# The Trilemma of Energy Transition on Islands

WHITE PAPER

ADEX

# ABSTRACT

**Over 875 million people live on islands**, approximately 11% of the world's total population but occupying only 5% of the world's total land mass (filtering vast uninhabited areas of Greenland and Australia).

Due to the geographic location and exclusive dependency on imported fossil fuel for power generation, most of the island countries **face the world's uppermost energy costs**, with vulnerability in the supply chain and frequent interruptions. For example, the average cost of energy in the Caribbean is almost five times that of the mainland U.S. The scenario is even worse in the Pacific Islands, where in some countries the tariff is increased by more than seven times.

With the continuous development of society, the demand for energy supply is increasing gradually. Island countries are the **most suitable** marketplaces in the world for standalone renewable energy sources. However, technical constraints, such as grid frequency stability and voltage control, or economic constraints, such as the lack of enough investment in low-carbon power, are **delaying renewable penetration in islands**.

Small island economies are diverse (services, manufacturing, industry), which triggers the need for **different solutions to advance the energy transition** while maintaining system reliability and stable production costs.

A good score to measure Energy Transition is the Energy Trilemma Index by the World Energy Council. This Index shows the relationship between the security and availability of electricity, its price, and the level of sustainability. Apart from highly developed and populated islands such as the UK or Japan, the **Trilemma Index shows that islands have a lower performance**. A lack of enough interconnection with the mainland to exchange electricity, the deficit of critical mass for some initiatives, or a typically less meshed power grid, make energy systems on islands less robust and economical than their peers on the mainland.

New Technologies will help islands increase energy sovereignty and sustainability, while decreasing electricity prices. Nevertheless, the availability of these **solutions may take 10, 20, or even 40 years to come** about. As an example, utility-scale energy storage in batteries is still in the early stages, and it will need some years to be available at affordable prices.

This means that **Thermal Power Plants on islands will be forced to remain for a long time**. But their role has to change drastically, from comfortably providing base load generation to operating in a very demanding and equipment-damaging flexible mode, completing intermittent renewable sources, and maintaining grid frequency stability.

Thus, to make successful steps in the following 5 to 10 years towards Energy Transition will **require the coexistence** of incumbent Thermal Power Plants adapted to the new market requirements with the Renewable Energy challengers.

Solving the Energy Trilemma on islands **will demand more imagination, planning, and patience** than on the mainland, as resources, power grids, and blackout risks are not the same.

# 1. ISLAND ENERGY SYSTEMS MAGNIFY THE ENERGY TRILEMMA

The World Energy Council (WEC) introduced the concept of the “Energy Trilemma” back in 2010. As you can read in Figure 1, the following is a suitable definition for the current situation of the energy context, particularly in electricity generation.

trilemma

/trʌɪˈlɛmə/

*noun*

a situation in which a difficult choice has to be made between three alternatives, especially when these are equally undesirable.

Figure 1 - Definition of "Trilemma" by Oxford Dictionary

We all desire an energy system that is (1) secure and reliable, (2) affordable and accessible to everyone, and (3) environmentally sustainable. However, current energy assets are not capable so far of fully providing all three at the same time. So, we have to prioritize. We need to choose between equally undesirable situations: reliable and cost-controlled but not environmentally sustainable enough; or green energy, but expensive and intermittent; among different cases.

This trilemma has an even harder-to-find solution on islands.

The small scale of island energy systems and their current high dependence on imported fossil fuels make them vulnerable to supply disruptions and price volatility, leading to energy insecurity. The limited availability of indigenous resources and economies of scale further increase the cost of energy, leading to energy unaffordability. Finally, the high environmental impact of hydrocarbons and the disproportionate way that climate change affects islands make sustainability a pressing concern for island energy systems.

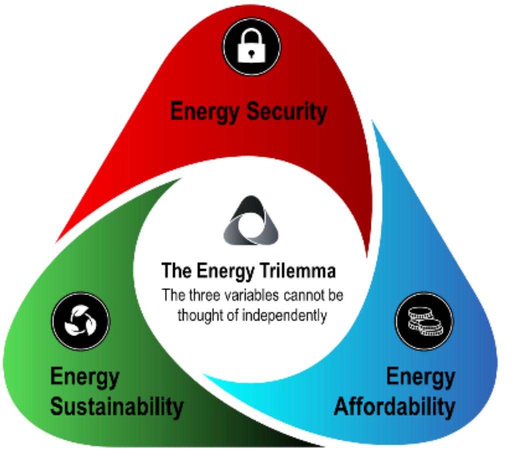


Figure 2 - Energy Trilemma Index.
Courtesy of "Unlocking the Energy Trilemma"

For island energy systems, the energy trilemma is particularly relevant, given the unique challenges they face. The concept of one-size-fits-all cannot be applied to islands: RES penetration, weather, and geographical conditions, population, tourism, distance from the mainland, and presence of industries make the energy needs of each island unique.

Let’s try to understand each of the vertexes of the triangle:

## 1.1. Security

The Energy Security dimension in the Energy Trilemma measures the ability to meet current and future energy demands. An energy-secure community will also be able to withstand and respond to supply shocks to minimize disruption to economic activity and consumers. In determining an energy security score, the dimension incorporates the effectiveness of management of domestic and external energy sources, along with the reliability and resilience of energy infrastructure.

Electricity is expected to take an increasing share of total final energy consumption in the coming decades, as we couple electricity with heating, transport, and other sectors as part of our drive to decarbonization. Especially in emerging economies, an enormous rise in demand is foreseen due to population and economic growth. All this puts electricity security higher than ever on the energy policy agenda.

Energy security is an especially critical concern for island energy systems, which are often highly dependent on imported fossil fuels for electricity generation. This dependence can leave them vulnerable to supply disruptions, price fluctuations, and geopolitical risks. Sometimes, the small size of an island can make the installation of LNG terminals unaffordable or unviable. That could help to move from diesel or coal to more efficient, less polluting, and very flexible gas power plants. Transitioning to renewable energy sources can improve energy security by reducing dependence on imported fossil fuels and increasing local energy production. Until energy storage solutions are available at utility-scale, current renewable intermittency will continue to decrease availability and secured access to electricity.

As a reference, it's been five years since Hurricane Maria left Puerto Rico without electricity, but even with $12 billion in recovery funding committed, the future of the island's grid is still in doubt. Puerto Rico's electric grid is still prone to regular outages and extremely vulnerable to storms. Hurricane Fiona, a far weaker storm, knocked out power to the entire island in September 2022.

After Maria, solar power was widely seen as a solution to high energy costs driven by the price of imported fuel and the grid's vulnerability to storms. Approximately 40,000[1] people have installed solar panels on their roofs since the storm, and numerous communities and organizations have launched local solar projects.

In 2019, Puerto Rico passed legislation mandating the island convert to 100 percent renewable energy by 2050 — an opportunity to redesign the island's energy system to be cleaner, cheaper, and more resilient. There are two important milestones on the way, as the energy system must obtain 40% of its electricity supply from renewable resources by 2025, and 60% by 2040. But in islands, utilities and their local regulators often lack the resources and financial incentive to pursue renewables, delaying their deployment and pushing them to continue in the business they know. For the fiscal year 2022 (July 2021—June 2022), only 3% of Puerto Rico's electricity came from renewable energy, making long-term goals very challenging.

## 1.2. Affordability

The Energy Affordability dimension assesses a country's performance in providing reliable access to affordable energy. This includes a metric of quality energy access, too, required to enable economic growth. Energy affordability is determined by a combination of energy prices and broader socio-economic improvements, which influence how affordable a commodity like energy really is.

Island energy systems are typically characterized by their limited size and constrained resources, which can make electricity generation expensive. Energy costs are typically higher on islands due to the additional costs associated with importing fuels and building and maintaining the energy infrastructure. This high cost of electricity can have serious economic consequences, particularly for low-income households and small businesses. Renewable energy sources, such as wind and solar power, have the potential to reduce electricity costs over the long term, but they can require significant upfront investments.

Following the previous reference, Puerto Ricans pay more than twice the US's average rate for electricity[2] but with a worse service than on the mainland.

Renewable Energy Sources often have lower OPEX but they require high CAPEX and years to get the proper permits. To fix their intermittency, they need energy storage systems attached, which are still very expensive and limited in capacity. Moving to sustainable energy requires time and money, that end up in the consumer's bill, one way or another.

## 1.3. Sustainability

Environmental Sustainability measures the performance of a country's energy system in avoiding environmental damage and mitigating climate change. It considers energy resource efficiency, decarbonization, carbon dioxide and methane emissions, and air pollution. In order to ensure a fair comparison across countries, the Sustainability score is calculated by incorporating information on population, overall energy production, and GDP.

Islands are often heavily impacted by climate change and are more vulnerable to its effects. Tough storms or the rise of the sea level are two effects that make islands very sensitive to sustainability. Almost every year the Caribbean and Pacific islands face nationwide catastrophic tropical cyclones, which are a great barrier to renewable energy integration. As a result, there is a growing need to transition to renewable energy sources to reduce greenhouse gas emissions and mitigate the impacts of climate change.

Over the past two decades, Puerto Rico has been among three territories (along with Haiti and Myanmar) most affected by extreme weather such as storms, floods, heatwaves and droughts, according to the Germanwatch Climate Risk Index.

Now, more than 7,000[3] Puerto Rican homes equipped with solar panels and batteries will form the U.S. territory's first virtual power plant, with plans to start operations in 2024. Although they will mean only 17 MW, this project also represents a significant milestone in the regulatory path that besets clean energy efforts across the island.

The political traditions of the islands reflect the diverse ways and time they target for renewable energy integration in the grid. The United Nations classifies 52 countries and territories as Small Island Developing States (SIDS) with fifty million people. Forty-three million inhabitants are living in the Caribbean Islands and the Pacific Islands regions. The economical classifications are diversified within these countries. On the one hand, just a few of them are comparatively rich against developing country standards, such as Singapore and Bahamas, on the other hand, a number of them are still in the lower income group, including Comoros, Haiti, and Kiribati.

Global economic situations have influenced development prospects for both regions. Although most governments are trying to ensure law and order, and provide legal certainty, even today, there is still a great concern about security for investors in the Island countries. The presence of good policies is yet to be finalized in different countries which is not a suitable condition for potential investors. Additionally, island countries' economic developments have always been enormously interrupted by a series of external and internal factors such as a number of natural disasters (cyclones, earthquakes, flooding, and tsunamis), global oil shudders, and the global economic crisis.

As an example, SIDS are looking increasingly to renewable energy sources for their energy needs. And yet, despite the significant political will and abundant natural resources available, small island nations still struggle to unlock much of the potential of renewable energy to transform their societies.

## 1.4. World Energy Trilemma Index for islands

Figure 3 shows the qualifications of various Island States that have been studied for the trilemma index by WEC within a greater list of 90 countries. Some other countries that an important part of their geography consisting of islands (Malaysia, and Indonesia, for example) have also been considered. The top three island performers are Ireland, New Zealand, and the United Kingdom, while the bottom three are Madagascar, Jamaica, and the Philippines.

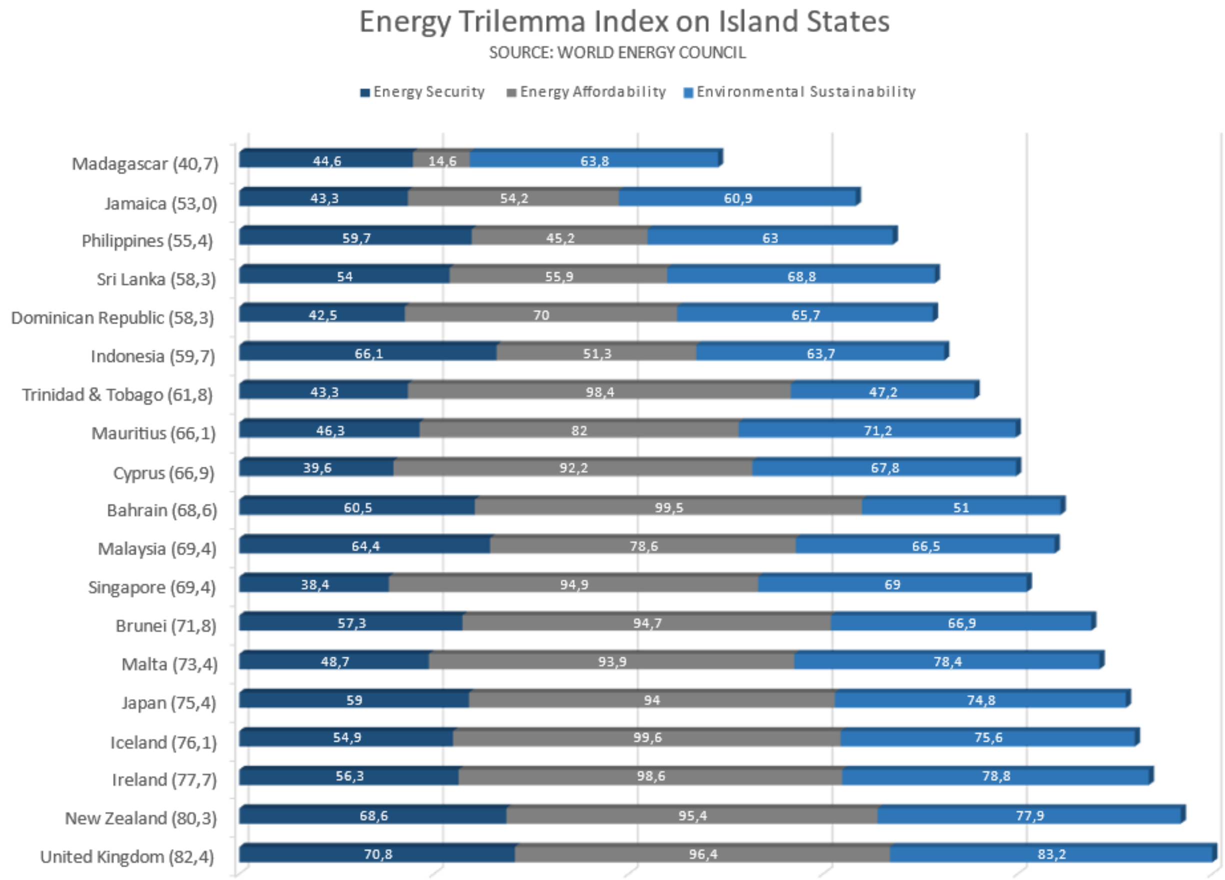


Figure 3 - 2022 WEC Energy Trilemma Index on Island States

The latest WEC report shows that islands tend to rank lower than non-island countries in Energy Sustainability, with an average score of 49,6 compared to 59.5 for non-islands. This is confirmed by the lower penetration of renewable energy on islands. Logically, more electricity is produced with dispatchable thermal assets that result in a way lower Energy Affordability score for islands, with an average of 37,3 compared to 55,2 for non-islands.

# 2. THE CURRENT SITUATION OF POWER GENERATION ON ISLANDS

The lack of interconnection with mainland grids and the limited capacity of transmission and distribution networks can make it difficult to stabilize the grid and maintain a reliable power supply. The integration of renewable energy sources into the power grid has become increasingly complex. This is particularly true for islands, which cannot see rapid growth in renewable generation without the power interconnections necessary to manage the associated challenges. That’s why the integration of renewable energy sources into the existing energy grid of islands is going to be more challenging than on the continent.

The concept of Non-Interconnected Island Power Systems (NIIPSs) has a perfect example in Greece (Europe) comprised of 100 inhabited islands, 60 of which are not interconnected to the mainland grid, forming 32 isolated electrical systems. They collect 15% of the Greek population and 10% of the total electricity consumption.

Three aspects stand out in this situation: the importance of the thermal power plants in the island energy systems, the state of affairs regarding renewable generation on islands, and the complex solution of energy storage through batteries.

## 2.1. Thermal Power Plants

Thermal systems form the basis of the current generation mix on islands. They provide a reliable source of energy, but they also have significant environmental impacts and are vulnerable to supply disruptions. While a decarbonized energy future of islands does not allow fossil fuel-based generation, the transition period requires optimal solutions to accelerate the clean energy transition, taking into account the existing system[4] . A significant part of the thermal fleet on islands is beyond decades of age, rendering them almost obsolete. While they could be replaced with renewable generation assets, the lack of flexibility and reliability of the thermal generation fleet on islands has become an obstacle to renewable energy integration and the security of supply.

> **“We live in a coal-power-plant-dominated island due to its richness of minerals and coal. Stakeholders are committed to energy transition, but it will take several years and a huge investment”**
> Power Plant Manager (Philippines)

That absence of flexibility in the aging thermal fleet reduces the amount of renewable generation that can be dispatched. High minimum loads of power plants translate to a significant thermal capacity that needs to be permanently connected, and an electricity system with several generators must be prepared to withstand incidences such as the failure of one of them. This requires having some units that are providing spinning reserve, working below their available capacity so they can rapidly increase their generation to compensate for a failure. These spinning reserve units would ideally be dispatched at zero to minimize costs and emissions and leave the maximum space for renewable production, but they must be dispatched at their technical minimum, preventing more renewable generation from being dispatched and causing curtailment in renewable production. Older units tend to have a higher technical minimum load, leading to higher emissions and costs and reducing the revenues of renewable generation.

In short, thermal power is the most important energy generation source on the islands today and in the near future. Moreover, it represents the very backbone of the energy transition to renewable energy, thanks to its ability to maintain a reliable grid. Nonetheless, thermal power plants need to be as flexible as possible, regarding their energy generation, to facilitate the so-called transition as smoothly and quickly as conceivable. The implementation of novel AI technologies in the thermal fleet may equip them with additional flexibility at an affordable price.

## 2.2. Renewable energy generation

Every island around the world has started to integrate wind, solar, and new geothermal energy sources into their electricity mix or has plans to do so soon. The International Renewable Energy Agency (IRENA) has studied the technical challenges of integrating variable renewable energy on islands. The basic principle for power system operation and planning is to deliver electricity to the final consumer at the least cost, while meeting pre-defined criteria in terms of reliability and quality of service. Historically, power systems on islands have been based mostly on conventional generation such as diesel and hydropower generation. Together with the network infrastructure, conventional generators provided all the services required to operate the system at given reliability and power quality levels.

The ability of the local power system to integrate renewable energy technologies while maintaining adequate levels of security and reliability is essential to achieving a successful transition. Integration of intermittent and not manageable renewable energy sources like solar photovoltaic and wind power intensifies the technical challenges that islands already face in operating their power systems.

The main problem islands face regarding renewable energy is the fact that these energy sources are variable. This means that a backup source is compulsory for the system, if it wants to be reliable. While on the mainland and the continent, having a large number of thermal power plants and a highly meshed power grid have allowed a quicker integration of variable renewable energy. The size of many islands, their often rugged terrain, and the limited number of thermal power plants make this integration more difficult without endangering the system's stability.

Utilities must carry out planning studies for integrating renewable energy to identify potential technical challenges and suitable preventive or corrective solutions. Failing to carry out technical planning activities may result in slower green technology deployment, the need to invest in expensive retrofitting of network assets, lower reliability of the power system, and having to curtail renewable production, impacting investment profitability.

The social pressure to transition to sustainable energy as soon as possible is balanced by the fact that planning, collecting the investment, obtaining the permits, building the renewable facilities, and starting to operate them may take years. Without forgetting that the amortization of the required CAPEX and the need for overbooked capacity available in the system will make the electricity bill more expensive for the mid-term.

As a sample, you can see below the evolution of generation by renewable energy sources (Wind power in GREEN and Solar PV power in YELLOW) in 6 different kinds of islands, showing that it is still a minority except in a developed and interconnected country such as Ireland:

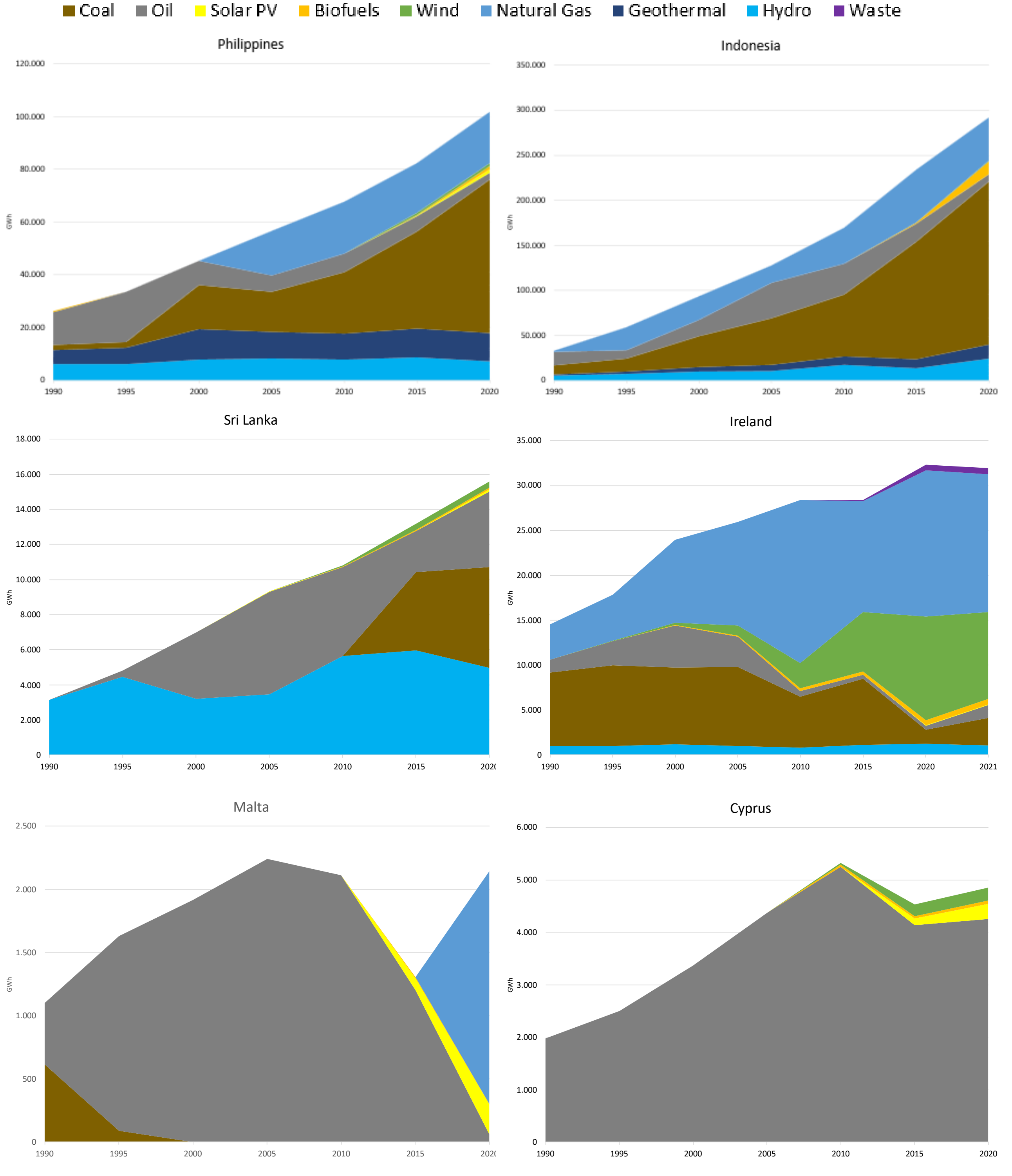


Figure 5 - Evolution of the Electricity Mix of 6 islands. Data Source: IEA, BP, and ADEX

## 2.3. Energy storage: batteries

Energy storage through batteries is, probably, the most popular “green” solution to the problem of the variability in renewable energy generation. It consists of accumulating the surplus of electricity generated by renewable facilities at moments of overproduction. Thanks to this system, the curtailments are minimized or even completely eliminated, and the electricity kept in the batteries will be used when renewable sources of energy are not available, getting rid of the necessity of thermal power plants.

Battery technologies can provide some hours of performance at a utility-scale grade. Unfortunately, they are not yet a viable solution in the majority of communities if there is a longer problem, such as an outage, a blackout, or even a natural disaster, due to economic and capacity reasons.

However, technological advances are being discovered every day, and funding does not stop flowing into the sector. 2022 was a year of acceleration in the growth of the global battery industry, growing up to $48,4 billion[5]. It is not an exaggeration to think that in the near future, energy storage through batteries would mean the final answer to the Energy Trilemma for islands.

In this context, for example, the Puerto Rico Electric Power Authority (PREPA) announced a tender for 1.5 GW of storage[6], this initiative being a part of its plan to rebuild the island’s power infrastructure with a stronger focus on renewable energy generation.

Pumped hydroelectric energy storage (PHES) is by far the largest-capacity form of grid energy storage available. Nevertheless, the specialist nature of the site required, needing both geographical height and water availability, make this option less feasible on islands. Suitable sites are likely to be in hilly or mountainous regions, and potentially in areas of natural beauty, making PHES susceptible to social and ecological issues. Thus utility-scale batteries seem the easiest option to deploy in many islands.

> **“We won’t achieve net zero without energy storage, but we are at the very start of market development. Compared to overall demand generation, storage capacity is almost insignificant.”**
> CEO of Renewable Energy Power Generator (Australia)

# 3. CHALLENGES AND OPPORTUNITIES FOR ISLAND ENERGY SYSTEMS

The current situation of island energy systems presents important challenges for communities, but it also presents challenges for the actors involved in energy generation and distribution.

In a survey conducted by ADEX about the biggest challenge for Energy Transition on islands, industry experts scored “Grid Frequency Stability” as the most important challenge with nearly half of the votes. “Flexibility of Power Plants” was the second option with one-third of the votes:

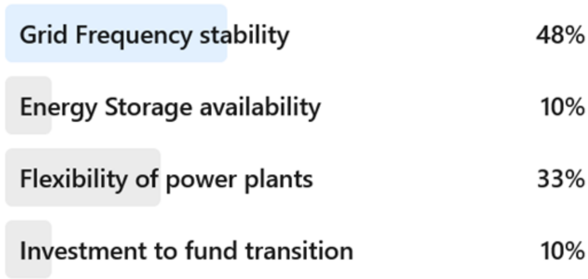


Figure 6 - Results of ADEX survey on Energy Transition challenges on islands

In this white paper, we will go deeper into 6 challenges we consider critical to the success of Energy Transition for islands:

- Stability of power grid frequency
- Renewable energy penetration
- Microgrids
- Interconnection of power systems
- The role of Thermal Power Plants
- The role of Governments

## 3.1. Grid Frequency Stability

Grid frequency stability is critical for the reliable and safe operation of an electricity grid. In the case of island energy systems, the importance of grid frequency stability is even greater due to the small size of the grid and the limited resources available for balancing the supply and demand of electricity. Any imbalance in the grid can quickly lead to power outages and disruptions in the energy supply.

The power grid frequency plays a central role in power system control, as it reflects the balance of power generation and demand:

- An oversupply of power leads to a frequency increase, while a shortage causes a frequency decrease. Large frequency deviations correspond to large power imbalances, which threaten system stability and may lead to large-scale blackouts.
- Frequency stability is regarded as a major challenge for the transition to a sustainable energy system, because renewable power sources do not provide intrinsic inertia.

There are several solutions available for maintaining grid stability on island energy systems. These solutions can be categorized into demand response programs, energy storage systems, flexible thermal power plants, and power-to-gas systems:

## Demand Response Programs

Demand response programs are designed to reduce or shift the demand for electricity during periods of high demand or low supply. These programs incentivize consumers to reduce their energy usage during peak hours and shift their usage to off-peak hours. This helps to balance the supply and demand of electricity and maintain grid stability.

## Energy Storage Systems

Energy storage systems can help to mitigate the fluctuations in grid frequency caused by renewable energy sources. These systems store excess energy during periods of low demand and supply it back to the grid during periods of high demand. The successful deployment of battery storage systems may be pivotal for the transition to more sustainable and affordable energy on islands.

## Flexible Thermal Power Plants

Flexible thermal power plants can help to maintain grid frequency stability by providing backup power when renewable energy sources are not able to meet the electricity demand. These power plants can quickly ramp up or down their power output to match the fluctuations in the demand and supply of electricity. They can also provide ancillary services such as frequency regulation and voltage control to maintain grid stability.

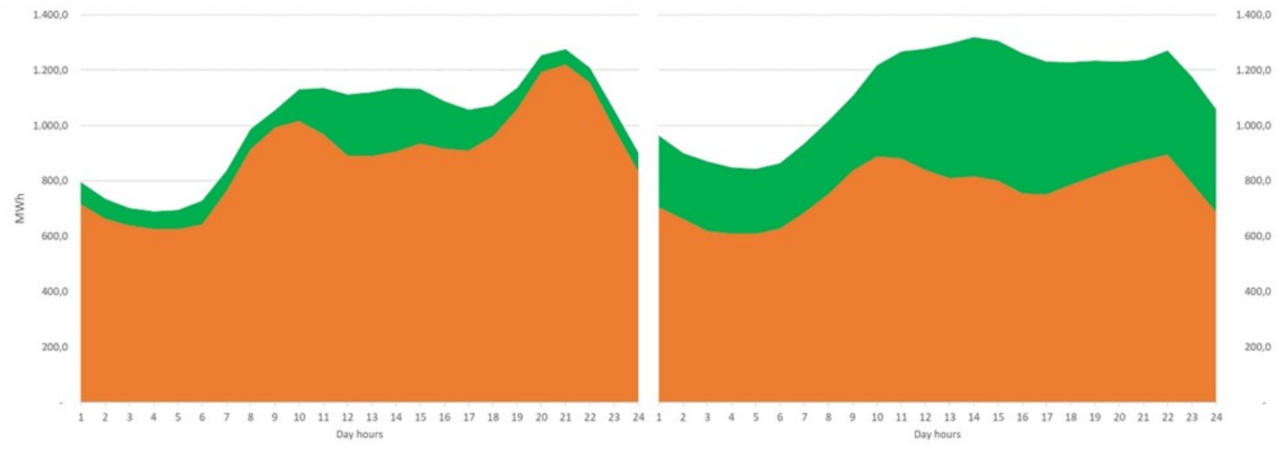


Figure 7 - Average working day electricity mix per hour in the Canary Islands (February 2023, left – July 2022, right)

## Power-to-Gas Systems

Power-to-gas systems are a relatively new technology that can help to balance the supply and demand of electricity in island energy systems. These systems convert excess renewable energy into hydrogen gas or synthetic methane, which can be stored and used as fuel for power generation or transportation. This helps to reduce the dependence on fossil fuels and maintain grid stability.

## 3.2. An increasing renewable energy penetration

Global electricity demand is expected to grow by 2.4% in 2022, bringing it in line with its average growth rate over the five years prior to the Covid-19 pandemic, according to the International Energy Agency. While electricity demand is currently expected to continue on a similar growth path into 2023, the outlook is clouded by economic turbulence and uncertainty over how fuel prices could impact the generation mix.

Because the output of renewable energy generators is difficult to control (except for curtailment actions) and difficult to predict with high accuracy, these technologies are more challenging to integrate into power systems as compared to other technologies, such as conventional fossil-fueled generators or dispatchable renewable generators (e. g., biomass, geothermal and reservoir hydropower).

According to IRENA[7], the main technical challenges that may arise when integrating an important renewable energy generation in island power systems are:

- Ensuring sufficient firm capacity, to guarantee that the generation fleet will always be able to supply the electrical load reliably.
- Addressing flexibility needs, in order to accommodate the intraday variations of the net load with the generation system.
- Secure system stability, as its response to grid disturbances drops due to the electro-mechanical characteristics of the system with high penetration of renewable energy.
- Maintaining power quality, as the integration of power electronics-based renewable energy sources (e.g., solar power) can lead to power quality issues

To increase renewable energy penetration, islands need to invest in energy storage technologies such as batteries and pumped hydro storage. Energy storage technologies can help smooth out the variability of renewable energy sources and provide backup power when renewable energy sources are not available. In some cases, this has led to islands achieving energy self-sufficiency through renewable energy. For example, the island of El Hierro in the Canary Islands (Spain) archipelago is entirely self-sufficient through its wind and hydroelectric power plants.

> **“The lack of sufficient inertia of renewable sources to arrest system frequency rate of decaying after a power system overload, in order to prevent system cascading collapse and rotational equipment damage due to prolonged under-frequency operation, is an important problem for IPP and Grid operators in small islanded electric systems”**
>
> C. Reyes, President at Ecoelectrica (Puerto Rico)

## 3.3. The introduction of microgrids

One solution to the challenges presented by renewable energy sources could be the use of microgrids. Microgrids are self-contained power systems that can operate independently or in parallel with the main power grid.

Sophisticated microgrids enable local energy generation equipment, such as conventional generators, renewable sources, and energy storage, to continue providing electricity to the local grid, even if the larger grid experiences disruptions or in islands where no connection to the main grid is available. Furthermore, microgrids facilitate the coordination of local energy assets, leading to reduced costs, prolonged energy supply, and additional revenue through market participation.

By generating and consuming electricity locally, microgrids can reduce dependence on imported fossil fuels and improve energy security. They can also help to reduce additional energy costs by optimizing the use of renewable energy sources, enhancing system reliability, and reducing energy losses during transmission.

Roof Solar Panels are democratizing the independency from formal Grid operators. Microgrids powered by new independent aggregators that are engaging homes and shops at a very local level

For example in Puerto Rico, business owners and residents will run a microgrid through a nonprofit called the Community Solar Energy Association of Adjuntas, which will sell electricity to the commonwealth's grid through a power purchase agreement. Money saved by not buying power from Puerto Rico's main power company will support maintaining the microgrid and starting new community projects.

However, due to the characteristic difficulties of islands (size and geography), microgrids are not available in all circumstances.

> **"Microgrids are the best solution for energy systems with out-of-reach or unstable central grids due to their independence and self-sufficiency. However, there are still challenges to be resolved e.g. battery price, grid frequency stability, etc."**
> F. Alhaq, Operations Manager at PT KEP (Indonesia)

During 2017 and 2021, the European Union ran a project called SMILE[8] (Smart Island Energy Systems) that consists of the study of the energy systems of different small islands in Europe. The goal was to evaluate the capabilities of small islands to enhance the security of their energy systems. The islands of Orkneys (UK), Samsø (DK) and Maderia (PT) were the regions selected. The three SMILE islands had the potential for the development of energy communities or community energy projects, but the development of microgrids is more complex. Despite potential benefits, the project concluded that there were more barriers to their development. However, if microgrids are established on these islands, they could provide essential services to local or mainland grid operators.

Research[9] in 2018 carried out by academics from the Max Planck Institute for Dynamics and Self-Organization in Goettingen (Germany) and Queen Mary University of London (UK) along with colleagues in Juelich (Germany) and Tokyo (Japan) found that splitting a large grid into small microgrids – as a way of integrating additional renewable power generation or creating smaller, mostly independent grids – will lead to larger frequency deviations which can potentially damage sensitive electronic devices. Researchers concluded that microgrids are therefore only an option if current frequency regulations are made less strict.

In conclusion, the difficulties of its development in islands make the microgrid a solution to the island Energy Trilemma that is not going to find a lot of scenarios in which it is applicable.

## 3.4. Bridging the islands

There is a great opportunity to solve the Energy Trilemma on islands through the interconnection of power grids, not only between islands but even with the mainland, strengthening energy security and transitioning to renewables through efficient resource sharing. This will allow islands to become a source of renewable energy that can be transferred to other areas when needed.

Bridging isolated Power Grids is a major undertaking that entails the development of hard and soft infrastructure, including transmission facilities and electricity trading mechanisms. The key challenges are deploying a submersible high-voltage line, which is quite costly, and investing in transmission grid upgrades to absorb the high penetration of variable renewable energy.

Two examples show us the benefits for citizens on both islands and the mainland:

- The ASEAN Power Grid to connect the Energy Systems of their 10 Member States (Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Myanmar, Lao PDR, Cambodia and Brunei Darussalam). This is an initiative to construct a regional power interconnection to connect the region, first on cross-border bilateral terms, and then gradually expand to sub-regional basis and subsequently leading to a total integrated South East Asia power grid system.

- The Tyrrhenian Link. This will hook up Sardinia with Sicily, Italy's other large island, and Campania, the region around the southern city of Naples. The result will be an enhanced stability of the electrical system of the two islands and allow a more flexible integration of the renewable energy sources, necessary to fulfil the objective of phasing-out of coal power plants by 2025. In some cases, gas is seen as a temporary alternative, but there is no gas in Sardinia, and therefore this phase can be "skipped" altogether.

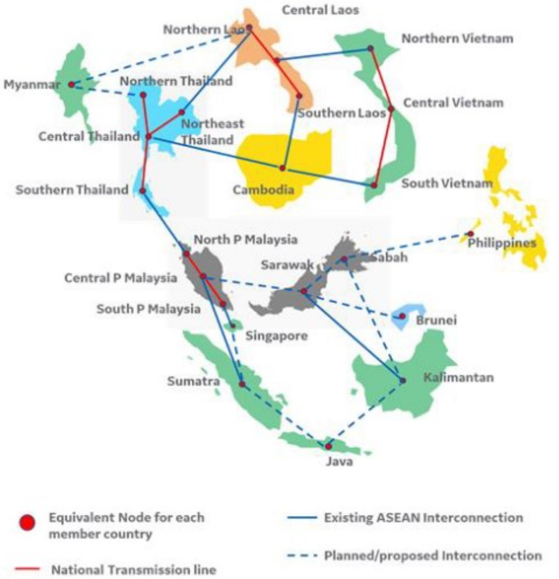


Figure 8 - The ASEAN Interconnection Masterplan Study (AIMS)

## 3.5. The new role of thermal power plants

It is in this context that thermal power plants become the most efficient and effective solution for the island Energy Trilemma. These sources of energy are, at the moment, the only ones that can secure energy generation and distribution in different scenarios that islands can present at an affordable price for their citizens. It is obvious that thermal power is going to be the main source of power in the islands in the short and middle term.

Although this affirmation could seem like a misstep for the energy transition to renewable sources of power, nothing could be further from the truth. Thermal power plants are the main characters in this energy transition. Thanks to their flexible capabilities, these generators are the only ones that allow renewable power plants to integrate into the energy systems without jeopardizing the reliability and security of the grid.

Thermal power plants have traditionally played a central role in island energy systems, providing baseload power and maintaining grid stability. However, the increasing penetration of renewable energy sources and the development of energy storage systems and microgrids have led to a re-evaluation of the role of thermal power plants in island energy systems.

One approach is to retrofit thermal power plants to utilize renewable energy sources, such as biofuels or waste heat recovery systems, to reduce the reliance on fossil fuels. As a reference, Waste-to-Energy means 4% of the electricity mix in Japan.

Another approach is to shift the role of thermal power plants from baseload power providers to backup power providers. This can help to reduce fuel consumption and greenhouse gas emissions, while still maintaining grid stability during periods of low renewable energy generation. However, it is true that a lot of thermal power plants, especially the older ones, do not have the required flexibility to allow the mentioned transition. This is why, in the short term, the flexibility and dispatchability of thermal power plants must be the first thing to be tackled regarding the strengthening of energy systems on islands.

Novel software technologies such as AI, Machine Learning, or Digital Twin tools can get quicker and much cheaper results than conventional hardware retrofits to achieve the desired flexibility.

Either if an island is planning to phase out thermal power plants entirely and rely solely on renewable energy sources or if it is planning to retain some thermal capacity available, the coexistence of power plants and renewables is mandatory for years. The role and operational behavior of power plants will be different from the ones they were designed for, so we need to make them as efficient and dispatchable as possible, while they remain in the mix.

> **"Thermal Power Plants will be the stabilizers of the system at the cost of increasing their O&M expenses due to more cycles of maneuvers and partial loads."**
> CCGT Operations Manager (Canary Islands, Spain)

## 3.6. The new role of Governments

Modern societies have been and continue to be ordered for a climate that no longer exists; therefore, the projected rapid changes in the climate system will pose major, evolving risks for economic, social, infrastructural, and governance systems in the coming decades.

Many nations are working to limit the impact of climate change. However, given the time it takes to transform the global energy system and for the climate to respond, the climate will continue changing at least until global greenhouse gas emissions fall to zero.

In the coming decades, more intense and frequent weather extremes and the uncertainty of the changing climate will present a range of economic and financial risks to the economy and will confront Governments with related fiscal challenges. Physical climate risks can be managed by anticipating and planning for coming changes in climate, a process known as **adaptation**.

Key parts of Governments' new role in a warming world are (1) to help people adapt to climate change and try to make that adaptation less expensive and (2) to support people to make smarter decisions on their own. It will often mean telling people things they will not want to hear:

- How we are going to adapt to a warming world and what it is going to cost.
- How risks of climate change look like, and
- How climate adaptation might completely append how we think about almost everything a Government does: how they spend money, how they influence people to do or not to do things, etc.

> **"Governments need to involve inhabitants as much as possible in energy literacy and new technologies."**
> G. Stravopodis, Grid Expert at European Science Communication Institute (Greece).

From their new role, Governments can contribute to solving the Energy Trilemma in three directions:

1. Promoting laws and security for investors to transition to sustainable energy as soon as possible: reducing permits for renewable facilities, providing credit taxes, creating capacity markets for reliable assets, forcing the flexibility of existing thermal power plants, or even subsidizing the decarbonization of the electricity mix.

   For example, India has ruled flexibility requirements for coal-fired power plants, through Central Electricity Authority Regulations and a formal roadmap to achieve a 40% minimum technical load.

2. Accelerating innovation in low-carbon solutions: not only through the regular R&D grants but particularly with the Public Sector becoming the first big user of innovations.

   As a sample, Spanish Administration is involved in an Innovative Procurement Program, so they lead other private corporations and citizens by example and provide commercial traction and a testbed for some disruptive technologies that can arrive sooner to the market.

3. Budgeting the consequences of climate change: many weather-related events are not forecasted in public budgets. Citizens' decision to build a house in a flood-risk area can imply an extra cost for the Government, if tomorrow there is a natural disaster.

   For example, the US White House 2023 Report of President[10] foresees the creation of a classification of risky areas (by wildfires, floods, etc.) in order to incentivize or disincentivize mortgages, insurances, investments, etc. So, private construction, crop plantations, or public recovery of affected areas would be conditioned by these potential rules.

Regional or national governments on Islands will have an exacerbated responsibility, as the three directions above are even more relevant in their isolated territories than on the mainland.

# CONCLUSIONS

The transition to renewable energy sources in island energy systems presents several challenges and opportunities. Islands face unique challenges due to their small size, limited resources, and isolation. However, that reduced size is also an advantage that makes it easier to deploy renewable energy sources and energy storage technologies. In this global race to transition energy systems, some islands can become pioneers and even skip steps that other regions with critical land masses have had to pass through (e.g., coal to gas to renewables). Their size and unique characteristics make them ideal testbeds for disruptive new technologies and solutions.

The Energy Trilemma on islands can be fixed through careful planning and management. Islands need to invest in energy storage technologies, flexible and smart grids, and microgrids to integrate renewable energy sources successfully, minimize the impact of their variability and intermittency, and improve grid stability.

Nevertheless, this is a long process that might require relevant investments and lengthy deployment schedules (tenders, permits, purchases, commissioning, etc.). We must be aware that this can take 10 years or longer in several cases, so it is pivotal to make a plan to maintain and optimize current power generation systems.

The transition can also provide several opportunities. In the long term, Islands can reduce their dependence on imported fossil fuels, to increase the independence from third parties, control the electricity price and reduce greenhouse gas emissions. New jobs can emerge, and others might require adaptation.

However, to achieve a successful transition towards renewable energy sources, it is important to consider the unique characteristics and challenges of island energy systems, including the importance of grid stability and the role of thermal power plants. Islands must balance the energy trilemma of security, affordability, and sustainability. This requires a holistic approach, careful planning, coordination, investment, and collaboration between various stakeholders, including governments, energy companies, and local communities.

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