INNOVATION IN ISOLATION

ISLANDS AND THE ENERGY TRANSITION

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Islands are uniquely situated to become leaders of the energy transition. Typically, the ability to lead a technological transition is determined by a nation's or company's capacity to invest in research, manufacturing, and installation. These wealthy entities have the ability to support early-stage development, quickly expand production of new technologies, and distribute these technologies in well-established markets.

However, when it comes to the transition to renewable energy, technology development and production is only half of the equation. Other factors, such as public support, logistics and management, and local leadership quickly come into play. Leaders in the energy transition are those who can demonstrate that deep decarbonization is achievable, and that economies and societies can thrive within a zero-carbon energy system.

Those leaders are not necessarily the biggest or richest countries, nor are they necessarily the countries or states where renewable energy technologies can be deployed most cheaply. They are the communities that are able to switch quickly and galvanize public buy-in through the use of another tool: strong and innovative public policy.

Although islands often lack access to financing and affordable manufacturing, they have every reason to embrace renewable energy and sustainable local solutions. Investors should, therefore, feel confident in supporting decarbonization efforts in small island states and nations where the community and local leaders are highly motivated to embrace and support new energy investments.

For one, islands are uniquely vulnerable to climate change, the consequence of inaction on carbon emissions—not necessarily in terms of aggregate economic loss, but in terms of the risks of catastrophic system failure. Islands also experience some of the highest energy costs and resource insecurity and are often home to important and unique ecosystems. These ecosystems can be extremely vulnerable to the existing energy infrastructure serving island communities.

There is also a unique investment opportunity inherent in island states: they face an acute version of the renewable energy challenges faced by the rest of the world—namely, limited land area and the inherent variability and intermittency of renewable energy resources. While this presents a considerable challenge

EXAMPLE 1

GALAPAGOS ISLANDS

Because of their unique ecological and historical significance, the Galapagos Islands have been remarkably successful at attracting funding for renewables deployment. These projects have begun to displace the local dependence on diesel fuel. This transition has been led by Ecuador's Ministry of Energy and Non-Renewable Natural Resources in collaboration with the islands' primary electricity company Elecgalápagos.

This effort to decarbonize the Galapagos energy supply is primarily driven by concerns over the vulnerability of local habitats to diesel imports and diesel spills. This concern was catalyzed by several destructive oil spills near the island ecosystem over the last decade, including an oil tanker incident in 2001 and another that was dramatically caught on film last year (de Moura 2019).

for energy planners, it also offers a valuable learning experience with minimal financial risk owing to the smaller size of the energy system.

With sufficient external financing for renewable energy projects, island communities could be powerful leaders in the energy transition and become hubs of innovation and experimentation—if a policy or system can balance load on an island, it can certainly help balance load in far more integrated and robust mainland energy systems. This provides investors with perhaps the best reason of all to invest in local island energy projects: it's not just about the return on investment, it's about developing widely applicable energy solutions.

This paper will discuss several of the reasons why islands are uniquely situated to lead the world in deep decarbonization. In doing so, a number of case studies from islands around the world will be discussed. The success and failures that each of these profiled islands has experienced in relation to their respective energy systems offer important insights into the opportunities and challenges inherent in the nature of isolated and small-scale energy systems.

These islands were chosen because of their unique energy history over the last several years and because all of them share a number of traits that make them especially good illustrations of the nexus between energy, ecosystems, and economy that islands around the world face.

These five islands:

1. Are home to at least one UNESCO natural world heritage site, meaning that they all encompass areas of profound ecological significance.
2. Have a resident population of less than 300,000 people.
3. Are sub-national entities, meaning that they are, to a varying extent, subject to an external centralized government.

In contrast, these islands intentionally represent a range of economic and governance capacity to change their energy systems and have made varying levels of progress in cutting their dependence on imported fossil fuels.

EXAMPLE 2

MADEIRA

Madeira has received millions in EU financing to increase local energy generation as part of the Union's Cohesion Fund, an effort to support less financially stable and outlying member states (European Commission). This funding has been used to expand hydroelectric power plants and invest in wind energy.

Madeira's rate of renewable energy generation still lags far behind Portugal's national rate of approximately 45% (Rodrigues et al. 2012). Last year, Groupe Renault, the world's largest automaker, announced a plan to turn Madeira into the world's first "Smart Island," utilizing EVs, second-life batteries, and smart charging technology to promote renewables on the island (Bremner 2019). This is a perfect demonstration of an innovator using an isolated island as a laboratory for smart and clean technologies, while at the same time, helping the island improve energy affordability, security, and independence.

In Madeira's case, critical laurel forests, the rarest of ecosystems on earth, are not as threatened by coastal spills of imported fuels but may actually face more threats from the expansion of renewable energy and smart-grid technologies. The forests of Madeira are already threatened by poor land management practices and increasing urban development, and the expansion of energy infrastructure must be pursued carefully to prevent further destruction of this vulnerable habitat (Regato 2020).

UNIQUE REASONS TO DECARBONIZE

CLIMATE CHANGE

For many years, small island states have resolutely pushed for rapid and ambitious action on climate change in international negotiations; and for good reason (Rosenthal 2018). Although climate change threatens ecosystems and communities around the world, islands are especially defenseless in the fight against rising seas, changes in rainfall, and extreme temperatures.

In the Galapagos, for example, changes in ocean currents and weather patterns are disrupting treasured ecosystems. Flagship species and dozens of coral atolls around the world risk becoming entirely uninhabitable because of flooding (Casey & Haner 2018, McSweeney 2018). Yet despite this increased exposure to climate impacts, most small and remote islands depend heavily on fossil fuel energy owing to limited local generation capacity and a historic dearth of funding opportunities. Not only does this reliance on imported oil and gas further contribute to the threat of climate change, it also introduces a number of additional risks that islands could avoid by transitioning to locally generated energy.

TABLE 1: A SAMPLE OF ELECTRICITY PRICES ON ISLANDS AROUND THE WORLD AS COMPARED TO US AND GLOBAL AVERAGE PRICING. (EIA, DOE, IEA)

Name	Country	Population	Per Capita GDP	UNESCO Site	Current Energy Mix
The Galapagos	Ecuador	30,000	~$6,200 (for Ecuador, from the World Bank data portal)	Whole Archipelago	Wind farm meeting 30% of the island of San Cristobal's energy demands, a hybrid power plant on the island of Isabela, and an additional $55 million allocated for renewable construction funded by international institutions (Siemens, Lonely Planet, Eras Almeida et al. 2020).
Madeira	Portugal	268,000	~$18,100 (DREM)	Primary Growth Laurel Forests	Madeira's energy mix consists of 140 MW (763 GWh) from imported fossil fuels, 50 MW (113 GWh) of locally generated hydroelectric power, 17 GWh generated from locally produced solid waste, and approximately 10 MW (17 GWh) of wind power. The island is 80% reliant on fossil fuels. (Rodrigues et al. 2012).
Yakushima	Japan	13,500	~$32,000 (Japan Statistical Yearbook, 2019)	Whole Island	Yakushima has a 58 GWh/y electricity demand. Although there is sufficient hydroelectric potential to meet all of the island's energy demands, only one third of electricity is generated from hydro power. The remaining two thirds of energy demand is met by fossil fuels. There is an effort to make it a CO2 free island using H2 by 2030 (Global Islands Network n.d.).
New Caledonia	France	270,000	~$30,000 (CIA World Factbook n.d.)	Lagoons and Reefs	New Caladonia uses 2,700 GWh of electricity, 87% of which is generated from fossil fuels. 8% is hydroelectric power, and the remainder (~6%) is from other renewables. The island is 95% percent dependent on imported fossil fuels including 20,000 bbl/day of petroleum imports. (CIA World Factbook n.d.), (Clean Energy for EU Islands n.d.).
Socotra	Yemen	60,000	$944 (for Yemen, from the World Bank data portal)	Whole Archipelago	Detailed data is unavailable, especially following the conflicts of the Yemani civil war, however the island is heavily dependent on diesel generators and steam power plants using imported natural gas. All fuel is imported (Aldaghbashy 2019).

EXAMPLE 3

YAKUSHIMA

Yakushima, like Madeira, has recently seen commitments by large private investors to convert the islands energy system to 100% clean and renewable energy (Global Islands Network n.d.). In this case, one of these private investors is based locally. Yakushima Denko Co., Ltd. is based on the island, which mines and produces silicon carbide (SiC)—a rare semiconductor and durable abrasive material (Encyclopedia Britannica n.d.).

Currently, 30% of the island's energy use is met by hydroelectric power, with most of this renewable electricity being used by Denko's operations (Global Islands Network). In 2002, Denko launched a campaign to ensure that Yakushima island was powered entirely by renewable electricity and hydrogen no later than 2030. Since then, both Honda and Nissan have invested in hydrogen fueling stations and EV infrastructure.

Given the corporate buy-in and relatively high wealth of this island prefecture, it is likely that Yakushima will achieve energy self-sufficiency relatively soon. This is an example of an island taking the resources available to it—silicon carbide—and leveraging that value to catalyze private investment and community buy-in. There remains some uncertainty about how expanding hydroelectric power generation on the island could affect the ancient forest ecosystems. Depending on how new dams are constructed, flooding, sedimentation, and stream continuity could have negative impacts on the island's ecosystems, communities, and tourism industry.

RESOURCE INSECURITY

Small Island states share a number of unique economic and ecological vulnerabilities. Islanders depend heavily on the resources of an inherently limited environment, and any resources not provided by the island (fuel, food, labor, etc.) must be imported at great expense (Ewing-Chow 2020). Any disruption in the supply of imported goods, or change in the natural balance of the island, can have extremely detrimental impacts on communities living there.

Under normal conditions, this trait manifests itself in higher-than-normal energy prices. While the global average price for electricity is $0.133/kWh (IEA 2020), Island electricity prices are often at least double that (see Table 1).

These high energy costs are a constant dampener on island economies and limit their ability to invest in infrastructure that could reduce imported fuel dependence. Even though locally produced renewable energy would be far more affordable for many island communities given the inflated cost of imported fossil fuels, it requires an upfront capital investment out of reach for many islands.

Under abnormal or extreme energy conditions, these resource vulnerabilities can be crippling. For example, Relying heavily on imported diesel leaves islands economically vulnerable to fluctuations in the price of oil. During price spikes, some islands can experience extreme financial distress that takes years to recover from (Patel 2015). In the event of a major fuel disruption, islands can be incapacitated by blackouts.

ECOSYSTEM VULNERABILITY

A third energy challenge faced by islands is the risk to local ecosystems. This challenge is indirectly related to their profound level of isolation from mainland infrastructure and supply routes. Marine transportation of fuel oil and diesel is a relatively risky method of energy delivery, but unfortunately the only delivery method available for most islands.

Transporting, off-loading, and storing imported diesel fuel inevitably results in spills (see Example 1 and Example 4). Depending on the severity and location of these spills, they can present a devastating threat the local environment, especially for islands that have exceptional marine or coastal ecology and those that depend heavily on eco-tourism. An intense dependence on imported fuels also presents a considerable risk to inland and forest ecosystems in the event of a disruption in fuel access. Under these conditions, islands can be ravaged by deforestation as residents look for any possible local source of energy to meet their most basic needs (See Example 5).

AN OPPORTUNITY TO LEAD

All of the above energy risks can be effectively addressed by developing local methods of energy generation. Many islands have access to abundant wind, solar, hydro, tidal, biofuel, or geothermal energy resources and could significantly cut ties with the fossil fuel industry. This transition away from imported, carbon-dense fuel could improve local economic and ecological resilience, reduce electricity prices, and dramatically reduce per capita carbon emissions. However, in order to catalyze this transition, islands need access to financing.

Island infrastructure is often badly in need of maintenance. High energy costs, limited financing, and a lack of local labor, expertise, and materials means that building or maintaining critical energy infrastructure such as transmission and distribution lines, load balancing systems, and fuel transportation networks without external support is not always possible.

A historical pattern of limited external support has left many islands with poor system efficiency, high energy losses, and reduced capacity to incorporate and balance new local generation. However, as the world races to transition to carbon-free energy, this dearth of financing for islands can and should change for the betterment of island communities and ecosystems, external investors, and ultimately, the world. Achieving this shift in resource allocation will require energy developers to reconsider the parameters by which they select new investment opportunities. To draw support, islands must coordinate local strengths and assets to incentivize external support (see Example 3).

Clean energy projects offer investors more than just the direct return on their investment from electricity sales. These projects also can provide valuable experience and lead to important insights that will improve the design, development, and management of future energy projects.

Islands are uniquely positioned to offer investors and developers valuable learning opportunities—for the same reasons outlined above (see Example 2). These opportunities are rooted in the fact that islands acutely experience one of the greatest clean energy challenges faced by energy systems around the world—resource intermittency and load balancing.

Locally available energy resources such as wind, solar, tidal, and hydropower are all, to some extent, variable

EXAMPLE 4

NEW CALEDONIA

New Caledonia, like the Galapagos, is home to UNESCO protected marine habitats including lagoons and reefs. These ecosystems are similarly vulnerable to the 20,000 BBL/day of fuel oil, diesel, and other petroleum imports the island requires (CIA). In 2017, a container ship called the Kea Trader grounded itself and eventually split in two off of New Caledonia's coast, spilling oil and drawing local opposition to the industry (Radio New Zealand). This incident, among other factors, led to a coalition of pacific islands with the intent of designing the "Pacific Islands Regional Marine Spill Contingency Plan" in 2019, further highlighting the serious risks these fuel imports pose, not only to the receiving island, but to all islands, communities, and ecosystems in the region.

Despite this, New Caledonia is not pursuing an energy transition to clean, local resources as ambitiously as some of the other islands discussed here. Like Yakushima, New Caledonia is relatively wealthy because of its plentiful nickel deposits (making up 20–30% of the world's known reserves), yet their Energy transition plan only calls for a 25% reduction in energy consumption, modest reductions in CO2 emissions, and 100% renewable electrification for public distribution by 2030, not including the energy demanded by local industry (Clean Energy for EU Islands Secretariat).

These commitments are still ambitious from a global perspective, but considering the potential for private investment and the possible avoided risks to the island's valuable marine ecosystems, they could be strengthened. New Caledonia's commitment to a 25% reduction in final consumption of energy is an interesting commitment not seen in any of the other island case studies discussed here. This is likely because communities in New Caledonia are already relatively well developed and do not expect considerable economic or population growth. This sets it apart from islands like The Galapagos and Socotra.

either on an hourly, daily, or even seasonal basis. Most renewable energy projects built on the mainland can be connected to large regional grid interconnections that allow this inherent variability of a single facility to be, to some extent, smoothed through aggregation and demand response. Islands do not have this capability. They are inherently limited in their ability to smooth generation through aggregation and cannot transport surplus electricity to areas of surplus demand.

Nor can they easily over-deploy generation, since land availability is often more restrictive on small islands than on the mainland. Wind, solar, and hydro power are all relatively land intensive, competing against the preservation of protected and highly valued ecosystems (see Example 2 and Example 3).

If islands are to become self-sufficient in carbon-free energy production, they must instead use storage technologies and policy innovation to balance load. Although an enormous challenge for local communities, this constraint also makes islands ideal locations for innovation as the world tries to develop new ways of transitioning to carbon free energy.

Load balancing across large interconnected grids can lessen the challenges of the energy transition, but alone cannot solve all of the limitations of renewable energy (Serpell et al. 2020). Islands have the potential to lead the world in the adoption of more experimental and innovative energy system transformations using technologies such as large-scale and seasonal batteries, renewable hydrogen production, heat recycling, and efficiency improvements as well as market levers such as local electricity price structures and efficiency incentives.

EXAMPLE 5

SOCOTRA

The Islands of the Socotra Archipelago is an extremely significant location for two reasons. Ecologically, the islands are home to a large number of endemic species including the alien looking Dragon's Blood tree (*Dracaena cinnabari*) which have been largely isolated for millions of years (Global Trees Campaign). The islands are also surrounded by thriving coastal reefs—an increasingly rare occurrence in our warming and acidifying oceans.

Socotra is also a highly sought-after territory for geopolitical and strategic reasons. Situated right at the mouth of the Gulf of Aden, Socotra is of extreme military significance. During the Yemeni civil war (2015–present) the island was captured by the UAE-backed Southern Transitional Council and was then just recaptured this month by Yemeni government forces (Baser 2020). During this period of conflict, and made worse by a series of cyclones that destroyed critical infrastructure, residents of Socotra have faced an increasing shortage of imported fossil fuels, a critical cornerstone of the island's energy system (IUCN).

These energy shortages, and resulting price increases, have forced many residents of Socotra to turn to local resources for fuel. This is causing a disastrous increase in deforestation of one of earth's most unique and valuable ecosystems (Aldaghbashy 2019). In June, 2018 IUCN recommended that World-heritage change Socotra's status to "in-danger" following these disruptions to the islands energy system. These tragic recent events demonstrate the enormous vulnerability of island states to energy system disruptions made worse by a dependence on imported fossil fuels.

CONCLUSIONS

Island communities stand to benefit more than anyone from cutting ties with fossil fuels, but few have the capacity to effectively pursue this transition on their own. The five case studies presented in this paper serve to illustrate the many nuanced ways that an island's economy and ecosystems can be dramatically impacted by the characteristics of its energy system.

Steps taken by Madeira, Yakushima, and New Caledonia demonstrate the important role of private investment and innovation, Socotra demonstrates what can happen to islands when critical energy systems fail, and Galapagos demonstrates that there is the potential for international buy-in to preserve these critically important ecosystems.

Supporting islands as they transition to clean, environmentally responsible, and locally generated energy will not only help to protect local ecosystems and communities, it will also help demonstrate to the world that society and global economies exist with, and even benefit from, a fully carbon-free energy system.

The challenges faced by islands are a distillation of the challenges faced by energy systems around the world. As the world begins to undertake the global energy transition towards clean and intermittent energy sources in an effort to avert climate catastrophe, the lessons, technologies, and policy innovations that emerge from small-scale island decarbonization initiatives could have global implications that far outweigh the modest investments needed to transform island energy systems.

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