Global Potential for Small and Micro Reactor Systems to Provide Electricity Access
Dr. Amy Schweikert, Colorado School of Mines, USA

Berta Oates
…introduction is Dr. Patricia Paviet. Dr. Paviet is the Group Leader of the Radiological Materials group at Pacific Northwest National Laboratory. She is also the Chair of the Gen IV International Forum – Education and Training Working Group. Patricia?

Patricia Paviet
Thank you so much, Berta. Good morning, everyone. It's a pleasure to have Dr. Amy Schweikert with us today. She is a Research Assistant Professor in Mechanical Engineering at the Colorado School of Mines. She is a Fellow in the Payne Institute for Public Policy and co-appointed in the Nuclear Science Program. Her work focuses broadly in the areas of infrastructure resilience and development. This includes a focus on quantitative risk modeling for infrastructure related to climate change and hazard events. Additionally, her work looks at socio-technical options for energy expansion for underserved areas of the globe, including the role of nuclear energy as a component of the low-carbon energy technology portfolio.

She is a graduate of the Santa Fe Institute's Summer School on Complex Systems and hired as a coordinator for the 2019 and 2020 sessions. She has consulting experience with the United Nations, the World Bank, and a number of public and private entities. She is a Colorado native, holds a Ph.D. in Civil Systems Engineering from the University of Colorado Boulder, a Master's of Science in Civil Systems Engineering, and a certificate in Engineering for Developing Communities from University of Colorado Boulder, and completed her undergraduate Bachelor of Arts in International Relations from Boston University. Thank you again, Amy, for volunteering to give this webinar.

Without any delay, I give you the floor. Thank you, Amy.

Amy Schweikert
Thank you for the introduction, Patricia. I am excited to be here today. I gave an initial version of this presentation almost exactly a year ago at the International Atomic Energy Agency's conference on Nuclear Power and Climate Change. It's really exciting to see that there is so much interest in some of these topics. And, yes, excited to share with you today a lot of the work that I do at the Colorado School of Mines. I work with Professors Mark Deinert and Andrew Osborne, looking at some of these broader questions. Obviously, the technical side of nuclear power is

a really important area of research. But today is going to be a little bit different, focusing a lot more on the context for energy growth and infrastructure development in emerging economies of the world.

I want to start with kind of outlining the motivation for this talk. If you saw in the biography, my background started in International Relations, and I have a certificate in Engineering for Developing Communities, and that's because a big part of my interest really sits in this idea of how do we move away from poverty in all areas of the world. Energy poverty is a particularly acute problem in many regions. You can see from the picture here that you have a woman with her two children in her home, bending over a cookstove. This is probably how she cooks dinner, all her meals. Heats her home. Probably boils water, depending on the storage of water that their family has. You will notice that the left-hand wall here is very black. This is actually soot from the cook fire that has embedded itself on the wall. If you spend much time in indoor areas with smoke or, in my region, we have a lot of wildfires at the moment, and the air quality has a huge impact on your health. Over time, chronic respiratory illness is actually one of the leading causes of death for children under 5. And over 4 million people a year die of chronic respiratory illness. Well, that's probably a bit of a morbid start to the talk. I think that it really motivates the idea that energy poverty isn’t just a development issue, an economics issue, but it has real implications for the well-being of people around the world.

‘Health’ here is one of the huge motivations. ‘Water and sanitation.’ Collecting firewood – if you are familiar with some of the issues around that, things like security and safety, potentially have big implications.

But the other implications include things like ‘gender equity’ and ‘education.’ So, the burden for cooking, gathering firewood, taking care of the home often falls to women, and in areas where deforestation has proliferated, that takes a lot of time. And often that means that women and girls are not going to school at the same rates. You can think about electricity access having huge impacts on education. Things like this webinar only happened because we have access to electricity and the internet. And there are just huge gaps with the idea that if you work all day and you want to study at night, you have to have a lightbulb to do so. And so there are lots of different facets to the direct impacts of a lack of energy access.

But there are also broader implications. ‘Economic development,’ things like industrial processes take a lot of electricity. Emerging areas of research, something my group is thinking about a little bit, is the intersection between conflict, infrastructure, energy access, and resources, and there is this quite a good background of work there. And then ‘governance.’ Things like voting, here, in the United States, it’s happening next week. And to do research, you get on the internet. You do a lot of research and there is a lot of implication for lack of access to a lot of different services.

Obviously, there are lots of other issues that go with the problem. But I really just want to set the stage that this is a complex issue and it affects a lot of people around the world.

And it's also really highly funded. This is a development problem, and it’s being looked at by many of the development banks. We have the Asian Development Bank up here, the Inter-American Development Bank, the World Bank, lots of different groups looking at these issues. But increasingly, the idea of clean energy and energy growth is becoming a broader financial question. So, you will see here, I put facts of JP Morgan from October 2020. There was a news article that talked about $200 billion for green business financing has been committed. They hope to go carbon-neutral by 2021. Just last year, there was an estimate that the Green Bonds market, so including energy infrastructure but not limited to it, was $163 billion. Single loans for different infrastructure projects have exceeded $100 million and more by private entities. The Caribbean Development Bank spent $3 billion on clean energy and energy growth in the last couple of years, probably more depending on the projects. So, there is a lot of financing, a lot of focus on this question of energy access and clean energy growth.

Again, it’s receiving global attention. This isn't really a new problem obviously. I’ve highlighted here just a brief timeline that kind of outlines some key times in the growth of kind how energy is being approached in the international context, and particularly where nuclear has begun to sort of step on to the stage. You’ll see on the left here, I’ve highlighted the ESMAP program. This is the World Bank’s ‘energy sector management assistance program.’ And it dates back as far as 1983. Again, not a new problem, it’s been around for upwards of 30 plus years. But more recently, things like the Millennium Development Goals. This was an initiative that started in 2000. The idea was to really highlight some of the key development problems that needed to be a focus of kind of bringing together the development initiatives around things like hunger, maternal health. Different issues are really important. Energy wasn't a complete focus of the Millennium Development Goals, although it underpinned a lot of the progress that would need to be made.

That ended in 2015. Clearly, there was a lot of progress to be made. Currently, we are in the middle of what’s called the Sustainable Development Goals Agenda, the SDGs. The SDGs kind of built off the Millennium Development Goals and said, broadening from kind of emerging regions of the world to the entire world, how do we move towards sustainable development. The SDGs are 17 different goals that look at a lot of different aspects of what it means to be sustainably developed. I'll talk about two of them here in a minute that are really important. But the idea here is that by laying out an agenda with specific goals and targets, that a lot of different efforts moving towards these goals like energy access, clean energy, could be really wrapped around on a single idea.

In the interim, I just want to highlight a couple of things here. In 2010, the Clean Energy Ministerial was founded. Many of you may be familiar with that. You'll see at the very end here that in 2018 nuclear power was included for the first time in the Clean Energy Ministerial. But that was 8 years after it was founded. The Sustainable Energy for All initiative was founded in 2011. This is a joint partnership of the World Bank and the United Nations, looking at this idea of how do we move towards sustainable energy for all people. You'll see, the SE4ALL group come back in a little bit because they have some really useful ways of thinking about what it means to end energy poverty.

2012 was the International Year of Sustainable Energy for All and in 2014 it kicked off the decade of sustainable energy. People are really thinking about these ideas. But, like I mentioned, the Clean Energy Ministerial just recently included nuclear. This was partly from a recognition that if we want to move towards clean energy access for all people around the world, that it takes a broad portfolio, using all of the technologies we have available to make that a sustainable development opportunity

I am just going to focus briefly, quickly, on the Sustainable Development Goals. That's because, again, the idea behind them is to really coordinate a lot of the different efforts in development, and saying, how do we move towards a single target and begin to really make progress. Goal number 7 is to ensure access to affordable, reliable, sustainable, and modern energy for all people. Not a small goal but a commendable one. But there is also Goal 13. This is, 'take urgent action to combat climate change and its impacts.'

One of the ideas behind the Sustainable Development Goals is to say, as we move towards a certain target such as energy access, how do we consider the broader implications of what it means to be sustainable. Things like Goal 13 need to fold in and inform how we move towards these different targets that are being set up.

One of the great things about setting goals and really specific guidelines is that it allows you to begin to measure and define what you are moving towards. When you think about lofty goals such as ensuring access to affordable, reliable, sustainable, and modern energy for all people, that very quickly becomes a hard thing to measure. If you just take the first part of that, ensure universal access to modern energy services, that's still kind of a hard thing to measure. What does modern energy, what does access mean? In this case, there are proxy indicators. For example, the percentage of the population with electricity access in some regions and the percentage of the population with primary reliance on non-solid fuels. So, not using things like wood that you saw on that first photo, gives all of the kind of health implications that come from burning biomass indoors.

Again, the idea to measure it says we have to have a reference point. We want to move towards 100%. That's access for all people. But where are we coming from and how quickly do we need to make the changes? In 2010, this was sort of set as the baseline, they looked backward and said if we want to be somewhere in 2030, 20 years from now, let's look backward 20 years and see how quickly we made those changes. You can see here that in 20 years the percentage of population with electricity access in 1990 moved up towards 83%. But that still leaves a pretty big chunk to move towards for 2030. The same is true for the percentage of the population with primary reliance on non-solid fuels. You'll see here that, particularly for the second indicator, there was an increase of 12% between 1990 and 2010, and that is excellent. But the rate of expansion here will have to more than double. Obviously, we are half way through this now in 2020. Then, I'll show you in a few minutes that these goals are making progress, but they are definitely not where they need to be, to be moving towards these 2030 goals at the moment.

I mentioned 2020, we are half way through that 2010 to 2030 period. These numbers are from 2017. Again, the State of Electricity Access Report from the Sustainable Energy for All group had the numbers that we are currently – about 1.06 billion people have no access to electricity at all, and over 3 billion still rely on solid fuels or kerosene for the majority of their energy needs related to home cooking, those sorts of issues. I was going to update this with 2020 data or 2019, but there are good numbers out there that under the COVID-19 pandemic, that some of the progress that had been made in many areas of development has been slowed down, or perhaps reversed in some cases, due to all the implications. I wanted to kind of stick with these numbers and say that either way there is a lot of room for these targets to be met as we move towards the 2030 type timeline. Again, as of 2017, the estimate was that in 2030 in Sub-Saharan Africa alone there will still be over 500 million people without access to reliable electricity. This is a problem that I think – while it is receiving attention and getting a good amount of funding, there is a lot of room here for this work to have a big impact as we move forward.

I just want to put up a map here to kind of help ground these numbers. Because it's not 1 billion people around the world evenly spread out through every country. More than two-thirds of the people with no access to electricity globally sit in the global south, particularly in about 20 countries, many of which are in Sub-Saharan Africa. You can see here. These 48 countries in Sub-Saharan Africa – again, slightly older data, but in 2017 the estimates were that the total electricity used in these countries in Sub-Saharan Africa used the same amount of electricity as Spain despite having 18-times the population. When we talk about a need for growth and a need for access, it's a really significant amount and I’m going to get to how we are actually measuring that within our group.

Obviously, there is a portfolio and a number of different technological ways to address these issues. This is a graphic that sort of shows some estimates looking at for meeting clean energy growth goals. Are they on track? Are they making progress but need accelerated improvement? Are they not on track? You will see that up on the top, the solar photovoltaics and onshore wind, energy storage, and electric vehicles are moving along. Then nuclear sits kind of at this threshold that there is an accelerated improvement needed to help contribute to these near-term goals, but it's very much in the race, and I think is something that is increasingly been recognized as a really interesting potential opportunity.

In our group, we wanted to take kind of this broad context for understanding some of the challenges that exist and say, how can we more accurately understand the market for energy expansion. The study actually started looking at what's the potential of small modular reactors around the world. And that's a multifaceted question but the first thing to ask is how many would you need. The second one is what are the technical options? For a variety of reasons, nuclear may be ideal or less ideal depending on the location. Either way, it clearly needs to be clean. So, nuclear fits the bill there. It needs to be affordable and resilient. I will talk about both of these because I think that, particularly, in the context of nuclear power and the context of emerging markets, both of these terms mean something a little bit different than they might when we talk about them, say, in the United States context. They also need to be sized appropriately. I’ll talk about this as well. Gigawatt scale reactors don't make sense everywhere and so that's one of the things that we were really focusing on is how do you understand the market and the size of the market in different locations. Obviously, it needs to be very safe, particularly if we are looking at new geographies for this to expand to. Again, the timeline here, when we talk about energy access and sort of the investments and the coordination that's happening around the 2030 goals, make the timeline a little bit different than we may be used to talking about in the nuclear domain.

I say this because the technological lock-in when we hit 2030 or as we move towards 2030 becomes increasingly important. So, trying to understand the data that we have, the data that we need, and how can it really fold into this broader conversation around clean energy and energy poverty. I think it's a huge advantage to say, let's really build on all of the data and the opportunities that we have.

The first question here is where and how much electricity is needed, because, surprisingly, this was actually a question that we began to dig in wasn't very well answered.

There were 'estimated demand maps.' This was from a Rolls-Royce report looking at the SMR potential for the United Kingdom as they looked at different ways to capture the market. You'll see there are some pretty high estimates here, 85 gigawatts of global demand, a $300 billion market size, lots of jobs, and this idea that first-mover advantage in exports, if you really want to capture the SMR market. The highlight here, that there is very little market considered in many of the developing regions, particularly in Sub-Saharan Africa. The data I just showed you says, one, this is where two-thirds of the people without access to electricity, or a very large chunk of that, two-thirds sit. And that in 2030 there is still likely to be an unmet need in this region. I think it's a little bit interesting here that it's not even really on the map at all.

And we decided, okay, so let's look at places where energy poverty still exists, sort of, other potential market. The Sustainable Energy for All initiative, again, has these estimates of about 1 billion people without electricity at all, and about 3 billion people globally that rely on biomass primarily. We found that there was a state-level analysis available for many countries. For example, in India, you can see here that there is some breakdown, and between different states you have very high access to electricity in certain locations. And then in others you have less than 50%. While this is useful, this isn't a particularly detailed map. It also relies very heavily on country reporting. Depending on how that is carried out via surveys or different things, you can imagine that there are obviously some data gaps here if you really wanted a really high-resolution approach. Again, this is still a pretty course assessment. So, particularly when we are trying to think about the market for SMRs and MMRs, smaller units. This doesn't necessarily give us all the information that we would want.

So, we decided to come up with market estimates for ourselves. If you haven't played with the 'world at night' data, it's extremely interesting. It's very high-resolution satellite imagery. It's available on a daily basis so that we use annual composites so that there was more of a picture of longer-term access, so throughout the entire year. It's available at very high resolution of about 1 square kilometer for the entire globe [ph]. And it has been used in a number of studies like this. So, estimates from the Human Development Index, looking at income inequality or infrastructure development, there is a lot of work that sort of use these graphics.

I’ll highlight that – you can see that Africa here is pretty dark at night whereas places like Europe, Japan, the US, even parts of India are very, very bright. This is kind of an interesting indication that there is not a lot of nighttime light in different regions and I’ll talk about why that matters.

Coming back to this India example where I just showed you the state-level analysis. You can see here that the granularity of the data here, about 1 square kilometer resolution is much, much better for estimating where is visible nighttime light. You can see all the major cities here. Very, very bright pockets that pop up. And then some much more dark areas. The question remains, “Are these areas dark because nobody lives there?” like the ocean, you’d expect to be dark, or “Is it dark because the people living there don't have things like lights visible out their windows, or streetlights, like roadways, things that come along with access to electricity.

First, we wanted to get the annual composites. You’ll see here again, this is just a global map, looking at the visible light per square kilometer, and the scale here is from 0 to 250 with 250 being the brightest location. If you have a high-resolution screen you are looking at, you can see some of the big cities in Asia. You can see, right along the Nile here, some pretty bright settlements. New York City pops out. There are a few places that are very bright and quite a few that are kind of scattered in between.

Again, you zoom in, and you see here in Europe, there are some hotspots when you look at where all the major cities are. But again, the question is, whether or not the light is not there because there are no people, or because those people don't have access to adequate electricity, and I’ll talk about how we determine that.

But here is the map of the population. The Oak Ridge National Lab has a wonderful data product called the LandScan data. At the same resolution, about 1 square kilometer throughout the world, there is an ambient annual average population. Both of these datasets are from 2016 but we are updating those as we go. You’ll see here that the number of people per square kilometer ranges from 1, in blue, and you’ll see there is scattered blue throughout some very rural areas. Parts of the United States. Lower population density through the Sahara, very low population. But moving upwards into the yellow, the orange and the red, you have population densities from 100 to up to 500 persons per square kilometer. You can see that that's really concentrated. India, and China, Southeast Asia, parts of Africa are very densely populated, as well as certain areas throughout the Americans.

Just here kind of zooming in on the eastern part of the United States. You can see New York City or Boston, all these major cities kind of pop out.

What we did is we overlaid these two datasets. In this case, we have changed the resolution a little bit to make it a little bit more visible but overlaid the visible nighttime light with the ambient population, and said, "Where do people live but there is no visible nighttime light?" This isn't a perfect measure. You can see very scattered areas of the Americas. I live near the mountains. Often when you go up you don't want light inclusion so kind of more rural areas there may be someone or two people living without visible light. But you can also see that there are some pretty high-density regions here, particularly Sub-Saharan Africa, parts of Southeast Asia, where we know that energy poverty is a major issue. Again, you can see that there are some pretty dense population areas here, ranging from 10 to 100, 500 persons per square kilometer, living in areas with absolutely no visible nighttime light. This is the proxy that we are using for energy poverty. Again, our estimate here actually was surprising when we did it, that it falls right in between that estimate of 1 billion people with no access to electricity at all, not even a light bulb, and the 3 billion people who may have access to charter cellphone and perhaps use a light bulb, but definitely don't have access to electricity in adequate amount for wellbeing; things like cooking still happening with solid fuels and kerosene. So, this is how we are defining 'electricity poverty' for this study. The geospatial resolution of this, again, is a square kilometer, so much higher ability to understand what specific needs exist in different locations around the world.

That was great. We found out where people lived. But the question then was, "How much electricity do they need?" How do we understand what's reasonable? Is it a light bulb because then you have access or are we looking at trying to move towards more economic development, health, some of these broader implications of adequate access to electricity, what does that mean to be adequate. I mentioned the ESMAP program earlier, the World Bank's 'Energy Sector Management Assistance Program, and it came in really handy again. One of the things they focused on is trying to define what it means to have access to electricity. At tier 1, they do recognize that being able to have lighting after dark and charge your phone has big implications for your well-being. There are a lot of markets and sort of tasks that can be improved by even just a small access to electricity. But they moved this one up to tier 3, 4, and all the way up to 5. At tier 5, you are able to have general lighting in your home, you can charge your phone, you can have a television or a fan, and then high-power appliances such as refrigerators that have very big implications for the type of lifestyle that people are able to live. In this case, the tier 5 access level is sort of the goal for energy investments.

Again, luckily, they measure it, and they outline kind of different types of access to electricity. So, for household electricity consumption, they define what it means in annual consumption kilowatt-hours as well as daily consumption levels. This allows you to look at different aspects of the capacity factor, the reliability, the types of payment schedules that are necessary for this to operate. It's a very comprehensive look at what type of electricity demand is needed. In this case, tier 5 access is defined for household as 3000 kilowatt-hours per year, and they also look at things like commercial and community uses, lighting, street lighting, things like that, that would be sort of a communal approach to electricity demand.

What we did is take this annual demand of 3 megawatt-hours electric, and we said, "If you wanted to move towards this goal, per capita, so including household, community uses, what did that look like?" We've scaled it up to 50 kilometers resolution here on the map for a couple of different reasons. One of them being you probably wouldn't go build an SMR/MMR every square kilometer. So, I wanted to bring up the scale a little bit but didn't want to make it very large because there are some really big resilience implications to the size of the system and the geographic distribution of it. I am going to move towards that here in a moment. But the idea here is that 50 square kilometer resolution throughout the globe, the size of systems that are needed to meet people's access levels at tier 5 I think are a little bit surprising when we think about energy poverty. Often, people talk about solar panels, maybe a battery pack on their roof. And while that is a very important step, it's insufficient for meeting things like the needs of a refrigerator or streetlights or some of those broader uses that you want to move towards when you think about energy access in the community. You can see here that – in the yellow and the green, you are looking at kind of the MMR sides, 20, 50 megawatts electric. Then if you move into the orange and the red, you are getting to slightly bigger systems, looking at 100 to 200 megawatts systems for the 50-kilometer resolution area. Again, we can see a lot of it contains Sub-Saharan Africa, Asia and China, Southeast Asia, there is quite a big set here. Haiti has a pretty dark red circle here. So, yes, pretty high-resolution map of where we want to think about both the need and the potential markets for growth.

Again, this is where SMRs I think are particularly interesting. There are a number of different options on the market right now. NuScale being the leading one I think is updated to 50 megawatts thermal and 57-megawatt electric I believe at this point. But looking at different sizes of systems and how those fit into different regions. There is also a number of microreactors. Oklo being one. Actually, within our research group, Professors Mark Deinert and Andy Osborne, we've been looking at how we could build an MMR that would actually be much, much smaller, so sort of addressing some of the smaller needs in different regions, and what would be sort of the implications of that. The technological side, I think the size component really, really matters, and there is a lot of importance there. But it's definitely not the only consideration, particularly when we are thinking about these new markets.

Things like ‘resilience,’ this is where I spend a lot of my time these days, thinking about what does it mean to be resilient, what is a resilient system, how do we size it, things like cost, and obviously safety as big considerations for how we understand the feasibility of building MMRs and SMRs around the world.

I’ll start with resilience.

Obviously, when we are talking about nuclear power, we’re talking about a generation facility. Nuclear is resistant by design to most natural hazards and this is a safety consideration. It's also very, very expensive. But one of the benefits of the money being spent upfront is that it incorporates a lot of different design elements that make it resistant to many natural hazards. This is actually one of the early projects that our group did with the World Bank trying to understand the resilience of energy systems. The idea was to investigate whether or not there is an inherent benefit to the overall system resilience coming from different types of generations. We looked at coal, oil-fired petroleum, natural gas, nuclear power, solar photovoltaics, diesel generator, geothermal, hydroelectric, and wind. What we did was look at different case studies around the world and try to understand what were the performance differences from each different type of fuel, two different types of hazards in different locations. Here are just two examples of that. On the left, you have a solar panel utility-scale farm in the Caribbean. This is what happened after some hurricanes and very high winds blew through. While it's absolutely possible to design solar panels to be resistant to higher wind loads, it's not part of the original design. And so, it results in a cost increase to build wind-resistant solar panels and anchor them down differently. One of the things I think that nuclear can think about here is the benefit of having all of those costs incorporated upfront, make it more resilient. So, when we are doing comparisons between technology types, it's really important to understand the level of resistance of the different technologies to different hazards, particularly in regions like the Caribbean where hurricanes are probabilistically predictable. We know they are going to happen again. And trying to understand over the life cycle of those assets how important is it that they withstand these high winds and increased costs throughout their lifetime. On the right-hand side, we have a flooded thermal plant. I put this here because one of the biggest vulnerabilities of many types of power plants is their reliance on cooling water. That includes most conventional nuclear power plants as well. The challenge here is that obviously too much water can be a problem. Not enough water, so times of drought. But also, things like heatwaves. Between 2000 and 2015, I believe there were 15 nuclear curtailments or shutdowns in the United States related to water issues. In the European Union, you are seeing this as well. I think France had several shutdowns because the water temperature gets too hot for cooling. You can't actually take it and use it for cooling and then send it back out into its environment. There are some big implications here for reliance on water. This is something that I think MMR and SMR designs are taking into account. I believe NuScale has a closed-loop cooling design here. The idea being that this vulnerability of water, which is probably the biggest one for nuclear power at this stage, is being addressed as we look forward into the next generation of technologies.

But generating electricity is not the only problem. It's great to have a power plant that is going to keep generating electricity through a hazard. But – let's see if we can the slide advance here. We looked at this, as I said, in a case study implication. This is the slide from Hurricane Harvey in the United States in the Gulf Coast. Here you can see that we just compared the nuclear generation capacity over time to the petroleum refinery capacity over time. You can see that in terms of landfall, where the hurricane came in and made landfall, that the nuclear power plant was able to prepare. They brought people in. And they were operational the entire time. Whereas a large chunk of other fuels had this delay of a couple of days. And depending on the location and how diverse their portfolio is, this could be a huge problem in different regions. We looked at hurricane Sandy and the impacts on New York and New Jersey. Again, nuclear power was the fastest to rebound, coming back from some of the damages that happened to the energy infrastructure.

In Puerto Rico – this is probably one of the most talked-about case studies in the last couple of years. But the 2017 season with hurricanes Irma and Maria had implications for the power system in Puerto Rico. This is a really diverse problem. When we think about generation, most of the fuel in Puerto Rico is imported, natural gas or other types of imported fuels. It has to be brought into ports. It has to be driven or piped up to their power plants. Then, once it's generated it has to be transmitted across the island. You can see in the blue here; the high voltage transmission mines transect the island or go around it. If you are familiar with hurricanes in the Caribbean, they tend to run south-east to north-west. In this case, that means they go straight across Puerto Rico and sever a lot of the power lines here. So regardless of what type of generation or how reliable your generation might be, if you can't get power to people, the system has failed, and is not resilient.

That's kind of the second component of resilience. When we talk about transmission and distribution, smaller generators allow for more distributed grids. I think that that's a really important component when we think about nuclear power sort of from where we are at today with very large gigawatt-scale facilities. And as we move towards this idea of small and micro-modular reactors, that the resilience kind of benefit not only sits in the generation capacity but on the grid capacity. You can see here that you've got wind poles in the foreground that has been bent by a hurricane and broken. In the background you have these steel monopoles which tend to be much more resilient to things like high winds. When we think about the resilience of the power system, it's an engineering question that extends beyond just the facility and the fuel type itself.

Finally, when you talk about resilience of the power system, you can't ignore things like fuel and maintenance supply chains. On the right hand here, you can see a very damaged road, again, from a hurricane I believe. In the middle, you see ports that have been heavily damaged. Again, in places like Puerto Rico, one of the issues for the power system resilience was that most of their fuel, I think, upwards of 99%, 95%, prior to the hurricane were relying on imported fuels. So, it had to be brought into a port and it had to be driven to the facility on demand. Nuclear power here obviously have an advantage in that you can have a lot of fuels stored on-site at any given time so that disruptions to your supply chain have very, very little impact at least in the short and perhaps even medium-term to their operations.

The other component of feasibility is the size and the cost. How do SMR and MMR technologies address some of the issues that we've talked about so far?

I think cost is a really interesting one. There are a lot of goals around how to bring down the LCOE, the capital cost of different nuclear power systems. I think that that's obviously a very important question but it's a question that needs to be put in context. When we're talking about potentially emerging economies like we are today, the cost that we might consider acceptable in the United States is very different than the costs that might be acceptable in other regions. This is a complicated question, but I thought that this graphic was kind of an interesting visualization of – diesel generation is one of the primary fuel sources particularly in rural areas. You can see here that it in euros per kilowatt-hour, the costs are extremely high. In the Sahara and the [Unclear], we are looking at upwards of 1 euro to 2.5 euros per kilowatt-hour. But even in large parts in Sub-Saharan Africa, we're looking at the order of 0.4 to 0.7 euros per kilowatt-hour. So, really, really high costs compared to what we might consider acceptable in the United States or parts of Europe. So, understanding what is the competitive landscape, what's currently being offered, how do you think about the cost and context and what might make sense in different regions is something that I think can really benefit from a regionally specific understanding.

The other part here is – the Goal 13 of the SDGs that I introduced is climate change and how to understand climate change in the overall way that we are thinking about energy expansion. Particularly relevant in this case is the transition risk. The idea behind transition risk is that there is a risk to companies, banks, portfolios, etcetera, related to clean energy and emissions. The ideas of a carbon tax or an emissions treating scheme goes into play, how does that affect the overall cost not just in direct delivery but in how your carbon emissions are accounted economically.

This is something that particularly in places like Europe, is becoming a very, very large component of the discussion. So, banking organizations, insurers, investors, and governments. The United Nations Environment Programme Finance Initiative recently released a climate-related Financial Disclosures document. Participation included 16 global banks and is definitely growing. Even in the United States, US Commodity Futures Trading Commission recently released a report that said "When we want to understand climate risk and the risk to different aspects of the market related to climate and hazards, the number 1 recommendation to address these risks is carbon tax. There is a lot of kind of momentum around what does it mean to think about a lower carbon future.

This is something we think about in our group. Building on an NEUP grant that the group received several years ago, we were able to build an energy cost tool that shows for any location in the United States what is the energy mix and what's the cost associated with that. For here I just picked an example of Mitchell County, Georgia, and you can see that the majority of their electricity comes from natural gas here in that red bar. But a good component comes from nuclear. So, somewhere between 25% and 30% comes from nuclear power. They also have a significant chunk coming from coal, and then, wood, hydroelectric, solar and a few others. You can see their costs here are lower than the US average. This is a nice understanding of where different energy mixes sit. But building on this, one of the things that we've been interested in asking is would transition risk affect some of the prices and the important components here.

And so, have built in a tool to understand what is the levelized cost of electricity in dollars per kilowatt-hour for the different types of technologies. You'll see that I've added here the NuScale estimates based on their different production. Looking at where would that fit into the portfolio. You can see that right off the back just current LCOE. SMR or NuScale is predicting that they are going to be a lower cost in just about everything except for solar power. And when we look at the potential impacts of carbon tax, what would the transmission risk be? You can do that for certain technologies like natural gas and coal. It increases the cost. Whereas, for the no carbon generation options like nuclear and solar, you can see that there is no impact to cost here. The overall resulting levelized cost of electricity changes when you start to consider a carbon tax. Obviously, this is something that is very much in flux, the price of the carbon tax, the timeframe in which it's implemented, all have huge implications here. But for one estimate here in terms of a midline estimate, we found that even a small kind of medium-term carbon tax would have conventional nuclear PWRs lower expense than natural gas, just barely. For nuclear, again, it sits at this really low kind of price point here for the SMRs. NuScale is able to move towards in their projections; this is a potentially really promising component of clean energy generation as well.

I touched on a lot of different pieces around the size of the market, and why you would want electricity access, resilience, size, cost, but how do we put it all together? I've showed you a lot of maps and I do a lot of geospatial analysis. I think it's fun. I also think it's a really neat way to analyze a lot of different datasets. We looked at demand estimation. Where is visible nighttime light and where do people live. We can look at exclusion criteria. I didn't talk too much about this but when we think about nuclear power or even things like safety or resilience, you would want to think about where do you place it? Do you plop it in the middle of a city? Not conventional nuclear but I think this is something that SMRs and MMRs have the potential to really ameliorate as an exclusion criterion with the boundary level planning zone potentially really have a lot more opportunities. But you wouldn't want it built in a flood zone. You can't build it in a protected area, an environmental protected area. But building something where there is high earthquake risk increases the cost and potentially lowers their resilience. And things like landslides. So, you could look at a number of different exclusion criteria, and say these are important for the technology that we are interested in. Again, it looks different for nuclear than it would for solar, and you can kind of understand different locations and why they would be more less ideal for different technologies.

You might be interested in social factors. Nuclear power provides a lot of educated labor jobs which means that there needs to be educator labor in the region or at least it's something you want to think about. We also put in something here about litigation and environmental law. Potentially, nuclear power may not be the best option in a very litigious county perhaps. Then, you need resources. Transmission infrastructure being a big one. Otherwise, the cost of your facility will be increased for that electricity delivery component. But you might want to be really close to major roads or rail. Rivers and water currently are one of the limitations of conventional nuclear for many technologies whereas for the SMR and MMR I think that this is a resource that is being addressed in some really interesting and useful ways.

But from all these datasets, what it allows us to do is go beyond just data acquisition to understanding the market demand per capita, like for those early maps I showed, as well as the feasibility of siting. We could say, what are the ideal locations, where are they able to be, how big is our facility, and what's the footprint it would have. And can we fit that facility in the available land? So, a lot of the work that we do uses the resources that I have talked about and can put them into a geospatial planning tool or opportunity, and say, where are the ideal zones for building. Based on all these different criteria, what is the resource availability, and where is the market demand, where is this actually needed well enough to replace the existing high-carbon generation forces or looking at places that made electricity and where there is going to be a big demand especially as we move towards more [Inaudible] people.

We did this for Africa. This is a very preliminary assessment, just looking at a few of the acceptable and ideal criteria for siting. In this case, in the green you have ideal for siting and yellow is acceptable. The differences in those two just have to do with the distance to high voltage transmission line that already exists, as well as cooling water availability. But we looked at where big populations and we set over certain population density that's probably not the ideal location. We looked at active fault and seismic zones. Then we looked at things like protected environmental regions, so you wouldn't go and do a major construction in a protected environmental region or area. You can see here that the biggest limitation, all those squiggly lines, mostly comes from the high voltage transmission infrastructure or the water. When you create smaller modular reactors that don't need very high voltage transmission to get the power up, that increases your regional viability. When you don't necessarily need on-demand cooling water all the time or you can be further from it, that also will really increase the feasibility of building in a number of different locations. But the idea here is that, by using geospatial parameters and understanding the multiple components that are required for nuclear to be built, you can really quickly select and site different regions, looking at the demand, and identify, say, where the most important or viable regions are from a number of different aspects. Again, here, we are not considering things like security, or educated labor or anything like that. So, there is a lot of different components that would need to be included in this as well.

Just a closing point here. When we talk about electricity demand, I think that rooting it in the need for access to electricity as a humanitarian consideration, thinking about 2 billion people living in poverty, and needing access upwards of 3 when we think about cooking and some of those tasks. And I think there is a humanitarian imperative there. But I also think that there is an economic opportunity. When we take these 1.75 billion persons that we got from our satellite assessment of high-resolution data, what we see is that there is a pretty big market. I assessed it here looking at the tier 5 access level which is that 3 megawatt-hours electric annual use. Then I also put in US access level here. So, kind of an estimate is about 10.8 megawatt-hours electric per capita use. So, much higher than the 3 megawatts that's considered sort of the tier 5 access level goal.

But when you look at the market size of that 2 billion people nearly here, and what that means, we are looking at 5 million gigawatt hours or almost 20 million gigawatt-hours. When we look at this in the US dollar in the US market, the lowest cost US region in July 2018 was 10.84 cents per kilowatt hour electric. We are looking at an extremely big portfolio. This is a back of the envelope calculation, absolutely, not a technical analysis in this case. But just saying, if we just understand the market and the current potential, this is a very big economic opportunity, upwards of $500 billion for this tier-5 access level, and over $2 trillion if we start thinking at US levels. Although I think there are probably some implications here when we think about climate change and different resources. So, somewhere in between here probably is ideal.

Yes, just to kind of wrap this up and then I am ready to take any questions or listen to the discussion. But when we think about equivalent energies use per capita of just over 3-megawatt electric, in this case, we've done a number of different capacity factor assessments, but at 0.85, the electricity production would have to be over 1000 gigawatts to address the electricity poverty for the 1.75 billion people estimated from our assessment living in electricity poverty. Again, this is a huge initial market potential. But the 2030 technological lock-in matters. How nuclear power can be a part of that conversation in the near term I think will really affect the types of technologies and infrastructure that are getting built out. As many of us are aware, once those decisions are made and that infrastructure is in place, it often has a cost to change out that technology.

I will say, I didn't talk about this today, but regulatory infrastructure, security considerations, and an educated workforce are critical to include when we think about the inspections and all the different things that go along with the operations of a nuclear power plant. This is something that does need to be considered, particularly if we're looking at emerging economies. And, size matters. I think one of the real benefits that nuclear power has in this conversation is if the technology related to small and microreactors can really understand why their size is a huge advantage in so many locations. It's often better just in terms of the population density in terms of the proximity to population centers. Again, it could be considered more resilient in the overall power system because of lower transmission line distances and some of the implications for hazard resilience there.

Just finally, I think reliability is really important. Understanding collaboration versus competition between different technologies to meet the goals of expanding electricity access. I think we need as much as we can get in terms of different options and understanding the nuance between different locations.

With that, I am done for this morning. I am happy to take any questions that you guys might have.

Berta Oates
Thank you, Amy. Thank you very much. If you have questions, please go ahead and type those into the question pane now. While those questions are coming in, we'll take a quick look at the upcoming webinar presentations that we have scheduled. In November, a presentation on Neutrino and Gen IV Reactor Systems. December, a presentation on the Development of Multiple-Particle Positron Emission Particle Tracking for Flow Measurement. In January, MOX Fuel for Advanced Reactors.

There are several questions that have come in.

Amy Schweikert
I can't see them.

Berta Oates
Hang on with me for just one second. I am going to see if I can make you – if I can elevate you. There is a question that reads "Even though the United States is hard to suffer the construction cost, how do you consider those developing countries as potential markets?"

Amy Schweikert
Okay. Thank you for the question. I think – I am not quite sure I understand exactly what the question is here but how do you consider developing countries' as potential markets. Well, I think that this is sort of the overall context that there are many locations in the world where there is very little to no electricity access. Globally, there is a commitment from the United Nations, from the World Bank, from a number of non-profit organizations in development, agencies, that electricity access is something people are moving towards. I think they are markets because things are being built there and because there is a need for infrastructure. That being said, I think identifying the locations that are ideal for nuclear is something that needs to be multifaceted. It's a security consideration. It's a reliability consideration. There is kind of benefits and challenges all around. When we think about potential markets, I think that's always how they should be approached. I think the idea hopefully that came through today was that SMRs and MMRs have a particularly interesting niche potentially to sell in terms of both, reliability and size that make them part of the conversation. I think that's

being recognized, say, from the Clean Energy Ministerial that's saying, nuclear needs to be part of our portfolio and how we think about this. Yes. So, I think construction cost being one element of that, but I think there is a much broader consideration to the market.

Berta Oates
Thank you. It looks like many of these comments point out the cost factor. There is a question on the energy poverty maps, so the areas in Europe, the US. Are these baseline areas or is such a concept defined here for a given standard of living?

Amy Schweikert
This is a great question. Thanks for asking. The energy poverty map that I showed that was looking at where there are people living but no visible nighttime light, which is how we define energy poverty for this project. It does show areas in Europe and the United States. I will say that all of those areas are very light blue which sort of meant the less than – like very, very small amounts of power would be needed. What that indicates is that there are people living there with no visible nighttime light; it doesn't necessarily speak to energy poverty. Again, places that are more rural may not have street lights which is one of the kinds of things that allows you to see it from space. Locations where light pollution is becoming a more recognized issue, particularly places perhaps in the mountains, or environmental regions you are actually working against light pollution. For environmental reasons, those might fill up.

We'll say that we looked at a number of studies related to how visible nighttime light compares to on the ground measurements. There are estimates that villages, particularly in Africa, because that's kind of the areas we were concerned with, the villages with as few as I think 30 houses do fill up with some visibility. What you are seeing in Europe and American are often just very rural places that for a lot of reasons don't have light, and it doesn't necessarily indicate poverty. That's a great question.

Berta Oates
Thank you. Did we have any success in getting you – can you read the questions, Amy? Do you see the questions pane?

Amy Schweikert
I do. Yes. Thank you.

Berta Oates
So many of them have a reoccurring theme, do you want to scroll through and select some of the ones that could be bundled together so to speak?

Amy Schweikert

Yes. I am seeing a lot of questions here about cost. I think that that shows that people are thinking about some of the challenges that nuclear might face when it's talked about in the broader portfolio scheme of clean energy technologies. I think that there are a couple of things to consider there. The first one being that I think nuclear has the potential to change the way that it's viewed when we think about things like resilience. In this case, resilience being the power system, so the delivery of electricity. When you think about that, the cost of building a nuclear power plant is very expensive relative to things like solar panels. But if you think back to that graphic that I showed of the Caribbean, without extra design considerations, solar panels are not very resilient to things like high winds. Whereas nuclear power has to be. By design, the facilities have to be resilient to things like high wind and be resistant to those hazards. That extra cost is non-trivial, but if the power plant is able to withstand that, it's able to continue to deliver power. When you think about the overall system resilience delivering electricity, that's an important component. Things like natural gas or on-demand fuel supply sources. The entire supply chain, there is a lot of moving parts there. Particularly in isolated regions or island regions, you need things like ports, you need road, you need pipelines, and all of that infrastructure adds vulnerability to the entire system. That's something that I work on a quite a bit. I think it's hard to value. There aren't set ways to value the cost of resilience although it is an emerging area of research and we are working pretty actively on that. And so, I think you can look at lifecycle costing and you begin to see that LCOE or just immediate construction cost doesn't capture the whole picture. Although I think it's a really important consideration if not the entire story. The other thing I'll say about cost is that we don't have great estimates for this. A couple of questions noting that for SMRs and MMRs to be competitive, it would have to be batch production, and I think that is well understood. The first-of-a-kind cost is always more expensive and definitely not feasible for many locations. But I think that this is something to keep in mind. Obviously, many people are aware of it that the cost component of nuclear is one of the challenges, and I think hopefully is on the minds of everybody working in the new generation of how we are going to move towards what it means to have viable and feasible SMR and MMR technologies.

I see a couple, a question here about nuclear and processed heat and thermal heat and I think that's a good question as well. I think there is a lot of room for nuclear power to not just provide electricity access. Thermal heat being potentially a great add particularly in areas where industrial processes might be growing or have good markets for a number of reasons including labor costs or different economic considerations. I think thinking about the co-benefits of nuclear power and not just from electricity but also in these other aspects is a great added benefit to the nuclear power.

Berta Oates
Great. Thank you.

Amy Schweikert
I think some of the other questions I am seeing here have to do with security or regulation in new markets. I really appreciate those questions. I think that this is an interesting question, and I think it's a policy question. I think the IAEA obviously works in this domain of regulatory infrastructure. We did sort of some initial assessments of looking at the number of inspectors and sort of professional security and regulatory oversight in the United States and how that corresponds to a number of reactors. I think it's a non-trivial consideration. If you are going to build out nuclear power in new locations, you need new infrastructure that goes with that from the regulatory in the employment side. I think given limited existing designs for SMRs and MMRs have a lot of information, NuScale has talked about this that one of their goals is to have some very educated job positions that require perhaps Ph.D. and Master's degrees but also that have a lot of employment opportunities for less-educated workforce, opportunities on site. So, trying to understand the population of people that are needed to make a nuclear power plant work I think is very important, and thinking, both, in the plant, on-site, managers and operators, and things like that, but remembering that it has to include this regulatory infrastructure I think it has to be something that, if nuclear power, particularly SMRs and MMRs, as we look towards new markets, if they are going to be successful, that component of a regulatory infrastructure needs to be talked about. And I think that that's actually something that if people take this 2030 kind of near-term goal into consideration, might be one of the great contributions that nuclear can make in the near term is to talk about some of these challenges, workforce opportunities, and say, here is what that would look like. And come up with a plan for addressing some of the things that are very real challenges but also potential opportunities for employment.

So, yeah, I think that that might be something that if people are interested in some of these emerging markets, might be a way to start talking about that now so that as the technology begins to mature over the next couple of years, that when it's ready to go and be deployed, that infrastructure is in place or at least there is a plan to put it in place.

Berta Oates
Great. Thank you. Amy, is there a link to the energy cost calculator that can be shared.

Amy Schweikert
I believe there is. I can find out for that. If anybody is particularly interested, please just email me, and I'd be happy to send that to you as it's available. If it's not available right now, it will be soon.

Berta Oates
Great. Thanks.

Amy Schweikert
I am just scrolling through some of the questions here. This is an interesting one. I see one here that says, "Why carbon tax doesn't consider the CO2 emissions or backup plans needed for renewable?" I am not sure that that's true in every location. I think, one of the interesting things about carbon tax discussions or emissions trading systems ideas is that they are very much still coming into fruitarian. I know the European Union has had versions of this in place, different phases they are walking through for several years now. Different countries are considering this either voluntarily or by legislation. I think one of the things that is kind of happening in the climate change realm is to try to standardize the approach to this because right now it's very disaggregated. It looks different in different locations. I think sometimes that's good because it's taking into account regional and political considerations. But I also think that that poses challenges because the way that carbon or other greenhouse gases that contribute to global warming are considered, when it changes in different locations that becomes really challenging from a technological perspective, trying to address those issues in different locations.

I think it's a good point that when we talk about solar power for example, and I even showed the LCOE cost of solar, that it's much lower than nuclear even in Georgia when I did the energy cost calculator. That's true for the LCOE. But thinking about different reliability metrics or the capacity factors of particularly some of the more very low generation sources, I think it's a salient point. They are not often thought about in terms of, say, 24-hour or 7-day reliability. And when they are, you start talking about battery packs and storage systems some of those things really raise the cost. Whether it's the carbon tax or the overall economic accounting for different technologies, I think there is benefit in taking a lifecycle's approach. I think that also includes [Unclear] resilience and how likely is the plant to be damaged by hazards. When you do that, the economic accounting begins to look a little bit different than some of the conventional metrics that we use.

Berta Oates
Great. Thanks. "Have you been able to gain any lessons learned from the UAE which recently started commercial nuclear power operations from scratch by building a regulator education system workforce, etcetera, to support the program?"

Amy Schweikert

Personally, I haven't looked as much into the UAE's current work, but I think that it's a great case study. I think that there is a lot of benefit from trying to understand what this looks like in a new environment as opposed to one with institutionalized memory. For both, better and worse, in the United States we have a long history with nuclear and that comes with a lot of challenges politically and socially. It also comes with some benefits. Understanding perhaps what those differences are in a new market like the UAE I think could be really informative. I think there is always benefit in trying to understand how things like the political and the financial structure affect the feasibility of construction and operations because there is a lot of issues around regulation and financing that affect nuclear power that I think it might look different in different locations. So, I think that would be a great case study to look into. I will add it to my list.

Berta Oates
Great. Thanks. There is another one that's kind of along that same vein of thought process, that reads, "Some of the literatures suggest that operating costs will be managed by leveraging high levels of automated monitoring with remote access by experts; that is, versus a large staff on site. How hard would it be to add connectivity to overlay the applicability grids that you shared?"

Amy Schweikert
If I understand that question, the idea is sort of, when we think about microgrids or emerging locations with less redundant infrastructure, there might be challenges. Let me see if I can find that question.

Berta Oates
It's near the bottom and I just shared it with everyone, so hopefully, it will be the last one on your chat.

Amy Schweikert
Okay. I don't see it. Can you read it again? Sorry.

Berta Oates
"Some of the literatures suggest that operating costs will be managed by leveraging high levels of automated monitoring with remote access by experts versus a large staff on site. How hard would it be to add connectivity to the overlaid applicability grids that you shared?"

Amy Schweikert
Okay. That would be just the dataset. I think one of the really useful things about geospatial analysis and something that our group really specializes in is that once you have a nice framework built up which is not a trivial endeavor – once you have a geospatial system in place, you can add any dataset to it. Some of the works that recently came out of the

World Bank looking at how to identify the likely locations for transmission lines using satellite imagery is really helpful and something we are working with. Because one of the biggest challenges of understanding all of these components isn't the technological aspect, it's not an incapability of doing the analysis, it's actually the data itself. So, particularly, when we are looking at economies outside the United States and parts of Europe, data can be extremely hard to come by for a number of reasons, either it is privatized or because it doesn't exist. But if you can get that data, overlaying it on the geospatial map allows you to ask a lot of questions. If you remember that layered graphic that I put in, that's exactly why we do this. It's because if you look at any of these one aspects by itself, you might get a specific answer, it might give you some insights. But broadening it out to be a really multifaceted discussion, both in analysis and in visualization, I think can sometimes provide really unique insights that you can't necessarily find by looking at each thing individually.

Berta Oates
There is a suggestion. "Have you considered using the carbon intensity maps produced at the following link by countries or regions for opportunities to reduce carbon emissions?" And I have shared that just now. It's in electricitymap.org.

Amy Schweikert
Okay. I think kind of similar to what I was just talking about, I think that there are a lot of different perspectives that you can take when you are trying to consider what is the role of nuclear power and how can you contextualize it. I think today I've talked about electricity poverty and the potential markets related to access for people that do not currently have high levels of access or any access at all. But I think an equally valid and potentially something that has just as much momentum is the idea of reducing carbon intensity. I think that that actually is that very first graphic that I show from Rolls-Royce in the UK. That's what they were doing is they were kind of saying where is carbon intensity a priority to reduce and what would it look like to replace that and would be the market for doing so. Again, I think this is where the geospatial assessments and some of the tools that our group has put together can be particularly useful, because when you change the question you are asking, you might still need many of the same datasets, but you want to look at them a little differently. And being able to filter that data very quickly to ask those questions and come up with the right perspective I think it can be very useful. But I think carbon intensity is a huge component of the context for nuclear power, whether it be in emerging economies or those that are already very carbon-intense and need to reduce.

Berta Oates

Thank you.

Amy Schweikert
I see another question here about connectivity. It says, "If a location doesn't have good internet or telecommunications, is that a deal-breaker?" Assuming this is talking about a deal-breaker for expansion of MMRs and SMRs, I would say, I think that depends on the technologies as they get developed. Right now, a lot of the SMRs and MMRs are still in a kind of early to mid-stage development and so kind of the questions of how reliant they are in internet and telecom, is probably something that would need to be answered as we continue to learn more. But I think the broader issue here that it brings up is the interdependencies of infrastructure. I think that the power system on – like, the lot of my works sits in the resilient space and the power system is extremely important for the operation of a lot of other infrastructure systems, including the internet and telecommunications. So, there are always some feedback loops between these critical systems that I think are hugely important when we want to understand the impact that we can have in a region or the challenges that exist there.

So, roads, pipelines, ports, transmission systems, internet, telecommunications, all of this kind of circles back together. I think that it becomes a much more interesting question and one that is a little bit challenging to get at. I think there is a lot of work to be done about what infrastructure is required for optimal or acceptable MMR and SMR viability, and also the role that they can play in the broader infrastructure development in sort of teasing out those feedback loops. It's a great question and I think one that's really been worked on in a lot of different areas.

Berta Oates
Thank you. There are a couple of questions that have specifically mentioned Alaska. One dealing with temperature and the other wanting to know about the remote communities and whether the assessment is able to identify these types of communities, or whether it's too fine of a resolution for this current approach.

Amy Schweikert
If I am understanding that, the question is probably about the satellite data, looking at population and night lights. I haven't dug into Alaska. I do think that there are ways to validate the application of this method in a specific geography which would be taking the LandScan data, taking maps that we have around where a town sits, perhaps existing infrastructure data, and trying to validate, "Is this a really good measure for this location?" My intuition is that it would capture – like I said, the ground [Unclear] in Africa, the studies that have been done, have shown that anywhere upwards of 30 households do show up on the visible nighttime

light. So that's definitely imperfect metric and I think geographically weather-dependent, snow reflects things, stuff like that. But I think you could definitely apply this approach to Alaska and it's something that we haven't done as of yet partially because of the focus on some of the more emerging economies with some of our work but would obviously be applicable. I think potentially, there would be a lot of utility in doing that because infrastructure maps and data, things like roads and transmission lines in the United States tend to give a pretty good picture. Airports and things like that give a good picture of where there are populations. I think it could be very quickly be utilized in that capacity.

Berta Oates
Thank you.

Amy Schweikert
I don't know if we have time for maybe one more question. What do you think?

Berta Oates
If you have the time to take another question, that would be perfect.

Amy Schweikert
Okay. Let's see. I see one question here that says, "Were any sensitivity analyses performed on the parameters such as future population growth or decline?" I'll just speak to that real quick to kind of round out the context of this talk, being on the emerging markets. No, in the data that I showed today, it was not forward-looking at all. Part of that was because when we just take the current snapshot, I think there is a pretty compelling reason to think about where we are at today, much less moving forward, in terms of electricity poverty. But I do think that there is a huge amount of utility in looking forward to the markets. I think one of the challenges there is how do you decide which model is correct. But we spend a lot of time thinking about climate change and some of the issues with uncertainty associated with modeling. I think those same applications could be applied to population growth and technology and things like that. Again, it's just another dataset. In this case, if there is a model or a dataset that's of interest, it's really easy to fold in to these geospatial assessments once the system is set up, which is really what we've focused on. I think that for a research perspective or a market perspective, these are questions that we are continually asking, and love to partner, and keep working on, because I think there is so much out there that we can ask. Having data-driven assessments I think are particularly compelling. Not just sort of speculation or calculations but actually showing them on maps and coming up with really robust data assessments can help reduce some of the uncertainty, can speak to different aspects, and hopefully, yes, continue to inform some of these really important topics.

Berta Oates
Thank you very much, Amy, for sharing your expertise and your time with us this morning. Your presentation was enlightening if I use to such a bad pun. I really appreciate you sharing your expertise with us though and for fielding so many questions.

Amy Schweikert
Thank you so much. I am happy follow up over email if anybody has any specific ideas. So, yeah, thank you very much.

Berta Oates
Thank you, everyone.

Patricia Paviet
Thank you, everyone.

END
