How to Accelerate the Deployment of Renewable Energies in Atlantic Insular Energy Systems

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INTRODUCTION

Energy technology and the use of various energy sources have continuously evolved alongside human development. This evolution is driving us toward a planet that consumes cleaner energy more efficiently.

Until the onset of the Industrial Revolution, biomass had always been the dominant fuel used by humanity. It is important to note that biomass is also the dirtiest fuel per unit of energy produced, when evaluated from the standpoint of pollutant emissions and health impacts.

Humanity transitioned from biomass to coal, a cleaner fuel than the former. This shift also helped save many forests, as the planet's population was increasing significantly. From coal, we began transitioning to oil as the dominant fuel in the latter half of the 19th century. Oil is even cleaner than coal, reducing environmental degradation, such as deforestation and coal mining, whether open-pit or underground. From oil the transition has been moving somewhat to natural gas, also a cleaner fuel than the former. We are now gradually moving towards the use of modern renewable energies (excluding biomass), mainly electrical, which are the cleanest and aim to replace all fossil fuels and nuclear energy. This evolution has been particularly significant for insular energy systems, as these territories often lack fossil fuels.

Traditionally, the number of inhabitants on islands was largely limited by the territory's ability to produce food and other water-related resources. However, the transition from biomass to fossil fuels provided islands with a great opportunity, due to an exponential increase in fuel trade. As a result, many islands today are considered overpopulated relative to their indigenous resources without facing the risk of supply shortages.

The challenge now arises with the deployment of modern renewable energies, particularly solar, wind, and hydroelectric, as they once again require significant land use, which insular systems are often not well equipped to handle. This issue becomes apparent when reviewing the territorial planning instruments of these areas, which are typically developed slowly due to the need to build consensus on long-term land use. It is evident that in many places these planning instruments did not account for the future location of renewable generation and storage.

In some areas, this has led to tensions, particularly when it comes to using rural land, which may be scarce on islands, located near inhabited areas, or when placing power and pipelines lines that could affect communities or the landscape. The proponents of renewable generation and storage on rural land recognize that the rights generated can create business opportunities spanning several generations, and they pressure local administrations and politicians to quickly adapt the land planning to accommodate these installations. This generates social and political tensions that need to be mitigated.

In parallel, insular territories are generally unique and diverse, which can serve as laboratories for accelerating the energy transition towards renewable systems in the Atlantic region. Each of these territories can function as a laboratory where any innovation can be tested comprehensively at a lower cost compared to continental territories. Atlantic islands, particularly those located in areas with extreme climatic conditions, can offer unique settings for testing the massive penetration of wind and solar energy, or a combination of both. These extreme climatic conditions may not necessarily mean abundant solar or wind resources but rather environments where it could be more interesting from a technological standpoint to place laboratories with extreme environmental conditions such as temperature, humidity, salinity, or dust. These territories exist somewhere in the Atlantic region.

DEFINITION OF AN INSULAR ENERGY SYSTEM

To properly frame the discussion, it is useful to first define what we mean by insular energy systems.

Geographically, islands are small landmasses surrounded by water, but from an energy perspective, some islands are interconnected through electrical grids, gas pipelines, or oil pipelines. These interconnected territories should not be considered as energy islands, but rather as part of larger territories upon which they depend for their energy needs.

On the other hand, many islands that are currently fully disconnected from other territories may, in the future, find it attractive to establish electrical or fuel connections with larger territories. This may be because interconnection technology is not sufficiently developed at present for long and deep paths, or simply because the economic resources are not available to pursue it. These territories would no longer be considered energy islands from a technical perspective.

For these reasons, the most appropriate definition of an energy insular system is one in which conditions make it economically unattractive to interconnect with larger energy systems compared to alternatives based on a combination of endogenous energy sources, storage systems, and locally produced fuels, which may or may not be renewable.

WIND AND SOLAR RESOURCES IN THE ATLANTIC

As mentioned earlier, the global energy transition to renewables primarily revolves around two energy sources: solar and wind power. This is because these energy sources offer the greatest global potential. Other renewable sources, such as geothermal, hydroelectric, marine energy in its various forms, and biomass, have characteristics that make them less feasible as general elements of the energy mix.

It is also important to note that within solar energy, photovoltaic (PV) technology has emerged as the most economical method for generating electricity in most inhabited regions of the world. Additionally, this low cost is expected to persist over the long term. Other solar energy variants, such as solar thermal, have proven less capable of generating electricity economically and require more maintenance compared to PV systems. Furthermore, solar thermal has a strong competitor in the production of heat and cooling from the combination of PV systems and heat pumps.

The other solar thermal technology, concentrated solar power (CSP), has also not achieved sufficient cost competitiveness compared to its main rival, PV technology. Moreover, it requires high levels of direct solar radiation and access to water for economic electricity production, which is only found in specific regions of the planet.

Given that the Atlantic is a vast region extending from northern to southern latitudes, it contains extraordinary locations offering high levels of both solar and wind resources. Therefore, technological recommendations for the Atlantic region would prioritize the deployment of renewable production technologies, with a focus on PV and wind power depending on the specific location's resource availability.

Another important factor is that the Atlantic region has diverse topographies, which also facilitates the consideration of storage systems, whether through batteries or pumped hydro. In insular systems, there may be a greater tendency towards batteries due to the scarcity of water and differences in elevation in many locations.

However, a challenge in this regard is the tendency of countries to export renewable energy surpluses through electrical transmission networks, reflecting political relationships. In the case of insular systems, these connections do not exist, necessitating reliance on their own endogenous resources, not only for renewable energy production but, in the increasingly near future, for storage systems that are preferably also endogenous.

Therefore, in insular systems, the limitations for defining an efficient energy mix are more constrained by the lack of interconnections with other energy systems that could complement both generation and storage.

INTEGRATION OF RENEWABLE ENERGIES IN INSULAR SYSTEMS

In insular power systems, particularly in the smaller ones, a paradox occurs. These systems are the most attractive in terms of costs for the massive penetration of renewable energy in the early stages, but they are also where achieving complete carbon neutral scenario is the most expensive. This is especially the case when political goals demand total energy independence based on local renewable energy sources.

In this context, extreme positions, particularly in energy matters, that require the total abandonment of fossil fuels in the short term, without strong technical backing, often lead to increased costs, which must be avoided. Therefore, although all territories aspire to full carbon neutral scenarios and energy independence, it is clear that, in order to reduce costs in energy systems, some level of renewable fuel trade will still be necessary. This trading would allow for the optimization of the final cost per unit of energy consumed in the insular system.

In the case of the Canary Islands, for example, we are currently observing that, according to our grid codes established by the system operator, the penetration of renewable energy without storage hardly exceeds 20%. This is because the renewable energy sources on which the electrical system primarily relies—photovoltaic and wind power—present uncertainties and steep power ramps, both up and down, making it necessary to have access to reserves of primary, secondary, and tertiary regulation. As a result, once renewable penetration exceeds 20%, various storage systems must be introduced to continue increasing renewable penetration.

Regarding storage systems, there is some controversy around the competition between pumped hydro energy storage and batteries. However, once these options are analysed, it becomes clear that without an adequate hydraulic resource or prior territorial planning, developing pumping technology is highly complicated, especially if there are no significant elevation differences. Therefore, territory is essential, as hydroelectric energy consumes much more surface area per unit of energy than batteries. In the case of insular systems, batteries are proving more competitive in the short term.

Additionally, insular systems often require not only short-term storage systems (hours or a few days) but also seasonal storage systems to address fluctuations in renewable energy resources over longer periods. Returning to the Canary Islands example, wind resources show a significant seasonal cycle, particularly scarce in the autumn. These seasonal cycles are also seen in hydro resources, often attributed to El Niño and La Niña effects. Therefore, as we approach the goal of 100% renewable energy penetration, it becomes increasingly necessary to incorporate storage systems capable of addressing demand fluctuations over weeks or months due to prolonged resource availability variations.

In this context, hydrogen is gradually emerging as a key energy vector, either directly or through its transformation into another renewable fuel, which is more versatile in meeting consumption needs.

This suggests that, in some cases, when renewable energy penetration reaches around 80%, hydrogen will play a fundamental role in achieving 100% renewable penetration. Moreover, hydrogen offers a great advantage for insular systems: its minimal territorial impact. In other words, the land use required per unit of energy stored is comparable to that of fossil fuels and much lower than that of batteries. It is always important to remember that many of the world's islands suffer primarily from a shortage of land, making these low-land consuming storage systems particularly attractive.

Another important aspect of hydrogen is its role in introducing sustainable fuels for maritime and aviation transport, which are of strategic importance for insular systems. Therefore, it is essential that insular energy systems have hydrogen production capacity.

MARKET ASPECTS IN INSULAR SYSTEMS

In many smaller island territories today, the energy sector often operates with monopolistic characteristics, both for electricity and fuels. These are operational schemes derived from highly centralized production methods, where natural monopoly situations were inevitable. Additionally, in islands belonging to countries located on continental Europe, the regulation defining how demand prices are assigned is often artificial, not directly influenced by costs and/or supply and demand rules.

However, renewable generation—particularly photovoltaic energy—is decentralized. This means that, de facto, energy systems are moving from centralized energy systems, where a single actor holds a dominant position, to systems with a multitude of actors who are energy producers (currently only for electricity; but in the future they will also be able to produce and store hydrogen). This hydrogen could be supplied via distributed generation. Similarly, batteries are being established as elements of distributed storage, acting as flexibility resources for the electrical system. Therefore, the idea of natural monopolies – the regulation of which assumes only one actor, and a scenario, particularly in the electricity sector, in which market mechanisms for price assignment are not established but rather rely on a dispatch regime – should lose all relevance.

Thus, it is considered appropriate and viable to establish electricity markets in insular systems in the near future, given the growing role of distributed generation and soon also distributed storage. This also will make price assignment more efficient.

In the case of the Canary Islands, a paradox arises: conventional generation is regulated by the dispatch regime with price determination based on an economic merit order. However, renewable generation is sold within the Spanish mainland electricity market, although it is actually injected into the Canary Islands' electrical grids. This means that this system is halfway to having an electricity market for all electricity production units, although the current situation generates many inefficiencies and incorrect price signals. For example, electricity can be consumed in the Canary Islands at very low prices during the last months of autumn, when renewable resources (mostly wind) are scarce, and photovoltaic production is lower than in summer. However, the intense wind resource in mainland Spain results in very low demand prices in the whole country, Canary islands included.

Therefore, it is time to introduce market mechanisms in insular electrical systems, both for generation and storage. These market mechanisms could even cover smaller spatial areas if the collective self-consumption regulations, currently developed at the European level, are also applied..

TECHNOLOGY ADVANCES FOR CREATING ELECTRICITY MARKETS IN INSULAR SYSTEMS

In addition to the idea of establishing local markets, insular electrical systems could also evolve into what could be called capacity markets based on batteries and renewable fuel generation. A range of technological advances is being implemented and will lead to a more complex but also more efficient future.

It is important to highlight the European regulation on electricity markets and the promotion of renewable energies derived from the Paris Agreement of 2015. This new regulation places European citizens at the center of the energy transition to achieve net-zero emissions by 2050. To this end, very interesting concepts have emerged, such as renewable energy communities, citizen energy communities, active consumers, and independent aggregators. All these entities are, to varying degrees, based on distributed energy generation and storage, which can be shared, and the ability of communication networks and algorithms (likely using AI) to manage all distributed generation and demand connected to the system.

Starting with energy communities, these are of interest in insular systems as they are tools that can provide greater cohesion to the structure of collective self-consumption, both in generation, consumption, and storage. The active consumer is a more advanced figure that simplifies the relationship between producer and consumer, adapting it to the future. Lastly, the independent aggregator is a new figure in the electricity sector that seeks to optimize generation and demand in a distributed manner, independent of the interests of retail companies. It is clear that these entities hold significant potential in insular systems, where market rules are more limited, and the justification for natural monopolies is more pronounced. They can help drive the technological revolution associated with achieving carbon neutrality without requiring substantial regulatory changes.

For all of this, the development of technology is necessary. This technology would be highly beneficial if demonstrated in selected Atlantic insular systems based on their characteristics and the availability of endogenous resources. Additionally, it is crucial that these devices be interoperable. This is particularly important because if distributed generation and storage bring the possibility of establishing local markets in insular systems typically governed by natural monopolies, it would make no sense for these monopolies to persist through the proprietary control of devices that enable the major leap towards emissions neutrality. The European Union recently established this in its energy efficiency Directive for Efficiency in Buildings, mandating that all devices contributing to system flexibility must be interoperable. This interoperability must also extend to logistics in decentralized renewable fuel production.

This leads to another key aspect, the resilience of energy systems. Concepts like grid-forming inverters (GFI) will make electrical systems more resilient to extreme weather events, as was demanded in Puerto Rico. These GFIs, which are still being introduced into European and U.S. regulations, will enable faster reconnection of unaffected electrical zones after severe weather disruptions. This will allow insular systems, which are not interconnected to stronger continental grids, to better handle such incidents.

RENEWABLE FUELS FOR AVIATION

Finally, the process to reach carbon neutral emissions involves new energy technology and regulation reaching the maritime and aviation transport sectors. For aviation, this means progressively increasing the blend of sustainable aviation fuel (SAF) with kerosene. Many insular energy systems, especially those where tourism plays a central role in the economy, fear that SAF mandates will reduce their competitiveness due to rising transportation costs and have requested exemptions from these mandates.

However, the SAF blending requirement with kerosene could present not only a necessary path to reaching carbon neutral emissions, but a significant opportunity to address another major issue in insular systems: municipal solid waste (MSW). Through processes like gasification of MSW, and Fischer-Tropsch with hydrogen upgrading, a substantial reduction in waste volume could be achieved.

Many insular systems, due to scale economy issues, either poorly manage or fail to treat their waste. The Atlantic region could coordinate its insular systems to centralize waste treatment, producing SAF and contributing to more sustainable air transportation.

A similar strategy based on waste-to-energy processes should be considered for maritime transport, particularly for bunkering.

CONCLUSIONS

Energy insular systems are defined as those where it is economically unviable to interconnect with continental systems compared to maintaining their isolation. The Atlantic insular energy systems face several challenges by 2050, primarily concerning land use for energy generation, storage activities, and renewable fuel production, areas in which they seem inadequately prepared.

However, the diversity of insular systems in the Atlantic offers countless locations that could serve as real laboratories for testing energy technologies that can later be deployed on a larger continental scale.

Regarding resources, it is clear that the Atlantic region must prioritize photovoltaic and wind energy, along with improving electrical interconnections between many African and Central and South American countries. This would ensure that the energy mix resulting from the transition away from fossil fuels is as efficient as possible concerning the endogenous resources of the various regions comprising the Atlantic zone. However, in the case of insular systems, which will not pursue interconnections as defined here, scenarios of strict energy independence could be tested and later projected on a larger scale. These scenarios would first focus on batteries as storage systems, but for total carbon neutrality, they will need to be also based on other systems that address seasonal storage demands. In this regard, hydrogen, from which other renewable fuels can be derived, presents the greatest potential. All of the above should be supported by proper territorial planning for the new energy infrastructure.

The involvement of many new actors, particularly distributed energy producers and storage providers, indicates that the time has come for local markets to economically replace the natural monopolies that have traditionally managed insular energy systems. This shift must be accompanied by new energy actors and the interoperability of devices in logistical networks and energy supply and demand flexibility, providing greater market guarantees.

Finally, the opportunity to centralize waste management in Atlantic insular systems should be leveraged to produce SAF, reducing the environmental impact of air transport and MSW.