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# Energy Supply Sustainability For Island Nations: A Study on 8 Global Islands

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**Abstract**

Energy supply sustainability is a multifaceted challenge for all countries and especially for small island nations that might have limited adaptive capacity. Previous studies showed that islands experience energy scarcity and isolation from energy markets due to their remote location. Our focus is on a range of islands spread out globally: Malta, Cyprus, Curacao, Mauritius, Iceland, Jamaica, Trinidad and Tobago and Bahrain. They are selected for their varying energy development paradigms that facilitate cluster elicitation. For the first time, we combine the estimation of fuel mix diversity and energy import dependence with established metrics Shannon-Wiener index (SWI), Herfindahl-Hirschman index (HHI) and Energy Import Dependence to assess energy supply security. SWI and Energy Import Dependence are then presented against carbon intensity to highlight two angles of sustainable energy supply. We argue that islands are clustered to those that have fossil fuel reserves and are locked in low diversity, low dependence and high carbon intensity, those that rely almost exclusively on imported fossil fuel reserves and have low diversity and high dependence and high carbon intensity and finally those that have entered a decarbonization trajectory that allows them to reduce their fossil fuel import dependence, increase their diversity and reduce their carbon intensity.


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*Keywords:* Islands; Energy Supply Security; Carbon Intensity; Diversity; Dependence

## 1. Introduction

Energy is a key aspect of a country's economy and access to affordable energy is a prerequisite for growth and

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competitiveness [1]. Climate change amplifies risks associated with disruption in supply and demand and combined with infrastructure vulnerability it can create long-term energy security stresses or short-term episodic shocks affecting various types of consumers including increasingly demanding households [2–4] and industrial users [5]. Prioritisation of energy security against climate change mitigation policies and vice versa can have a direct impact on a country's energy roadmap and hence on large scale investment decisions [6]. In this context, it is necessary to evaluate the resilience of existing energy systems as their availability and accessibility are considered essential parameters to the sustainability of a country's economy.

Security, carbon neutrality and affordability are the parameters forming what is known as the energy trilemma; and nowhere is the energy trilemma more widely pronounced than in the confined space of remote and isolated islands [7,8]. Islands usually are locked into expensive fossil fuels imports, in isolated markets leading to low fuel mix diversity and high carbon and other emissions relatively to their economic growth [9]. In addition to that, their economy and lifeline are often dependent on the tourism industry and connections with a mainland country. Energy poverty is omnipresent because islands cannot take advantage of renewable energy potential especially solar and wind, because of the poor grid infrastructure [8,10]. However, islands lend themselves to excellent testing case studies for innovative energy solutions which could set the example for larger scale, on-grid applications. Their remoteness, relative small size and flexible governance makes them potentially adaptable to change and capable of significant shifts unlike large regions with monolithic energy governance [11].

For this research, we evaluate 8 islands; Cyprus (CY), Malta (MT) and Iceland (IS) in Europe; Curacao (CW), Jamaica (JM) and Trinidad & Tobago (TT) in the Caribbean; Bahrain (BH) in the Persian Gulf; and Mauritius (MU) in the Indian Ocean. In this regard, we perform a security evaluation [12] of their energy supply and contrast the results with their carbon intensity as a measure of environmental sustainability for energy supply. We identify island clusters based on the aforementioned attributes and look into the potential for fuel mix innovation as an enabler for energy supply sustainability and security [13].

## 2. Results and Discussion

### *2.1 Energy Import Dependence*

With regards to imports dependence, islands can be clustered in 3 groups (Fig 1): those that are highly dependent at close or over 100% (as a result of feedstock changes); those with middle dependence; and finally, those that are net energy exporters, enabled by their indigenous reserves. Referring to the high dependence group the two EU member states, Cyprus and Malta, have been historically locked into fossil fuel imports from neighbouring exporters, making them the two most energy dependent EU countries. They both have enormous potential for renewable energy generation within their energy systems and specific renewable energy targets to meet for 2020 [14,15]. Cyprus also has promising natural gas reserves in the Eastern Mediterranean Sea which may lead to longer-term lock into fossil fuels [16]. In the same group, we can include the Caribbean islands that do not produce indigenous fossil fuels.

On the other end, Bahrain is a large oil producer in the Middle East and Trinidad & Tobago is the largest natural gas producer of the Caribbean therefore they both are net fossil fuel exporters. Iceland is a distinct case as it supplies approximately 89% of its primary energy with renewable resources; mainly geothermal and hydro. Even though Iceland's energy demand has grown by 250% since 1990, this growth has been met by renewable energy. The imported fossil fuels are mainly used in transport and the fishing industry although there are ambitious plans to became almost a zero emissions island with a turn to electric cars [17]. That could silence the criticism for electric vehicles when they are charged by fossil fuel based electricity since only 1.7% of the total fuel mix was sourced from coal back in 2013 [18,19].

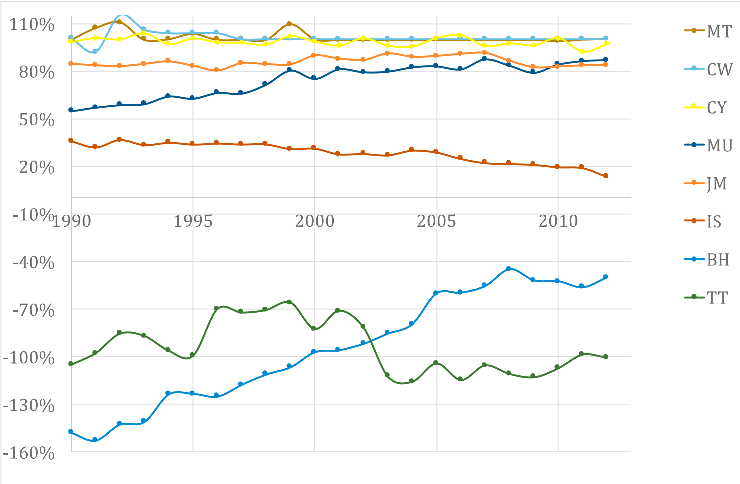


Figure 1: Primary energy import dependence in selected islands, 1990-2012. Data Source: IEA.

### 2.2 *Energy Supply Diversity Indices*

Energy import dependence is only one dimension of the multifaceted issue of energy supply security. Fuel mix diversity is equally important for a sustainable energy future and can be considered as a strategic response to energy scarcity and uncertainty that challenges most islands. We used two indices, Shannon-Wiener Index (SWI) and Herfindahl-Hirschman Index (HHI), to measure diversity and concentration respectively. Both are sensitive to the balance among the fuel options and to their total number; therefore, they tend to show a disproportionately large diversity increase even when an option with relatively negligible contribution is introduced to the fuel mix. Most of the islands examined in this manuscript have a relatively low number of options in their fuel mix.

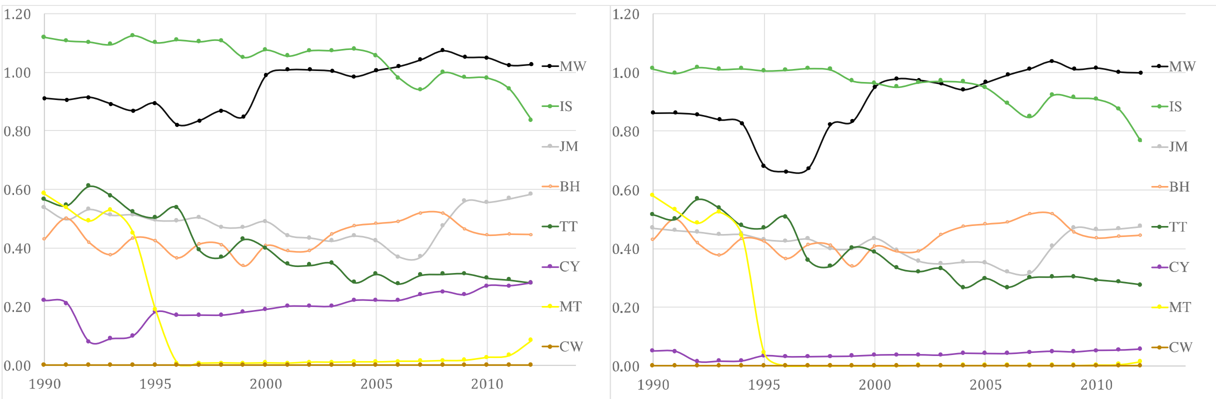


Figure 2a and 2b: Primary energy supply diversity, measured with SWI for all fuel options (2a) and for fuels contributing more than 5% (2b) between 1990-2012. Data Source: IEA.

Overall, primary energy supply diversity in Malta and Cyprus has been improved only slightly in the last decade. A major drop in Malta's diversity back in 1993 was caused by the abandonment of coal as an energy source which left the country relying only on fuel oil. Iceland's diversity falls gradually as a result of the increased role of geothermal energy and the gradual reduction of all other resources apart from hydro. Looking closely into the fuel mix of the examined countries we can see that the main drivers for diversity growth have been a substitution of fossil fuels by renewable energy sources. Throughout our analysis, Curacao comes out as the country having the least diverse fuel mix while Mauritius and Iceland have the most diverse fuel mix.

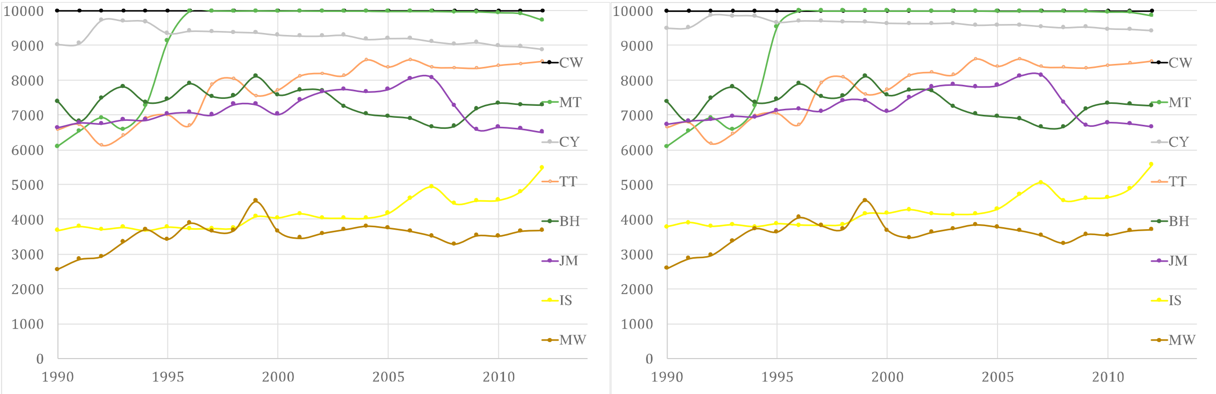


Figure 3: Primary energy supply concentration, measured with HHI for all fuel options (3a) and for fuels contributing more than 5% (3b) between 1990-2012. Data Source: IEA.

## 3. The Interplay between Energy Supply Security and GHG Emissions

Most often policymakers and the research literature treat energy security and climate change as two distinct policy goals [20]. At the same time, complex optimisation modelling is often employed to support decision makers to adopt appropriate sustainable energy paradigms [21]. On one hand climate change policies aim to transform the global energy trade by transitioning from reliance on fossil fuels to low carbon energy sources. Most studies find that climate stabilization policies reduce imports by up to 75% on average globally, however this number varies on a regional level, depending on whether the region is a net importer or exporter of energy [22]. Nevertheless, renewable energy growth results in a larger share for indigenous energy and reduces imports. Combining dependence and diversity indices to measure energy supply security along with power and heat emission factor ($gCO_2/kWh$) as a proxy to quantify carbon intensity, we identify paradigms of development for international islands [23].

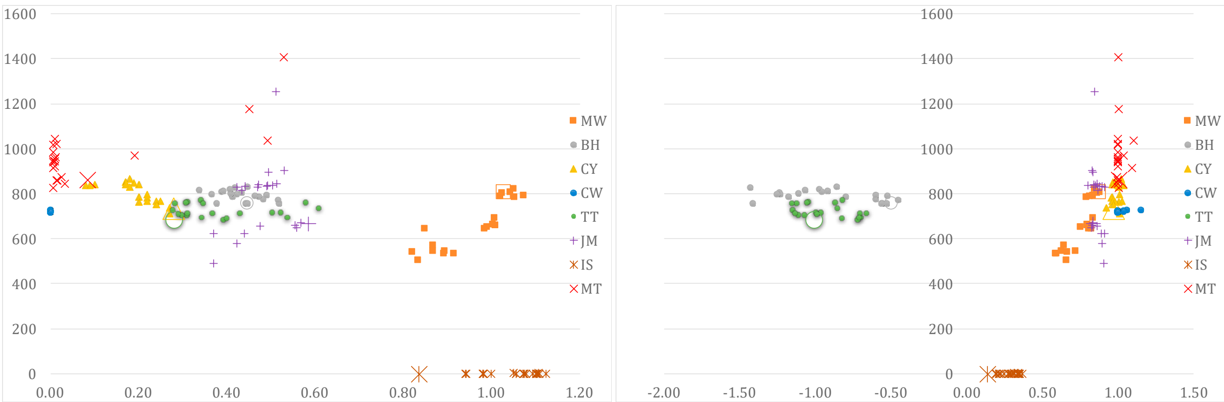


Figure 4: SWI Diversity and Import Dependence Index against g $CO_2$ per kWh scatter (4a) and (4b) correspondingly between 1990-2012 with larger data points showing 2012. Data Source: IEA.

Emissions intensity of the examined islands has not changed drastically over the past 20 years (Figure 4). Although the use of renewables has improved fuel mix diversity and energy supply security, Mauritius' case highlights that diversity is not always combined with lower emissions proving that energy security optimization policies sometimes may have a reverse effect on climate change policies. Since 1992, Mauritius increased its carbon intensity by 51.1% strengthening its diversity by 12.1%. The changes reflect the replacement of biofuels in the fuel mix with petroleum products. On the other hand, Jamaica and Malta experience the steepest decrease in emissions. Malta achieved carbon intensity reduction by shutting down its coal-fired power station which had a side effect of lowering its fuel mix diversity [24]. Jamaica's fuel mix remained unchanged through the years with only a slight improvement in diversity which means that its carbon intensity had been reduced because of efficiency improvement.

Renewable energy growth is typically linked to growth in indigenous energy use, which translates to lower import dependence and lower carbon intensity. When looking at the combined view of import dependence and carbon intensity (Fig 4b) there is no strong link to specific island characteristics. Our selected islands are clustered in the same groups as those defined in Section 2, as import dependence is linked to carbon intensity only for islands without indigenous exporting oil resources. From the exporting islands, Trinidad seems to keep a low level of carbon intensity compared with Bahrain since it covers 92% of its energy needs with natural gas compared with approximately 84% in Bahrain. Energy importing islands have lowered their energy dependence levels in years when carbon intensity was lower, which demonstrates the role of strong renewable energy production in delivering these results. A great example is Mauritius' decrease of 23.25% in biofuels which came with a corresponding increase of 33.8% in carbon intensity.

Iceland's case is unique since it achieves almost zero carbon intensity with negligible use of fossil fuels. Its low carbon intensity is combined with high diversity and low dependence making a paradigm for sustainable energy supply. The energy supply security and low emissions patterns of Iceland are more significant if we consider that hydro power and geothermal energy present lower variability and stochasticity in comparison to other renewables, such as wind or solar energy.

## 4. Conclusion

Energy security is important for all countries especially those exposed to multiple supply vulnerabilities. Islands, due to their remote location, experience energy isolation and scarcity. Vulnerability is greater for most of the islands that are not producers or net exporters of fossil fuels. These islands are locked-in long-term fossil fuel import dependence which is usually combined with higher carbon intensity and lower fuel mix diversity. Thus, their energy supply is unsustainable both in terms of carbon intensity and supply security. On the other hand, producer islands, despite relying on oil and gas have a relatively better diversity and lower carbon intensity when they use indigenous gas, instead of heavy fuel oil.

Within this study, we assess the energy import dependence and fuel mix diversity of large island nations. Then, we highlight the link between energy supply security and carbon intensity. It is shown that growth in renewable energy sources directly benefits energy independence, improving the overall energy security and sustainability outlook. Using a wide range of international islands with different resource capabilities we identify paradigms for their sustainable development. We find that islands that are producers and exporters of fossil fuels tend to be over-reliant on these resources, which makes them vulnerable to very low fuel mix diversity and high emissions intensity. Partial substitution of fossil fuels by renewable energy sources will improve diversity and reduce emissions without harming their very low energy dependence. However, not all types of renewable energy are the same, as Mauritius' case indicates. Its reliance on biomass has increased vulnerability because of uncertain availability and challenging environmental performance. Thus, this leads to the conclusion that risks associated with different renewable energy sources vary.

Half of the examined islands (Cyprus, Curacao, Jamaica and Malta), are locked-in imported oil products; hence, any addition in their fuel mix, except coal, will improve their diversity and emission levels. Locally produced renewable energy has the additional advantage of reducing their import dependence. Nevertheless, the integration of large-scale renewable energy in existing grids will require adoption of innovation such as energy storage that can deliver multiple benefits for energy supply sustainability [25,26]. It is clear from our findings that the pathway to tackle the global energy trilemma can be achieved only with the wider use of renewable energy. Islands can be used as testing cases to show how the global community can benefit from this transition. Further research is required to include more islands and isolated off-grid areas for which region specific data is not readily accessible.

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