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Solar PV in Island Contexts: Key Considerations

—Transcript of a webinar offered by the Clean Energy Solutions Center on 20 May 2019—
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Toby Couture Good day, everyone. Welcome to the International Solar Alliance Expert Training Course. This is Session 42, focusing specifically on Solar PV in Island Context. This webinar series is supported by the International Solar Alliance, in combination with the Clean Energy Solutions Center. This training is part of Module 7, which looks specifically at the issue of off-grid solar. Throughout the series, there's been a range of different topics, focusing on everything from policy to grid integration to the socioeconomic aspects. This module, number 7, focuses specifically on the issues, challenges, and opportunities of using solar in island regions.

So, a quick overview of the presentation before we dive in. We'll look at some of the key characteristics that Solar PV has making it attractive as a technology to meet energy and, in particular, electricity needs in island regions. We'll look at some of the characteristics of conventional power systems in islands. We'll look at cost and financing issues, as well as a few case studies before wrapping up. At the end, as with all of these ISA Clean Energy Solutions Center Training Series, there will be a knowledge check with some multiple-choice questions. So, let's get started.

The focus of this series, in particular, on island renewables is to try to convey the fundamentals of solar PV technology as they apply to island regions or what are often called off-grid systems in island regions, sometimes mini grids or micro grids. The aim will also be to understand innovations emerging to improve grid integration in island regions including innovations such as demand response and storage technologies. We'll look at the cost competitiveness landscape and a few case studies briefly looking at some of the islands around the world successfully scaling solar power.

So, why solar in island regions? The first and perhaps most obvious reason is that the insolation is abundantly available. Most island regions around the world benefit from comparatively good solar resources on a global scale, meaning that islands have, in most cases, abundant solar potential to meet their electricity needs. Other renewable energy sources like hydro and biomass are typically less available or have a restricted availability for a host of geographical and resource-related reasons. Solar, on the other hand, is fairly—widely and fairly readily available, particularly in SIDS countries, so Small Island Developing States. This makes solar particularly attractive.

In decades previously, solar was often considered one of the costliest sources of power generation. Therefore, the economics made it difficult to develop in island regions. Many islands didn't want to develop solar partly due to concerns over the viability, the readiness of the technology, but also due to the cost. So, systems remained quite small and were often on private households for reliability or backup reasons, not so much to represent a major part of the island sort of electricity ecosystem.

This has started to change in recent years as solar PV costs have come down, as we'll see in a few moments, making solar in islands really one of the hottest trends and one of the hottest topics in the solar industry worldwide. There are, of course, exceptions to this in northern regions near the artic as well as in deep southern climates, near the Antarctic. The availability of solar, particularly during the winter months, can be quite restricted, which means that complementary sources of generation of backup sources of generation are likely to still be needed to supply power 365 days a year. But for many of the islands that are part of the International Solar Alliance Network of countries around the equatorial and central regions of the earth, the potential for greater development of solar power is tremendous, indeed.

This map shows global solar insolation, looking at markets, jurisdictions all around the world. You can get a sense of the tremendous potential, particularly in islands with very little renewable energy development today, very little solar development, such as Madagascar. Many of the islands here in this map are too small to adequately visualize. But much of the solar resource is concentrated around that mid-band of the world, meaning that island nations typically have solar insolation rates between five and six kilowatt hours per meter squared, which puts them really on the upper end of the quality of the solar resource globally.

The second factor as we discussed a moment ago is that PV costs continue to decline and improve in terms of performance and efficiency. So, solar has become one of, if not the least cost resource for meeting new power supply needs in virtually every market around the world. There's a range of new reports including for major agencies like the IEA and IRENA, as well as AGOA and AGIVENDA showing that solar is becoming an increasing cost-competitive force in markets around the world. Because of the realities in island regions, in particular, where the reliance on diesel generators remains high, the potential is even greater, and the cost effectiveness is often—continues to get better. As we're seeing in a number of island regions, the combination of solar plus storage is poised to shake things up even further and really accelerate the transition to more renewable island-based power systems.

Solar PV has declined in cost by approximately 80 per cent since 2010. We now see module prices quoted in the 20 to 40 U.S. cents per watt range. Installed costs, under $1.00 a watt. That means fully installed. We're seeing some markets at even half of that. So, we're talking $0.50 a watt installed, which is just staggering and is a testament to the rapid cost declines that have swept across the industry.

Now, some of those lower cost install—install costs are found more at the utility scale of the market. In other words, the larger systems. Island renewable energy or island PV systems are typically smaller, on average, than large mainland installations. For a range of reasons that we'll cover in more detail throughout this presentation, they also face higher costs than systems installed in mainland regions. But despite those higher costs, the economics can still be compelling and, in many islands, in virtually all islands, are.

Third key advantage for island regions is its solar systems require comparatively less skilled labor. So, once the systems are installed, cleaning them, basic maintenance is fairly straight forward. Battery systems require their own maintenance and do need trained staff, but the basic—the underlying sort of labor needs are quite limited which suits island regions, in most cases, quite well. The contrast to conventional generators or even more complex renewable energy systems like biomass-based systems is quite stark. PV systems, by contrast, are fairly low-maintenance and therefore the challenge is really getting the upfront cost financed because the O&M is only a fraction of total lifecycle costs.

Fourth, as highlighted a moment ago, solar PV in combination with storage is becoming a very cost-competitive source of power in island regions around the world. We are starting to see a number of islands, in recent years, have issued tenders, have issued calls for proposals on bids for solar plus storage systems. We've seen record after record broken for solar plus storage installations showing that, essentially, PV plus storage can beat, in many cases, grid-based power supply from islands even without subsidies. So, on a pure sort of apples to apples basis, the combination of solar power plus storage is really starting to open up tremendous new opportunities for island utilities to reduce power costs to their customers and reduce their overall operating costs when generation assets need to be replaced. So, again, this is, in many ways, a very exciting time in the island renewable energy and island solar markets. I hope to be able to convey some of that in the slides to follow.

Here's a quick snapshot of some of these island regions that have recently issued, in the last couple of years, tenders for solar plus storage systems. Start at the middle here with Guadalupe and Martinique, a series of projects in partnership with or with backing from the French government to develop a number of PV plus storage. We see the sizes there. The average PPA duration as well as the average bid price. In the Cook Islands, similar but smaller project. One megawatt PV with a 5.6 megawatt-hour storage unit, a PPA duration over 20 years and a PPA price, again, slightly higher due to, primarily, to the larger storage installation. But also due to the remoteness of the Cook Islands.

So, the further you get away from mainland infrastructure, the higher the logistics costs, the higher the delivery costs, the higher labor—flown-in labor costs become for installation and O&M. So, the overall project costs tend to go up. That said, there are island region and remote areas around the world where the cost of—due to their remoteness where the cost of the diesel generation used to power the island is in the sort of $0.60 to $1.00 range per kilowatt hour, in some cases even beyond $1.00 per kilowatt hour, which gives you a sense of how attractive against that backdrop solar power can be.

Looking at Palau, there's an ongoing tender for a solar plus storage system to essentially convert over half of the island's power system to PV plus storage over a long-term PPA. Details are still being ironed out. But the PPA price range looks to be somewhere in the $0.18 to $0.20 range based on numbers from earlier in 2019. In Hawaii, at the beginning of the year, a recent flood of projects based on tenders launched in 2018, sees solar PV coming in at ranges of between $0.08 and $0.12 per kilowatt hour for quite large volumes of PV plus storage capacity.

20-year contract terms, Hawaii is comparatively more mature solar market than, say, the Cook Islands or any of the other featured here. That helps explain how the costs are so much lower than the previous ones. Another key factor here is that solar projects in Hawaii benefit from national-level tax incentives. So, the ITC, Investment Tax Credit, that helps bring down the cost as well as a range of other incentives or support policies like accelerated depreciation that helps bring down the cost of the system.

Now, Hawaii, given that it's also the latest out of all of these tenders along with Palau, is an interesting sign of things to come. If island PV plus battery systems converge in worldwide in the range between say $0.08 and $0.12 with potential to go even further down in the years ahead or to reach this range or a comparable range without subsidies in the years ahead, the potential for solar PV plus battery systems to replace a significant share of island-based power generation around the world is tremendous. Many islands have aging infrastructure, aging diesel gen sets, many of which have been installed—purchased and installed in the '70s and '80s. These systems will need to be replaced.

As these—as utilities start to look at their capital expenditures and look at what kinds of investments to make in the future of the island, a growing number of them are starting to shift more in the direction of Palau and starting to say, "Well, how far can we get here, in terms of solar share, solar plus storage share in the overall power mix?" Given that the market is driven increasingly by economics, the fundamentals are quite strong. The potential for more of this, for more example's like Hawaii and Palau and, indeed, in other parts of the world is really—continues to grow.

So, let's take a closer look now at island power generation. Many island grids around the world continue to be powered by diesel generators with a configuration essentially similar to what you see there. A different network set up with a bit more distributed power supply, including solar PV plus storage is shown below. Diesel generators have the advantage that they can provide power on short notice at all times of day. They can ramp up and ramp down quite cost effectively and quite rapidly. But they have high marginal fuel costs compared with the almost zero marginal costs of solar power. So, the main driver in diesel costs is not the upfront cost of the diesel gen set. Diesel gen sets are very cheap. There's an active secondary market. They can be had for very little in terms of upfront cost. The real issue comes down to operating them over time. That has been a function of the fuel cost.

In many island regions, fuel costs are subsidized or exposed to distortionary factors for a range of different reasons, partly to support low-income customers, partly because it's the government buying the fuel and not a private player. Often tax exemptions apply, a range of other factors, to keep diesel—or ultimately, to keep electricity prices for customers lower. Solar—it continues—it benefits in many markets from a support policy environment. There are very few markets where the policy support compares to the level of diesel-based subsidies and support that diesel generation continues to receive in island markets around the world.

There are some examples of islands moving to relatively/fully unsubsidized electricity pricing. One interesting case is Vanuatu in the Pacific Island regions where you would be seeing how high-power costs would be if there were no explicit or very few explicit subsidies in the market. Unsurprisingly, in markets like Vanuatu where it is unsubsidized, they also have among the highest power rates of any major island group island nation in the world. So, against that backdrop, again, the economics of solar plus storage start to look even more compelling than they would—then they do in markets where power prices and/or diesel prices are subsidized by the government. So, again, this is always interconnected with national level tax policy and other issues.

Another important factor characterizing island grids is that most island grids are massively over-dimensioned with diesel. In other words, because the diesel generator capacity itself is so cheap, many islands err on the side of caution, anticipating future load growth, and have over-dimensioned their generation capacity. Often, this leads to lower efficiency operation and a reluctance to shift to other generation sources because, again, there's adequate capacity with the diesel gen sets in the system to meet any future generation. So, the any generation needs and any demand needs.

So, the—for utilities that have significant excess diesel capacity, if you're accepting new renewables into the system, you essentially decrease the likelihood that that tail-end of the diesel capacity in the system will ever get called upon which decreases their utility and means they could be disposed of or disconnected altogether from the grid and potentially sold in the secondary market. So, there are a number of islands wrestling with these challenges of overcapacity. One benefit of having the excess—of having extra capacity in the system, of course, is that if you do need it during times of emergency, extreme weather events, during times of maintenance on some of the work horse power plants that supply the island, then you at least have it there. So, it's as a security measure. Many island utilities continue to keep that excess capacity just for the proverbial rainy day.

Now, looking at this over a—in relation to solar power, solar power generates power according to the position of the sun in the sky, which means the power supply is concentrated during the daylight hours. Most island regions around the world are, again, around the equatorial belt, which means sunset/sunrise is more, give or take, 6:00 AM to 6:00 PM. But mostly the electricity demand is in the first few hours of the day and then, again, in the evening as the sun is setting and after the sun sets. So, this creates a mismatch, which is one of the reasons why the use of storage and the interest in scaling up storage in island regions is growing in order to balance the system.

We're also seeing some islands developing alternative storage technologies like pumped hydro in order to better integrate on-shore, on-site, or on-island renewable energy production like wind and solar. I've cited here the example of El Hierro, which has recently completed an innovated pumped hydro system in an island using an old volcanic crater to improve integration of renewables on the island. There are a number of islands around the world that have potentially interesting geography for similar pumped hydro storage systems that could help integrate more and higher shares of solar power. So, the solar power would essentially be generating power during the day, when the sun is shining. Could be used to pump the water up into the crater and allow that to then dispatch over the course of the day to meet—over the course of the evening to meet evening loads into the overnight period.

So, the attractiveness of these systems and these kinds of installations is obviously there. A growing number of islands are starting to look at this and develop their own. There's been feasibility studies conducted in places like Cape Verde on the west coast of West Africa, on islands in Madagascar. There's been discussion in Navet Vinion in the Indian Ocean, as well as a number or islands in the Caribbean and in the Pacific. Again, often with the aim of not only adding more storage and more resilience to the grid, but specifically to help improve the integration of technologies like solar and wind.

So, this gives you two different views of the power system; the power system in the past, which was the same virtually if whether you're on a mainland grid or an island grid with loosely base-load power with some dispatchable on top combined with peak generation to meet the—often specifically, the evening loads. In the near future, however, as the share of solar and storage grows and variable renewables, the need to have more dispatchable generation and the need for more storage generation becomes particularly acute.

We see this in island regions more quickly than in others because the systems are so small. Most island grids have total installed capacity under 100 megawatts and you therefore see the effects of high shares of renewables more quickly. This is one reason why islands like Samso in Denmark, parts islands off the coast of Scotland, as we'll see a bit later in the presentation, islands off the coast of certain regions in the Caribbean are starting to explore very high shares of renewable energy, effectively displacing base-load generation from the system and turning them more into dynamic, highly-variable, dispatchable power systems.

Now, combining traditional power generation assets like diesel generators with intermittent or what are sometimes called variable sources of power like solar PV and wind, can be quite complex. Integrating these is often achieved using a controller, an electronic device that limits—that measures demand and controls the overall output of the generator. Now advanced controllers are able to control output from a range of different generation sources and provide feedback in real-time to control the power plants to deliver either more or less. This becomes tricky with solar because so much of solar is, again, weather dependent. As soon as there's light cloud cover or heavy cloud cover, which can happen from one moment to the next over a larger solar array, the impacts on grid stability, on the one hand, on voltage, on frequency, on reliability, in turn can be quite substantial.

This is why a number of utilities, a number of island utilities, in particular, are starting to explore better ways, smarter ways of integrating solar into the system, partly in order to mitigate curtailment but also just to make—to improve overall system operation and boost reliability. At the end of the day, island utilities like all major power utilities in mainland regions are fundamentally about maintaining reliability. That's the ultimate function. Anything that challenges that or jeopardizes that hard, one, reliability is seen with skepticism. That's one reason why we're seeing a lot more discussion of advanced integration technologies, advanced controllers, and using demand response and other technologies, other solutions to better improve the integration and better improve power system reliability. We'll get to curtailment a little bit more in a moment.

Interestingly, evidence from a number of markets around the world shows that wind power typically experiences fairly low generation during the middle of the day when solar produces and fairly high generation in the early mornings and overnight, which suggest, at least for some markets—this is by no means a universal, nor is it the case on every single day of the year, but that there is a complementarity in many island regions between solar and wind output, enabling the solar to meet a good portion of daytime demand and wind power to support during the evening and early morning hours.

Interestingly, there's also growing evidence from markets with larger volumes of renewable energy generation, including here, in the case of wind power, although a similar principle applies to solar, as we'll see in a moment. The combination of multiple variable generation units has important smoothing effects. So, you see here on the very top, one turbine and this dicastic (sp?) sort of dynamic real-time output of one wind turbine combined over a group of wind farms combined over the entire country, in this case, Germany, for a particular stretch of time. You can see here the important smoothing effects.

So, the more variable generation you have—be it solar, wind, et cetera—the smoothing effects become more prominent. Obviously the larger your balancing area, in other words, the larger the geographic area over which those renewable energy assets were located, the greater the smoothing effects.

Islands often don't have the advantage of having major geographic span, major smoothing effects, although for solar, just the fact of diversifying the location of the systems, of the solar systems, smooths output across varying cloud cover patterns can itself be significant. So, from discussions with utility representatives in place like Cape Verde on the West Coast of Africa, the evidence from the integration of a large, relatively large, for the island of Santiago five-megawatt PV system is much more difficult than it is to integrate a number of smaller PV systems in the network. Because as soon as the clouds hit that large five-megawatt plant, in part or in full, the effects on the grid are immediate and need to be counterbalanced with measures elsewhere in the system. So, you can get some of this kind of geographic smoothing by having a more distributed approach to siting and constructing, ultimately, solar PV systems.

So, there are some islands in the Pacific, in response to this, who are looking at, essentially, tendering a block of solar power, but instead of installing it in one location on one island or one atoll of the island network, they've decided to break it up over a number of different installations. The one example, ongoing, in Tuvalu. A similar approach has been used in other mainland countries, even like Nepal, essentially spreading out the solar power across a number of major substations in the country in order to improve the integration and reduce some of the issues with cloud cover and, again, harnessing some of these smoothing advantages. So, again, this is increasingly—these are all some of the challenges that need to be bridged when you're an island utility with limited or no interconnection with neighboring islands or neighboring grid systems and where the balancing needs to happen in real time for the entire island or islands in the network.

So, a similar example here, showing the smoothing effects across different PV systems in California, in this case. So, you see here, the blue line represents one plant, red is two plants. The green line is six plants. The orange line represents an aggregation of 25 PV plants in California. The smooth curve is from all of the power, the solar power, in Southern California. So, again, this really underscores the point that, on the one hand, the more solar you have but also the wider geographic spread of that solar, the smoother the overall generation profile becomes. Integrating this nice bell curve here is much easier for utility to do than integrating the dynamic profile of a single PV output, PV facility.

Another key factor in all of this is the improving economics of battery storage. As you've no doubt heard and read in recent years, battery storage costs have been coming down gangbusters. There's been a tremendous amount of excitement in the batter industry as costs continue to come down more rapidly than even industry representatives expect. Technologies are getting better. Systems are getting higher performance. Costs are coming down. Economies of scale are emerging and we're seeing, for the first time, really the emergence of a global utility scale battery storage market. That makes this, indeed, a very exciting time for island regions.

Lithium ion battery costs, which are one of the leading battery chemistries in the market have come down 79 per cent since 2010 and continue to decline. There are forecasts showing the battery cost could have further between now and 2025 and projections, anything beyond 2030 is guesswork at this stage. But costs continue to come down. There is broad industry consensus that there is significant potential for further cost reductions.

So, you can see here some of the curves of different battery chemistries here on this axis from an IRENA report and some of the roundtrip efficiencies of these different technologies. We won't get into all the details but, again, this shows sort of the lay of the land in terms of battery chemistries and some other positioning in terms of efficiency and cost.

Now we get to come back to the topic of curtailment. So, as we discussed, solar power is produced in real time, needs to be injected into the grid, and grids operate by matching supply and demand, which means there needs to be a constant effort to maintain supply and demand in balance. Otherwise, you run into problems. Curtailment happens when the utility says, essentially, or when the grid says—sometimes it's based on just system physics—that the power can't be dispatched to end users or can't be exported to reach end users on the system. Because solar is non-dispatchable and weather dependent, this means that solar effectively gets curtailed.

There's a lot of debate around how curtailment should be compensated, whether solar output should be compensated even though the utility wasn't able to relay the power. In mainland regions in major countries like in Germany and Spain and so forth, the curtailment rules are typically more in favor of the generator, in other words, the solar producer, where they protect the investment security of the investor. If the utility is unable to deliver that power, they still have to pay the feed-in tariff. They still have to pay the agreed power purchase price.

On islands, a much more nuanced and, in many ways, less favorable to the investor, to the developer, set of circumstances if common. Curtailment rules are often more ambiguous or at least have—allow the utility to not purchase the power and only compensate a portion rather than all of the generation on—that's supplied to the system or that—and that needed to be curtailed, was unable to reach end users. So, one example here from Cape Verde is shown. You can see here, the curtailment varies. This is just a quick map. Curtailment varies, currently, in Cape Verde from 2 per cent on the main Island of Santiago where Praia is located—you can see there—to up to 46 per cent on the Island of Sal, in the north. But very high discrepancy in the level of curtailment from PV on these two islands. There's a host of circumstances behind that. You can read more here in the report recently done on Cape Verde.

One of the reasons there's so much interest, again, in storage technology is that storage can help alleviate, mitigate, eliminate even some of these curtailment issues by enabling the plant, the solar project, to be operated in conjunction with the solar output. So, this—or with the battery storage unit, which means the battery storage can essentially back up the PV and at least provide some security so that electricity won't be lost. So, if you look at their recent project, major island project, that was cited earlier in Palau, the major company that's behind the Palau proposal essentially proposed, up front, a combined solar and storage unit, partly because it recognized that there's going to be issues integrating this. We need to have the security that we can manage essentially the output and ensure that we aren't subject to too much curtailment.

It would be very difficult to cite the, say, 25, 30, 35-megawatt—in this case I believe a 35-megawatt solar PV project on that island or on a set of islands without experiencing curtailment. Because island grids are quite small. Loads are quite small. There's not much industry, in most cases, which means that curtailment during the day time is to be expected as soon as you get beyond sort of five, ten per cent of total power mix from solar. So, again, to mitigate that, storage is really emerging as the solar industries best friend in island regions.

Here, another key tool in the toolkit is controlling demand or what's often called demand response. Demand response essentially enables you to dispatch loads and enables you to control demand on the system in order to improve the integration or the reliability of the network. You can see here, from the graph, that there are times when that excess or that peak demand can be shaved off by simply flicking loads off. So, there's a number of different demand response projects underway around the world focusing mainly on industrial and commercial loads. There are some looking also at even residential loads, hot water heaters, air conditioning units, in some cases refrigeration, and other appliances like lighting that can be integrated into a demand response system, which essentially, again, enables you to avoid curtailment because you can bring demand down and modulate it better to meet supply.

Conversely, you can also increase demand by shifting thermal loads around, for instance, when there's excess supply on the network. So, if you have an abundance of solar power in a given hour and the island, for example, have a substantial fishing industry or commercial fishing industry, there's potential to connect that with ice production. So, when there's an abundance of solar in the network, there could be preferential tariff structures or preferential dispatch to communicate to ice—let's say to fishing operations to produce ice during those hours when there's abundant solar on the network, effectively dispatching a load to take up that excess solar output.

So, again, in many ways, we are at the very beginning of the smarter control of demand to better connect it with solar power output in island regions. But there's a lot of promising case studies happening in mainland regions that suggest the potential on island regions to grow further and, again, to improve reliability in islands is quite significant.

Now, let's look at some of the costs and financing issues relating to solar PV on islands. As we saw earlier, a growing number of solar PV plus battery systems can be built at an unsubsidized cost of between $0.12 and $0.18 per kilowatt hour. For example, in Hawaii, the basket of recent projects that we mentioned, contract prices have been put forward between $0.12 and $0.16. That's an unsubsidized basis. If you remove the ITC and you remove the other tax incentives in the market, you get in that price range. Around the world, a wider number of them include prices in the similar range. So, we are seeing convergence there.

As prices continue to decline, the economics here are going to get even better. This means that when you map that out against an island based on—this is illustrative cost ranges for island systems. When you map that out against island system utility economics, you get a sense of the new reality that's emerging. The diesel-only fuel cost range depicted here, conservatively, at $0.20 to $0.35 per kilowatt hour is 2 to 3 times higher than the cost range for battery plus storage systems—battery plus PV-equipped systems.

If you add the entire island generation system cost, the range here, again, for illustrative purposes, between $0.20 U.S. and $0.60, you get an idea, again, of just how cost competitive solar plus storage can be. Especially if solar plus storage can effectively replace the functions of the traditional diesel-based island power system. Now there are many islands that make use of hydro power.

There are many islands in the Caribbean like St. Lucia, Dominica and so on that have significant shares of hydro in the mix. However, looking globally, when you take a step back, many islands that do use hydro, it's a fairly small share of the overall power mix. The bulk of the power systems remains either diesel based, or heavy fuel oil based, which means again, the cost range shown here, remains broadly reflective of where the market is. There are, of course, some islands that are even more expensive than this. But this gives you an idea, which means solar PV plus storage is really well-positioned purely on competitive economics terms.

A key factor, however, is that it's not just about the raw production cost. A key factor is the financing costs that go into financing that particular solar project. So, if you look here at the graph, this just shows an illustrative financing for a project at an assumed install cost of $718.00 per kilowatt hour. So, this is a benchmark price range for utility scale solar to the end of 2018. You can see here that the production cost—the total RE project cost goes up under different financing scenarios.

So, the financing cost itself would only be in the $35 million range. But as you add the cumulative interest payments over a ten-year loan, you get much higher sums, which means the higher the interest rate, the more money you have to pay back, the higher the total levelized cost of the system is. If you assume—you factor all the generation, all the output, over all the costs during lifetime of the system or the repayment of the loan, as the case may be. So, financing costs have a major impact on levelized costs. That's particularly the case for solar power projects that have high upfront costs and very low operating and maintenance costs.

Islands can play a role in helping reduce the financing costs by providing stable, long-term policies including power purchase agreements, guaranteed interconnections, streamlining some of the procedures, providing more planning security as well as by partnering with multi-lateral lenders, for example, to provide backstops on the loan or concessional financing on the loan used to finance projects so that the rates can be lower and the costs can be even lower for both utilities and rate payers in the country.

You get a sense here, from this graph, at how all this plays out when mapped against different scales of user. So, this shows the residential, commercial, industrial, and utility scale PV plus storage cost ranges. Clearly, the residential ones are still much more expensive than the commercial, industrial, and even utility-scaled ones. Now, the important thing to recall is that all of these are coming down over time. But already, at the commercial end, and particularly at the utility end of the spectrum, the economics are already quite compelling, as we've seen from previous slides.

Now, if you look at this from an LCOE standpoint, just factoring the costs of the generation, not of the storage, you can see here the PV, while the most expensive technology in the 2009, '10 period has emerged as one of the least cost systems or technologies on the market. So, for utilities who are looking for new power supply, solar has forced its way, in a way, to the top of the lead tables and is increasingly being considered as one of the leading sources of new generation in the consideration for a new power supply in island context, in particular, but also beyond in mainland regions.

This is a remarkable shift and I think it's important for those of us who work in the industry and for those of us who are active in this space, I think it's important for us not to forget just how fundamental that shift has been. This last decade of renewable energy development and cost declines has been absolutely staggering and has really paved the way for a much easier, much more economically driven transition to a cleaner renewable power system than was ever thought possible in decades previously. Renewables long had to argue around the co-benefits of renewable energy instead of arguing on the grounds of economics. Now, solar, in particular, but also wind power and a range of other renewable technologies can make their case on the basis of economics alone. Again, there's no technology that demonstrates that quite as dramatically as solar PV.

This shows a—it comes back to one of the arguments or one of the points we discussed earlier around the up-front cost of a diesel system being so low. If you see here, just the OPEX end, it shows that you're—over a short-time horizon, diesel may be your cheapest source, but over a longer-time horizon, PV clearly becomes the most cost effective.

Now, that's the power system side, the economics side, the financing side. All of that is well and good. Many of you may have known—may be well-aware of the landscape in island regions and known about the broad technological and economic reality of where things stand. Now, what's stopping islands from moving forward? Why—if the economics are there now and the technologies are there now, the performance is there now, what's stopping utilities in island regions from around the world from transitioning fully to solar plus storage?

For example, installations. There are a number of barriers that remain and some of the barriers are market-based. Some of them are connected to the regulatory environment, the permitting environment. Some of them are tied up in politics of individual island countries. Some of them are also tied up in just simple good-old-fashioned lobbying. Others, however, are tied up more in material.

Realities like the lack of local skills. In island regions, regardless of whether you're talking about smaller islands in the Caribbean or the Pacific or, indeed, in islands in the Indian Ocean, the need for local skills is critical. Many islands simply don't have adequate skills training programs and many of the people who develop the skills that would be needed leave and go elsewhere, which leaves island utilities often understaffed and facing tremendous challenges at the same time with very little resources.

It's also important to underscore the project costs. Both CAPEX and OPEX are often significantly higher in island regions than in mainland regions, which means even if we're getting solar power for $0.03 or $0.04 per kilowatt hour in mainland regions, costs are likely to stay higher for some time yet in islands. That remains a reality. Financing costs are also higher. Island-based systems need to be adapted to island context. This is another increasing critical point.

Most companies are now—most EPC companies who are actually developing projects know this. But it still bears repeating that PV systems designed for island regions need to be protected against. They need to be designed for salt spray, from waves, and just from salty air that contributes to more rust, more issues with wiring. Islands face greater risk due to extreme weather events, which means that often the anchoring infrastructure associated with PV systems needs to take that into consideration.

This means that the mounting costs, the infrastructure costs associated with the mounting infrastructure is often higher. Again, because there's no domestic manufacturing often for PV components or module components or mounting infrastructure even, a lot of the materials have to be flown in. Which means, again, the costs are higher, and delays are more common.

A further challenge that explains why utilities aren't jumping on the bandwagon all at one at once to scale up solar PV plus storage systems—mind you, many are—but there are many reasons why that transition is not likely to be from one day to the next. One of the critical factors is that many utilities just don't have the money. Many utilities are lost making in island regions and are supported by the national government to break even.

That means that decisions around the power mix, decisions around new investments in solar or storage technologies require broad-based approval, need to go through the political channels and, therefore, all of that tends to take longer and be less market-based in terms of a transition, market driven, and more politically driven, for lack of a better way of putting it. Which means that islands, even if they want to—even if island utility representatives would like to, there are often a number of factors that constrain them and make them move more slowly than they otherwise might like to.

The fact, however, that utilities are lost making makes them problematic off-takers. In other words, problematic buyers of that solar output. So, if you're trying to build a 5-megawatt or 20-megawatt solar project on a medium-sized island like Santiago in Cape Verde or like Reunion Islands in the Indian Ocean or in Jamaica in the Caribbean, for instance, the challenges you face in terms of assuring that you have a bankable power purchase agreement are significant and often require government involvement or some kind of multi-lateral support to de-risk the power purchase agreement. So, a host of issues there, again, that make this challenging.

There's a few other issues we'll come back to the end, but before that, let's dive into a few case studies. Now, Tasmania, off the southern coast of Australia. Fairly small population on Kings Island, one island off the coast of Tanzania, 2.5-megawatt peak load, 6 megawatts of diesel and roughly 450-kilometers rather powerlines. You can see here government owned. Essentially the utility is responsible for everything, generation, distribution, and retail. This is common, virtually almost without exception for utilities operating in island environments. Whether or not they're government owned, most of them are. But the fact the generation, distribution, and retail are all connected and under one roof.

Tasmania is looking to transition its power mix. You can see here their snapshot. The existing mix previously was diesel and diesel dominated. Now a significant share of renewables has been added in in the following form. So, roughly 390 kilowatts with solar PV, a couple of wind turbines have come on the line. They've introduced advanced automated control to control the system. Invested in smart grid. Even a flywheel to try to improve the overall control and operation of the system as well as storage technologies.

So, you can see here, a fully full-spectrum approach to trying to meet the power needs of King Island in Tanzania—Tasmania. The interesting insight here is also that it saves money, every year. $2 million a year estimated in savings, Australian dollars. So, that's about $1.5 million U.S. per year. Cost savings are likely to continue to go up as fossil fuel prices—if and when fossil fuel prices increase in the future.

Now, shifting to Scotland. Number of islands, number of tiny islands off the coast of Scotland. It's often joked that Pacific islands have very few—some Pacific islands have very few inhabitants. Well, these are very much in the same basket among—along with—one of them here, Fair Island, has 55 inhabitants. The other, 15 inhabitants. These are tiny islands with very small power demand, indeed. Here are some more project details. I've put a lot of this in in detail just for those of you who have more of an engineering background, more interested in looking at exactly what was done and what are the loads to be met so that you can get a sense of how these systems are configured.

Throughout the Pacific Islands Region, it occurred to me as I was pulling all of this together, there would be dozens of examples, if not more, that could be drawn on from a range of different places. The Cook Islands, the Philippines. There are dozens of islands within the Philippines alone that could feature in this. Islands off the coast of Japan, Palau, Tonga, the Marshall Islands, Vanuatu. There are lots of great cases of solar PV being integrated into island systems. As we saw previously, it's really increasingly the economics that are the driven and not so much—although, of course, policy, climate policy, awareness plays a big role. The push of many donors active in this space is also a major factor. But by and large, many of these systems are increasingly benefitting just fundamentally from the positive economics of solar and of solar plus storage installations.

The Caribbean region is home to over 28 island nations and more than 7,000 individual islands, many of which, in recent years, have been facing extreme weather events. We've seen extreme weather events in the Pacific Island regions as well. Vanuatu was hit very hard a few years ago. These extreme weather events are a major factor for island power systems. The interest in resilience, in reliability, in all of these things for island regions is really, really critical. The fear of power loss is also driving a lot of residential and commercial customers of utilities to invest in their own backup, either investing in their own diesel generators or in PV systems with storage. So, it's really triggering a whole host of changes throughout the island utility—throughout island utility systems.

One example here from Puerto Rico. Recently, there's been a push to increase the share of renewable energy, specifically in order to improve the resiliency and reliability of the power system in Puerto Rico. Independent power production has been a really key part of that. Lower income communities, there's been a range of different efforts to try to boost power supply using specifically solar power in the country. Again, this trend is likely to gain ground in island regions around the world whether led by governments, by utilities, or simply by individuals and small businesses within the island.

Now, this presents a tremendous opportunity to increase resiliency and boost energy security in island regions and, critically, to keep power rates stable. As we saw, the economics are there. It's increasingly cost competitive. Solar plus storage can deliver cost-effective power below the rate at which just the fuel portion alone of a diesel gen set can operate. So, the time is indeed upon us where PV and/or PV plus storage is really going to start shaking up island utility systems. As the examples we saw from the Caribbean, Palau, Hawaii, and others show, this is already starting to happen.

So, a few concluding remarks. It remains more challenging to operate and provide maintenance services for remote power generation assets. On an island, everything is a bit more challenging in terms of operations. Often, if there's a missing part or a broken piece, you need to order it. You need to have it shipped in and flown in and driven in by boat. All of those issues increase delays and, ultimately, costs for the systems. So, again, there are a number of realities that need to be born in mind throughout this transition.

Low-cost financing remains a key component of the picture as does more skills training. There are some efforts to boost more skill training for solar installations and solar maintenance in island regions. A good example of this—I mean there are some in the Pacific Island regions in places that we've already discussed. The real key there is to try to create a committed, domestic island-based workforce that can help island's smooth the transition towards higher shares of solar and higher shares of renewable in the system. The best way to do that is not by flying in expertise and experts as needed on an emergency basis. As much as possible, islands are increasingly striving to try to create that knowledge and keep that knowledge locally.

Learning by doing is another really key factor. I'll take the example of Santo Antão in Cape Verde. When they started integrating a local renewable plant on the island, they were having major issues over the first 18 months of operation. Everything from huge frequency and voltage issues. Grid integration was very challenging because it's a small island system with very little prior experience. It took that first 12 to 18 months to get a sense of operations, improve internal procedures, improve communication, improve forecasting.

Now, this system has brought down its curtailment rates significantly just by improving those internal procedures. So, learning by doing is a really important part of all of this. I think this is echoed across many of the, if not all, island-based renewable energy installations. Yet another reason why having the knowledge locally is so important. So, that that knowledge, ultimately, can inform and create that skilled base over time.

Systems needs to be adapted to island contexts because island wear-and-tear, as we saw, is fundamentally different from that in mainland regions and fundamentally bankability—in other words, improving the credit worthiness of island utilities—is going to remain really important for getting to high shares of renewables and, in particular, getting high shares of investment in island regions.

Now, a few closing remarks here on some of the risks of customer-sited solar plus storage. As we start seeing the economics getting better and better for utilities, they're also getting better and better for customers, which means high-income customers or upper middle-income customers can start to disconnect or at—in part or in full from the power supply traditionally supplied by their utility. This increases the risk that utilities face revenue loss. Not only revenue loss but revenue loss from their most valuable customers. In other words, the customers that ultimately help keep the utility's finances stable. That's a major risk.

In addition, island utilities have to manage multiple threats. They have climate-related threats, storms, depopulation and out-migration, decreasing load growth, in certain cases aging infrastructure both on the generation side as well as on the side of the distribution side, all of which requires constant costs and constant maintenance and investment. So, adding this additional threat, if I can refer to it that way, of customer-sited solar plus storage really makes it difficult and it likely to make it difficult for many islands in the years ahead to remain viable going concerns as businesses, if the economics continue to tip in this direction and if, for example, reliability leads to so many customers being fed up that they just go and do it themselves, for those who can afford it, leaving the remaining lower-income customers with the traditional utility.

Now that outcome, the risk of that kind of an outcome happening makes it all the more important to seek out win/win solutions, including solutions that allow local utilities to be partners in the transition to sustainable power systems in islands. Because utilities, in many cases, in island regions have the knowledge. They have the staff and the history of customer relationships and so forth required to sustain a—essentially a utility-based model of power supply in island regions.

For many, if the rise of customer-sited solar plus storage happens too rapidly or too suddenly, the utility—the underlying basis of economics of the utility leaves, again, the lowest-income customers potentially stranded and with a cost base that goes up, because all the most valuable customers start defecting from the grid. So, there is a need for much more strategic thinking in island regions around how to solve these challenges and, ideally—and how to solve them together between the various stakeholders in the island.

So, with that, thank you very much for your attention and for your patience in going through this. This has been just over an hour. Now I'll shift quickly to some further reading, a couple of key reports, and some databases with additional information. Like to say a quick word, this webinar series, again, brought to you by the International Solar Alliance. I—and the Clean Energy Solutions Center. I'm Toby Couture, Director of E3 Analytics. Grateful that you could join us today for this ISA training series. Now you can shift gears into the knowledge checkpoint and there'll be a few multiple questions. Thanks again. Wishing you all a great day.