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S4. Flagship Research Actions

CONTENTS

COMMUNITIES OF PRACTICE AND ENERGY COMMUNITIES AS LOCAL PILLARS OF ENVIRONMENTAL GOVERNANCE: A SOCIOLOGICAL AND POLICY PERSPECTIVE IN TIMES OF TRANSITION

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ABSTRACT

From a sociological and public governance perspective, this paper copes with the relationship between Communities of Practice (CoPs) and Energy Communities (ECs) placing emphasis on environmental governance at the local scale in the context of green transition. In places like Nisyros and other insular or peripheral regions, these associations offer critical avenues for social resilience, adaptive capacity, and energy sovereignty. Their interplay may foster inclusive governance, counters policy alienation, and supports locally driven transitions in alignment with national and EU sustainability targets. The paper draws on theoretical insights from political and environmental sociology—such as governance through civil society, power decentralization, and collective identity—and valorizes qualitative research findings from the JustReDI project on the social impact of the green and digital transition in Greece (https://www.justredi.gr/) as well as from the PLEDGE Project, an Horizon Europe funded project focusing on the emotional dynamics of political grievances and their implications for democratic politics (https://www.pledgeproject.eu/).

Keywords: Communities of practice, energy democracy, environmental governance, energy community, policy innovation, sustainable transition, civil society, local governance, island resilience

1. INTRODUCTION

1.1. The Context of Local Environmental governance

As societies grapple with the imperatives of green and energy transition, local-level associations and grass-roots initiatives are increasingly recognized as vital leverages in the production of sustainable governance and the proliferation of democratic innovations. Democratic innovations are usually understood as tools designed to revitalize democracy, at central and local level, by strengthening citizen participation in decision-making. They refer to processes or institutions that expand the role of citizens in governance through greater opportunities for participation, deliberation, and influence (Gonthier et al 2024). When it comes to environmental governance, Communities of Practice (CoPs) and Energy Communities (ECs) are regarded as crucial means to promote win-win solutions securing a sense of environmental justice among local populations.

From a strict sociological perspective, CoPs and ECs are social groups of various sizes with certain structure and functions. Although they are coined as 'communities', caution is warranted since there is not a generally accepted definition of community in social science. If anything, a methodological blurring between what a community is (empirical description) and what a community should be (normative prescription) is not uncommon. Be noted that already in 1955, George Hillary, an American sociologist specializing in community research had recorded ninety-four different definitions of 'community'.[1] Most sociological definitions of community include the spatial-local dimension as a sufficient and necessary condition for the existence of the other elements that make up a community: commitment, continuity, memory, and devotion. This is the so-called "ecological" view of community, which was established by the Chicago School. Nevertheless, although the place is an integral part of many interpretations of the community, its contribution to the formation of the concept has been questioned for very many years due to the conceptual distinction between 'place' and 'space' which in the meantime gained currency.[2] Space is no longer defined solely in local terms, i.e. as a three-dimensional spatiality, but as a network of interaction, as a relational situation established through the means of digital communication by distant others. In addition, it has been realized that communities are not simply collective entities characterized by all-inclusive and 'authentic' interpersonal communication, characterized by egalitarianism, and uniformity, but are human associations characterized by inner differentiations, tensions, and power relations.

There is a need then to conceptually clarify CoPs and ECs; I will do this by adding to my comments a third cognate concept, namely, communities of interest.

a) Communities of Practice (CoPs) fall within the intersection of the theoretical Paradigms of collaborative governance, network governance, polycentric governance, and participatory democracy as well as the model of co-production (Ansell and Gash 2008; Powell 1990; Rhodes 1997; Ostrom 1990; Barber 1984; Voorberg et al. 2015). Collaborative governance is defined as a decision-making process in which public and private actors work together to solve problems that cannot be addressed unilaterally; network and polycentric governance entail interdependence, negotiation and common resources, on the one hand, and multiple decision-making centers interacting and complementing each other, allowing for adaptive responses to local needs within a common framework for action, on the other. The model of participatory democracy refers to a form of government where citizens are actively involved in public decision making, going beyond mere voting, through devices like participatory budgeting or public consultations through mini-publics; in this respect, top-down policy making is complemented by horizontal procedures fostering the co-production of public policies. Under these terms, CoPs may function as mini-publics to enhance local democratic innovations (Elstub & Escobar 2019) through collaborative co-production and networking contributing thus to citizens' self-efficacy and trust to political institutions. Yet, there is always the risk of local elite manipulation, low

[1] George A. Hillery Jr., "Definitions of Community: Areas of Agreement" στο: *Rural Sociology*, 20 (June 1955), σελ. 111-123.

[2] Anthony Giddens, *The Consequences of Modernity* (Oxford: Polity Press, 1990), σελ. 17-21, 100-101.

engagement and/or pseudo-participation, and limited impact onto decision-making processes (Fung 2006; Gonthier et al 2024; Cornwall & Coelho 2007).

b) Communities of Interest (COI) are groups of people who share common concerns, characteristics, or goals that bind them together socially, culturally, economically, or politically not necessarily included within a single geographic district for purposes of effective and fair representation. To put it otherwise, a community of interest is a gathering of people assembled around a topic of common interest. Its members take part in the community to exchange information, to obtain answers to personal questions or problems, to improve their understanding of a subject, to share common passions (Henri & Pudelko 2003). From a computer science perspective, a community of interest is a collection of entities that share a common goal or environment (Aiello et al 2005). From a political sociology perspective, a community of interest is generally thought of as a group of individuals united by shared interests or values derived from a common history or culture, a common ethnic background, or a variety of other ties that create a community of voters with distinct interests. Although the perimeter of a community of interest may correspond to the boundaries of an administrative division, this is not necessarily the case. So, the criteria related to communities of interest can be divided into three categories: (1) criteria related to administrative or geographic boundaries; (2) criteria related to common interests or common characteristics; and (3) criteria related to patterns of interaction.[3] At a more general plane, therefore, COI can defined as the overlapping sets of neighborhoods, networks, and groups that share interests, views, cultures, histories, languages, and values.

c) Citizen Energy Communities and Renewable Energy Communities (CECs/RECs) are players in the energy sector who take control of their energy production and consumption. Through the Clean energy for all Europeans package, adopted in 2019, the EU introduced the concept of energy communities in its legislation for the first time, notably as citizen energy communities and renewable energy communities.[4] Sociologically speaking, CECs/RECs are formal, open and voluntary groups of citizens, local businesses, and sometimes local authorities, working together to produce, share, and consume energy from renewable sources. Evidently then, ECs/RECs have a definite local anchorage, and their main purposes are to promote energy independence, reduced energy costs, environmental sustainability, and energy democracy. CECs/RECs are controlled by local communities or through a partnership with commercial or public sector partners and are run according to strict legal criteria provided nationally or internationally. Being formal legal-social entities, they can take many forms, both in terms of ownership/development structures and technologies used. Small-scale wind, solar, and hydropower systems are the most common forms of community energy technologies[5] but as energy consumption and environmental protection become even more urgent issues, one can find a variety of ECs as depicted in Figure 1:

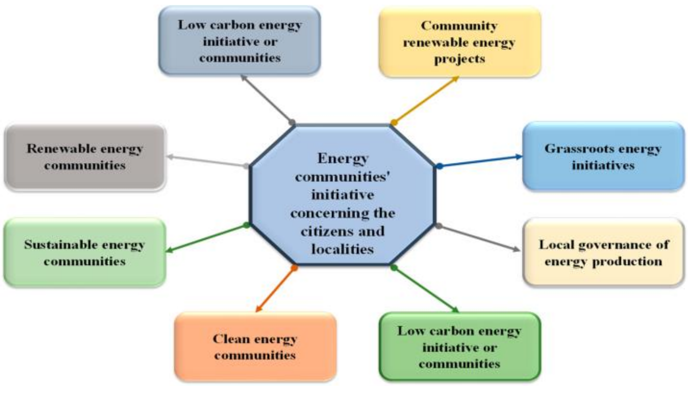


Figure 1. Types of energy communities and various terms for initiatives led by localities (Ahmed et al 2024).

[3] https://aceproject.org/main/english/bd/bdb05c.htm
[4] https://energy.ec.europa.eu/topics/markets-and-consumers/energy-consumers-and-prosumers/energy-communities_en.
[5] https://www.eesi.org/topics/communities/description

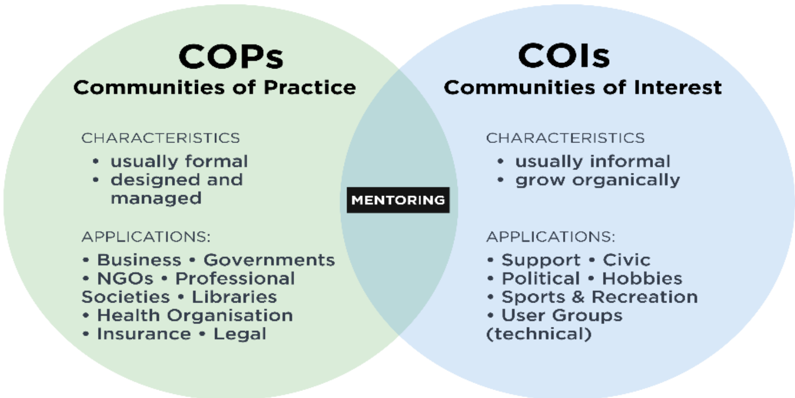
1.2. Commonalities and differences

CoPs, COIs, and ECs/RECs serve as the common ground of local environmental governance. To the extent that all three exist at the same time at the same place they interact synergistically with, but they are not reduced to each other. COIs and CoPs are both foundational means for consolidating group identity, social learning, and collective action, but, as shown in Table 1, they have different characteristics and serve distinct purposes.

Table 1: Comparisons between CoPs, COIs, and ECs

Aspect	**Communities of Practice (CoP)**	**Communities of Interest (CoI)**	**Energy Communities (EC)**
Purpose and Focus	Develop expertise in a specific domain through regular interaction and collaboration.	Unite individuals with a common interest to share information and network.	Jointly produce, manage, or consume energy (often renewable), aiming for local sustainability and empowerment.
Structure and Membership	Structured with regular meetings involving practitioners who actively engage in their domain.	More open and less structured, including anyone interested in the topic.	Legally structured (e.g. cooperative, association); includes citizens, SMEs, and/or municipalities.
Outcomes and Impact	Enhance skills, knowledge, and problem-solving; contribute to organizational learning and innovation.	Disseminate information, exchange ideas, and expand networks; raise awareness and drive advocacy.	Deliver clean energy, reduce costs, increase energy autonomy, foster community engagement and energy justice.

As shown in Figure 2, there are hybrid zones where a Community of Interest evolves into, or overlaps with, a



Source: https://www.platformos.com/blog/post/differentiating-communities-of-practice-from-communities-of-interest

Community of Practice—and vice versa. A COI can evolve into a CoP when interest leads to sustained collaborative activity, and a CoP can generate a COI when practitioners identify shared social or political concerns and values. A COI is defined by shared *what* (concerns) whereas a CoP is defined by shared *how* (doing). Similarly, the most likelihood is that an energy-focused CoP may end up in an EC/REC, although the reverse does not always happen (see Table 2).

Table 2: Conceptual links and fences between CoPs, COIs, and ECs

Statement	Truth Value	Why
An Energy Community is a Community of Interest	Often	Shared concerns about energy, justice, sustainability
An Energy Community is a Community of Practice	Typically	Requires shared learning, skills, and operation
All CoPs are ECs	❌ No	Many CoPs don't produce/consume energy
All ECs are CoPs	✔ Mostly	Functioning ECs require collaborative practice
All COIs are ECs	❌ No	Many COIs remain in advocacy stage

At any rate, to the extent they are interjoined, these three pillars of local environmental governance contribute to the renovation of local democratic political participation beyond energy or any other ecological concerns. They tacitly cultivate civic competence and aid the redesigning of democratic principles in practice; they also enhance bridging social capital and foster solidarity by making it easier for participants to share their emotional needs and grievances especially regarding environmental injustices and inequalities (Leigen & Celis 2024).

2. RESEARCH ON COPS AND ECS IN GREECE

Most of the research in Greece concerning CoP centers around education. Deviating from this pattern and scrutinizing the social impacts of green and digital transition, the project JustReDI is carrying out a detailed mapping of the ecosystem, as well as the creation of a registry of innovative actors for the green and digital transition. The identified actors are organized into a community of practice that plays a key role in: a) identifying and recording problems in relation to the green and digital transition at all levels that the project will approach (businesses, trade, households, etc.), b) investigating the positive and negative impact of the green and digital transition and their synergies with other sectoral policies, c) the detection of "ideal" pathways for fair, sustainable and inclusive digital and green transition.

In addition, through co-creation workshops and living labs during 2024-2025 in the cities of Athens, Komotini, Larisa, and Thessaloniki, with the participation of 120 representatives from the public and private sectors, academia, and civil society, the project provided: 1) a tailored made model for the development and sustainability of CoP in Greece in the field of the twin transition (Melides et al 2025); 2) a practical playbook for CoPs focusing on key principles, methodologies, best practices, and specific policy recommendations (Deligiannis et al. 2025). As far as the green transition is concerned, according to the methodological tenets of the JustReDI project the CoPs are at the same time ECs if not COIs as well (see Table 2).

Ever since their provision by law, specific research on ECs in Greece is more afforded. Through the Laws 4513/2018 and 5037/2023 Greece implemented the EU Directive 2019/944 to establish Energy Communities. The Law 5037/2023 differentiates between Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs). [6] As April 2025, 1,703 energy communities of all legal forms were operating in Greece[7] and it is estimated that only a small portion are for self-production and not for commercial purposes (Katsaprakakis et al 2022). Since 2020, several agents like the Centre for Renewable Energy Sources and Saving (CRES), the Green Peace Greece, the Green Tank, and the Research Unit SmartRUE of the National Technical University of Athens (NTUA) have been conducting quantitative and qualitative research on ECs funded by EU and national projects.

[6] https://www.catf.us/resource/clean-energy-ground-up-energy-communities-european-union/
[7] https://thegreentank.gr/en/community-energy-watch-en/. See also https://www.google.com/maps/d/u/2/viewer?mid=1Ib0zwm5fQACnQbmIUU_nPxjd2YwEMIVN&ll=37.89741924668955%2C23.484410868895758&z=6.

Indicative CECs/RECs in Greece are, Minoa Energy in Crete (est 2019)[8], Hyperion Energy Community in Attica (est 2029)[9], Prometheus Energy Community in Ioannina (est 2021), Collective Energy in Athens (est 2020)[10]

3. CECS/RECS ON THE GREEK ISLANDS

Islands present significant challenges and opportunities regarding the implementation of CECs/RECs. Be noted that non-interconnected islands cannot easily support renewable energy installations, but at the same time utilizing locally produced, clean sources of energy like the sun or wind, may increase the islands' resilience, self-sufficiency and local economic development and social engagement.[11] Islands like Tilos, Chalki, Nisyros, and Astypalaia can support energy autonomy, grid stability, and resilience to external energy disruptions through financial support, and facilitation via EU-funded advisory services.

Nisyros benefits from its inclusion into IANOS Project, funded by EU,[12] which provides ICT solutions for implementing decarbonization strategies. Specifically, in the IANOS project Nisyros is designated a 'fellow island', benefiting from smart grid and Virtual Power Plant (VPP) technologies combining AI-based forecasting, demand-response, and crowd-equity funding tools. Yet, Nisyros is more benefiting from the Project ZEN (Zero Emissions Nisyros) funded by the EU Islands Facility NESOI under Horizon 2020[13] (budget: €2.6 million). By the ZEN project the villages Mandraki, Paloi, Nikia, and Emporio are designed to acquire energy autonomy. The project will deploy small-scale solar PV and wind turbines, energy storage and net-metering. Besides that, it will cover demand of public infrastructures such as desalination plants, wastewater treatment, public buildings, streetlighting, and it will apply a sustainable mobility plan including electric vehicle infrastructure. A recent techno-economic study (Tsiaras et al 2025) evaluates four scenarios for Nisyros' electricity autonomy, showing the most cost-effective involves a three-wind turbine setup for full coverage of electricity demand.

These initiatives in Nisyros foster know-how on clean energy technological applications and networking and may enhance citizen participation, as well as local democratic environmental governance to meet local community's grievances over increased energy costs. They also lay ground for the creation of an energy community with the question, however, being the kind of community; namely, will it become a CEC or a REC? Taking stock from other national and European cases ZEN matters because it demonstrates how local governance and EU support can translate citizen-driven interest into actionable renewable projects, on the one hand, and may bridge energy justice, technical practice, and policy compliance under one integrative framework, on the other. In this respect, and in view of its inclusion in the 'GR-eco Islands' National Project to be implemented any soon in Greece, Nisyros may become a paradigmatic case where the social and solidarity economy model could contribute to energy security and environmental sustainability through the combination of practices and protocols drawn from COIs, CoPs, and ECs.

4. SHORT CONCLUSION

Applying CoP and EC as means to deal with the local energy sustainability problems of the Greek islands means to adopt the model of Transformative Innovation Policy (TIP)[14]. TIP refers to a strategic

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8 https://minoanenergy.com/.
9 https://energycommunityplatform.eu/communities/hyperion-energy-community/.
10 https://coen.coop/poioi-eimaste/.

11 https://electraenergy.coop/en/chalki-an-island-wide-energy-community/.

12 https://ianos.eu/about/project/?utm_source=chatgpt.com. See also https://clean-energy-islands.ec.europa.eu/all-set-net-zero-solutions-decarbonise-italys-islands?utm_source=chatgpt.com.

13 https://nesoi.eu/system/files/private/nesoi/Briefs/nesoi_z006_zen_brief.pdf.

14 https://tipconsortium.net/about-tipc/.

and proactive approach that will advance innovation in ways that lead to meaningful changes in society, the economy, and the environment. The island of Nisyros may espouse this model which can be replicable for other insular communities in Greece or even the EU seeking autonomy and resilience. Provided that EU and national funding instruments are available, what is actually needed is the local authorities' political will and civic engagement initiatives.

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DESIGNING PATHWAYS FOR SUSTAINABLE ISLAND COMMUNITIES: A METHODOLOGICAL FRAMEWORK FROM THE NISOS PROJECT

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ABSTRACT

This paper presents the methodological framework developed under the NISOS project, which aims to assess and amplify the impact of green technologies, educational initiatives, and circular economy models on the resilience and sustainability of island community. The proposed framework is focused on the implementation of the Interactive Green Park on Chalki Island, which is designated to function as a demonstration and engagement hub. The objective of this hub is to facilitate the experience of green technologies in a practical setting for both residents and visitors. The proposed framework integrates three key pillars: (a) Community awareness and behavioural change through experiential engagement; (b) Capacity-building and skills development via structured educational programmes tailored to island settings; and (c) Entrepreneurial activation through business models that promote circular economy solutions and local employment. The anticipated advantages encompass enhanced public awareness of sustainability, increased local engagement in green initiatives, novel employment prospects for residents, and a reduction in the skilled youth migration out of the region. The framework has been designed for replication and adaptation in other Greek islands, and the paper outlines this process. It offers practical steps for integrating research, innovation, and local engagement into sustainable development strategies in island regions. Despite the ongoing nature of the project, the presentation of this structured approach provides a valuable reference for other regions aiming to build resilient, self-sustaining island ecosystems.

Keywords: Island sustainability, circular economy, community engagement

1. INTRODUCTION

Sustainable islands are a growing priority as they face combined challenges from the climate crisis, social inequalities and energy sufficiency. The NHSOS project responds to these issues by integrating green technologies, educational initiatives and circular economy models, aiming to create practical and replicable solutions for island communities. In doing so, it positions islands not only as vulnerable territories but also as living laboratories of innovation that can drive broader sustainability transitions.

The NISOS project is an initiative that has been developed in response to these challenges. It employs a holistic framework that combines green technologies, educational initiatives, and circular economy business models. NISOS adopts a distinctive approach to sustainability, integrating social engagement and entrepreneurial activation to generate solutions that are both practical and replicable across island contexts. This approach stands in contrast to the conventional technical focus of sustainability initiatives, emphasising a more holistic and integrated approach to addressing environmental challenges. The Interactive Green Park on Chalki Island will operate as the primary demonstration hub, with a focus on familiarising residents and visitors with green technologies, fostering behavioural change, and stimulating local entrepreneurship.

The objective of this paper is to present the methodological framework developed within NISOS and to assess its potential for enhancing island resilience through education, innovation, and circular economy practices. The primary research question guiding this study is as follows: In what manner may an integrated framework encompassing technology, education and the circular economy contribute to the enhancement of the resilience and sustainability of island communities, whilst providing a replicable model for wider implementation?

2. THEORETICAL BACKGROUND AND RECENT APPROACHES

Recent studies underline that islands are well-suited as “sustainability laboratories” but face challenges linked to limited scale and isolation (Ali et al., 2025). Beyond energy, issues of water management, including freshwater scarcity, desalination needs and sustainable groundwater use, are central to long-term resilience. While renewable energy and storage remain important, equally critical are integrated solutions that combine microgrids and smart control systems with efficient water and resource management, often highlighted in case studies from Europe and the Pacific as transferable models.

The circular economy (CE) has also emerged as a pivotal principle in the context of sustainability transitions, emphasising the continuous circulation of resources through reuse, repair, remanufacture, and recycling (Geissdoerfer et al., 2017). In island settings, where scarcity of resources, challenges in waste management, and dependence on imports prevail, CE gains particular importance as an alternative to the linear "take–make–dispose" model. Within the NISOS project, CE is approached as a practical mechanism for local development rather than as an abstract policy. A dedicated deliverable focuses on the design of circular business models to promote and commercialise sustainable solutions, products, and services from green islands. This approach is intended to ensure the commercial and scientific exploitation of project results and innovative technologies. By establishing a connection between research outcomes and market-oriented applications, CE assumes a pivotal role within the NISOS framework, thereby promoting local value chains, green employment opportunities, and mitigating youth migration trends. The transition is catalysed by sustainable innovation, with the deployment of green technologies being associated with entrepreneurial opportunities (Boons and Lüdeke-Freund, 2013). Demonstration activities, such as the Interactive Green Park, thus evolve into platforms for experimentation and business incubation, extending CE benefits from environmental protection to economic resilience and social empowerment. It is imperative to acknowledge the significance of citizen engagement in this context. Through the implementation of co-designed programmes, participatory workshops, and interactive park experiences, residents are able to contribute their knowledge and feedback, while researchers provide expertise (Voytenko et al., 2016). This exchange has been demonstrated to enhance social acceptance, trust, and adaptive capacity, thereby ensuring that CE solutions are socially embedded, economically viable, and environmentally effective.

3. THE PROPOSED FRAMEWORK OF THE NISOS PROJECT

The NHSOS project is an initiative designed to accelerate the transition of Greek islands towards sustainability, energy independence and climate adaptation. Rooted in the broader objectives of the European Green Deal and the national strategy for clean energy and digital transformation, the project seeks to create living laboratories that combine innovation, community engagement and environmental protection.

The main objectives of the NHSOS project include:

- **Demonstrating sustainable mobility systems** such as electric vehicles and smart charging infrastructure.
- **Promoting renewable energy integration** by deploying advanced solar, storage and smart grid solutions.
- **Enhancing environmental stewardship** through modern waste management, water resource management and air quality monitoring.
- **Engaging local communities, visitors and other islands' residents** through interactive, educational and experiential activities that foster awareness and behavioural change towards sustainability.
- **Creating replicable business models** of green transition that can be adopted by other islands in Greece and across Europe
- **Addressing the "brain drain"** by fostering green entrepreneurship and offering viable professional opportunities.

The Green Park on Chalki has been conceived as an integral component of the NHSOS project, extending beyond the conventional role of a demonstration hub to show the principles of a circular economy business model that links environmental objectives with socio-economic development. It showcases advanced technologies such as renewable energy with storage, V2G charging, waste and water management systems and real-time environmental monitoring, while also serving as an educational space where residents, students and visitors can actively engage through interactive activities, exhibitions, and digital tools. Situated in Chalki, a small island with a modest population, an insular economy and growing interest in sustainability, the park provides an ideal context for experiential learning and innovation. Initial observations indicate positive participation levels and encouraging reactions from the local community, reflecting both curiosity and a willingness to embrace new solutions.

The second pillar of the NISOS framework is focused on skills development and awareness-raising through educational initiatives specifically adapted to the conditions of small islands. In the case of Chalki, the programme is focused on audiovisual educational material, with an emphasis on videos that showcase the unique characteristics of the island's sea ecosystem. These materials underscore the significance of marine biodiversity, the vulnerability of coastal habitats, and the inherent connection between ecological preservation and community well-being and long-term resilience. This digital content is complemented by the Interactive Green Park, which functions as a living classroom. In this classroom, residents, students and visitors have the opportunity to observe and engage with sustainable technologies in practice. Demonstrations of renewable energy systems, energy-efficient equipment, and water-saving technologies facilitate the connection between theoretical concepts of sustainability and tangible applications, thereby enhancing the experiential learning process. This dual approach, ensures that knowledge transfer is both accessible and impactful, equipping local communities with the environmental mentality and practical awareness necessary to actively contribute to sustainable transitions.

The third methodological pillar of NISOS is founded on the concept of community learning and educational initiatives, extending them into the domain of entrepreneurial activation. This approach establishes circular economy principles – namely, reuse, repair and resource efficiency – as integral to local development strategies, thereby conceptualising sustainability not only as an environmental objective, but also as an economic opportunity. Within this framework, educational and experiential activities are designed to act as catalysts for the emergence of entrepreneurial initiatives. The integration of practical demonstrations and structured learning modules within the project design is a strategic initiative implemented by NISOS to facilitate the evolution of knowledge transfer into business potential. This methodological orientation is further reinforced by dedicated project deliverables, which integrate the design of circular economy business models with pathways for commercialisation and replication. The integration of these components ensures that pilot actions do not remain isolated demonstrations, but function as prototypes for market-oriented applications. The intended outcome of this initiative is twofold: firstly, to enhance the socio-economic resilience of island communities by creating employment opportunities and, secondly, to position them as active contributors to the wider green economy through the export of knowledge, services, and sustainable practices.

4. CASE STUDY: THE INTERACTIVE GREEN PARK ON CHALKI

A central pillar of NHSOS is the development of the Interactive Green Park in Chalki island, which will serve as a public demonstration site and educational hub where citizens, students and visitors can directly experience innovations in the fields of energy, transport and the environment. The park is designed as a hands-on space that encourages exploration, learning, and inspiration through real-world applications of sustainable technologies.

The Green Park will include:

- **Transport Innovation Zone** showcasing a Vehicle-to-Grid (V2G) charging system and a V2G-capable electric vehicle**.** Visitors will learn how electric cars not only consume but also return energy to the grid, supporting stability and efficiency.
- **Renewable Energy Hub** with photovoltaic (PV) systems connected with batteries**,** demonstrating how solar energy can be stored and used to balance demand, making island systems more resilient.
- **Circular Economy Corner** featuring an integrated waste management system that highlights modern solutions for reducing, reusing and recycling resources.
- **Water Sustainability Pavilion** with videos and digital content explaining sea water and underground water management practices, emphasising the importance of conserving natural resources.
- **Digital Energy Advisor** through interactive monitors that present tools capable of suggesting tailored energy saving solutions for households and businesses.
- **Environmental Monitoring Station** including air quality sensors and monitoring systems**,** helping the community understand local environmental conditions in real time.
- **Maintenance and Smart Management Demonstrations** where visitors can explore how digital tools improve the performance and efficiency of green infrastructure.

Through these installations, the Green Park aims to raise community awareness by transforming abstract concepts like energy transition, climate neutrality and resource management into tangible, everyday experiences. By engaging citizens in an experiential and interactive way, the park strengthens local ownership of the green transition, builds environmental literacy and fosters a culture of sustainability that extends beyond the island itself.

For the Green Park on Chalki, has been developed a business model canvas tailored to its operational and financial characteristics. A key element of this model is the presence of a diverse range of customer segments. Local residents and households benefit directly from awareness-raising activities, repair and reuse services, and training opportunities, while schools and students engage with the park through educational videos and on-site visits. Another significant segment of the local population is constituted by tourists and visitors, who are attracted by guided tours, interactive experiences, and eco-tourism packages that highlight Chalki's natural and technological assets. Furthermore, the adoption of circular practices is encouraged among entrepreneurs and small enterprises. The park is regarded by external stakeholders, including municipalities, regional authorities and research institutions, as a replicable blueprint for sustainable island development.

The value proposition of the Green Park lies in its ability to combine practical exposure to sustainable technologies with high-quality educational content, thereby facilitating the bridging of the scientific and societal domains. The audiovisual material on Chalki's marine ecosystem, coupled with demonstrations of renewable energy systems and water-saving equipment, provides both scientific insight and tangible learning experiences. Concurrently, the park generates added value by promoting eco-tourism, supporting vocational training, and creating pathways for green entrepreneurship. These services are delivered through a range of channels that blend physical and digital access. The park itself functions as a living laboratory where visitors can directly observe sustainable technologies in action, while digital platforms disseminate educational videos and training material to schools, social media networks, and online learning communities. The initiative has been further expanded through partnerships with tour operators, schools, and local businesses, thereby embedding it within the broader social and economic fabric of the island. The relationship with customers is founded on participatory engagement. The involvement of residents is facilitated through the organisation of co-design workshops and community events. The aforementioned relationships are reinforced by public-private cooperation with local authorities and NGOs, which ensure institutional validity and facilitate scaling. The business model under discussion is one which anticipates the generation of revenue from a number of different sources. Guided visits and eco-tourism experiences have been shown to provide an immediate income stream, while training programmes and workshops have been demonstrated to create added value through skills development. It is anticipated that revenues of a more protracted nature may be derived from the commercialisation of sustainable products and services developed through the park, as well as from consultancy and knowledge transfer to other islands that seek to replicate the model.

In order to achieve these objectives, the Park depends on a series of key resources and activities. The installation of green technologies and audiovisual content constitutes the foundation of educational and demonstration activities, while skilled personnel ensure their effective operation and interpretation. The park's infrastructure serves a dual purpose: as a physical venue for learning and as a symbolic landmark of Chalki's transition towards sustainability. The day-to-day activities of the organisation include the maintenance of installations, the delivery of educational material, the organisation of workshops and events, and the provision of support for repair and reuse initiatives that embody circular economy principles. The viability of this model is contingent on effective partnerships. The Municipality of Chalki, in collaboration with local schools, research institutions such as CERTH and the University of Piraeus, local authorities as well as tourism operators and NGOs, collectively ensure that the park is rooted in local needs while benefiting from national and international expertise.

However, the cost structure of the model reflects the realities of small island projects, with significant upfront investments in infrastructure and audiovisual content, followed by ongoing expenses for staff, maintenance, and communication. By articulating these elements into a coherent business model, the Green Park demonstrates how circular economy principles can be embedded in island contexts. The initiative has been shown to engender value for a diverse range of stakeholders, whilst also ensuring economic and operational sustainability. Furthermore, it has been demonstrated that the initiative provides a replicable template for green entrepreneurship that extends well beyond Chalki.

5. RESULTS AND DISCUSSION

Beyond these immediate outcomes, the implementation of the framework related to NISOS project has revealed several broader dynamics that shape the sustainability transition of island communities. A key observation relates to the role of participatory processes in enhancing social acceptance and legitimacy. The involvement of residents, students, and local institutions in educational and entrepreneurial activities has cultivated a sense of ownership, reducing resistance to behavioural change and increasing trust in innovative solutions. The integration of circular economy practices within the local context has begun to demonstrate their potential scalability. The early expression of interest from local businesses and municipal actors suggests that the Green Park may function not only as an educational site, but also as a site for the replication of sustainable services, ranging from eco-tourism to small-scale resource management. This finding suggests that the primary value of the initiative lies not only in its direct impacts, but also in its capacity to stimulate subsequent initiatives. The results of the paper demonstrate the strategic importance of integrating technological demonstration with institutional support. While community engagement and entrepreneurial interest have proven strong, the long-term sustainability of the framework will depend on financial mechanisms, regulatory facilitation, and partnerships that enable the scaling of pilot activities into durable economic and social structures.

However, Chalki’s Green Park faces challenges related to cost, institutional processes and community acceptance, while offering strong potential as a hub for awareness and innovation. The installation and operation of advanced technologies such as V2G systems, storage solutions and environmental monitoring require significant investment, which can be eased through targeted funding schemes and collaborative partnerships. Institutional barriers, including regulatory complexity and administrative coordination, may slow down implementation but can be overcome with clearer governance frameworks and support from local and national authorities. Community acceptance is another key factor; sustained engagement, hands-on educational activities and transparent communication are essential to ensure that residents and visitors view the park not only as a demonstration space but as a shared asset that reflects their needs and aspirations.

6. CONCLUSIONS AND FUTURE PROSPECTS

Despite the fact that the NISOS project is still ongoing, it has already yielded valuable insights into the potential benefits for island communities of integrating green technologies, educational programmes and circular economy business models. The early experience from the Interactive Green Park on Chalki suggests that such initiatives can enhance awareness, support skills development, and stimulate interest in entrepreneurial activity. Preliminary observations suggest the possibility of contributions to the mitigation of youth outmigration and the enhancement of socio-economic resilience. However, further evidence is necessary to validate these trends. A notable aspect of the project lies in the replicability of its framework. The combination of experiential learning, tailored educational content, and circular economy entrepreneurship appears to form a transferable blueprint that could be adapted to the specific conditions of other islands. While the potential for replication is promising, it will require careful alignment with local socio-economic realities, governance arrangements, and resource capacities to ensure effectiveness.

In the longer term, island administrations and research institutions may draw upon these preliminary results to inform their own development strategies, while also leveraging EU and national funding mechanisms to support future applications. It is evident that further work is required in order to conduct quantitative impact assessments, examine economic benefits, and integrate emerging technologies into the framework. The establishment of a network of island green parks, drawing upon Chalki's experience, has the potential to foster knowledge sharing, promote inter-island cooperation, and position islands as pivotal actors in driving broader sustainability transitions.

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WATER PRICING CHALLENGES FOR SUSTAINABLE WATER MANAGEMENT IN AEGEAN ISLANDS

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ABSTRACT

The Greek islands face persistent challenges in water resource adequacy and management, driven by geographic fragmentation, limited natural reserves, climate variability, and strong seasonal pressures from tourism. Reliance on desalination, water transport, and insufficient infrastructure imposes significant economic and social costs. Rational water pricing is a key instrument for sustainable water management, serving both as a mechanism to recover costs and as a policy tool to ensure equity and efficiency. This study examines the heterogeneity of water pricing across selected Aegean islands, including Naxos, Mykonos, Nisyros, Santorini, and others, by analyzing tariff structures, consumption tiers, and distinctions between user categories. The analysis highlights three main aspects: (i) the variation in total costs for specific consumption levels, showing the impact of tariff design on households and businesses; (ii) the differentiation of pricing between domestic, commercial, and tourism-related users, reflecting local socio-economic priorities; and (iii) the disparities created by supply methods, such as desalination or transported water. The findings reveal wide inequalities in tariff structures, shaped by local demand patterns, political decisions and resource constraints. These results provide critical insights into the economic and environmental challenges of sustainable water management in insular contexts, particularly under the dual pressures of climate change and expanding tourism demand.

Keywords: water pricing, sustainable water management, consumption – based pricing

1. INTRODUCTION

Water is not only fundamental to human survival but also integral to the quality of life. Positioned at the physiological base of Maslow's hierarchy of needs alongside air, food, and shelter, water represents one of the most essential public services. The imperative to ensure safe drinking water and adequate sanitation for all individuals, households, and communities is indisputable. Access to safe water is far more than a matter of convenience; it is a public health necessity that particularly safeguards vulnerable populations [1].

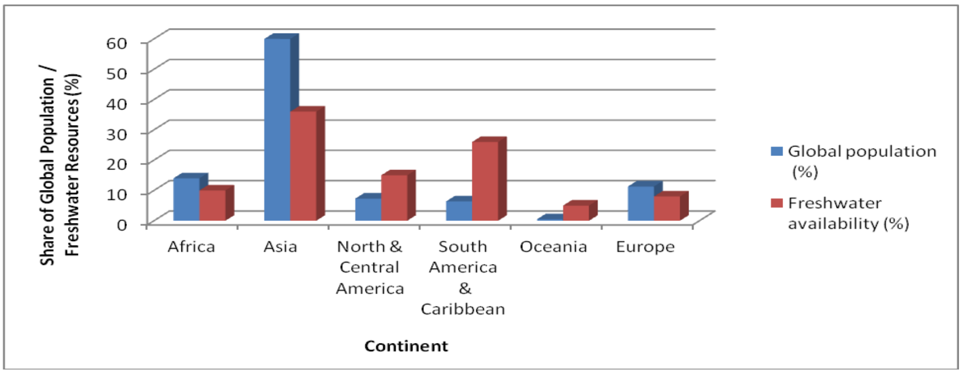


Figure 1: Comparison between the global population and freshwater resource availability across different regions of the world [5]

Global sustainability is unattainable without securing safe water for all—an imperative codified in United Nations SDG6, which targets universal access to water and sanitation by 2030 [2]. Yet water scarcity is accelerating across residential, commercial, industrial, and agricultural users as climate change and prolonged droughts intersect with rapid population growth, rising consumption, and decades of inadequate management; global demand is projected to rise by ~55%, and about one-quarter of the world's largest cities already face water stress [3–6]. Nearly four billion people endure severe shortages for at least one month each year, while ~2.2 billion still lack access to safe drinking water [7–9]. This crisis foregrounds water security—the reliable availability of acceptable quantity and quality for health, livelihoods, and production at an acceptable level of water-related risk—spanning household needs, economic and environmental sustainability, urban and transboundary dimensions, resilience to water-related disasters, and the maintenance of safe water quality [5].

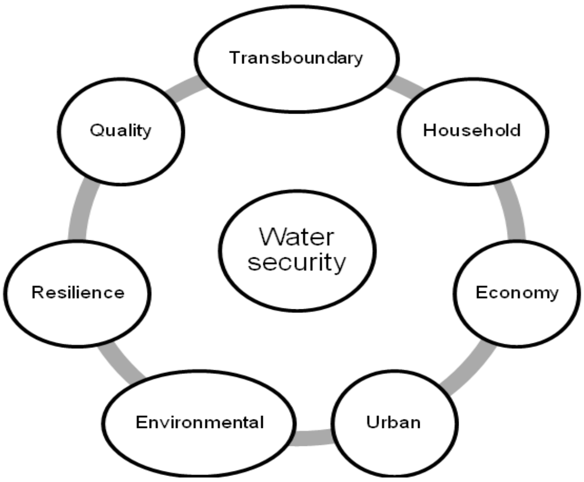


Figure 2: Key dimensions of water security [5]

Within this framework, water pricing serves as a central policy tool, shaping consumer behavior, encouraging conservation, and funding infrastructure. It can also protect vulnerable groups and ensure fairness. Globally, strategies vary: some countries apply progressive inclining block tariffs to curb overuse, others adopt seasonal pricing to manage peak demand, and many combine fixed and variable charges to balance stability and efficiency.

In island contexts—especially the Aegean—pricing plays an even more complex role. Isolation, varying resources, reliance on desalination or tanker supply, and seasonal tourism surges create wide differences in costs and tariffs, both between and within islands. This paper explores water pricing inequalities and sustainability challenges across selected Aegean islands through tariff comparisons and spatial analysis, emphasizing the interplay of economic, social, and environmental factors in local water management.

2. WATER PRICING: CONCEPTS AND APPROACHES

Water pricing is more than an accounting mechanism; it is a cornerstone of modern water policy, commonly framed around three objectives: equity, efficiency, and environmental sustainability (Rogers et al., 2002). Equity ensures that low-income households retain affordable access to essential services, while higher-income or high-consumption users bear a larger share of costs. This is critical in many developing contexts where vulnerable groups often pay more through informal vendors, making equitable tariff design a matter of social justice [10].

Efficiency arises when prices reflect water scarcity and encourage conservation. Accurate tariffs reduce waste, reallocate use, and optimize distribution across residential, agricultural, and industrial sectors [10]. Globally, economic growth is increasingly decoupled from water use: between 2015–2018, water-use efficiency rose 9%, reaching USD 32/m³ in industry and USD 112/m³ in services, while agriculture remained lowest at USD 0.6/m³ [11]. From 2006–2018, industrial withdrawals fell 18% while value added grew over 30%, showing that effective policies can boost efficiency and growth simultaneously.

Sustainability concerns long-term resource viability. Tariffs reflecting full costs, including environmental externalities, allow utilities to maintain infrastructure, invest in resilience, and discourage overuse. In practice, water pricing balances these goals, though trade-offs between competing objectives are inevitable.

2.1. Full Cost Pricing: From Cost to Value to Price

In many parts of the world, water is priced below its actual cost, resulting in chronic underfunding of utilities, inefficiencies in consumption, and an unsustainable reliance on overexploited resources. The principle of full cost pricing addresses this gap by incorporating all relevant dimensions of cost into tariff design. This includes operation and maintenance expenses, capital costs for infrastructure development, the opportunity cost of water in alternative uses, and environmental externalities associated with water abstraction and pollution [12].

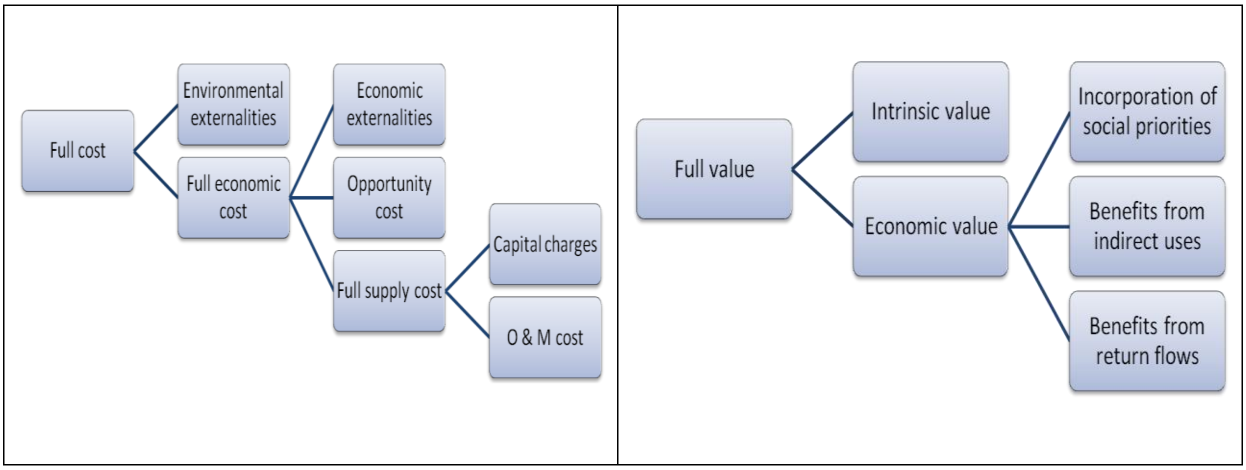


Figure 3: General principles for full cost and value of water pricing [12,10]

A further distinction must be made between cost, value, and price. Cost reflects the financial, environmental, and opportunity burdens required to deliver water. Value, by contrast, represents the social and economic benefits derived from water use, which range from meeting basic human needs to supporting agriculture, industry, and ecosystem services. Price is the policy lever that connects cost and value: it balances the recovery of financial and environmental costs with broader social objectives, such as equity and universal access. This tripartite framework underscores that water pricing is not a purely economic exercise but an instrument of social and environmental policy.

Although the principles of equity, efficiency, and sustainability are universal, their application becomes particularly complex in insular contexts. The geography of islands often implies limited and highly variable freshwater resources, heavy reliance on expensive alternatives such as desalination or bulk water transport, and extreme seasonal fluctuations in demand driven by tourism. These factors result in cost structures that differ sharply from those on the mainland and make tariff design a sensitive policy issue. In such settings, water pricing must simultaneously address the high unit costs of provision, ensure social fairness for resident populations, and promote sustainable use of limited resources.

3. WATER CHALLENGE IN AEGEAN ISLANDS

Water resource management in the Aegean islands of Greece represents a persistent and complex challenge, which has intensified in recent years due to the increasing water demand from both permanent residents and seasonal tourism. Most Aegean islands lack sufficient freshwater reserves and possess limited infrastructure for storage and distribution, rendering them particularly vulnerable to water scarcity, especially during the peak summer months.

The growing demand is directly linked to the ongoing expansion of tourism and urban development. In popular destinations such as Santorini and Mykonos, water consumption has surged dramatically. For example, Santorini's annual water demand increased from 929,000 m³ in 2013 to 2.36 million m³ in 2023 — an overall rise of approximately 154% over the decade. Similarly, Mykonos saw its annual water consumption grow from 955,000 m³ in 2020 to 1.62 million m³ in 2023, marking an increase of nearly 70% within just three years. This rapid escalation often exceeds the capacities of existing supply systems, placing mounting pressure on local resources and ecosystems [13]

At the same time, declining rainfall levels exacerbate the issue. In Andros, annual precipitation in 2023 was measured at just 363 mm, significantly lower than the long-term average of 506 mm, while Ios received 195 mm instead of its average 285 mm [13]. Smaller islands such as Fournoi, with just 1,300 residents, hosted over 8,000 tourists during the summer of 2023. Their annual water demand exceeded 90,000 m³, although natural water production is limited to only 30,000–40,000 m³. Forecasts indicate that this demand may reach 200,000 m³ by 2030 [14].

In light of the growing water stress, particularly on insular areas with limited supply capabilities, pricing emerges as a critical component of water resource management. Effective water pricing mechanisms can function not only as a cost-recovery tool but also as a demand-regulating instrument, especially in regions where water scarcity is seasonal yet severe.

3.1. Historical overview of water pricing in Aegean Islands

The evolution of water pricing in the Aegean islands reflects broader structural challenges in water governance. Historically, water tariffs in the Greek islands have been set by local municipal water utilities (DEYAs), often without a standardized methodology or cost-reflective basis. This led to a highly fragmented pricing system, with significant variation not only between mainland and island regions but also among the islands themselves. In many cases, water was priced well below production cost, especially in islands dependent on expensive supply methods such as seawater desalination or water transport by tanker. For example, in Mykonos, household tariffs in 2023 followed a tiered structure ranging from €0.73/m³ for 0–30 m³ to €2.44/m³ for consumption above 200 m³, while the cost of desalinated water on the island was estimated to exceed €1.20/m³ [15]. In comparison, average water tariffs on the mainland were lower for basic consumption but escalated steeply for higher volumes, reaching €3.05/m³ beyond 35 m³ [15].

Despite the elevated cost of supply in island settings, water pricing has remained politically sensitive and often underregulated, with flat-rate or semi-volumetric pricing schemes that discourage conservation and leave utilities financially vulnerable. In many municipalities, the actual cost recovery rate is estimated at only 30–50%, leading to chronic budget deficits and dependency on state subsidies [16].

3.2. Characteristics and typologies of water pricing schemes in the Aegean islands

Water pricing in the Aegean islands is characterized by significant heterogeneity, both in terms of tariff structures and price levels. This variation reflects the diverse supply conditions, institutional capacities, and political dynamics across the islands. While the majority of municipal water utilities (DEYAs) have adopted some form of volumetric pricing, the degree of cost reflectiveness, conservation incentives, and affordability varies widely [17].

Three broad types of water pricing schemes are commonly found across the Aegean islands [18]:

- **Inclining Block Tariffs (IBTs)**: These are the most widespread, particularly in larger or tourism-heavy islands. They impose progressively higher unit prices as consumption increases, theoretically encouraging conservation. However, the number of blocks, block widths, and price jumps vary significantly across municipalities.
- **Flat or Uniform Tariffs**: Found primarily in smaller or less organized utilities, these charge a single price per cubic meter, regardless of consumption level. While administratively simple, they offer limited incentives for efficient use .
- **Semi-volumetric Tariffs**: These combine a fixed charge with a variable component that may or may not reflect actual consumption. They are often used in areas with outdated metering infrastructure or fragmented supply systems.

According to data from the Ministry of Environment and Energy (2023), about 68% of Aegean islands apply a tiered pricing model (IBT), 21% use flat rates, and 11% adopt semi-volumetric or hybrid structures [19]. IBT schemes typically include 2–5 tiers, with the first covering 0–30 m³ per quarter and the highest often beginning above 100–150 m³ [20].

Tariffs vary widely due to supply technologies, production costs, and political factors. In 2023, the average domestic tariff in the Aegean was €1.12/m³, compared to €0.88/m³ on the mainland [20]. On desalination-reliant islands, production costs range from €0.60–1.20/m³, depending on technology and salinity; reverse osmosis is most common, though small-scale or energy-intensive units increase costs [21, 22]. Despite this, end-user tariffs often remain below €1.00/m³ because of cross-subsidies and political resistance to full cost recovery [23]. On smaller or remote islands supplied by tankers, costs can reach €4.91–8.32/m³, yet consumers pay only a fraction, as full-cost pricing is socially and politically unfeasible [21]. More broadly, water pricing is shaped by non-economic considerations: political sensitivities keep prices low for households and small businesses, while limited metering (often <80%) and infrequent billing (quarterly or biannual) further weaken the link between consumption and cost [21].

4. CASE – BASED OVERVIEW OF WATER TARIFF STRUCTURES IN AEGEAN ISLANDS

Water pricing across the Aegean islands is far from uniform. In fact, it reflects a highly fragmented landscape, where each island — and in some cases, even different areas within the same island — applies its own pricing rules, consumption blocks, and user categories. While some municipalities implement uniform (flat-rate) pricing regardless of consumption level, others have adopted inclining block tariffs (IBTs), where the unit price increases as water usage rises. However, the structure of these IBTs varies significantly, not only in terms of the number and width of the consumption blocks, but also in the starting thresholds and price increments.

Additionally, several islands apply differentiated tariffs by sector, distinguishing between domestic, commercial, and sometimes agricultural users. In certain cases, public institutions or hospitality businesses are subject to entirely separate pricing policies. There are even examples where intra-island variations occur, with different communities or administrative zones applying their own water charges — often based on localized infrastructure or governance arrangements.

4.1. Tiered pricing for domestic water use

Tiered (or block) pricing is one of the most common tariff structures applied to domestic water use in the Aegean islands. Under this system, water is charged at progressively higher rates as consumption increases, with the goal of promoting conservation while ensuring affordability for basic needs. However, the design and implementation of these tiered tariffs vary significantly from island to island.

Key variables include the number of consumption blocks, the threshold volumes that define them, and the corresponding unit prices.

The chart below illustrates how water charges vary across different islands based on tiered pricing structures. For a set of standardized consumption levels (measured in cubic meters), we compare the total cost incurred by domestic users in each location. The analysis highlights how the design of consumption blocks, threshold levels, and unit rates significantly affects the final bill — even for identical usage levels. These differences reflect not only pricing policy choices but also underlying factors such as water availability, infrastructure costs, and governance models.

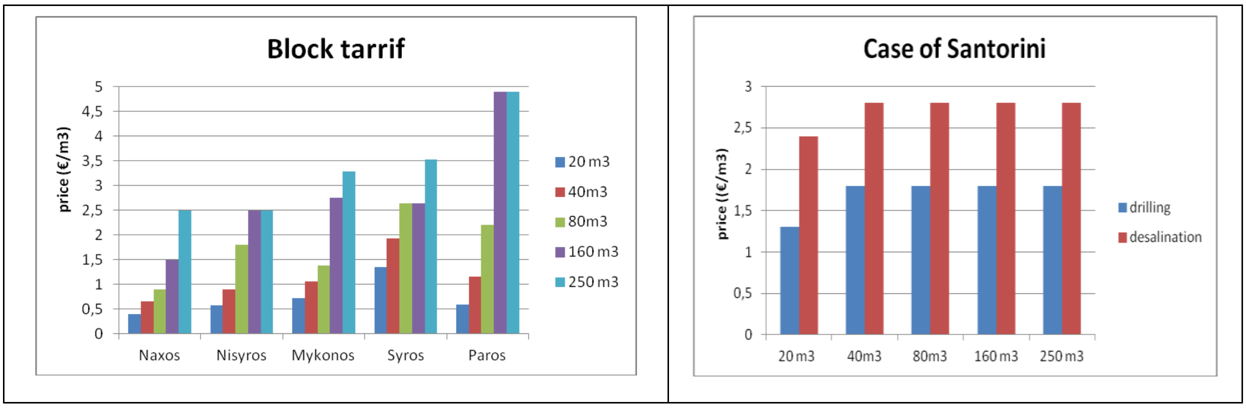
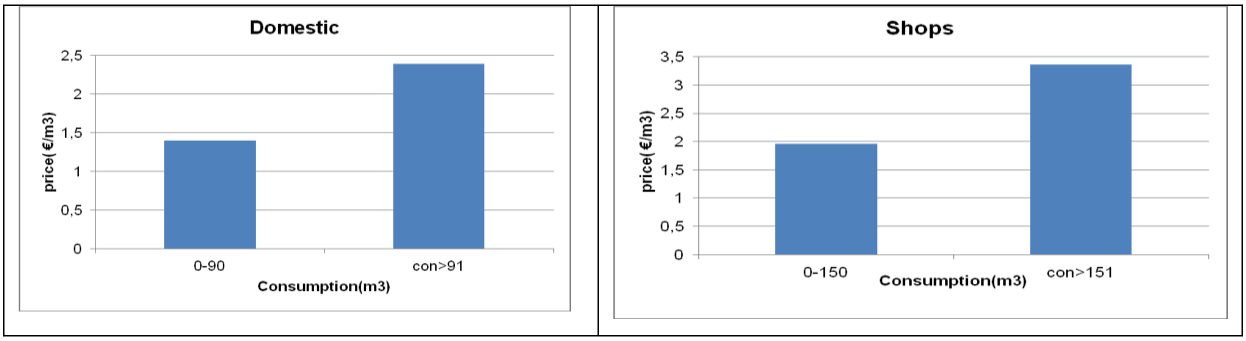


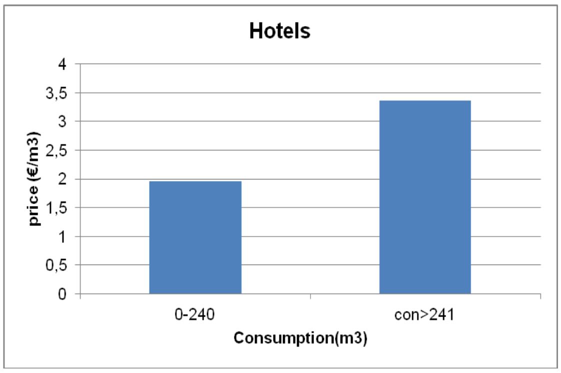
Figure 4: Tiered water tariffs (DEYA personal communication)

4.2. Different water pricing by category of use

In several islands, water pricing does not follow a single, uniform scheme but is instead adjusted according to the type of consumer. This approach reflects both the social role and the economic impact of water use in each sector. As a result, distinct tariffs are applied to different categories of users. Households are typically charged at a lower rate, with the aim of ensuring affordable access to water for residents and covering essential domestic needs. Commercial establishments, such as shops, are subject to higher tariffs, as water consumption in this case is linked to economic activity and profit-making. Hotels, which represent the tourism sector, usually face even higher charges. This reflects the intensive seasonal demand they generate and the additional strain placed on limited local water resources during the peak tourist months. Finally, industrial users such as quarries are assigned a separate and often significantly higher pricing category, since their consumption is large-scale and considered to have a more substantial environmental impact.

The following figures illustrate these differentiated pricing schemes, highlighting the way in which water tariffs vary across households, shops, hotels, and quarries. This differentiation underlines not only the economic dimension of water use but also the need for sustainable management in insular regions with fragile water balances.





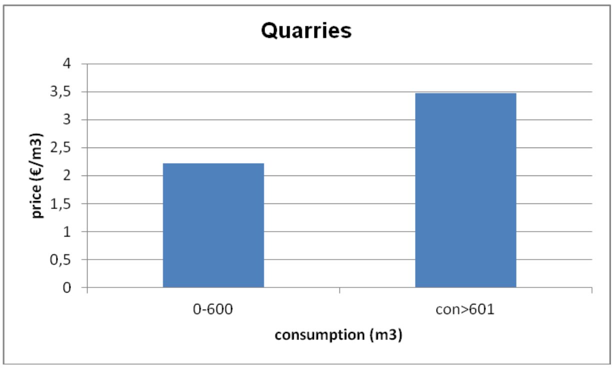


Figure 5: The case of Sifnos (DEYA personal communication)

4.2.1. The case of Karpathos: Expanded user categories

Karpathos represents an interesting example where water pricing moves beyond the simple household–professional distinction and introduces a more detailed categorization of users. In addition to households and general commercial consumers, hotels are charged separately, with tariffs differentiated according to their number of beds. This reflects the significant role of tourism in shaping seasonal water demand and the need to link charges to the actual scale of consumption. Furthermore, farmhouses are treated as a distinct category, acknowledging their specific patterns of water use that differ both from ordinary households and from purely commercial activities.

Domestic	
cubic meters	price
0-40	0,29
40-120	0,38
121-180	0,76
181-300	1,71
301- ..	2,38

Farmhouses	
cubic meters	price
0-60	0,38
61-120	0,95
121-180	1,33
181-…	2,19

Figure 7: Water tariff policy of Karpathos – Domestic and farmhouses

Commercial & hotels up to 160 beds	
cubic meters	price
0-300	0,76
301-1000	0,95
1001-1500	1,24
1501-…	1,9

Hotels with 160 beds and above	
cubic meters	price
0-1500	0,76
1501-3000	0,95
3001-6000	1,24
6001-…	1,9

Figure 8: Water tariff policy of Karpathos – Commercial and hotels (DEYA personal communication)

4.3. Population – based tiered pricing: The case of Rhodes

Rhodes provides an illustrative example of population-based tiered water pricing. In this system, tariffs for domestic and commercial users are adjusted according to the number of residents or the scale of the service area. Smaller population zones face lower initial rates for essential consumption, while larger population centers are subject to higher tier thresholds and tariffs to reflect increased demand and supply pressures.

This approach allows local authorities to align water charges with both consumption patterns and the social and economic context of different communities. By linking pricing to population, Rhodes aims to promote fairness, ensure affordability for residents in smaller settlements, and maintain financial sustainability in more densely populated areas. The following figures illustrate the tiered structure, highlighting how rates increase with both consumption and population size.

Domestic	
>10,000 residents	
cubic meters	price
0-10	0,32
11-30	0,4
31-50	0,56
51-75	0,76
76-100	1,05
>100	1,15

Domestic	
<10,000 residents	
cubic meters	price
0-10	0,16
11-30	0,2
31-50	0,28
51-75	0,42
76-100	0,56
>100	0,65

Commercial & Construction	
cubic meters	price
0-30	0,4
31-150	0,54
151-300	0,8
>300	0,95

Figure 9: Rhodes water tariff policy (DEYA personal communication)

5. CONCLUSIONS

The analysis of water pricing in the Aegean islands demonstrates that existing tariff structures, though diverse, often fail to achieve a balance between affordability, cost recovery, and sustainable resource management. While inclining block tariffs and differentiated user categories provide a foundation for promoting efficiency and fairness, persistent political, social, and institutional barriers limit their effectiveness. In many cases, tariffs remain below production costs, utilities face chronic financial deficits, and conservation incentives are weakened. The rapid growth of tourism, coupled with declining rainfall and limited infrastructure, exacerbates these challenges. To ensure long-term water security, pricing policies must move toward full cost reflectiveness while embedding principles of equity and environmental sustainability. Strengthening metering systems, standardizing tariff methodologies, and linking pricing to demand management are essential steps. Ultimately, water pricing should not be viewed solely as an economic mechanism but as a key policy tool for advancing resilience, social justice, and sustainability in island communities. The comparative evidence across different islands also shows how local choices and priorities shape outcomes, underscoring the need for integrated strategies that bridge technical, economic, and social dimensions. In this sense, water pricing reforms in the Aegean can serve as a valuable reference point for other insular or water-scarce regions facing similar sustainability pressures.

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GREEN AND DIGITAL TRANSITION ACROSS REGIONS IN GREECE: INSIGHTS FROM THE JUSTREDI SURVEY

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ABSTRACT

The green and digital transitions represent both critical challenges and emerging opportunities for all Regions (NUTS-2) in Greece. This study aims to highlight prevailing trends, perceptions, and barriers related to this twin transition by analyzing data from the newly derived sample survey under the title “The Green and Digital Transition” in Greece. A survey hosted by a significant flagship action under the title “Resilience, inclusiveness and development: Towards a just green and digital transition of Greek regions” (JustReDI) investigating in particular the social impact of green transition and digital transformation in Greece.

Based on statistical and econometric analysis of a large-scale field survey data comprising more than 5,000 observations, the study focuses on key thematic dimensions of the green transition, such as energy poverty, perceived impacts of climate change, institutional trust, and future outlook, and the digital transition, including user experience with digital public services, concerns over inequality, and perceived improvements in quality of life. The analysis focuses on capturing the differences between the three island regions (namely North Aegean, South Aegean, Ionian Islands), the region of Crete, the region of Attica, the group of the four regions constituting Northern Greece, and the group of four regions in Central Greece, within the studied dimensions. The findings might also be relevant for certain aspects of the EU Cohesion Policy; especially in the case of the twin transition mega-trend. Addressing disparities which may be derived by the green and digital transitions can be the necessary step towards a realignment among the national and EU-level strategies for inclusive growth.

By exploring how individuals and households in different areas experience and interpret these transitions, the study seeks to uncover region-specific dynamics and identify policy-relevant insights to support a more inclusive, equitable, and resilient transformation. The findings aim to inform the design of targeted policies that respond to local conditions while promoting regional and societal cohesion.

Keywords: Green and digital transitions; quantitative research; regional cohesion.

1. INTRODUCTION

The green and the digital transitions are widely acknowledged as mega-trends with the potential to reshape the structural dynamics of the economy and society [1,2]. They not only generate new opportunities for growth, innovation, and social well-being, but can also entail negative consequences, including adaptation challenges, rising inequalities, and threats to resilience. Crucially, the unfolding of these transitions might have a strong spatial dimension: regions differ in their capacity to respond, and structural changes may reshape production systems, reallocate resources, and intensify or mitigate existing regional inequalities. Green and digital transitions might not be spatially neutral [3,4,5] as their benefits and costs might be unevenly distributed across regions.

This paper contributes to the literature by examining how citizens in different geographical areas of Greece perceive, experience, and adapt to the green and digital transitions. Comparing the performance of Greece's island regions with that of other regions, it addresses the following research questions:

- How do perceptions of personal impact from climate change, energy-related pressures, and the effectiveness of national green policies differ across regions, with particular attention to the island regions compared to mainland areas?
- How do individuals evaluate the benefits and challenges of digitalization in everyday public and private services, and how do these perceptions vary regionally?
- To what extent do regional factors, after controlling for socio-demographic characteristics and general attitudes, influence citizens' evaluations of policies for both the green and digital transitions?

Overall, this study seeks to provide insights into the spatial dynamics of Greece's green and digital transitions and their policy implications for regional inclusiveness and resilience.

2. DATA AND DESCRIPTIVE STATISTICS

The empirical analysis of this study draws on data from the field survey titled "The Green and Digital Transition" in Greece, conducted in 2025 within the research project "Resilience, Inclusiveness, and Development: Towards a Just Green and Digital Transition of Greek Regions". The sampling covered 5,010 individuals aged 18 and above across the 13 Greek regions at the household level. The sample survey aimed to collect data on citizens' attitudes, opinions, behaviors, expectations, evaluations, and perceptions regarding the green transition and the digital transformation, as well as the development of national strategies and policies related to both issues.

Given the focus of this study on regional-level analysis, with particular emphasis on comparing the performance of the island regions (North Aegean, South Aegean, and Ionian Islands) with other regional units in Greece, the 13 NUTS-2 level regions have been grouped as follows: i) **Aegean and Ionian Islands group**: North Aegean, South Aegean, Ionian Islands (sample size: 324 observations); ii) **Crete** (sample size: 291 observations); iii) **Northern Greece**: Eastern Macedonia and Thrace, Central Macedonia, Western Macedonia, and Epirus (sample size: 1,445 observations); iv) **Central Greece**: Thessaly, Central Greece, Peloponnese, and Western Greece (sample size: 1,176); v) **Attica** (sample size: 1,774). This grouping allows for a clear comparison of regional dynamics across the country. Detailed sample sizes for each group are presented in Table 1.

Table 1: Sample size by group of regions

Groups of NUTS-2 level regions	Sample Size
Aegean and Ionian islands group (North Aegean; South Aegean; Ionian Islands)	324
Crete (Crete)	291
Northern Greece (E. Macedonia & Thrace; C. Macedonia; W. Macedonia; & Epirus)	1,445
Central Greece (Thessaly; Central Greece; Peloponnese; & Western Greece)	1,176
Attica (Attica)	1,774
Total	5,010

Attempting a descriptive analysis of dimensions related to the green transition, Figure 1 shows the weighted share of respondents who endured heating or cooling (or both) over the past 12 months to save money. The figure highlights significant regional differences, with the island regions (Aegean and Ionian Islands) exhibiting the highest proportion at 58.7%, substantially above the national average of 40.2%. In contrast, Crete and Northern Greece report much lower shares, at 25.1% and 24.8% respectively, while Central Greece and Attica show intermediate values of 51.1% and 44.2%. Furthermore, taking Attica as the base category for each possible comparison of mean values, all four differences are statistically significant at 0.01 level. These results suggest that households in the island regions are particularly exposed to energy-related pressures compared to other areas.

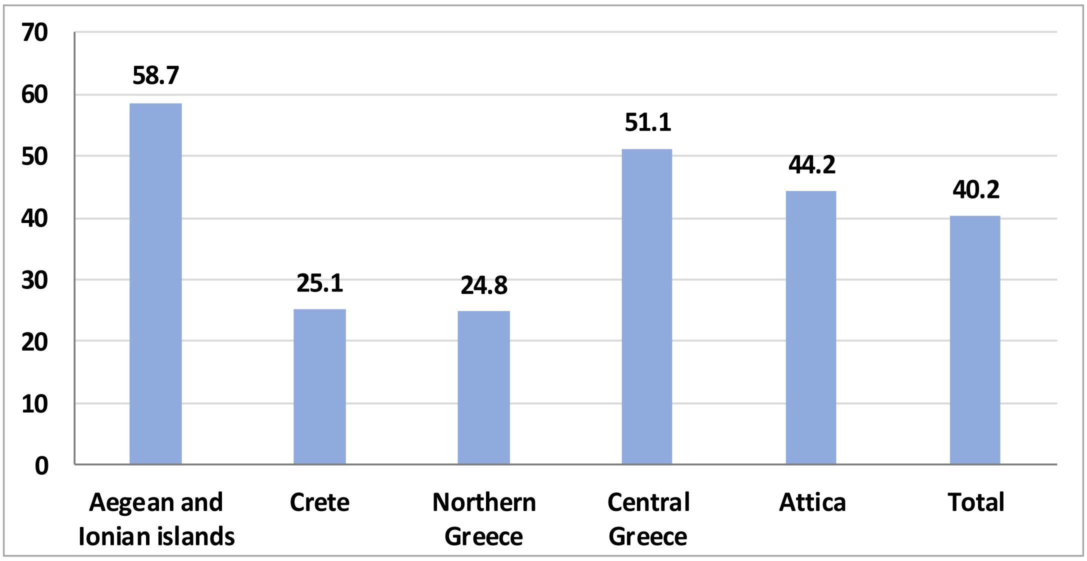

Figure 1: Percentage of households that, in the past 12 months, endured cold or heat to save money and keep their expenses low (2025)

Reflecting responses to the question *"To what extent do you think climate change affects you personally today?"*, the data reveal notable regional differences. In particular, the island regions of the Aegean and Ionian Islands exhibit the highest share of respondents reporting being affected *extremely* or *a lot* (28%), well above the national average of 19%. By contrast, Crete shows a much lower proportion at 12%, while Northern Greece, Central Greece, and Attica report intermediate values of 23%, 18%, and 17%, respectively (Figure 2). These patterns suggest that residents of the island regions perceive a stronger immediate personal impact from climate change compared to other areas.

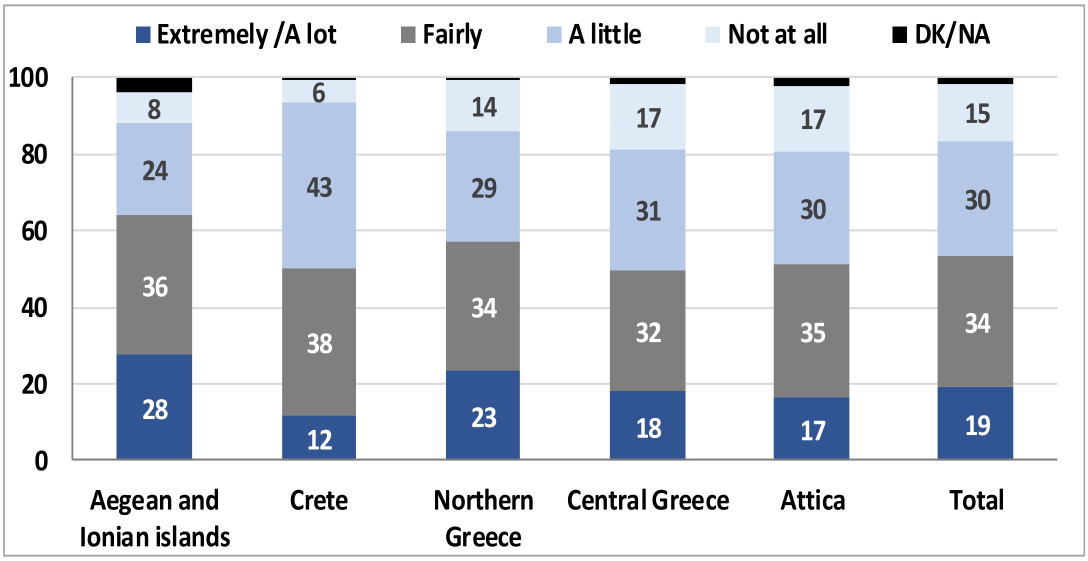

Figure 2: Percentage distribution of responses to the question: 'To what extent do you think climate change affects you personally today?

Focusing on the question of primary interest in the present analysis (regarding the green transition), Table 2 reflects public perceptions of whether Greece is moving in the right or wrong direction. Overall, only 29.2% of respondents believe the country is heading in the right direction, indicating a general level of skepticism. Notably, the Aegean and Ionian Islands exhibit a comparatively lower share of positive responses at 21.7%, well below the national average. This lower confidence among residents of the island regions likely reflects, inter alia, the local challenges already highlighted, such as energy access and higher costs, which may shape their more cautious outlook on the effectiveness of green policies.

Table 2: In your opinion, at this time, is Greece moving in the right or wrong direction regarding the green transition?

Groups of NUTS-2 level regions	In the right direction	Neither in the right nor in the wrong direction	In the wrong direction	DK/NA	Total
Aegean and Ionian islands	21.7%	36.0%	31.4%	11.0%	100.0%
Crete	55.4%	20.2%	19.0%	5.5%	100.0%
Northern Greece	23.7%	43.4%	25.7%	7.2%	100.0%
Central Greece	28.8%	37.9%	25.8%	7.5%	100.0%
Attica	30.9%	30.6%	30.2%	8.3%	100.0%
Total	29.2%	35.6%	27.4%	7.9%	100.0%

The focus now turns to individuals' perceptions of the benefits and challenges of the digital transition, reflecting their views on whether the digitalization of everyday public and private services makes life easier or more difficult. Overall, 71.2% of respondents report that digitalization has made their lives easier (Table 3). Notably, the island regions of the Aegean and Ionian Islands report an even higher share at 79.2%, compared to 68.5% in Attica, suggesting that residents of the islands seem to benefit from the convenience and accessibility of digital services, likely due to their greater dependence on online solutions to overcome geographical constraints.

Table 3: Do you consider that the digitalization of everyday public and private services makes your life easier or more difficult?

Groups of NUTS-2 level regions	Easier	More difficult	No change / Does not affect my life	DK/NA	Total
Aegean and Ionian islands	79.2%	10.7%	8.0%	2.0%	100.0%
Crete	79.0%	6.0%	15.1%	0.0%	100.0%
Northern Greece	75.8%	16.6%	6.7%	0.9%	100.0%
Central Greece	65.7%	21.5%	12.3%	0.6%	100.0%
Attica	68.5%	20.2%	10.6%	0.7%	100.0%
Total	71.2%	18.0%	10.0%	0.8%	100.0%

Examining how citizens evaluate policies for the digital transformation, the data in Table 4 reflect their views on whether, in their opinion, at this time, Greece is moving in the right or wrong direction regarding the digital transformation. Overall, 44.8% of respondents believe the country is heading in the right direction, with regional shares ranging from 36.7% in Northern Greece to 65.6% in Crete, while the Aegean and Ionian Islands report 46.2% and Attica 49.2%. This positive assessment is consistently higher across all regions compared to the corresponding evaluation of policies for the green transition, indicating greater public confidence in digital initiatives. The comparatively strong approval in the island regions may reflect the benefits of digital services in overcoming geographical constraints and improving access to public and private services, highlighting the value of digitalization for residents in more remote areas.

Table 4: In your opinion, at this time, is Greece moving in the right or wrong direction regarding the digital transformation?

Groups of NUTS-2 level regions	In the right direction	Neither in the right nor in the wrong direction	In the wrong direction	DK/NA	Total
Aegean and Ionian islands	46.2%	30.6%	12.7%	10.5%	100.0%
Crete	65.6%	18.2%	9.3%	6.9%	100.0%
Northern Greece	36.7%	41.5%	13.1%	8.7%	100.0%
Central Greece	41.8%	34.4%	14.4%	9.5%	100.0%
Attica	49.2%	27.1%	16.4%	7.3%	100.0%
Total	44.8%	32.5%	14.3%	8.4%	100.0%

3. METHODOLOGY

The preceding analysis provided a descriptive overview of individuals' perceptions of the green and digital transitions. To further investigate the determinants of these perceptions, and in particular to examine the potential role of spatial factors in shaping them, this study employs methodological tools grounded in econometric techniques. Specifically, given that the evaluation of policies for both the green and digital transitions is based on a multinomial scale (in the right direction; neither in the right nor in the wrong direction; in the wrong direction), the present analysis applies the econometric approach of the multinomial logit model.

To investigate the determinants of citizens' evaluations of policies for the green transition, the dependent variable is derived from the question *"In your opinion, is Greece currently moving in the right or wrong direction regarding the green transition?"*. The analysis considers the probability that an individual selects one of three response categories: (i) in the right direction; (ii) neither in the right nor in the wrong direction; (iii) in the wrong direction (with the “don’t know / no answer” category excluded). The explanatory variables incorporated in the econometric model include:

a) **socio-demographic characteristics** of respondents (age, gender, household size, marital status, educational attainment, and employment status);

b) **variables reflecting broader attitudes and perceptions related to climate** change and the green transition, such as:

- the extent to which individuals feel personally affected by climate change,
- the degree to which they consider themselves personally responsible for climate change,
- their perceptions of whether their region benefits from green energy investments (e.g., job creation, local development),
- the extent to which they view climate change as a serious and immediate threat to the planet, and
- the level of concern that climate change will make their lives extremely unpleasant;

c) **a spatial variable capturing the effect of place of residence**, structured around the five regional groups defined in this study.

The objective of this approach is to examine whether, and to what extent, spatial factors continue to exert a significant and statistically robust influence on the formation of perceptions regarding the effectiveness of green transition policies in Greece, once socio-demographic and attitudinal characteristics are taken into account. By estimating Relative Risk Ratios (RRRs), the analysis provides a quantified assessment of the extent to which geography shapes citizens’ evaluations of green transition policies.

Similarly, the dependent variable used to investigate the determinants of perceptions regarding the effectiveness of digital transformation policies is based on the question *“In your opinion, at this time, is Greece moving in the right or wrong direction regarding the digital transformation?”*, where respondents could choose among three categories: (i) in the right direction; (ii) neither in the right nor in the wrong direction; (iii) in the wrong direction (the “don’t know / no answer” category was excluded from the analysis). The explanatory variables include the same set of socio-demographic characteristics and regional groupings specified earlier for the green transition model, as well as additional variables capturing attitudes towards digitalization. These cover aspects such as:

- whether individuals believe the digitalization of everyday public and private services makes their lives easier or more difficult;
- whether the mandatory digitalization of certain basic procedures (e.g., banking transactions, public services) facilitated or hindered them;
- whether they face a lack of necessary digital skills in using digital technologies;
- whether they experience technical barriers (e.g., system malfunctions, limited internet access) in using digital technologies;
- and whether they perceive artificial intelligence as something beneficial or harmful for humanity.

As in the case of the green transition model, the analysis estimates Relative Risk Ratios. This approach enables a quantified assessment of how socio-demographic factors, regional context, and individual attitudes towards digitalization influence the likelihood of evaluating digital transformation policies as moving in the right or wrong direction.

4. RESULTS

This section presents the findings of the empirical analysis derived from the estimation of multinomial logit models that explore the determinants of individuals’ evaluations of (a) policies for the green transition and (b) policies for the digital transition. To maintain brevity, the reported results focus exclusively on the estimated coefficients of the regional grouping variable, which distinguishes between the five regional clusters defined in the study, with Attica serving as the reference category because not only encompasses the entire Athens metropolitan area but it is also the largest administrative region in the country.

Table 5 presents the estimated Relative Risk Ratios (RRRs) from a multinomial logit model examining the likelihood that individuals perceive Greece as currently moving in the right, as opposed to the wrong, direction regarding the green transition. The reported RRRs focus on the effect of regional grouping, with Attica serving as the reference category. The RRRs indicate how the probability of reporting that Greece is moving in the right direction changes relative to the reference category (Attica), while controlling for socio-demographic characteristics and perceptions related to the green transition. An RRR greater than 1 implies a higher likelihood relative to Attica, whereas an RRR less than 1 indicates a lower likelihood.

Specifically, the coefficient for the Aegean and Ionian Islands is 0.6731 (p = 0.045), meaning that, compared to individuals in Attica, residents of these islands are significantly less likely to report that Greece is moving in the right direction regarding the green transition. In contrast, Crete shows an RRR of 2.1544 (p < 0.01), indicating a substantially higher likelihood of positive evaluation compared to Attica. Northern Greece (0.7664, p = 0.022) shows a moderately lower likelihood, while Central Greece (1.3323, p = 0.012) exhibits a moderately higher likelihood relative to Attica.

These results highlight significant regional disparities in perceptions of green transition policies. Residents of the Aegean and Ionian Islands appear more skeptical about the effectiveness of these policies, possibly reflecting local challenges such as higher energy costs and logistical constraints. Conversely, the positive evaluation in Crete and Central Greece may reflect either perceived benefits from green investments or stronger local engagement with environmental initiatives. All estimated Relative Risk Ratios (RRRs) for the regional groups are statistically significant, indicating robust differences in perceptions of the green transition across regions.

Table 5: Estimated Relative Risk Ratios (RRRs) of the likelihood that individuals state Greece is currently moving in the right (as opposed to the wrong) direction regarding the green transition

Variable	Estimated RRR	P-value	95% Conf. Interval	
Aegean and Ionian islands	0.6731**	0.045	*0.4573*	*0.9908*
Crete	2.1544***	0.000	*1.4916*	*3.1120*
Northern Greece	0.7664**	0.022	*0.6105*	*0.9623*
Central Greece	1.3323**	0.012	*1.0650*	*1.6668*
Attica	RF			

Notes: a) The reported adjusted Relative Risk Ratios (RRRs) are estimated controlling for all other explanatory variables included in the models, as described in the methodology section.
b) RF denotes reference category.
c) ***, ** and * denote statistical significance at 0.01, 0.05 and 0.1 level respectively.
d) Number of observations: 4,625

The results presented in Table 6 show the estimated Relative Risk Ratios (RRRs) from the multinomial logit model examining perceptions of whether Greece is moving in the right direction regarding the digital transformation. In contrast to the model for the green transition, most estimated RRRs for the regional groups are not statistically significant, with the exception of Crete (RRR = 2.5592, p < 0.01). Specifically, the coefficient for the Aegean and Ionian Islands (RRR = 1.0962, p = 0.665) indicates no significant difference from Attica. This lack of statistically significant regional effects suggests that, unlike the green transition, perceptions of digital transformation policies are more homogeneous across regions.

Table 6: Estimated Relative Risk Ratios (RRRs) of the likelihood that individuals state Greece is currently moving in the right (as opposed to the wrong) direction regarding the green transition

Variable	Estimated RRR	P-value	95% Conf. Interval	
Aegean and Ionian	1.0962	0.665	*0.7231*	*1.6617*

islands				
Crete	2.5592***	0.000	*1.5877*	*4.1252*
Northern Greece	0.9020	0.421	*0.7018*	*1.1595*
Central Greece	1.1717	0.217	*0.9111*	*1.5068*
Attica	RF			

Notes: a) The reported adjusted Relative Risk Ratios (RRRs) are estimated controlling for all other explanatory variables included in the models, as described in the methodology section.
b) RF denotes reference category.
c) ***, ** and * denote statistical significance at 0.01, 0.05 and 0.1 level respectively.
d) Number of observations: 4,609

5. CONCLUTIONS

Drawing on data from the JustReDI field survey, which covered a sample of 5,010 individuals across 13 regions of Greece, the primary aim of the present analysis was to investigate regional divergences—with particular emphasis on comparing the group of island regions with the rest of the country—across dimensions related to individuals' experiences, perceptions, and attitudes regarding: (a) the green transition, and (b) the digital transformation.

For the green transition, the descriptive analysis highlights pronounced regional differences, with particular emphasis on the island regions. Similarly, the island regions show the highest share of respondents who feel personally affected by climate change "extremely" or "a lot", compared to the national average. Special attention was given to the question assessing whether Greece is moving in the right direction regarding green transition policies. Here, only 29.2% of respondents overall report a positive assessment, reflecting a general level of skepticism. Notably, the Aegean and Ionian Islands exhibit an even lower share at 21.7%, suggesting that residents of these regions perceive national green policies as less effective relative to other regions.

For the digital transition, descriptive statistics indicate generally positive perceptions across regions. Overall, 71.2% of respondents report that digitalization of everyday public and private services has made their lives easier, with the island regions of the Aegean and Ionian Islands showing an even higher share compared to Attica. Regarding the evaluation of national policies, 44.8% of respondents believe that Greece is moving in the right direction, with regional shares ranging from 36.7% in Northern Greece to 65.6% in Crete, and 46.2% in the Aegean and Ionian Islands. This generally positive assessment, higher than for the green transition, suggests broader public confidence in digital initiatives, and highlights the particular value of digital services for residents in more remote or geographically constrained areas.

Overall, the descriptive analysis reveals more pronounced regional divergences in the case of the green transition, with the island regions consistently exhibiting lower confidence and greater exposure to energy-related challenges. In contrast, the inter-regional picture for the digital transition appears more balanced, with generally positive perceptions and less marked regional inequalities.

Applying multinomial logit models to identify key determinants of individuals' evaluations of policy effectiveness. The findings confirm that regional differences appear to be more pronounced in perceptions of the green transition, with residents of the Aegean and Ionian Islands expressing significantly lower confidence in national policies compared to Attica, while Crete and Central Greece report more positive assessments. In contrast, perceptions of digital transformation policies are generally more homogeneous across regions, with most regional coefficients not statistically significant, suggesting a broadly shared evaluation of digital initiatives nationwide.

These findings might also be relevant for considerations of EU Cohesion Policy. Addressing disparities in the green transition could strengthen territorial cohesion by ensuring that peripheral and remote regions are not left behind, aligning national and EU-level strategies for inclusive growth. Moreover, persistent regional inequalities in access to green services and benefits may contribute to citizens' dissatisfaction with policy outcomes, potentially fostering political discontent or a sense of exclusion from decision-making processes. Targeted interventions aimed at reducing regional disparities could therefore not only improve the effectiveness of green transition policies but also enhance social trust and mitigate risks of political unrest.

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APPENDIX

Table A1: Estimated Relative Risk Ratios (RRRs) of the likelihood that individuals state Greece is currently moving in the right (as opposed to the wrong) direction regarding the green transition

Variable	Estimated RRRs	Standard Error	P-value
Age	0.993	0.004	0.095
Household size	1.041	0.045	0.347
Female	0.774	0.069	0.004
Marital Status			
Married	RF		
Cohabitation	1.234	0.277	0.348
Divorced	1.344	0.231	0.086
Separated	0.234	0.134	0.011
Widowed	1.435	0.279	0.064
Never married	0.994	0.142	0.966
DK/DA	1.807	1.444	0.459
Educational level			
ISCED-level 0	RF		
ISCED-level 1	0.996	0.492	0.994
ISCED-level 2	1.048	0.517	0.924
ISCED-level 3	0.956	0.461	0.926
ISCED-level 4	1.165	0.578	0.758
ISCED-level 5	0.776	0.378	0.603

ISCED-level 6	1.400	0.719	0.512
DK/DA	2.811	4.645	0.532
Activity status			
Employed	RF		
Unemployed	0.939	0.188	0.753
Inactive	1.070	0.124	0.558
DK/DA	2.401	2.354	0.372
Group of Region			
Aegean and Ionian	0.673	0.133	0.045
Crete	2.154	0.404	0.000
Northern Greece	0.766	0.089	0.022
Central Greece	1.332	0.152	0.012
Attica	RF		
Affected by climate change			
Extremely	RF		
A lot	1.609	0.363	0.035
Fairly	2.397	0.515	0.000
A little	2.884	0.649	0.000
Not at all	5.567	1.452	0.000
DK/DA	4.132	2.061	0.004
Degree of personal responsibility for climate change			
Not at all	RF		
Little	1.359	0.158	0.008
Fairly	1.362	0.194	0.030
A lot	0.825	0.255	0.534
Extremely	0.719	0.379	0.532
DK/DA	2.286	0.957	0.048
Regional benefits from green energy investments			
Extremely	RF		
A lot	2.278	0.961	0.051
Fairly	2.840	1.110	0.008
A little	1.178	0.449	0.667
Not at all	0.351	0.134	0.006
DK/DA	0.999	0.392	0.998
Some see climate change as an urgent global threat			
I’ve always believed that	RF		
Over time, I began to believe that	1.044	0.102	0.663
I’ve never believed that	0.251	0.065	0.000
DK/DA	0.478	0.147	0.016
Worried about climate change affecting your life and family			
Not worried at all	RF		

Slightly worried	2.157	0.678	0.014
Somewhat worried	2.678	0.879	0.003
Quite worried	3.517	1.165	0.000
Extremely worried	4.347	1.553	0.000
DK/DA	0.857	0.559	0.813
Gone without heating or/and cooling to save money	0.575	0.053	0.000
Constant term	0.245	0.192	0.073
Number of observations	4625		

Note: RF denotes reference category.

Table A2: Estimated Relative Risk Ratios (RRRs) of the likelihood that individuals state Greece is currently moving in the right (as opposed to the wrong) direction regarding the digital transition

Variable	Estimated RRRs	Standard Error	P-value
Age	0.997	0.005	0.571
Household size	0.996	0.050	0.942
Female	0.843	0.085	0.091
Marital Status			
Married	RF		
Cohabitation	1.456	0.402	0.174
Divorced	1.612	0.339	0.023
Separated	1.050	0.534	0.924
Widowed	1.321	0.288	0.203
Never married	1.038	0.172	0.824
DK/DA	0.378	0.351	0.294
Educational level			
ISCED-level 0	RF		
ISCED-level 1	1.720	0.903	0.302
ISCED-level 2	1.791	0.948	0.271
ISCED-level 3	1.494	0.777	0.440
ISCED-level 4	1.576	0.856	0.402
ISCED-level 5	1.483	0.787	0.458
ISCED-level 6	1.464	0.827	0.500
DK/DA	n.a		
Activity status			
Employed	RF		
Unemployed	0.890	0.206	0.614
Inactive	1.475	0.200	0.004
DK/DA	n.a.		
Group of Region			
Aegean and Ionian	1.096	0.233	0.665
Crete	2.559	0.623	0.000

Northern Greece	0.902	0.116	0.421
Central Greece	1.172	0.150	0.217
Attica	RF		
Perception of whether digital services make life easier or harder			
Easier	RF		
Harder	0.200	0.041	0.000
No change	0.341	0.066	0.000
DK/DA	0.113	0.066	0.000
Perception of mandatory digital processes in daily essential tasks			
Made it easier to complete tasks faster	RF		
Made it harder, so tasks are more difficult	0.577	0.106	0.003
Completely prevented completion	0.353	0.091	0.000
DK/DA	1.090	0.521	0.857
Lack of essential digital skills for public services			
Yes	RF		
No	0.680	0.102	0.010
DK/DA	0.881	0.557	0.841
Technical problems encountered with public digital services			
Yes	RF		
No	1.791	0.192	0.000
DK/DA	1.380	0.304	0.144
Perceived impact of artificial intelligence on humanity			
I haven’t heard of it	RF		
It is bad for humanity	0.483	0.111	0.002
It is good for humanity	2.128	0.524	0.002
DK/DA	1.505	0.377	0.103
Constant term	3.138	2.213	0.105
Number of observations	4609		

Note: RF denotes reference category.

JUST AND FAIR TRANSITIONS IN ISOLATED AREAS: ADDRESSING THE SOCIO-ECONOMIC IMPACTS OF RAPID DECARBONIZATION

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ABSTRACT

The global imperative to decarbonize energy systems has accelerated policies aimed at phasing out fossil fuels. These policies significantly affect regions historically reliant on coal and lignite for economic production and employment, as well as on communities that, until recently, depended almost entirely on fossil fuels to meet energy needs and sustain economic activity. While such measures are vital for addressing climate change, they tend to disproportionately impact peripheral, rural, and island communities that are structurally anchored in carbon-intensive economies. These regions often have limited influence in policymaking processes and face a range of complex challenges during rapid decarbonization, including rising energy poverty, declining business activity, job losses, and brain drain. Many rural and insular areas also lack the infrastructure and adaptive capacity required to navigate the profound economic and social shifts that decarbonization entails. The shift from lignite and oil-dependent economies has resulted in the structural marginalization of these populations. This study examines regional differences in energy consumption patterns, energy mix, population trends, employment levels, Gross Domestic Product (GDP), and Gross Value Added (GVA). West Macedonia, which accounts for 2% of Greece’s GVA and has a GDP of approximately €4 billion, continues to struggle with a persistently high unemployment rate of nearly 20%. In this region, a clear link has emerged between the decline in domestic coal energy production and a reduction in its contribution to national GDP. Similarly, the region of Arcadia, centred around the lignite-based economy of Megalopolis, has a population of about 75,000 and a regional GDP of roughly €1.2 billion. Megalopolis, too, is experiencing the rapid impacts of delignitization. Beyond the mainland, Greece's islands (excluding Crete) are home to approximately 750,000 residents, about 7% of the national population, yet they contribute nearly 6% of the country's GVA. Nevertheless, the Non-Interconnected Islands (NIIs) continue to endure exceptionally high energy costs, with up to 80% of electricity still derived from imported fossil fuels. These islands, especially the NIIs, are on the cusp of an accelerated implementation of delignitization policies. This study highlights the critical intersections of demographic change, unemployment, GDP and GVA shifts, energy demand growth, energy intensity, and energy mix. It underscores that without inclusive, strategically informed, and data-driven planning, a fast-paced decarbonization process risks deepening socio-economic vulnerability and regional inequalities. The paper examines how data processing could contribute to the design of a local transition plan, aiming for a fair approach to the energy transition. An approach that combines climate change mitigation with inclusive economic restructuring, social resilience, and sustainable regional development tailored to the distinct geographical areas of Greece.

Keywords: Energy Demand, Energy Mix, Energy Intensity, Just Transition, Isolated Areas

1. THE IMPERATIVE TO DECARBONIZE ENERGY SYSTEMS AND THE ELECRTICITY SUPPLY

The climate crisis is quickly becoming a critical concern for humanity, threatening the stability of the planet's ecology. A pivotal transition from conventional carbon-based energy sources is essential to tackle the urgent challenges of human-induced global warming and the impending exhaustion of natural resources. European economies have mostly relied on fossil fuels to meet their energy needs. Moreover, nine EU member states are extracting coal, including lignite, to fulfil their electricity supply. The European coal sector supports local economies by creating jobs, increasing local GDP, and improving the living standards of communities. Furthermore, it contributes to energy security as an essential source of dependable, local energy. In contrast, human-induced global warming and fuel shortages present an increasing danger to the sustainability of contemporary electricity supply, requiring a significant transition from a conventional, centralised fossil fuel-based generation system to a decentralised system that depends on renewable energy sources. In alignment with the European energy plan, this requirement is becoming increasingly urgent for remote, isolated, and fossil fuel-dependent regions (Kaldellis, J. K., and Ktenidis, P., 2024). In light of the climate-neutral policies implemented all around Europe, this paper examines the initial outcomes of the ongoing fast energy transition in West Macedonia (W.M.), the Peloponnese, and the forthcoming decarbonization in the Aegean Islands.

2. EU POLICIES FOR “DE-CLONG” (COAL, LIGNITE, OIL, AND NATURAL GAS)

As described in the European Green Deal (EGD), the European Union (EU) aims to be the first climate-neutral continent by 2050. To reach this ambitious goal, the decarbonization of the energy sector is crucial. The production and energy use are assumed to be responsible for more than 75% of the EU’s greenhouse gas emissions, since the EU energy system relies on fossil fuels. Therefore, the successful implementation of the EGD depends on the phase-out of unrestricted burning of coal, natural gas, and oil (Boulogiorgou D and Kaldellis JK)

Decarbonization signifies the reduction of carbon dioxide (CO_2) emissions originating from anthropogenic activities, particularly those associated with the combustion of fossil fuels, including coal, oil, and natural gas. The objective is to shift energy systems, industries, and many economic sectors towards low-carbon or, when feasible, carbon-free alternatives to alleviate climate change. Decarbonization can be accomplished through several ways, such as enhancing energy efficiency, utilizing renewable energy sources (including wind, solar, and hydroelectric power), implementing carbon capture and storage technology, and advocating for sustainable practices and laws (European Commission, 2025).

The EU’s transition for coal regions began with the 2015 Paris Agreement[15], committing to climate neutrality. In 2017, the Initiative for Coal Regions in Transition[16] was launched, providing targeted support. The 2019 European Green Deal[17] further prioritized a just transition. In 2020, the Just Transition Mechanism[18] and Platform[19] introduced key funds and support schemes, including the Just Transition Fund[20], Invest EU[21], and a public sector loan facility. The 2021–2027 EU budget[22] operationalized these tools. Between 2022 and 2023, Member States’ Territorial Just Transition Plans[23] were approved, enabling tailored funding and support for coal-dependent regions to drive sustainable transformation (see Figure 1).

[15] https://www.consilium.europa.eu/en/policies/paris-agreement-climate/
[16] https://energy.ec.europa.eu/topics/clean-energy-transition/eu-coal-regions-transition_en
[17] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[18] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en
[19] https://ec.europa.eu/regional_policy/funding/just-transition-fund/just-transition-platform/about_en
[20] https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/just-transition-fund_en
[21] https://investeu.europa.eu/index_en
[22] https://commission.europa.eu/strategy-and-policy/eu-budget/long-term-eu-budget/2021-2027_en
[23] https://ec.europa.eu/regional_policy/information-sources/publications/communications/2021/the-territorial-just-transition-plans_en

Figure 1: Key EU Timeline and Support Frameworks for Coal Regions in Transition

The European Union's "Just Transition" mechanism aims to support regions heavily dependent on coal and other fossil fuels in transitioning to a sustainable economy. While there isn't a single, fixed timetable for all coal regions in transition across the EU, the EU has outlined targets and frameworks guiding the phase-out and transition efforts (see Table 1).

Table 1: Key EU Timeline and Support Frameworks for Coal Regions in Transition

EU Climate Targets 2030	Coal Phase-Out Targets	EU Just Transition Fund (JTF)	Regional Timetables and Commitments
- EU's commitment to cut greenhouse gas emissions by at least 55% compared to 1990 levels. - Achieve zero net emissions by 2050 (European Green Deal).	Several EU member states have set individual coal phase-out deadlines, often aligned with Brussels' broader goals: - **Greece:** Close all coal-fired power plants by 2028 - **Germany:** Close all coal-fired power plants by 2038 (with a transition period and support). -**Poland:** Some provinces plan to phase out coal by 2049, though discussions and policies are evolving.	- 2021-2027 programming period: - €19.32 billion allocated for supporting coal-dependent regions. - Focused on restructuring economies, creating jobs, and supporting impacted workers. - Distribution of funds is region-specific, with detailed timetables negotiated regionally.	- **Greece:** Already withdrawn 60% of lignite power stations (3000 MW of 5000 MW) - **Germany:** Closure of lignite mines and plants by 2038, with some regions aiming for earlier closures (e.g., Lusatia by 2030). - **Poland:** Claims developing countries' status and will maintain the 2049 hard coal phase-out date

The Greek National Energy and Climate Plan (NECP) attempts to incorporate European energy policy and the Sustainable Development Goals (SDG) of the United Nations. In this context, the Greek State utilizes the NECP as a key tool for shaping the national energy and climate policy for the next decade.

One of the most noteworthy features of the updated (final submitted at the end of 2024) 3rd NECP version is the target to decrease the national GHG emissions by 58.6% from 1990 levels (p. 92 NECP), in contrast to the initial (2019) prediction of a 40% reduction. To achieve this ambitious objective, the primary focus is on increasing RES participation (from 22% in 2021 to 45.4% by 2030) in gross final energy consumption, while also targeting 76.8% RES participation in the national electricity mix by 2030. Additionally, it is predicted that the total national energy consumption will be the same between 2021 and 2030 (Kaldellis, J. K., and Ktenidis, P., 2024).

3. THE COMPLEXITY OF THE "DE CLONG" POLICIES IMPLEMENTATION AT THE LOCAL LEVEL

Coal phase-out policies, particularly in lignite (brown coal) regions, pose several challenges and negative effects that need careful management. Lignite areas are often economically and socially dependent on coal mining and coal-fired power plants, making the transition complex (Table 2).

Table 2: Challenges and Negative Effects for lignite areas

1. Economic Impact	**2. Social Challenges**
One of the primary challenges is significant job losses in coal mining, power generation, and supporting industries. The immediate reduction in employment can lead to unemployment spikes and economic decline in local communities. This economic disruption can also reduce local tax revenues, affecting public services like schools and healthcare.	Communities in lignite regions often have a strong cultural identity tied to coal. Transition policies risk creating social unrest or resistance if local populations perceive the shift as a threat to their livelihood and regional identity. Reskilling and economic diversification initiatives are critical but may take time to implement successfully.
3. Infrastructure and Investment Needs	**4. Environmental Risks**
Decarbonization requires substantial investments in renewable energy, grid modernization, and infrastructure development. These infrastructural shifts can be costly and technically challenging, especially in regions with outdated or limited infrastructure.	While the goal is to reduce greenhouse gases, decommissioning coal plants and mining operations can produce environmental hazards such as contaminated land and water. Without proper remediation, these can cause long-term environmental damage.
5. Transition Management and Policy Risks	
Policy implementation may face delays, funding shortages, or political resistance. Poorly managed transitions can exacerbate regional inequalities, creating "left-behind" communities with limited economic prospects.	

Effective transition policies should include comprehensive support, stakeholder engagement, and long-term planning to mitigate these challenges and ensure a just, sustainable transition.

4. REGIONAL DATA

4.1. West Macedonia

Considering that the lignite-based TPS (installed capacity of 5 GW_e) in West Macedonia (W.M.) provided 60% of Greece's electrical power until recently, the phase-out of coal in less than a decade is a strategic decision. However, this decision has caused significant disruptions to the labor market and the coal value chain, especially in areas that rely heavily on coal exploitation (Kaldellis, J.K.;Boulogiorgou, D.; Kondili, E.M.;Triantafyllou, A.G., 2023).

With a population of around 270,000 people, the prefecture of W.M. is one of the EU's less developed areas, spanning an area of 9,541 km². During the decade from 2010 to 2019, the per capita GDP of the Region of W.M. declined by 20%, reaching only 45% of the EU average. According to the Hellenic Statistical Authority, the 2021 GDP is even lower, reaching €14,100 per capita. Moreover, a significant portion (24.5%) of W.M. residents are elderly, having reached the age of 65. The weighted average unemployment rate for the third quarter of 2023 reached 19.5%. In the energy-related mining sector of the W.M. (an activity developed until now by the once State-controlled Public Power Corporation

(PPC)- now a totally private company), it supports the employment of approximately 5000 people. In relation to the changes in unemployment associated with the delignitization for the base year 2019, it is projected that around 12,000 workers in total will be impacted (both directly and indirectly) across the region, with the majority (about 11,000) residing in the Kozani & Florina Regional Units and the remaining individuals located in the Kastoria & Grevena Regional Units. Furthermore, the majority of W.M.'s employment is closely linked, directly or indirectly, to the exploitation of its natural resources, including land and mining.

4.2. Megalopolis

Similarly, the region of Arcadia, centered around the lignite-based economy of Megalopolis, has a population of about 75,000 and a regional GDP of roughly €1.2 billion. Megalopolis, too, is experiencing the rapid impacts of delignitization. In the Megalopolis region, 13% of the country's installed electricity generation capacity was located. Today, only one unit remains in the area, Megalopolis 4, with a capacity of 300 MW. It is estimated that the lignite phase-out will primarily affect the Municipality of Megalopolis (population 9,500). The impact that the lignite phase-out is expected to have on the economy and business activity of the Municipality of Megalopolis, as well as the wider area, is evident from the level of investments made to date, which have contributed significantly to the region's economic development. The evolution of the energy transition in the wider Peloponnese region is not recorded at the same rate of population and GDP decline as in the W.M. region. This is because both the installation of new Natural Gas power plants and the composition of the local economy (of which the Megalopolis region is a small subset) contributed to meeting the living needs of the local population.

4.3. Greek Islands

As with the regions of West Macedonia and the Peloponnese, all the islands—and especially the Non-Interconnected Islands—face a series of challenges arising from the EU's climate goals, which intensify the urgency of the energy transition and the need to promote it. Directive (EU) 2015/2193 makes it practically impossible for the units of the Electric Systems (ES) of the smaller islands to operate for more than 500 hours per year. The transition to clean energy sources by 2030 is the only viable path, especially for those Non-Interconnected Islands that will delay or will not be interconnected. Investments in renewable energy sources (RES) in these areas are costly and involve higher initial investment costs due to their small scale.

Table 3: Challenges and Negative Effects for Islands

High Initial Investment and Financial Barriers	Many islands face financial constraints and limitations on large-scale development
Technical and Infrastructure Challenges	Integrating intermittent renewables requires advanced grid management and storage solutions, which are still developing. Some islands lack sufficient grid capacity, leading to stability issues.
Social and Cultural Impacts	Transition may impact traditional industries like shipping. Local communities might resist change due to concerns over land use, aesthetics, or economic disruptions.
Limited Scale and Fragmented Policies	Small-scale projects may have limited overall impact if not scaled up. Lack of cohesive policies across islands can lead to uneven development and missed opportunities.

5. INDEXES EXAMINED

Data exploitation of the current energy transition has great importance. Transition is currently underway, and it is crucial to monitor the design and implementation of decarbonization policies. Regional differences in energy consumption patterns, energy mix, population trends, employment levels, Gross Domestic Product (GDP), and Gross Value Added (GVA) are the main indices interconnecting decarbonization policies, management, and social aspects. Although it is acknowledged that data plays a crucial role in evaluating the energy transition process and calibrating targeting and implementation procedures, the availability of official regional data on energy and environment is a time-consuming and often incomplete process.

5.1. Gross electricity production, Fuel Oil / Lignite, Greece, and islanded / delignitization regions' GDP per capita

Empirical analysis of data from 2000 to 2021 reveals a statistically significant Granger causality from A to B for the time series of Northern and South Aegean Islands, as obtained from Eurostat. These series were checked for stationarity and cointegration and transformed accordingly (Figure 2 & Table 3).

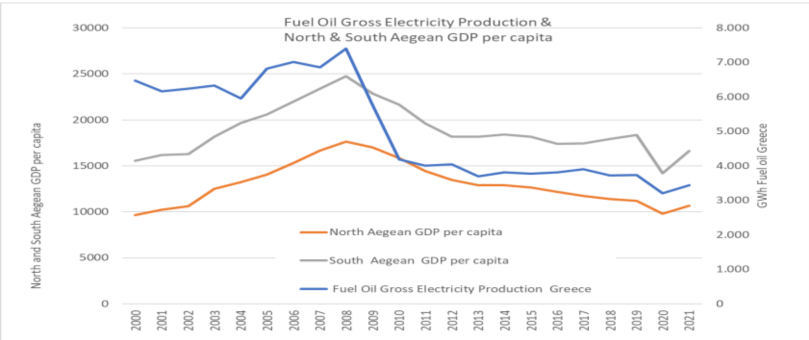

Figure 2: Fuel Oil Gross Electricity Production / North & South Aegean GDP per capita

Table 4: North & South Aegean Statistics

North Aegean Statistics				South Aegean Statistics			
B Granger Causes A	Lag	F-Statistic	P-value	B Granger Causes A	Lag	F-Statistic	P-value
	1	2.8323	0.1096		1	2.4967	0.1325
	2	1.5898	0.2365		2	3.8036	0.0509
	3	1.3658	0.3002		3	2.2991	0.134
A Granger Causes B	Lag	F-Statistic	P-value	A Granger Causes B	Lag	F-Statistic	P-value
	1	18.6029	**0.0004**		1	6.612	**0.0192**
	2	2.4796	0.1174		2	3.7091	0.0491
	3	2.3214	0.1269		3	3.5025	0.0495

Although unemployment and brain drain have risen in W.M. and Megalopolis, we didn't find a similar statistical correlation between energy production from lignite and GDP per capita in these areas (Figure 3). It is a very interesting finding and a notice of the holistic way we have to study the current energy transition. The lessons learnt from the coal phase-out areas of W.M. and Peloponnisos can be a valuable asset for the upcoming fuel oil phase-out of NIIs.

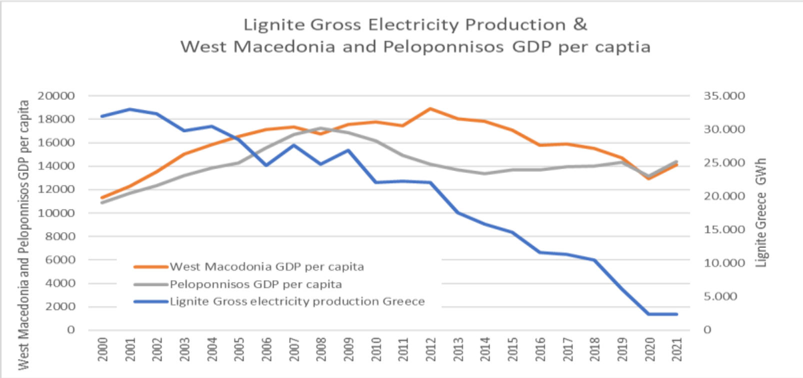

Figure 3: Lignite Gross Electricity Production / West Macedonia & Peloponnisos GDP per capita

5.2. Renewable Energy Adoption and Electricity Energy mix

Although Member States, and in our case, Greece, have partially achieved some goals of the Decarbonization policy (Figures 4 & 5), in other goals, the results are very burdensome for local economies and national energy safety (Figure 6)

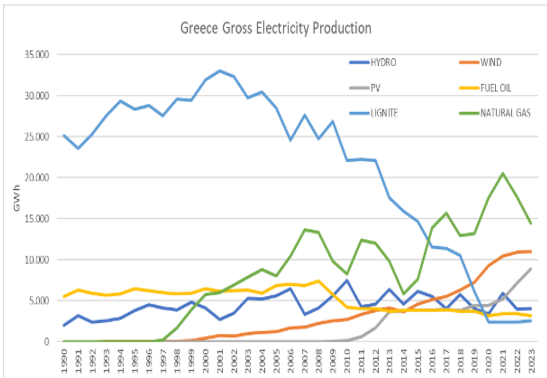

Figure 4: Gross Electricity Production evolution per source in Greece

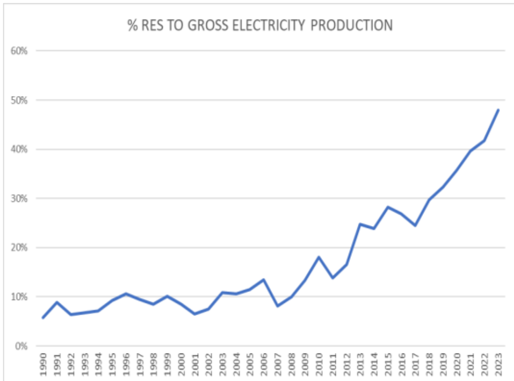

Figure 5: %RES Gross Electricity Production evolution in Greece

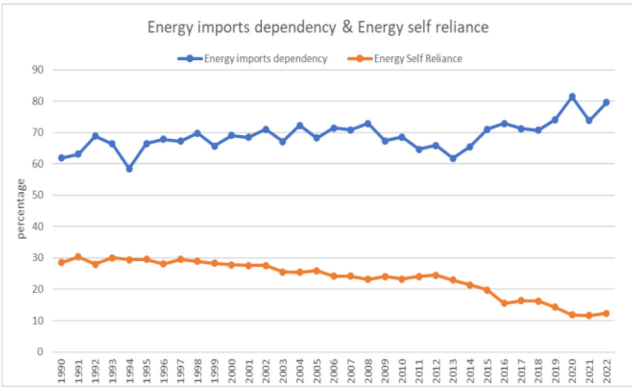

Figure 6: Energy imports dependency and energy self-reliance of Greece

Member States should align European policies with national needs and regional specificities. A very characteristic example is that of GHG emissions. Do we care whether the emissions come from lignite, oil, or natural gas? Of course, we do; it is about energy economics, energy efficiency, energy affordability, and energy security, as we already saw in the local impacts of decarbonization policy implementation (Figure 7).

Emissions from power generation per power plant type			
Period	***fossil gas***	***lignite plants***	***Oil-fired plants***
01-04/2025	52%	31%	17%

GW Installed	2025	2050
Lignite	1.985	-
Natural gas	6.030	6.300
Oil	992	60

Figure 7: Where the emissions come from and how we design De-CLONG

5.3. Carbon Emissions Reduction Index, Energy Intensity of GDP, and Final Energy Consumption

We face the same issue with the reduction of carbon emissions (Figure 8) and collateral effects in the energy intensity of GDP. Although there is a drop after 2013, as a country, we are above the EU median energy intensity of GDP (Figure 9). The same picture is for the final energy consumption (Figure 10). Although there is a total decline in final energy consumption, it is obvious that the same patterns are followed by the sectors we study. Only in the agricultural sector, after 2012, do we observe a significant reduction in the final energy consumption from the sectors we study. Is the reduction attributed to energy efficiency actions, the installation of PV to meet their energy needs, or the decline of the agricultural sector?

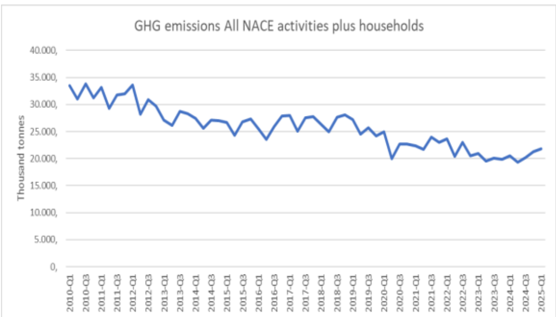

Figure 8: GHG emissions evolution in Greece

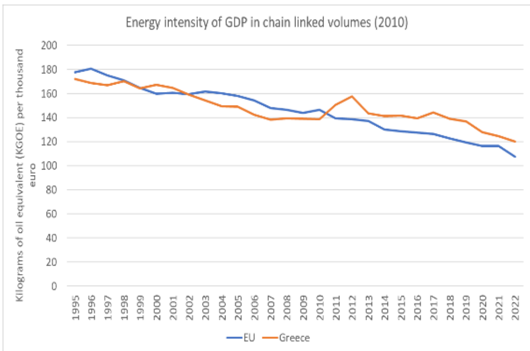

Figure 9: Energy intensity of GDP

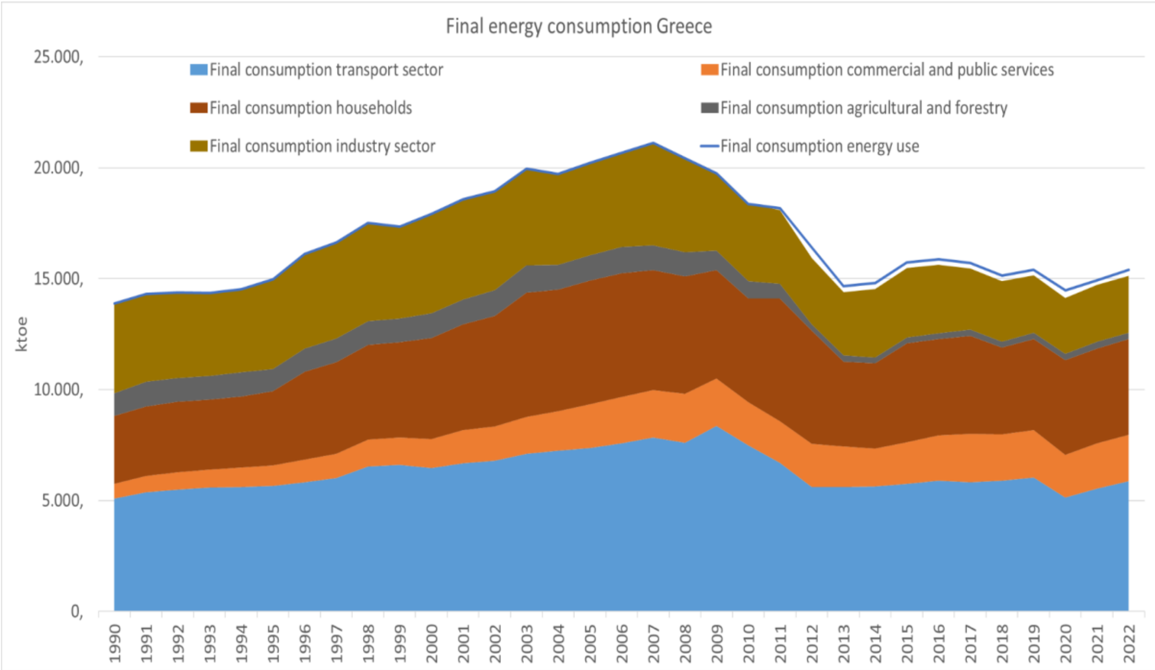

Figure 10: Final energy consumption in Greece

5.4. Socioeconomic and Social Equity Index

For the socioeconomic aspect, we observe the differences in every study region (Table 4) for population, people at risk of poverty, GDP per inhabitant as a percentage of the EU average, unemployment rate, and young people neither in employment nor in education and training (NEET). In Figure 11, we observe the rising long-term unemployment issue in W.M. and the connection we observe with the reduction in energy production by lignite. The imperative of reskilling and upskilling in those areas emerges. Also, we observe in Figure 12 the rising percentage of persons at risk of poverty or social exclusion for W.M. and the North Aegean regions.

Table 5: Regional Indexes

	Population (1 January) (number)	People at risk of poverty or social exclusion (percentage of population)	GDP per inhabitant (percentage of EU average in PPS)	Unemployment rate (percentage of labor force aged 15-74)	NEET (percentage of people aged 15–29)
Peloponnisos [EL65]	531 598 (2024)	32.3% (2024)	59% (2023)	7.6% (2024)	13.0% (2024)
Dytiki Makedonia [EL53]	247 270 (2024)	36.3% (2024)	55% (2023)	12.5% (2024)	13.0% (2024)
Notio Aigaio [EL42]	327 246 (2024)	20.3% (2024)	70% (2023)	9.9% (2024)	20.0% (2024)
Voreio Aigaio [EL41]	201 007 (2024)	33.2% (2024)	42% (2023)	7.1% (2024)	19.4% (2024)

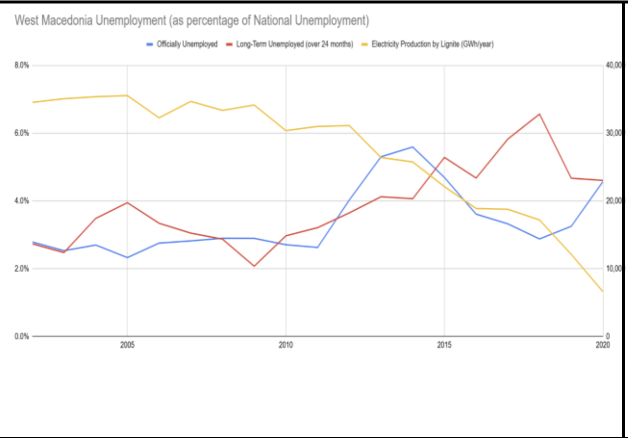

Figure 11: West Macedonia Unemployment

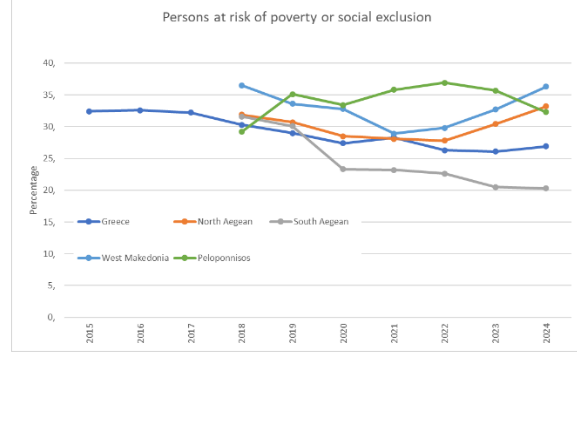

Figure 12: Persons at risk of poverty or social exclusion

In Figure 13, we can see the evolution of population, GDP per capita, and electricity production of the W.M. region. And in Table 5, we observe the GVA by sector for the study regions. In W.M. and Peloponnisos, it is clear that the lignite sector plays a crucial role in the local economies, particularly in the South Aegean, and in the public sector of the North Aegean.

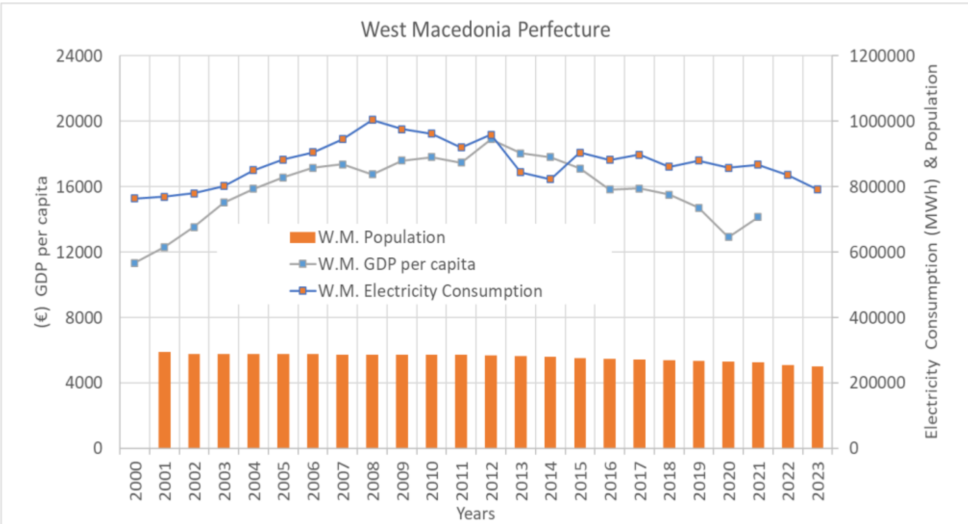

Figure 13: West Macedonia Prefecture

Table 6: Gross value added by sector (in % of total GVA by region, for the year 2021) ELSTAT data processing

	Agriculture, forestry, and fishing	Energy, mining, water supply	Commerce, hotels, catering, transportation communications	Financial and insurance activities	Public administration and defense, etc	Real estate management	Other services
North Aegean	4,2%	8,7%	23,5%	4,0%	**34,6%**	15,1%	9,9%
South Aegean	2,3%	7,9%	**48,8%**	2,6%	15,1%	12,6%	10,7%
West Macedonia	10,5%	**36,5%**	12,7%	2,5%	20,9%	9,2%	7,7%

Peloponnisos	9,4%	**27,8%**	19,4%	2,3%	17,3%	14,7%	9,0%

6. RESULTS / DISCUSSION

An approach that combines climate change mitigation with inclusive economic restructuring, social resilience, and sustainable regional development tailored to the distinct geographical areas of Greece is very important. The data repository for every region, free access to data, and the holistic approach to data statistical process are also of big importance. We must observe the evolution of policy implementation and its results in local economies to achieve the decarbonization policy objectives.

7. CONCLUSIONS

The energy transition policy, along with the additional environmental pressure to accelerate the transition, has a significant impact on local communities involved in the decarbonization process. To this end, the W.M. and Megalopolis residents experience the transition outcomes in their everyday lives. More specifically, coal-industry-dependent communities face rising energy prices, delays in reclaiming coal-related land for societal use, loss of income, and the brain drain of their young scientists. In the current energy transition, knowledge transfer is also a very important issue. It is very important for the citizens to understand how local affairs strongly affect their lives. The local community's ability to understand its central role in the current energy transition is a fundamental issue of the energy sector liberalization and democratization. Local societies should have access to relevant information and the skills to decide about their participation in the energy transition of their region. In this context, the State authorities must ensure justice and fairness towards local communities' participation in the W.M. and Megalopolis energy transition. Furthermore, the results of energy policy implementation should be evaluated on a regular basis by local communities. The current research demonstrates the significant impact of rapid decarbonization on the quality of life of W.M. and Megalopolis citizens, and also investigates the fuel oil phase-out of NII.

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REENERGY-MED PROJECT: DEMONSTRATION CASES TO SUPPORT RENEWABLE ENERGY TRANSITION IN EASTERN AND SOUTHERN MEDITERRANEAN

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ABSTRACT

Almost 80% of the global energy demand is covered by fossil fuel combustion, contributing vastly to the greenhouse gas emissions and global warming. The deployment and use of renewable technologies is more than necessary, especially in the countries around the Mediterranean Sea, which is a prominent climate change hotspot that warms faster than the global average rates. The energy demand over the area in the warm season is expected to increase and tensions on energy security, energy costs and environmental damages could be reduced by deploying sustainable solar energy as primary renewable source. ReEnergy-MED is a project supported by the Copernicus Joint Services and in the frame of the specific project climate services for the solar energy sector, specially tailored for three demonstration cases, will be developed. The selected demonstration cases - (i) three regions in Morocco, (ii) three Greek islands with different climatic conditions and touristic growth and (iii) Evros region in Northern Greece - will contribute to understanding the needs of the solar energy sector and to identify the potential of adding value to the decision making. An energy prediction system focused on seasonal and long-term time scales based on Copernicus C3S and CAMS data will be developed. Temperature, radiation, and aerosol data will be downscaled for the selected demonstration cases and energy production simulations under different scenarios will be conducted. Additionally, the energy needs of the selected islands will be estimated. Key messages of the C3S/CAMS products will be communicated to a wide range of potential users, regional and national energy policies, academic community and industrial researchers to facilitate capacity building and drive sustainability and innovation in the solar energy sector.

This project has received funding from the European Center for Medium Range Weather Forecasts under framework agreement ECMWF/COPERNICUS/2024/CJS_155b_NOA-A for the provision of demonstration cases to support renewable energy transition across the Mediterranean.

Keywords: solar energy sector, Copernicus data, Eastern and Southern Mediterranean

1. INTRODUCTION

The potential for energy production from PV or CSP depends primarily on the levels of solar radiation that reaches the Earth surface. Surface solar radiation levels are primarily influenced by cloudiness, and under clear skies, they are mainly affected by aerosols.

For this project two demonstration cases have been selected to contribute to understanding the needs of the renewable energy sector and to identify the potential of adding value to the decision making of the sector: two companies, representing the Eastern (Greece) and Southern (Morocco) Mediterranean regions.

During the warmer half of the year, Greece and Morocco experience dry conditions with predominantly cloud-free skies. Thus, aerosols, especially dust, play a key role for the formulation of surface solar radiation (SSR) levels. Wide regions in Morocco experience dry conditions and cloud-free skies during most of the year, as well as many regions of Greece. Under such conditions the production of energy from PV installations can contribute greatly to the energy mixture. At the end of 2022, renewable energy accounted for 38% of Morocco's electrical capacity mix (https://www.trade.gov/country-commercial-guides/morocco-energy), while 57% of the energy mix in Greece (https://www.admie.gr/en/kentro-typoy/press-releases/2023-record-year-clean-energy-greece) was covered by photovoltaics, wind, and hydroelectric power.

According to the African Union Commissioner for Infrastructure and Energy, Morocco is positioned as the African leader in RE and as an increasingly important player on the world stage [1]. Since the adoption of the Moroccan Energy Strategy (MES) in 2009, the installed electrical power capacity has grown at a global growth rate of 74.2%, increasing from 6.34 GW in 2010 to 11.05 GW in 2022 [2]. This growth is partly attributable to the share of Renewable Energy (RE), accounting for 37.6% of the total installed capacity in 2022, which is equivalent to 4154 MW (including wind, solar, hydro, and pumped hydro storage technologies) (ANRE, 2022). By 2030, Morocco aims to raise the share of RE to 52% of the installed capacity, with a reduction in greenhouse gas emissions by 18% [3]. Compared to other energy sources, solar photovoltaic (PV) systems are more cost-effective, and their infrastructure can be deployed rapidly

Thus, after the severe earthquake that struck near the town of Oukaïmedene in western Morocco on September 8, 2023 (https://www.britannica.com/event/Morocco-earthquake-of-2023), PVs and portable power stations were installed in a very short time close to earthquake affected areas and kept essential services running (hospital operation, communications, lighting, storage of food and medicine).

The European Green Deal provides directives to Member States for the clean energy transition, which will help reduce the net greenhouse gas emissions to meet the 'Fit for 55' package by 2030, towards a climate-neutral EU by 2050. The Greek National Energy and Climate Plan (NECP), drafted by the Ministry of Environment and Energy (MEEN), raises the country's targets for renewable energy sources (RES) to 28 GW by 2030 aiming to achieve 80% penetration of renewables in the country's energy mix by 2030. NECP projects that photovoltaic (PV) power will become the main source of RES in Greece. Towards the goal for net zero emissions until 2050, Greece has launched the GR-eco islands initiative (https://www.greeknewsagenda.gr/gr-eco-islands-smart-and-sustainable-greek-islands), with the aim to transform the Greek islands into innovation hubs and models of green economy, energy autonomy, digital innovation and ecological mobility. PV installations with integrated storage units can be key for the energy autonomy of the islands, either as stand-alone solutions, or as part of hybrid systems (e.g., the PV installations will be supplemented by wind turbines) (e.g. https://eunice-group.com/projects/tilos-project/; https://www.terna-energy.com/restories-en/ai-stratis-the-first-energy-independent-island-of-greece/; https://nesoi.eu/content/enersik-ikaria-island-greece). Additionally, Northern Greece and Evros has been identified as an energy hub with remarkable solar potential and thus it is of great importance for the energy balance of the country.

The large-scale integration and development of solar energy in Morocco and Greece face a number of challenges. Massive deployment of intermittent RE sources into the electricity grid requires investment in power-system flexibility, including energy storage, grid management, and eventually cross-sector coupling through the development of power-to-X in order to mitigate the effects of uncertainty in supply (intermittence) and demand (absence of demand-side management). Furthermore, the fast-changing climatic conditions at the Mediterranean Basin would impact the amount and timing of clouds, as well as the atmospheric conditions that determine the production and the transfer of aerosols at the two countries [4]. Thus, the average levels, as well as the spatial and temporal patterns of surface solar radiation are projected to change in the future, creating the need for long-term forecasts for the planning for investments in PV and CSP on a national level, as well as locally. The commitment of the two countries for decarbonization of the electricity sector increases the dependence of electricity production on weather extremes and climate variability/change and poses serious challenges in managing the variability and assessing risks of electricity generation in the national power system. The need for high-quality forecasts and high resolution long-term predictions for managing risk across all timescales has never been greater.

2.METHODOLOGY

2.1 Demonstration Cases

The demonstration cases will enhance understanding of the renewable energy sector's needs and identify opportunities to add value to its decision-making processes. In this project, two companies, representing the Eastern (Greece) and Southern (Morocco) Mediterranean regions, have been selected for this reason. The Hellenic Electricity Distribution Network Operator S.A (HEDNO) will also participate as a potential user and highly interested in the outcomes of the project at the three below mentioned Greek islands.

2.1.1 Demonstration case 1a: Evros, Northern Greece

The first demonstration case is a PV station in the Regional Unit of Evros, Northern Greece (Fig. 1) run by Zephiros. The importance of Evros to Europe and the Eastern Mediterranean's energy security has been widely identified and the interest in investing in solar power is steadily increasing in the region. Open-access environmental data from the European Union's Copernicus program, combined with the energy predictions generated, may significantly optimize the operation of existing photovoltaic stations.

2.1.2 Demonstration case 1b: Greek islands

About 6,000 islands and islets are scattered across the Greek Seas, of which 227 are inhabited. In recent years, many of the largest Greek islands have been connected to the national electricity grid. Nevertheless, Greek islands have the potential to become autonomous using renewable energy. Many Greek islands are attracting significant investments in renewable energy (mainly solar, wind, and geothermal) aiming to achieve autonomy and feed the surplus energy into the national grid. Despite the long sunlight hours, the amount of energy produced from PVs can vary greatly depending on the season. In many Greek islands the energy demand peaks in summer due to the large number of visitors. In the coming decades, increasing temperatures would result in increased energy demand, while the tourist season is expected to extend towards cooler months. Additionally, changes in the annual patterns of aerosols and cloudiness would also alter the seasonal patterns of energy production from PVs. For the demonstration case 1b, we have chosen three Greek islands where energy production from PVs is important (Fig. 2).

2.1.3 Demonstration case 2: Solar generators in areas with seismic activity in Morocco

Morocco has become a global model for utility-led electrification, achieving a remarkable increase in rural electrification rates from 18% in 1990 to nearly 100% today. However, in 2023, a magnitude-6.8 earthquake devastated parts of the country, particularly the Al Haouz region. The disaster claimed over 2,900 lives, injured thousands, and caused catastrophic damage to remote mountain villages. This disastrous incident raised new concerns about ensuring consistent electricity access in similar areas. In response to this tragedy, Morocco represented by Masen and The Republic of Korea have partnered to develop a solar-powered mini-grid electrification project in the affected areas. Valued at 15 million dirhams, the initiative aims to provide green electricity to nearly 3,000 people using solar energy and battery storage. This project will ensure a reliable power supply while supporting Morocco's broader electrification goals and helping communities rebuild.

This underscores the critical need for seasonal and long-term solar forecasts to support the electrification of these regions. The downscaled projections for the locations in Morocco will be used to identify the evolution of the potential for energy production per unit of installed PV capacity. By analyzing solar irradiation patterns, such forecasts help system operators identify the best locations for solar PV installations, in order to maximize and optimize the energy production in the affected areas. When traditional power infrastructure is compromised, long-term forecasts can guide the strategic placement of solar plants, ensuring rapid restoration of electricity and building resilience into the energy system. In addition, advanced weather forecasting tools allow operators to plan solar investments more effectively, reducing maintenance costs and ensuring a stable energy supply to support reconstruction efforts. Regions like Taza, Ouarzazate, and Laayoune (Fig. 3) present ideal demonstration sites for the project.

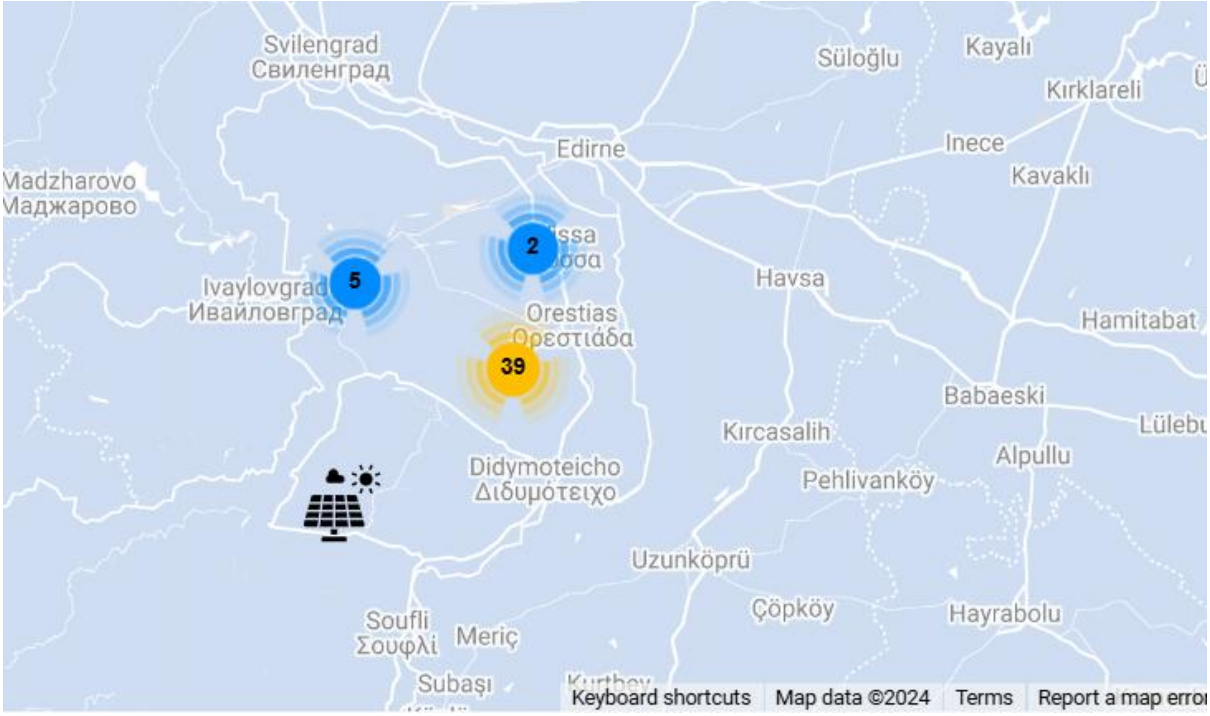

Figure 1: PV stations in Evros, Northern Greece

Figure 2. The three Greek islands of case study No. 1b

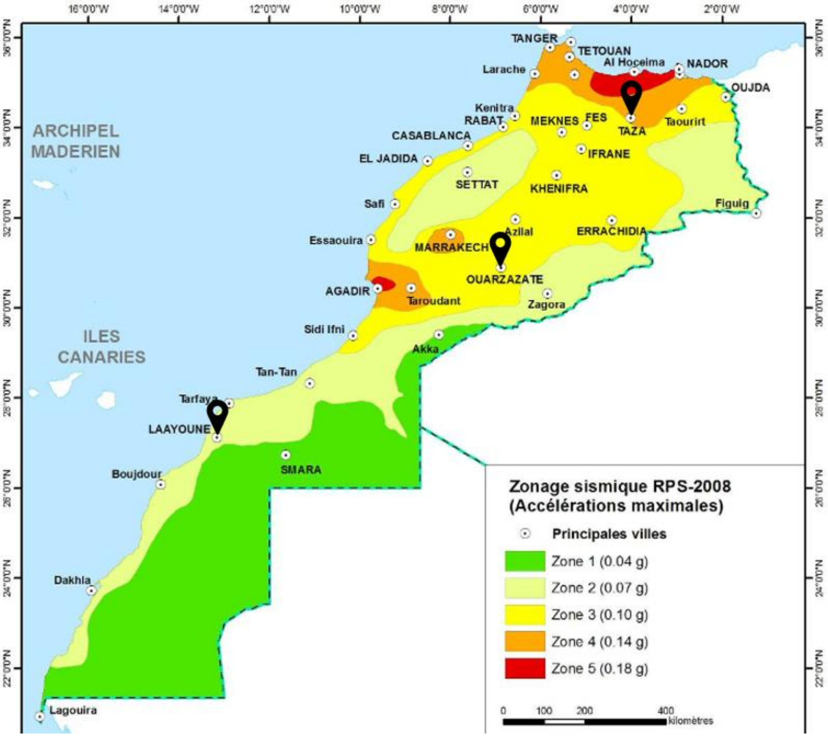

Figure 3. The demonstration sites in Morocco

2.2 Data Retrieval

The ReEnergy-MED project aims to utilize C3S and CAMS products to generate energy-related information. Climate projections and seasonal forecasts related to the solar energy production (operation of PV and/or CSP installations), will be retrieved from the C3S Climate Data Store (CDS) in order to provide climate predictions for the corresponding time horizons (i.e., seasonal and long term). State-of-the-art Global Climate Models (GCMs) developed within the CMIP6 projects at a horizontal resolution of ~100km, available in CDS will be utilized in order to provide future climate change projections of surface downwelling shortwave radiation, cloud cover, aerosol optical properties, as well as air temperature (mean, max, min) and to support renewable energy transition across Greece and Morocco. For the present climate the CAMS gridded solar radiation dataset, from Copernicus Atmosphere Data Store, will provide historical (2005-2023) values of Global Horizontal Irradiation (GHI) and/or Direct Normal Irradiation (DNI) . The CAMS reanalysis dataset of aerosol optical

The data for the long-term projections, available for a continuous period from 1971 to 2100and will be accessed through C3S-CDS. Future projections will be based on three of the so-called Shared Socioeconomic Pathways (SSPs), namely the SSP1-2.6, SSP2-4.5 and SSP5-8.5. The SSPs are climate change scenarios of projected socioeconomic global changes up to 2100 that the climate change research community has adopted to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation, as defined in the IPCC Sixth Assessment Report (AR6, 2021). Regarding seasonal forecasts, the multi-system seasonal forecast service of C3S will be utilized. C3S provides data with horizontal resolution of one (1) degree and the data are available at daily or sub-daily basis depending on the variable. The data includes forecasts created in real-time (since 2017) and retrospective forecasts (hindcasts) initialized at equivalent intervals during the period 1981-2016. Both the long-term climate projections and seasonal forecasts will be statistically downscaled (described below in detail) to a higher resolution (9km) using CAMS and ERA5-Land reanalysis as reference datasets. High resolution probabilistic seasonal forecasts of parameters related to solar energy production (i.e., downwelling surface solar radiation in terms of GHI and DNI, air temperature, etc.) will be provided. Furthermore, long-term climate projections of climate data (surface downwelling shortwave radiation, TOA incident shortwave radiation, total cloud cover percentage, aerosol optical properties, near surface air temperature) relevant to photovoltaic system performance will be produced for the estimation of the future climate changes related to energy production.

2.3 Downscaling

To statistically downscale both climate projections and the seasonal forecasts to the ERA5-Land horizontal resolution, a two-step approach will be followed. In particular, the raw climate projection and seasonal forecast meteorological data will be initially re-gridded to the ERA5-Land grid by means of bilinear interpolation, and next, bias correction will be applied using empirical quantile mapping (EQM). However, in order to overcome the risk that temperature data for the islands may not be available in the ERA5-Land dataset (9 km horizontal resolution), the Copernicus European Regional Reanalysis (CERRA) dataset, with a finer horizontal resolution of 5.5 km, will be used as an alternative. For the downscaling of the irradiance data, the atmospheric composition and - in the Mediterranean in particular - the aerosol load - are essential, therefore the CAMS datasets that have been produced using measured aerosol properties will be used instead of the ERA5-Land (where climatological aerosol information is used to produce SSR products). This two-step approach is the reversed order of the framework of bias correction and spatial disaggregation, which has been previously used to statistically downscaled global and/or regional models for both climate change and seasonal forecast studies [5,6,7].

2.4 Energy Production Simulations

All parameters related to energy production will be ingested to the Global Solar Energy Estimator (GSEE) [8]. GSEE is a widely used open access solar energy simulation library which takes as input the GHI, and optionally, the diffuse horizontal irradiance (DHI), the air temperature, and the surface albedo. It simulates the produced energy for various types of photovoltaics (PV) at the tilt angles specified by the user, or for panels that are rotating at one or two dimensions. The GSEE can estimate the solar energy production for specific locations taking as inputs SSR parameters (GHI and DNI) at timescales ranging from instantaneous to monthly integrals. Using the GSEE, seasonal and long-term forecasts of the potential for energy production from PV will be provided at the final stage of the workflow. The potential for energy production from CSP is proportional to the DNI and will be calculated using appropriate conversion factors [9]. Although this latter information is not necessary for any of the demonstration cases, it will be produced as an additional asset for training and national energy planning.

For demonstration case 1b, the energy needs of the Greek islands will be estimated by combining (i) C3S projections of energy demand from the Copernicus operational service for the energy sector in Greece (https://climate.copernicus.eu/operational-service-energy-sector), ii) the current state of energy demand by the HEDNO, as well as iii) communication with local authorities, if necessary. The energy demand information will be combined with the GSEE output to quantify the magnitude of the necessary investments for solar energy production at the Greek islands, at the present and in the future. Additionally, we will assess the impact of seasonal and long-term changes in the potential for solar energy production due to different parameters that are affected by climatic and/or air quality changes (e.g., changes in aerosol and cloudiness) using available C3S and CAMS data for all the demonstration cases to further contribute towards optimal national and regional planning to face future challenges.

3 EXPECTED RESULTS

The project aims to support the National Plans of Greece and Morocco by utilizing C3S and CAMS data in conjunction with solar energy modeling. In particular, it will support:

1) The plan for optimal energy exploitation through the provision of seasonal and long-term predictions of solar energy production towards the national Greek targets for decarbonization in the context of the Green Deal. Projections at the position of a PV park at the region of Evros (Demonstration case 1a) will be optimized and then they will be evaluated against real data to provide estimates of the accuracy of the used methodology.

2) The plan for energy autonomy of the Greek islands in the context of the GR-eco islands initiative. Long-term and seasonal solar energy forecasts for three Greek islands (Demonstration case 1b) will be used in conjunction with estimates of the energy needs at these locations to determine the magnitude of the necessary investments in PV at these areas that are needed to cover their energy needs, and how the potential for energy production by different types of PVs will change in the future.

3) The plan of Morocco for optimal solar energy exploitation towards its national targets through two different paths: (i) The provision of seasonal and long-term predictions at three different locations in Morocco that are in areas located near seismic zones (Demonstration case 2). Such information would

contribute to the national planning for the immediate provision of help at these areas in case of extreme seismic events. Furthermore, it can be beneficial for nearby PV and/or Concentrated Solar Power (CSP) installations. (ii) The provision of training to scientists from Morocco, who will be able to maintain and support these tools, as well as to produce similar projections for other locations.

4 CONCLUSIONS

The project will develop climate services for the energy sector related to solar energy. The services will be focused on the seasonal (weeks to months) and long-term (over the next 30 years) time scales of energy production and will be specially tailored for two selected cases in Eastern (Greece) and Southern Mediterranean (Morocco). Most solar energy forecasts focus on the short term (up to a few days), creating a gap in seasonal and long-term information. In the frame of the ReEnergy-Med project, data provided by the Copernicus Climate Change Service (C3S) and the Copernicus Atmosphere Monitoring Service (CAMS) will be used and the generated customized services will be a benchmark to support decisions and better management in the solar energy sector in the region.

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