic (PV) systems exceeds the energy demanded by the buses but in late autumn and winter the self-sufficiency is approximately 3%- 12%.

Therefore, instead of charging at any time, the buses will be charged in the middle of the day when there is high demand to take advantage of the high level of PV production, and when the buses should depend on charging the grid during the night in winter.

By bringing the suggested extra PV capacity of some 542 kWp concentrated at the terminal of Lacco Ameno marina, the corresponding amount would be sufficient to offset essentially the whole annual electricity consumption of the fleet together with the previously installed 95.6kWp, elsewhere on the island.

In general, the Renewable Energy Community (REC) on Ischia has the technical capability of providing the electric buses with solar energy fully. With a new power addition of about 0.55MW of PV power at Lacco Ameno, over and above the 95.6kWp one, the REC will be in a position to produce about 1.3GWh, the annual power required in the corridor. Daytime charging at the Lacco Ameno terminal can be done using locally made PV electricity, with the result that will save a significant amount of fuel and the related emissions.

CHAPTER 7: CONCLUSION

his thesis aimed at assessing the practicability of developing Renewable Energy Communities (RECs) on the isle of Ischia and exploring integrative mechanisms of a proposed electric mobility route into the same energy infrastructure.

The research question of focus was whether locally produced rooftop photovoltaic (PV) energy, which is allocated to residential building can contribute tangibly to the electricity demand in the island and whether this renewable source can also serve a decarbonised line of the public transport. Standardising geospatial PV potential analysis, hourly load modelling, and scenario-based evaluation, the study can offer a technical and spatial basis of REC development on Ischia and differentiate a perspective on a clear route towards sustainable mobility. The findings establish that Ischia has a significant technical potential of generating rooftop PV energy.

The solar is also abundant in the island with a high density of appropriately-placed rooftops consisting of a generation potential amounting to the total residential electricity needs annually. A considerable portion of the residential electricity can be supplied by distributed solar energy as the study shows by calculating hourly PV production based on roof geometry and orientation and superimposing the generated energy on hourly load profiles derived using residential load profiles that are in turn calibrated. Nonetheless, PV generation will not be able to completely stop dependence on electrical imports on the mainland; especially in winter months, there is always a significant disconnection between the local production and the local consumption.

This is not a disadvantage to REC feasibility, and it just makes sense of the realistic operational boundaries that RECs can provide value. One of the main lessons of the analysis is that the energy balance on the island is extremely seasonable. In the spring and the summer seasons, PV production is often higher than the demand at the residence over much of the day, thus producing significant excess energy. Conversely, the generation and consumption are also minimal in the winter season. This imbalance conditions the design of REC on the island: although absolute energy autonomy is not possible, a significant advance in self-consumption and self-sufficiency can be accomplished with the joint distribution of energy. This is supported by the spatial aspect of the analysis even more. It is observed that various census areas have significant differences in self-sufficiency because of variation in roof area, typology of buildings and population of residents.

Highly qualified areas in relation to demand can be used as energy-positive zones in the context of a REC and balance weaker ones to the benefit of the total collection. The suggested electric mobility line between Ischia Ponte and Lacco Ameno can be considered a significant opportunity to proceed with the local decarbonisation in this energy landscape. It was modelled that electric bus corridor has a fleet efficiency of around 1.3 GW of electricity demand per annum. This demand is less than the overall PV capacity that is available within the island but is operationally important. It is important to note that its seasonality follows that of the tourism season on the island and in part coincides with the five most productive seasons of PV.

This convergence generates a strategic contact between mobility electrification and REC construction: The electric fleet can serve as an adjustable, movable communalole which is capable of assimilating PV peaks, particularly at periods of greater production. The spatial assessment shows that the Lacco Ameno marina will be the best location of a PV-powered charging hub. This site has large parking spaces that can accommodate solar canopies, close rooftops that can accommodate more PV installation and already existing PV systems that can be incorporated into the REC. Along with being one of the terminals of the mobility corridor, Lacco Ameno also offers natural operational downtime in order to charge opportunities. The PV production peaks and is impacted largely by midday charging on this location which can significantly enhance the local self-conconsumption of the renewable energy.

It implies that a PV-integrated charging hub, located at Lacco Ameno would have the potential supply a significant share - possibly the entirety - of the yearly power demanded by the electric bus fleet. It is through a direct attempt to model the synergies between rooftop PV and electric vehicle (EV) charging that this thesis is introduced into an expanding research agenda that supports energy-mobility integration to be a part of the community energy infrastructure. Instead of showing electric mobility as an extra load of the electrical system, the results reveal that it also can be actively involved in optimising REC performance.

The bus fleet will be able to absorb additional solar energy during periods of high-generation and promote grid resilience in the local level, by levelling spikes in energy export. Concurrently, the social and environmental impacts of offering a renewable powered bus service would have a wider scope of benefits and various benefits, such as a drop in emission, congestions, and noise along the busiest coastal areas in the island.

These technical know-how should be interpreted in the expanded policy and regulatory environment. Community energy legal framework is found in the RED2 and RED3 directives issued by the European Union and the transposition is found in Italy by the RED2021 Leg.Dec., the TIAD issued by ARERA, and the Regole Operative issued by the GSE which govern and measure REC, the shared energy, and tariff arrangements. This framework along with the incentives provided in DM 414/2023 and PNRR capital grants will provide municipalities and the local actors with practical resources to start projects based on REC. The spatial and energy modelling proposed in this thesis directly aids in the initial phases of REC development in accordance to the national guidelines such as defining the perimeter, screening of appropriate rooftops, and analysis of the possibility of a genetic match in generation and load.

In this respect, the study does not only determine feasibility, but also provides practical grounds on which the study can be implemented in practise. The thesis, nevertheless, has a number of limitations. The demand modelling efforts, however, concentrate on the residential consumption and do not adequately consider the electricity consumption in a commercial, industrial, or tourism application that are collectively a large portion of the load profile of the island.

The research is also simplified in its assumptions of grid constraints, storage systems and the finer detail of EV charging behaviour. Economic feasibility, governance issues and community involvement which are important aspects of REC success are discussed conceptually without quantification. These limitations imply that the thesis is a technical and spatial feasibility study and not an entire implementation strategy. These shortcomings automatically lead to research directions in future. Giving the analysis a more detailed depiction would be to expand the analysis to include the non-residential demand. The creation of bankable integration projects of REC and EV would be supported by the development of economic and financial models as well as the technical assessment. Even with a storage modelling, vehicle-to-grid strategy, and network constraints would be included would provide finer detail into operations.

Lastly, implementing the workflow that was designed in this thesis into other Italian and European island settings might allow confirming its transferability, as well as pointing out the best practises regarding the implementation of REC in geographically limited settings. Conclusively, this thesis has shown that Ischia has a high technical base of the development of Renewable Energy Communities based on rooftop PV, and also that the incorporation of a decarbonised public transport corridor to this scheme is possible and advantageous. Although a rooftop PV is not the solution that will require turning the island into a fully self-sufficient power grid, it has the ability to cut the energy dependency on the mainland power grid significantly, raise the resilience, and introduce local mobility to electricity. The collaboration of the geospatial analysis, hourly Energy modelling, and the EV fleet simulation, with a regulatory framework based on the requirements of REC has produced in the work a replicable methodology to implement on other island territories to shift towards cleaner, more robust and community-enhanced energy systems.

BIBLIOGRAPHY

Agency, E. E. (2011). *Natura 2000 data form: IT8030022 Pinete dell'Isola d'Ischia.*

Agency, E. E. (2011). *Natura 2000 data form: IT8030022 Pinete dell'Isola d'Ischia.*

Agency, I. E. (2020). *Global EV Outlook 2020: Entering the decade of electric drive?* International Energy Agency.

ARERA. (2022). *Delibera 727/2022/R/eel – Testo Integrato Autoconsumo Diffuso (TIAD).* Rome: Autorità di Regolazione per Energia Reti e Ambiente.

Autorità di Regolazione per Energia Reti e Ambiente (ARERA). (2022). *Testo integrato autoconsumo diffuso (TIAD) – Delibera 727/2022/R/eel.* ARERA.

Battistelli, F. M. (2023). *Assessment of energy, mobility, waste, and water management on Italian small islands.* Sustainability.

Battistelli, F. M.-Y. (2023). *Assessment of energy, mobility, waste, and water management on Italian small islands.* Sustainability.

Bouzarovski, S. &. (2018). *Energy vulnerability in the grain of the city: Toward neighbourhood typologies of material deprivation.*

Busignani, S. (2022). *Ischia beyond mass tourism: Environmental diversity and seasonal regeneration.* Lampoon Magazine.

Caliro, S. P. (2012). *Ischia hydrothermal system: Geochemical characterisation of thermal waters and gas discharges.* Journal of Volcanology and Geothermal Research.

Caramizaru, A. &. (2020). *Energy communities: An overview of energy and social innovation.* Luxembourg: Publications Office of the European Union.

Centre), J. (. (2023). Photovoltaic Geographical Information System (PVGIS).

chen. (19). eenrgy.

Ciriminna, R. P. (2016). *Solar energy for Sicily's remote islands: On the route from fossil to renewable energy.* International Journal of Sustainable Built Environment.

CIVITAS. (2013). *Guidelines for developing and implementing a Sustainable Urban Mobility Plan.* CIVITAS.

Crosta, G. B. (2013). *The role of rainfall in triggering shallow landslides in pyroclastic soils: A case study from Campania, Italy.* Geomorphology.

Duffie, J. A. (2013). *Solar Engineering of Thermal Processes (4th ed.).*

Energy Community Secretariat. (2024). *Energy communities in the Energy Community Contracting Parties: Status and guidance.* Energy Community Secretariat: Vienna.

European Commission. (2021). *Clean Energy for EU Islands Award – El Hierro Case Study.*

European Commission Joint Research Centre. (2024). *Photovoltaic Geographical Information System (PVGIS) – Online tool and documentation.* European Commission Joint Research Centre.

European Commission JRC. (2020). *Energy Communities: Citizen Participation in the Energy Transition.* Publications Office of the EU.

European Parliament and Council. (2018). *Directive (EU) 2018/2001 (RED II).* Journal of the European Union.

European Parliament and Council of the European Union. (2018). *Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (recast).* Brussels: Official Journal of the European Union.

European Parliament and Council of the European Union. (2019). *Directive (EU) 2019/944 … on common rules for the internal market for electricity and amending Directive 2012/27/EU.* Brussels: Official Journal of the European Union.

European Parliament and Council of the European Union. (2023). *Directive (EU) 2023/2413 … amending Directive (EU) 2018/2001 … as regards the promotion of energy from renewable sources.* Brussels: Official Journal of the European Union.

Ferrari, S. Z. (2021). *GIS-based procedure for estimating the energy demand profiles of buildings towards urban energy policies.* Energies.

Fu, P. &. (2000). *The Solar Analyst 1.0: User manual.* Helios Environmental Modeling Institute.

Gestore dei Servizi Energetici. (2024). *Regole operative per l'accesso agli incentivi per le Comunità Energetiche Rinnovabili e altre configurazioni di autoconsumo diffuso.* Rome: Gestore dei Servizi Energetici.

Gössling, S. P.-P. (2012). *Tourism and water use: Supply, demand, and security. An international review.* Tourism Management.

Gössling, S. P.-P. (2012). *Tourism and water use: Supply, demand, and security. An international review.* Tourism Management.

Groppi, D. K. (2023). *Optimal planning of energy and water systems of a small island with an hourly OSeMOSYS model.* Energy Conversion and Management.

Gui, E. M. (2018). *Typology of future clean energy communities: An exploratory structure, opportunities, and challenges.* Energy Research & Social Science.

Harper, G. S. (2019). *Recycling lithium-ion batteries from electric vehicles.* Nature, 575.

Hledik, R. G. (2019). *The future of transportation electrification: Utility, industry and consumer perspectives.* The Electricity Journal.

Hofierka, J. &. (2002). *The solar radiation model for Open Source GIS: Implementation and applications.* Proceedings of the Open Source GIS – GRASS Users Conference.

ICCT. (2021). *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars.* International Council on Clean Transportation.

International Energy Agency. (2023). *Italy 2023 – Energy Policy Review.* Paris: IEA.

International Energy Agency. (2024). *Renewables 2024.* IEA.

IPCC. (2023). *Climate change 2023: Synthesis report.* Intergovernmental Panel on Climate Change.

ISTAT. (2023). *Bilanci demografici comunali e statistiche sul turismo.* Istituto Nazionale di Statistica.

Italy. (2021). *Decreto legislativo 8 novembre 2021, n. 199. Attuazione della direttiva (UE) 2018/2001sulla promozione dell'uso dell'energia da fonti rinnovabili.* Rome: Gazzetta Ufficiale della Repubblica Italiana.

Izquierdo, S. R. (2008). *A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations.* Solar Energy.

Izquierdo, S. R. (2008). *A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations.*

Joint Research Centre. (2020). *Energy communities: an overview of energy and social innovation.* Publications Office of the European Union (Joint Research Centre).

JRC. (2023). *Photovoltaic Geographical Information System (PVGIS).* European Commission Joint Research Centre.

Kempton, W. &. (2005). *Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy.* Journal of Power Sources.

Kougias, I. S. (2019). *ustainable energy modelling of non-interconnected Mediterranean islands.* Renewable Energy.

Legambiente. (2016). *Isole 100% rinnovabili: Come le isole stanno realizzando la transizione energetica.* Legambiente.

Lund, J. W. (2016). *Direct utilization of geothermal energy 2015 worldwide review.* Geothermics.

Maltese, I. &. (2021). *Sustainable mobility and tourism on small islands: The case of Ischia.* Sustainable transport and tourism destinations.

Martínez, W. R. (2023). *Decarbonising island mobility: Energy and environmental implications of an intermodal rail scenario in Gran Canaria.* Sustainability.

MASE. (2023). *ecreto 7 dicembre 2023, n. 414 – Incentivi per le comunità energetiche rinnovabili e configurazioni di autoconsumo per la condivisione dell'energia rinnovabile.* Rome: Ministero dell'Ambiente e della Sicurezza Energetica.

Matano, F. E. (2023). *Historical landslide events in the Campi Flegrei and Ischia volcanic areas.* Earth System Science Data.

Menyah, K. &.-R. (2012). *Energy consumption, pollutant emissions and economic growth in South Africa.* Energy Economics.

Meteotest. (2023). Meteonorm 8.0 Climate Database.

Miedema, H. M. (2001). *Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals.* Environmental Health Perspectives.

Ministero dell'Ambiente e della Sicurezza Energetica. (2023). *Piano Nazionale Integrato Energia e Clima – Aggiornamento 2023.* Rome: MASE.

Mutani, G. S. (2020). *Statistical data analysis for energy communities.* Tecnica Italiana – Italian Journal of Engineering Science.

Nappi, R. C. (2021). *The Casamicciola earthquake sequence and multi-hazard implications for Ischia Island.* Geosciences.

Nguyen, H. T. (2010). *Estimating potential photovoltaic yield with r.sun and the open source geographical resources analysis support system.* Solar Energy.

Ochoa-Correa, L. e. (2025). *ybrid renewable–storage systems for island decarbonisation.*

OECD/ITF. (2021). *Reforming road transport taxes.* OECD Publishing.

Onlus, L. (2020). *Isole 100% rinnovabili. Come 20 isole nel mondo sono in transizione verso uno scenario al 100% rinnovabile.* Legambiente Onlus.

Orsi, G. D. (1999). *The Ischia volcanic field: Structural setting, eruptive history and hazard.* Journal of Volcanology and Geothermal Research.

Orsi, G. D. (1999). *The Ischia volcanic field: Structural setting, eruptive history and hazard.* Journal of Volcanology and Geothermal Research.

Peel, M. C. (2007). *Updated world map of the Köppen–Geiger climate classification.* Hydrology and Earth System Sciences.

Peñalvo-López, E. A.-M.-M.-S. (2024). *Assessing energy transition in Mediterrain islands: A multi-criteria approach.* Advances in Electrical Engineering, Electronics and Energy.

Peretti, C. (2019). *Modelli per la transizione energetica delle isole minori.* Politecnico di Torino.

Piantadosi, A. B. (2018). *Marine protected areas and sustainable tourism: The case of Regno di Nettuno.* Marine Policy.

Pileri, G. &. (2017). *Quake kills two on Italian holiday island, young brothers saved.*

Pleijel, C. (2015). *Energy audit on Ischia (L'Isola Verde).* SMILEGOV Project Report.

Presidenza del Consiglio dei Ministri. (2021). *Piano Nazionale di Ripresa e Resilienza.* Rome: PCM.

REScoop & ClientEarth. (2019). *Transposing the EU Renewable Energy Directive (RED II) for citizen energy communities.* Brussels: REScoop.eu.

Roberts, J., Frieden, D., & d'Herbemont, S. (2019). *Energy Communities in the European Union.* REScoop.eu & ClientEarth.

Santo, A. D. (2012). *Coastal landslides in Campania: The 1978 Maronti Beach rockfall.* Rendiconti Online della Società Geologica Italiana.

Shindell, D. F. (2012). *Quantified, localized health benefits of accelerated carbon dioxide emissions reductions.* Nature Climate Change.

Sierzchula, W. B. (2014). *The influence of financial incentives and other socio-economic factors on electric vehicle adoption.* Energy Policy.

Soomauroo, Z. S. (2023). *Electrifying public transit in small island developing states: Opportunities, barriers and public finance benefits.* Transport Policy.

Sovacool, B. K. (2018). *The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region.* Global Environmental Change.

Terna S.p.A. (2023). *Rapporto Mensile sul Sistema Elettrico – 2023.* Rome: Terna.

Trull, O. P.-S.-D. (2019). *Electricity demand forecasting and tourism in Mediterranean islands.* Sustainability.

Ullah, Z. S.-A. (2022). *Integrating electric vehicles and renewable energy in distribution systems: A review of challenges, opportunities and solutions.* Renewable and Sustainable Energy Reviews.

Usta, Y. C. (2024). *Modeling and mapping solar energy production with photovoltaic panels on Politecnico di Torino university campus.* Energy Efficiency.

Volkswagen AG, &. H. (2022). *Astypalea: Smart & sustainable island – Project overview.*