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Assessing Energy Transition in the Mediterranean regions: A comparative analysis

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Abstract: The shift towards a more sustainable energy production, which necessitates gradually reducing reliance on fossil fuels is a worldwide goal. The European Union has established specific targets to guide the energy transition and to achieve climate neutrality by 2050 through policies like the European Green Deal. Member States are also playing an active role in the energy transition, through specific national recovery and resilience plans. This study proposes a method to compare the monthly trend of the carbon footprint in Greece and Cyprus, from 2021-2024. The study highlights valuable insights for energy transition policies in Mediterranean islands.

Keywords: Energy Transition; Carbon Footprint; Mediterranean insular regions

1. Introduction

The shift towards a more sustainable energy production, which necessitates gradually reducing reliance on fossil fuels like coal, oil, and natural gas, is a worldwide goal [1, 2]. The European Union has established specific targets to guide the energy transition and to achieve climate neutrality by 2050. The European Green Deal, which promotes renewable energy technologies, improvements in energy efficiency, and environmentally friendly transportation represent one of the most representative policies [3]. The European energy transition is supported by substantial financial resources, including initiatives like the Just Transition Fund and the InvestEU programme. Member States are also playing an active role in the energy transition, through specific national recovery and resilience plans [4, 5]. However, there are still many challenges to achieving the established objectives and targets [6]. Differences in economic development and energy infrastructure across EU countries have resulted in an "energy gap", complicating the formation of a consistent energy strategy.

Within this framework, the study proposes a method to compare the monthly trend of the carbon footprint in Greece and Cyprus, among the Mediterranean regions most involved in the challenges of the sustainable energy transition. The Mediterranean context offers significant potential for renewable energy development due to abundant solar and wind resources, coupled with declining technology costs and growing electricity demand. The International Energy Agency forecasts that renewable energy capacity in the Middle East and North Africa (MENA) will double over the next five years, driven largely by solar photovoltaics and increased private investment [7]. Islands offer unique insights into the spatial and social aspects of the energy transition due to their geographic isolation and the critical need for secure, autonomous energy systems [8, 9]. Greece and Cyprus are a focal point of the present study, which analyzes data for the period 2021-2024, in respect to the following indicators: direct carbon intensity, percentage of low-carbon energy and energy from renewable sources. The objective is to monitor progress in the decarbonization process, evaluate the diffusion of low-emission technologies, and

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measure the degree of integration of renewable sources into the energy mix of each one. The aim is to highlight the unique opportunities Mediterranean regions face and to outline sustainable strategies for their transition [9].

2. Method

The comparative approach used to assess the monthly evolution of the carbon footprint in Cyprus and Greece for the period 2021-2024 allows to identify both similarities and differences in the trends of the selected d indicators, as well as the identification of best practices and areas that require improvement. The comparative method analyzes three indicators [10]:

- Carbon Intensity (direct) [gCO_2eq/kWh], which measures the amount of greenhouse gases directly emitted for each unit of electricity produced and consumed, expressed in grams of CO_2 equivalent per kilowatt-hour (gCO_2eq/kWh), representing the direct contribution of electricity generation to emissions.

- Percentage of Low-Carbon Energy, which refers to the share of electricity produced from low-emission sources, including renewable energy (biomass, geothermal, hydroelectric, solar, and wind) and nuclear energy, excluding fossil fuels.

- Percentage of Energy from Renewable Sources, which measures the share of electricity generated solely from renewable technologies.

Each indicator is assessed both in absolute terms and in a normalized form (relative to the annual population of the related context) in order to better understand energy consumption patterns.

3. Case study

The present research analyzes the trend of the carbon footprint in Cyprus and Greece, selected as case studies due to its representative nature among large and geographically Mediterranean regions, that represent ideal contexts for studying the socio-spatial dimensions of the energy transition, due to the need to ensure energy security, and aspirations for political autonomy. Cyprus is making significant progress in the energy transition. The European program CITyFiED (2014–2019) promoted the transformation of cities into smart cities, creating a "Community of Interest" with 44 cities from 19 countries, including Cyprus. The main objective was to reduce energy demand and emissions, increase the use of renewable energy, and develop replicable models for energy retrofitting. As a member of the "Community of Interest", Cyprus benefited from the sharing of retrofitting methodologies, with the aim of disseminating the project's solutions [11]. In the Mediterranean context, Cyprus—despite tensions with Turkey—represents a potential energy player thanks to offshore gas reserves, such as the "Aphrodite" field. The EastMed project, which aims to connect Eastern Mediterranean gas reserves to Europe, is hindered by territorial disputes with Turkey [12]. Despite the challenges, Cyprus continues to explore ways to exploit its gas resources and invests in renewable energy. Geopolitical tensions, particularly with Turkey, influence energy cooperation initiatives, such as the EastMed pipeline [13].

4. Results and conclusions

This study compares Cyprus with Greece, with a focus on the years 2021 and 2024, as this period is representative of the post-COVID-19 phase and the subsequent energy transition. The data related to Direct Carbon Intensity, Low-Carbon Energy Percentage, and Renewable Energy Percentage, available on the Electricity Maps platform [10] are presented in a normalized form relative to the population (per capita values multiplied by 100,000). The results highlight the structural differences, recurring critical issues, and distinct energy development paths between Greece and Cyprus.

The population-normalized values of carbon intensity shows the difference in the performance of the case studies (Fig.1). Greece displays a strong positive trend: in 2024,

values consistently remain below 3.0 $gCO_2eq/kWh100,000$, demonstrating a notable improvement from 2021. This suggests that the Greek electricity system is gradually shifting toward a more sustainable model, with reduced dependence on fossil fuels such as coal and gas and an increased share of clean sources. The stability of the data throughout the year also confirms good management of the energy mix, with no major seasonal fluctuations. The situation in Cyprus is different: although there is a slight improvement in 2024 compared to 2021, the levels remain high, with peaks exceeding 42 $gCO_2eq/kWh100,000$. The significant monthly variability indicates a production system still heavily influenced by fossil fuels, lacking flexibility and highly sensitive to seasonal changes in demand and supply. Overall, the comparison shows that Greece has taken a more structured and decisive path toward decarbonization, while Cyprus still faces significant challenges in reaching more sustainable standards. The charts confirm that between 2021 and 2024, Greece consolidated a positive trajectory, while Cyprus, although showing progress, continues to depend heavily on high-emission sources, indicating that its energy transition is still at an early stage.

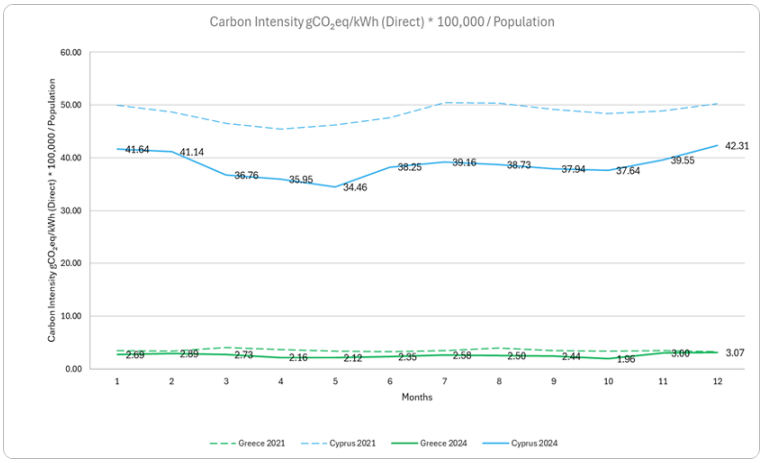

Figure 1. The comparison between Cyprus and Greece (2021-2024) of the Carbon Intensity in a normalized form.

As regards the share of electricity generated from low-carbon sources. Between 2021 and 2024, Greece shows relative stability. No significant peaks or drops are observed, nor are there marked seasonal changes. This data can be interpreted both as a sign of consistency and as an indication that more effort is needed to increase the presence of low-emission technologies to meet climate goals. Cyprus, on the other hand, displays a much more dynamic profile, with a seasonal trend. While Cyprus has increased the use of clean sources, it still relies heavily on intermittent technologies—particularly solar power. The absence of efficient storage systems and limited diversification of the energy mix leave the system invested by seasonal fluctuations, limiting the stability of clean energy production. Greece provides a more stable energy supply, while Cyprus shows stronger growth, although uneven and still affected by challenges related to seasonality. Finally, as regards the renewable component of electricity generation (Fig. 2), Greece's trend shows what was observed for low-carbon sources overall: stability is the dominant feature, but renewables still represent a relatively small portion of the total energy mix. Cyprus, on the other hand, continues along a more dynamic path. In 2024, the picture improves significantly in respect to 2021.This trend reflects the improvement of the renewable sector in Cyprus, due to investments in photovoltaics. However, seasonality remains a critical factor. In conclusion, Greece shows a stable path, though with still limited renewable energy supply. Cyprus, on the other hand, is progressing along a more dynamic and promising route, although there is a need to improve the consistency and year-round distribution of clean energy generation.

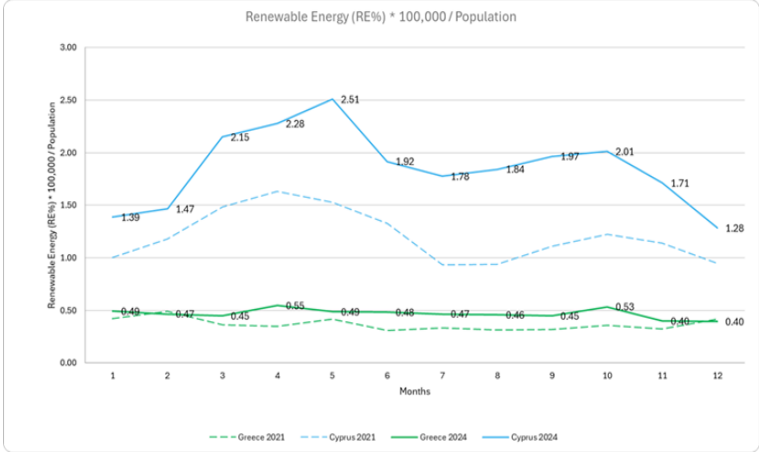

Figure 2. The comparison between Cyprus and Greece (2021-2024) of the Percentage of Energy from Renewable Sources in a normalized form.

In conclusion, the comparison highlights an overall improvement in the uptake of the percentage of low-carbon and renewable energy in Greece and Cyprus (2021-2024), with a positive trend toward decarbonization, albeit some differences still remain. Cyprus showed gradual progress in reducing carbon intensity and increasing the production of low-carbon and renewable energy, especially during the first half of 2024. However, it still lags Greece. The national scenario of Greece reveals positive and efficient trends, without significant seasonal or annual variations, with low emissions and a system already oriented towards sustainability. The proposed study proved to be valuable for informing policy decisions and developing more effective strategies to support the energy transition in the Mediterranean regions.

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