Geospatial Analytics for Energy and Resilience Analysis
Prof. Mark Deinert, Colorado School of Mines, USA

Berta Oates
Good morning, good evening. Welcome everyone to the next Gen IV International Forum Webinar presentation. Today's presentation on Geospatial Analytics for Energy and Resilience Analysis will be presented by Dr. Mark Deinert. He's with the Colorado School of Mines. Doing the introduction today is Dr. Patricia Paviet. Dr. Paviet is the group leader of the Radiological Materials Group at Pacific Northwest National Laboratory. She's the National Technical Director of the Molten Salt Reactor Program for the Department of Energy. She's also the chair of the Gen IV International Forum Education and Training Working Group. Patricia?

Patricia Paviet
Thank you very much Berta. Good morning, good evening, everyone. It's a pleasure to have with us, Dr. Mark Deinert. He is an associate professor in the Nuclear Science and Engineering program at the Colorado School of Mines. He holds external appointments in Electrical Engineering at Cornell University and as a consultant with the World Bank on climate resilience. His research is focused on modeling and simulation of complex systems with application to nuclear power, nuclear security, distributed energy systems, and risk analysis. So, without any further ado, I give you the floor Mark. Again, thank you very much for volunteering to give this webinar.

Mark Deinert
Well, thank you very much for having me and for everybody being in attendance and also for that introduction. Today, I'm going to talk a little bit about some of the work that my group does in geospatial analytics and its application to energy systems and resilience analysis.

Let me start by just saying that this work grew out of an NEUP project that was funded back in 2016. We were contracted to develop a little tool that could be deployed either through a web browser or on a handheld device that would allow people to click on a location and understand how different energy systems that could be sited in that location would compare on the basis of levelized cost of electricity, footprint of various kinds, water use, land use, but also carbon signature. Built into the system, we were going to put in an application programmer interface or what some of you probably recognize as an API that would enable third-party developers to request data from the system for educational, nonprofit and policy analysis purposes. Now, we actually want to build that system.

This is what the interface currently looks like if you call it up on a web browser. The system isn't currently live. We've had it up and taken it down on a number of occasions, and I'll explain why in a little while. But what you can see here is you can click on a location. This is Colorado, or specifically Boulder, Colorado where I live. The interface will allow you to see the cost of residential, commercial and industrial electricity and how those prices compare to national averages.

It will also allow you to see where the state of Colorado gets its electricity from. It's predominantly coal in Colorado followed by natural gas. We have a little bit of wind, a little bit of hydroelectric. And even though we're very sunny, and there are a lot of solar panels in Colorado, a relatively small fraction of the electricity in the state is generated by solar power.

There's currently no nuclear in the state of Colorado. Although as some coal-fired power plants are being retired, the discussion has turned to whether they could be replaced by small modular reactors. This system also allows you to look at how different energy technologies at this location might compare. In particular, here there's a comparison of conventional nuclear, solar power and natural gas.

Now, these are geospatially varying data because the price of commodities like natural gas varies within the United States from one location to another. It can be very cheap in some locations. In remote regions, it can be extremely expensive, but also the cost of labor varies a little bit as well. There's also a big variation in solar resources from one location to another. As you might expect for wind that's also true, and it would be true for water resources if you were putting in small hydro facilities in different places.

In any case, this will give you an idea of what the capacity factors are based on national data for things like natural gas-fired capacity or for nuclear and specific location, specific data for something like wind or solar. It will compute the levelized cost of electricity relative to a set of default input parameters that you can also change. If you're an expert user, you can change the input costs for these things at the time of construction. It will give a levelized cost of electricity. If you include a carbon tax, a land use footprint, greenhouse gas footprint, and then it will give you Cap X on a conventional basis, but also a capacity factor weighted basis as well, so you can get a true comparison of these different kinds of technologies.

Now, this is a very conventional way of comparing energy systems. Usually, people don't do this on the basis of LCOE and maybe carbon footprint. We've expanded that a little bit for land use footprint as well. But it's a conventional way of looking at these things. It became apparent to us when we were building this system that it isn't really a fair way of comparing energy technologies because they depend on a lot more than just local commodity prices and cost of labor.

In particular, there can be land use restrictions that vary from one location to another. You can't build in national parks, you can't build in national monuments. There are state boundaries inside of which you can't build certain kinds of things like state parks. That can even be true locally as well. In the area that I lived in Boulder, Colorado, there's actually a lot of open space, which has been preserved, and you can't build in those regions either.

Proximity to infrastructure and particular kinds of geology can be very important as well. As many people in the nuclear sector are aware, one of the reasons that vendors are looking at retired coal plants as places where you might put small modular reactors or Gen IV reactors is because those locations already have a grid hookup. Building those hookups can be extremely difficult. In some cases, people even claim it's more difficult to do that than to site the nuclear reactor itself.

Geology can also be really important. If you're trying to put a below ground carbon sequestration facility in, you need the right kind of geology to be able to do that, something that will actually entrain the carbon dioxide which you're sequestering. If you're trying to put in place a compressed air energy storage facility, then you also need geology that won't let the air leak out. As I said, local geology can be really important.

Proximity to skilled labor. This has a direct impact both on the ability to operate certain kinds of facilities but also have the ability to construct them in a streamlined fashion.

Something that doesn't get a lot of attention, but should probably get more attention is the proximity to receptive neighbors. If you've got people who are opposing whatever project it is you're doing, that's just going to make life more complicated and drag out the construction timeline. If you're trying to locate a nuclear power facility in a community that has a very high membership rate in something like the Sierra Club, there might be more pushback than you would find in a community where that membership rate is lower.

Also, proximity to potential hazards. People in the nuclear community are very aware of this. Particularly, in the United States, there's some very strict requirements by the Nuclear Regulatory Commission about where you can and cannot put nuclear power plants. Think about seismic activity as an example. It's less on the radar of different kinds of energy technology systems, particularly solar power facilities, but it impacts all of them. So, high winds, or high wind threat can be very dangerous for grid scale solar power facilities but also for wind towers. These things are also subject to seismic activity as well. They have to be constructed to be able to withstand that. You can kind of tick down the list of potential hazards that would impact energy infrastructure.

Increasingly, something which was on people's radar is the fact that climatological changes can also impact energy systems. Here in this figure, you've got sea level rise that might occur because of melting ice sheets, cyclones whose frequencies might become higher and whose rainfall might increase, wildfire, flooding. These things can all have an impact on energy technologies.

From a designer's perspective or from people who are looking for locations to put these facilities, the questions are really how much damage could be expected in a certain amount of time? Can it be avoided and what would be the associated costs? There are direct costs that are associated with damage to the facilities but also then the time to repair. How long is your facility going to be offline? What are the concomitant damages that go along with that?

Also, the indirect financial costs, if you've got power systems that rely on liquid fuels or coal, then the inability to actually get those commodities to the location of your power facility is an important consideration as well.

Finally, when it comes to climate change, you always have to worry about political and social costs as well. In the political domain, people can legislate in ways that affect particular kinds of energy technologies. This is referred to as a transition risk. If politicians enact a carbon tax, then that's going to wind up affecting anything that burns fossil fuels. If societies move away from certain kinds of technologies like the Germans moved away from nuclear power, it can result in the stranding of assets. These can have direct impacts on the balance sheets of corporations.

Climate impacts can also affect construction zones. Building zones in the United States and other countries are dictated in part or largely by what climate you have in that different region. As climate zones change as a result of climatological shifts, those standards wind up changing as well. This might seem like a small thing, but it really winds of affecting in building construction or the HVAC systems. But as the climate zones shift that has a direct impact on the kind of power requirements in different regions. And that can affect what utilities have to supply and should affect their planning for the future.

That's usually borne out in what's referred to as heating and cooling days as those shift the amount of time you have to heat during the year or cool during the year changes.

But there are other effects that you have to worry about. In particular, the temperatures of rivers, oceans, and lakes, these can affect power systems if you use these as cooling sources for a power plant. In particular, with nuclear power plants, they are very often licensed only to operate within certain ranges for the temperature of their cooling body. It can't go above certain thresholds. If it does, you have to power down or in some cases even turn the reactor off.

You can also expect in the future, changes to coastlines and floodplains. As certain regions become drier, things that are currently in a floodplain no longer will be. But one of the odd things about climate change is that you very often get the odd effect of both being drier through parts of the year and wetter through other parts of the year. The floodplains can disappear through certain times a year, but they can show up in other times of year in places where they don't currently exist. As global icecaps melt, the sea level will also increase and that can lead to increased coastal inundation. If you are siting power facilities close to a coastline that's something that has to be taken into consideration.

Also, changes in precipitation can affect river flows. Again, this can feed back into power systems if these rivers are used for cooling purposes. In some cases, rivers can expect to have dramatically different and lower flows than they currently do, or at least through part of the year. And so, what might be suitable for cooling a coal-fired power plant or a nuclear power plant now might not be in 20 years. Given the lifetime of these facilities that kind of thing has to be taken into consideration and planning.

So, really, what I'm trying to highlight here is that energy systems are complex. They couple to the environment in a number of different ways both because there are siting requirements for things like nuclear power plants, but also from a technical perspective, the environment winds up impacting these facilities as well.

We were really trying to get at a system that would allow us to understand the interactions of all of these things. The kind of data that you need to be able to do that isn't widely available. It's available from the major data vendors like Bloomberg or S&P Global Platts until very recently IHS Markit but they merged with S&P. These big data houses have this kind of data, but it's expensive, and it's really out of reach of academic users or the general public. You have to have deep pockets to get hold of it.

We decided to build a system that would allow us to encompass all of these problems. We started out by calling the system Terra Analytics just as an in-group platform. But this also became the name of the company that we then spun out that focuses on these kinds of data and this kind of analysis.

What sits behind the Terra Analytics platform is a very large dataset. It encompasses four general categories; resources, infrastructure, hazards, and then social data. Under resources, there are things like wind and solar resources at a particular location, precipitation levels, location of aquifers, oil and gas fields, local geology, soil types. These data are all global. At some level, we have these for everywhere. Global infrastructure, location of grids, generation facilities, roads, pipelines, rail systems, airports, seaports, hospitals, schools, and telecommunication systems. That latter one predominantly are the locations of cell towers globally.

We have a database of natural hazards so high wind locations, extreme heat, drought, rain, flood, a global fire database, seismic potential, tsunami potential, and then a large database of climatological data, which is based on the most recent and previous climate model intercomparison project. So, we have the CMIP-5 and CMIP-6 data that we can use for climatological analysis.

And then, we have social factors. For many countries around the world, data on crime, conflict in particular is something that we're spending a lot of time looking at right now, educational levels, longevity, employment, litigation rates, we have this for the United States geospatially. Human Development Index, which is a way of understanding the development level of countries globally and how that changes over time. And then, a database of costs that relate back to different kinds of infrastructures.

It depends a little bit on how you count. We very often process raw data to different spatial and temporal resolutions for specific applications that we're doing. But, in general, this database right now is around 200 terabytes in size. All of these, these different areas within the database are constantly evolving as new data becomes available.

It's legitimate to ask is the Terra Analytics system just data? The answer to that is no. Built into this, we also have energy flow and economic models that allow us to assess the performance of energy systems at different locations with coupled energy systems.

We have algorithms for data scaling for spatial and temporal analyses. Algorithms for data filtering. This would, in particular, allow you to set a series of criteria for identifying locations that you think might be suitable for different kinds of technologies, and then pulling all of those locations up globally or within a specific country, and algorithms for identifying climate sensitivity and sensitivity to natural hazards.

From a geospatial analytics perspective, the way that you might use these data would look something like this. You could create data layers. Here visible nighttime light that can be used as a proxy for identifying locations where people have access to electricity. You can combine that with ambient population data for regions, and then you can use that to determine how much light people are emitting per capita as a function of location. And that can roughly be correlated with people's access to electricity at different kinds of levels.

You can set filtering criteria, so maybe you're looking for areas that don't have a land slope greater than 3%. You're not sitting in a wetland and you're not sitting in a protected area. And then, if you're trying to site something like a solar power facility, you could have solar irradiance as a function of location, temporal data for this. And also, maybe, you're looking for particular kinds of underground geology because you want to couple this to a compressed air energy storage system.

You can then combine these kinds of data and say, well look, if we're trying to electrify people in this region to a certain standard, to a certain level of electricity access, you need a facility about this size. It has to be contiguous. And so, you can identify locations where you could actually put a facility like that. And then, you can take these data, and you can map them to every location on the planet and identify all of the regions on the planet where something like photovoltaic and compressor energy storage could be used to meet the local electricity needs of the population there.

As I said, we have global data on natural hazards, infrastructure, resources, demographics, and climate change. For the work that we do both research wise in the advising that we do for organizations like the World Bank, we use these data to help them understand risk disclosure. This has become a really big thing with the World Bank. They now try to have a climatological risk disclosure with every energy project that they are underwriting regardless of where it is so the people understand what the risks of current natural hazards are to that project, but how those will also change in time as the climate in those regions evolves.

We can use these things as well to do probabilistic risk analyses. And so, what are the impacts of those risks on a project over different kinds of time horizons? What are the concomitant costs that are associated with that? And then, these things can be coupled for decision analysis. You can use them to decide whether or not the project is located in an appropriate region or whether it should be moved to another region, or whether the project is appropriate period.

Now, let me just give an example of how you might do this to understand how to electrify people who are living in electricity poverty. Electricity poverty usually means people have no access to electricity at all. For the purpose of this figure, the way that we defined electricity poverty was these are locations where population is known to exist, but there's no measurable nighttime light that is visible. By visible here, I mean, visible to the NASA viewer satellite, which cruises throughout the planet and loops over pretty much every location on the planet twice a day. And so, you can get an image of whether or not there's any nighttime light being emitted from a particular region.

Now, all instruments have thresholds to them. And so, there are a lot of locations in developed countries like the United States, or developed countries in Europe, where you know that there's population in a particular location, but it's pretty rural. As a result that’s not emitting enough light from that particular region for the satellite to pick it up. That's why here when I'm saying electricity poverty, you've got places in the US that are lighting up, but also places here that are lighting up where you know people have access to electricity.

We could have added an additional filter to this that would have truly reflected people who are living with no access to electricity at all. What you'd find is that they're located almost entirely in Sub-Saharan Africa, a few locations in South America and in Southeast Asia. The actual population living in true electricity poverty is a little bit under a billion people. But by this measure right here, it's about 1.75 billion people or a little less than 20% of the world's population.

Now, you could develop a standard for pulling these people up to not only out of electricity poverty but up to the level of electrification that you would find in a middle income country perhaps like Iran. That would be around 3000 or around 3 megawatt hours of electricity per person, per year. If you're then trying to meet the electricity needs of all these people we've just shown to be in "electricity poverty," at this level of electrification in regions that are a half degree in size, just about 50 kilometers on a side, what you'd find is you don't actually need that much electricity to electrify that population. For many regions in the world, a 5-megawatt electric generator would do just fine.

There are some very high density areas for people who are living in electricity poverty. These are actually truly people who are living in electricity poverty in these regions where you'd need a little bit more than 200 megawatts of capacity to be able to meet the electrification needs of those populations. We just did a study of this actual problem. What we found is that for Sub-Saharan Africa, which has about 80% of the world's people living in electricity poverty, you can electrify a little bit over 75% of them to this standard, this middle-income level using generators of 50 megawatts or less in size, so very much in the range of small, modular and micro reactors.

Now that would present an enormous market. If you're going on the basis of this 1.75 billion people in electricity poverty by the measure, I just dictated, you could bring them up to 3 megawatt hours electric per year per person. That corresponds to what is referred to as an Energy Sector Management Assistant Program T5 level. ESMAP, Energy Sector Management Assistance Program is a program developed by the World Bank for understanding electrification in developing world at different standards. It goes T1 through T5; T5 is the highest level. It's an aspirational program to bring people up to a level of electrification that represents middle income countries. Again, when you think of that, think of something like Iran.

The important thing to note here is that if you're assuming the electricity sells for a little bit under 11 cents per kilowatt hour, you're talking about a $0.5 trillion market per year. And if you assume that these people were to come up to an electrification standard which represents the US average, then you're talking about $2 trillion per year market. There is an enormous market here. Again, people truly living in electricity poverty, it's about half of this value. But that's still almost a $300 billion per year market in the developing world or if they come up to a US standard of $1 trillion per year market. It's enormous potential for expansion of the electricity system in these regions.

These are geospatial data from the Terra Analytics system. Actually, we produced these for a project that we were doing for the World Bank to understand risk disclosure for an electrification project that they were underwriting in Mozambique. What's shown here is the country of Mozambique. It sits on the Eastern Coast of Southern Africa. There are three different kinds of risks shown here. There's flood risk, there's wildfire risk, and then there is risk of extreme heat.

On the flood risk, what you've got here is depth of flooding for 100-year event. That's an event that has a 1% chance per year. The color coding here represents different kinds of depths as a function of location that you could expect from a 100-year event. And then, there are the locations of primary substations that are a little bit difficult to see. But you've got one up here, you've got one right here, and then you've got one down in here. And then, you've got transmission infrastructure, which is shown in orange here. You can see the different locations of that. Here's a blow up that shows transmission infrastructure substation right here, transmission infrastructure, which was sitting right in the middle of the water for 100-year event.

Data like this can be used to tell you where you need to harden current transmission infrastructure and where you shouldn't be siting it if you're going to build additional transmission infrastructure. Don't put it right where the water is going to wind up being. The fact that you can get depth information as well allows you to say how high the flood wall should be built around transmission poles, or how much they should be elevated if you are going to build them on top of a mound as well. It can also give you important information as to how deep the anchorages for these towers should be in different locations.

This is historical data for the incidence of wildfire in Mozambique. This looks like the entire country is on fire. But what this represents is the percentages of the pixels that have experienced fire on average in a particular year. And so, these data are relatively granular. When satellites are looking down to determine whether or not there is fire in a particular region, they have a geographic area that corresponds to a pixel. If some sub-region in there is on fire, that pixel will register as having had wildfire in it. And so, this isn't representative of the entire country of Madagascar being on fire. But it does represent that there's a high degree of fire risk across all of Madagascar.

There's a lot of grassland in Madagascar. And so, you get a lot of spot fires that occur in particular regions. This does indicate that you have to be careful about engineering things to be able to be resistant to wildfire. In countries like Madagascar, and this is true even in the United States, usually what that means is that you have to do a lot of vegetation management around certain kinds of infrastructure like transmission lines. If you don't have any vegetation, which is right up against your transmission infrastructure, it usually does a good job of being able to withstand wildfires that move through a particular region.

So, up here are two different climate models. This one and this one for what can be expected in terms of extreme heat events in Madagascar in the timeframe of the 2030 decade and the 2040 decade under RCP 8.5 for the median climate model and RCP 8.5 for the extreme climate model.

In our group, we have run data from 22 individual climate models, and we do that for several different RCPS. RCP stands for Representative Concentration Pathway. While it sounds like it is related directly to the concentration of carbon dioxide in the atmosphere, it isn't. The 8.5 represents the amount of radiative forcing per meter that you would expect in the future. And so, 8.5 is an additional 8.5 watts per square meter over baseline.

The important thing to note here is both of these models, the extreme prediction and the median prediction out of those 22 different climate scenarios, both indicate that you can expect a considerable increase in extreme heat in Madagascar. It might not seem at first that this would matter very much to power systems. You don't have a lot of air conditioning being used in Madagascar but that will probably change in the future. Extreme heat events in the United States put a drain on generators because you need more power to run air conditioning systems. That's less the case in a developing region like Madagascar although that will be more US-like in the future.

But they do have a direct impact on transmission infrastructure. In particular, when transmission lines get hot, the lines sag and that can make it more likely that they'll interact with trees and biomass and cause fire. That's something that you have to worry about. That physical lengthening of the lines also winds up reducing the transmission efficiency because you simply have to move the electricity over a longer area. Increases in temperature also affect generators. Typically, generator efficiency goes down as the temperatures go up. There is a small penalty for the Carnot efficiency. But with fossil fuel generators, the combustion process actually becomes less efficient because the density of air goes down. It'd be less of an issue for nuclear power generators. But the efficiency of those generators decreases as the temperature goes up. If you're expecting hotter temperatures in the future, you have to design the systems to encompass that.

Another thing in power systems that's affected by extreme heat is the efficiency of transformers. It also goes down as the temperature increases and more importantly the lifetimes of the transformers decrease. If you're designing or expecting the design of transformer to take you 30 years, it's not unreasonable for that to drop by as much as a third if you're operating those transformers under extreme heat conditions. That's something that has to be built into the system design because you're going to have to factor that into the operation and maintenance costs, or you should factor it in.

Something else that we've become very interested in the group and that we're using the Terra Analytics system for is to look at what we consider to be often neglected complications when it comes to power systems. First and foremost are multi-hazard events. These are when you have an intersection of multiple hazards simultaneously or in quick succession. That can really complicate the response to a natural hazard event, and it can make it more difficult to repair the damages.

Think about some island state like Puerto Rico, it gets hit by a hurricane and then gets hit very shortly thereafter by another hurricane. Infrastructure was already damaged by the first event. Before you can repair it, you get hit by the second event and that might actually damage anything that you did, in fact, start to repair.

This can also put a real strain on institutional capacity. By institutional capacity here, I mean the ability of governmental organizations to respond to a particular event. This folds into what's referred to as resilience. Resilience in systems is really the ability of a system to continue delivering what it's supposed to be delivering even when some of its components fail. It's very often an adaptive property of a system. Institutions typically give you this adaptive ability. You can repurpose people to do something that they weren't normally doing. You can repurpose equipment to make sure that even though your power system has been damaged, it continues to deliver electricity.

The initial response to COVID was a great example of resilience within a society. In the United States, the university systems and the public school systems weren't able to meet in person, and very rapidly in about a week a lot of the instruction moved online. That's an example of resilience but also the use of technology that enabled that kind of resilience. In any case, multi-hazard events are known to strain this particularly in developing regions.

The overlap of conflicts and infrastructure shocks, this is also very poorly understood. Conflict can make it impossible to get into areas where shocks have damaged infrastructure. As we're seeing in Ukraine, conflict itself can wind up damaging infrastructure. Ukraine is actually a great example. The initial weeks of the war in Ukraine, two nuclear power stations were taken over. First Chernobyl, where the Russian army moved in and set up camp. In fact, they camped in the Red Forest there. They burnt wood that had radioactive contamination in it liberating the radioactivity. They drove heavy equipment through the area kicking up dust and dirt, which was also radioactive and dispersing this into the environment.

And then a few weeks later, they took over the Zaporizhzhia nuclear power facility, and there was active combat in that area. In fact, there was even a report that one of the reactor containment vessels was hit by a stray shell. It wasn't damaged, but it was hit. Both of those things showed that even if it's not intentional, power systems can get tangled up in conflicts, and they can impact their performance.

The Zaporizhzhia facility went offline multiple times because infrastructure in the area was damaged and severed grid connections and the facility itself was damaged. The reports from the utility that operated it initially when it was taken over, a shell took out a district heating line that supplied hot water to a large number of people in the area.

Later in the conflict, in recent weeks, it's been reported that the Russians have been deliberately targeting power infrastructure, transformers, transmission lines and generator facilities around the country. The Ukrainian government has even said the deliberate attacks have damaged every single one of the generators in the country to some level, with the exception of the nuclear power generators, which haven't been targeted.

Understanding how power infrastructure is entwined with conflict is an important consideration. It was something of a surprise that this occurred, a surprise for many people that this occurred in Europe with the invasion of Ukraine. But in a lot of developing regions around the world, conflict is something they simply lived with.

To illustrate this point, this is an image of Ghana on the West Coast of Africa. What's shown here is an infrastructure asset. Here's the transmission lines in Ghana. And then, these are conflict events. These data are pulled from the ACLED database, which is maintained by the US State Department. For the purpose of this figure, we defined conflict as conflict events, which are against the State, against the Ghanaian government or by the Ghanaian government against certain groups within the country. Every single one of these little red dots represents a conflict event, which has occurred in the last 10 years.

And then, you've got population density, people per square kilometer folded on top of this. The important thing to note here is that conflict events tend to cluster. You can see for the most part, these conflict events all occur, not all, but mostly occur in proximity to transmission infrastructure. That's partly because the population density is high around this transmission infrastructure, but they also cluster around particular cities.

This is the capital city of Accra on the coast. It’s a port city. This is the location through which things come into and out of Ghana. They also cluster around Kumasi, here in the lower middle of the country. A lot of these conflict events coincide with the locations of generators and transmission infrastructure as well. It's important if you're looking to site new power facilities in Ghana that you're at least aware of where conflict events concentrate. Because even if they don't directly damage the infrastructure that you're building, they might make it impossible for you to service that infrastructure, or at least service it during particular periods.

Now, as you might expect, where conflict occurs matters. That's also true for where shocks occur within systems. Here's a 30,000 foot view of energy infrastructure in the United States that was generated with the Terra Analytics database. What's shown here are the locations of roads, transmission lines, power plants greater than a megawatt, electric, petroleum production pipelines, natural gas hubs, natural gas pipelines, liquid natural gas terminals, hydrogen gas line network in the United States, which is actually pretty significant, particularly down in the southern parts of the country, crude oil, rail terminals, etcetera, coal mines.

These data don't look particularly dense in a lot of locations. But if you were to zoom in on this figure, what you'd find is that the detail increases the closer up to a particular location you get. There's a lot of data density here as you zoom into it. But the thing that I want to point out is these locations where you've got these nodes, these blue dots, these are locations with a high density of overlapping infrastructure. In particular, down here in places like Houston, over here in St. Louis. These are locations where you just have a high density of infrastructure. Houston is a particularly good point. You've got a lot of refinery capacity down there. You've got a lot of pipelines that move through the area. You have got power plants in this area.

This regularly winds up getting hit by hurricanes. When that occurs, a lot of that infrastructure shuts down. It winds up having a rippling effect that goes out through the broader network around it. If you were to have physical attacks in the United States, hitting these regions of nodes would have a disproportionate effect on the rest of the country as opposed to hitting locations where you don't have a whole lot going on. That's just a general property of networks. They tend to have nodes in them that make the broader network particularly sensitive to shocks that occur at those locations.

We know this to be true from past events like the hurricanes that have hit Puerto Rico in the past. This was an image of Puerto Rico. Here are the provinces within Puerto Rico. The ports in Puerto Rico are circled in red. Then, you've got population centers. These are mostly up in the northern part of the island. And then looping the island, you've got the transmission grid for Puerto Rico. It’s transected across the island in two different locations that couples to power plants that occur or exist in a bunch of different locations.

For electricity generation in Puerto Rico, this is pretty much fossil fuel capacity, and it's liquid fuel capacity. These are diesel generators. What happened when Hurricane Maria struck the island is, it wound up damaging the ports and that made it impossible to get fuel into Puerto Rico to resupply these generators and wound up taking out the transmission infrastructure as well, but it did a lot of other concomitant damage within the island.

In particular, it damaged a lot of the roads in Puerto Rico. You can actually see a transmission pole right here. Your transmission system was taken out, but there was no possibility of repairing it, because the roads within Puerto Rico were damaged. You have to repair these before you can repair these. What that indicates is that these two infrastructures are coupled to one another. Maintaining the power system requires that you have access to the roads. Because the power system relied on the importation of fuel, the ports which were damaged and rendered completely useless are also coupled to the power system. Here you've got three different kinds of infrastructure that are coupled; transmission infrastructure, roads, and then generation facilities. They're all coupled with the ports.

There was a location, one of the hospitals in San Juan, Puerto Rico that was smart, and they put backup generators on the roof in case they had a loss of grid connection. Unfortunately, you couldn't get any fuel from the ports to these generators because the roads were damaged, the ports were damaged. And so, when they ran out of fuel at this hospital, they were out of luck. You had to move fuel around in different ways, which was particularly difficult in the aftermath of Puerto Rico.

Understanding this kind of coupling between different kinds of systems isn't usually on the radar of people who are building power systems, but it needs to be, and particularly in developing regions of the world where recovering from a natural disaster like this is much more difficult because of limited resources and institutional capacity than it would be to recover from it on the mainland of the United States.

The geospatial system that we've built has the ability to help people to understand this. I'll show you some data that we generated for a project for the World Bank that was taking a look at small island states in the Caribbean, in particular, the data I will show you for the Commonwealth of Dominica.

And so, here, you've got Dominica. The color scale here corresponds to the geospatial variation in risk within Dominica. Risks here are defined relative to hurricanes, flooding, coastal surge, earthquake, seismic reactive island, landslide, and then climatological shifts that would occur. And so, when you weight all of these equally, you can create a relative scale of risk for locations within Dominica that range from very, very high to relatively low. And then you can ask, if you're going to invest in infrastructure in Dominica, what is most important to invest in? Do you invest in hospitals? Do you invest in roads? Do you invest in reducing flooding by building dams?

Dominica does have a limited amount of hydropower in country. And so, they already have dams there. But dams are very much dual use. They can be used both for flood control, and they can be used for generating electricity or both simultaneously.

Now, in order to understand how these kinds of natural hazards would couple to different kinds of infrastructure, the way that you approach a problem like that is you choose an infrastructure asset. Here, for example, transmission infrastructure in Dominica, and then the probability of a particular kind of hazard. What kind of probability distribution does it follow? Here one would be assuming that it follows a Poisson process. The frequency of events is given to you by Poisson distribution.

You can then create fragility functions that tell you how likely this infrastructure is to be damaged by something like wind speeds at different levels. These are referred to as fragility curves, and they come from fragility functions. And then that can be coupled to for a given a degree of damage, how long will it take you to restore that system to its original state? Or perhaps how long will it take you to build that system back to a better state? It's something that the Biden administration is very interested in now.

You can take a look at Dominica from a different perspective, not the local hazard potential as a function of location, but where infrastructure in the island sits. You can locate all of the ports in Dominica. There's really only one functional port, a deep water port on the southwestern part of the island. There's another port up here. But it's really functional only for putting a sailboat or maybe a small cigarette boat. You've got locations of people shown in pink here. That's where all their houses are. Power plants, wastewater treatment plants, and then hospitals.

There are three medical facilities on this island. There's a really functional one down here. And then you have what are the equivalent of two convenient care centers on the island as well. Again, you've got this question, we know where the hazards are on the island. We've mapped that. Now we've mapped where the infrastructure is, where do you wind up putting your money if you're going to invest in hardening Dominica or making it more resilient?

And so, you have to ask, what then is important here? Are you worried about the ability of people to get from their houses to hospitals if they're injured? Are you worried about being able to get water to hospitals if the water transmission and distribution system, the pipeline system is broken and so you have to truck it in? Are you worried about getting things from seaports to hospitals? Are you worried about getting things from seaports to power plants?

Most of the electricity in Dominica is generated using diesel generators. And so again, you've got the liquid fuels onto the island. You've got to get them from the port to the power generation facilities. And so, you can look at this from the perspective of the road network in Dominica, and you can then determine which road segments are critically important, and you can categorize that.

Here we've done that on a five category scale by quintiles, lowest priority to highest priority. And then you've got the locations of all these different kinds of infrastructures here. It's a little bit difficult to see in these figures. But if you were to study them from a while, what you'd notice is that the road networks or the road segments which were important for getting people to hospitals are not necessarily the same road networks that are important if you're trying to get liquid fuels from seaports to power plants. They're different networks.

And so, it becomes a question of which parts of your infrastructure do you harden to maintain different kinds of services that those infrastructures are important for? Really many of these things overlap with one another. So, if you're worried about people getting to hospitals, you're worried about the hospitals also being functional. Those hospitals aren't going to be functional if there's no power in

Dominica, or if you can't get fuel directly from the seaports to the hospitals. There's overlap between these different services that you're trying to provide. That's something that you have to take into consideration in the network analysis.

Now, these kinds of data can also be used for understanding the broader implications for the impacts of hazards on societies. This is something that we're using the system we've built for, we've built to help understand. This is shown schematically here. This is an interaction network where you've got hazard events. This could be hurricanes, drought, or terrorism and their impacts on different kinds of infrastructure, electricity, roads, ports, etcetera.

How do these hazards impact these infrastructures? And then how do these infrastructures interact with society? There are the direct impacts on people. People could be killed as a result of disabling these technologies. They can die from that. There can be injuries associated with it. You might have to evacuate people from different kinds of regions.

But then, there could also be societal impacts. What are the impacts to hospitals, schools, businesses, governmental institutions, and then the overall economic impacts or impacts to healthcare and education, all of these things can have long-term impacts. Really, in a broader sense, one of the holy grails for understanding probabilistic risk assessment in network systems is to understand how different kinds of natural hazards will impact local infrastructures and the downstream effects that that will have on societies. How do you make those societies more resilient by changing or hardening these infrastructures and making them less susceptible to these kinds of hazards?

You would think that this would be a problem that is well understood, but it's really in its nascent stages as a research field. It's also very much a local analysis. If you were to lose the power system in a country like the United States as an example, it winds up affecting everything. It impacts refineries, it impacts businesses, it impacts telecommunication systems, it impacts educational systems. It ripples across everything in the country. But if you were to lose the power system in a country in Sub-Saharan Africa where only 20% of the population has access to electricity, the loss of that infrastructure is going to have a very different effect, 80% of the population won't even know that it occurred. And so, this kind of analyses unfortunately you can generalize the process by which you pick it apart, but it's going to vary from one location to the next, the results will.

All of these things that I've touched on, they all kind of fold into societal sustainability as an overarching thing. Sustainability has a lot of value associated with it. Most of you are probably familiar with ESG; Environmental Social and Governance. This has become a significant issue in many industries from mining to power production.

Climate change is a major factor in ESG; Environmental Social and Governance because it winds up impacting all of them. When you put carbon dioxide into the atmosphere, it winds up having climatological impacts. That's an environmental impact. It can affect societies, and it typically does it disproportionately. Unfortunately, lower income countries are particularly susceptible to climatological shifts just by virtue of chance. This can then affect governance in those regions.

You will wind up getting population migration as a result of climatological shifts. Migration of populations always causes problems. We see that in Europe right now. We see that on the southern border of the United States. This feeds back into governance issues.

We were talking to people on the board at S&P Global Platts recently. One of them made the comment, can you make money by integrating ESG into a business? No. But you can lose money by not doing it. You can lose it for two reasons. One, the perception of not being sensitive to ESG issues is not taken well by many people in the public. They're less likely to want to interact with companies that are insensitive to ESG issues. But it can also have direct impacts.

I'll show you some data from a paper that we've got in review right now that kind of speaks to this. This is a busy figure. So, let me take a moment to walk you through it. It's based on some work that was published in a white paper by a group out of one of the Federal Reserve Banks and a group from the University of Arizona 2 years ago. What these people had done is they had taken a look at the US financial markets and the way the financial markets are behaving. They used that to estimate whether or not these markets are currently pricing in a cost of carbon dioxide. And they found that the answer is yes. Then they used the data to understand the probability that markets believe a carbon tax will go into effect. So, what is the likelihood per year that a carbon tax will go into effect, and also ultimately, what will that carbon tax be?

What they found was markets are currently behaving as though there's roughly a $3.5 or little bit less than $4 per ton cost of carbon but that they're anticipating the future cost of carbon in the United States of $45 per ton. And that the transition to that higher cost has an 8.5% probability per year. The likelihood the carbon tax $45 would go into effect at any year is 8.5%.

And so, this color scale, over on the left-hand side assumes a 7% discount rate, 8.5% annual chance of a fixed price of carbon going into effect, and then looks at the cost to the electric utility industry over a 30-year timeframe, and then projects that cost down to the zip code level within the United States.

This color scale over here corresponds to the same set of assumptions except it's not assuming a fixed price of carbon dioxide at $45 per ton, but an escalating cost of carbon dioxide that starts at $45 a ton, and then by 2050 escalates to $250 a ton, which many countries in the European Union assume will be the international price of carbon should an international carbon market come into existence so that the carbon price will escalate up to that level.

Again, what you see is that you've got locations in the United States that have a particularly high potential cost of carbon dioxide, discounted carbon dioxide in that location. On the low end, these locations have a cost that's associated to about $1 billion to a high-end cost of a little more than $2.4 billion at the high end within these zip codes.

If you take a look at the electric utility industry as a whole, the low-end estimate for this transition risk to a carbon price is a little bit more than a $0.5 trillion. Depending on your assumptions, it could be as high as $1.7 trillion. Now, to put that in contrast, the retail electricity industry, the retail sale of electricity in the United States is only about $450 billion per year. The transition risk to a carbon tax is greater than the entire retail sales in the United States in a particular year when you're looking out over a 30-year timeframe.

Now, because of the way the discounting works, half of that transition risk actually sits in the first 10 years of the 30-year timeframe. That's a non-trivial difference in price. You're talking about $250 billion to $270 billion in undisclosed risk within the electric utility sector relative to annual sales of $400 billion to $450 billion. If you were to annualize that, that's 6% of retail sales in an undisclosed risk. The retail sales don't represent the profit margin for these companies. They just represent the gross sales in there. And so, you've got a 6% undisclosed cost relative to some unknown profit margin for these companies. That is a non-trivial transition risk. It is borne disproportionately by location within the United States.

Now, let me also say that there are three figures here shown. There's a minimum cost per zip code, a median cost per zip code, and a maximum cost per zip code. The reason for that is because multiple utilities operate in certain zip codes. Based on that, these utilities have different carbon signatures for the electricity they generate as well. And so, we use those data to create a maximum, a minimum and a median value for these.

Also, I'll just note that for the aggregate transition risk over a 30-year timeframe of $550 billion, 20% of that is borne by five utilities in the United States. So, for 20% of that entire aggregate cost only five utilities have that risk. And so, for those utilities again that is a non-trivial unpriced potential cost for them.

Now, let me also say that sustainability has value in other areas as well real estate in particular. These are some data pulled from different sources; 60% of homebuyers are very or somewhat interested in sustainability. Those are data from the National Association of Realtors, 70% of residential and 74% of commercial real estate agents report the promoting energy efficiency as somewhat or very valuable, same source. Zillow Research estimates that 1.9 million US homes will be underwater due to climate change by the end of the current century. And then, an organization which looks at real estate investment trusts took a look at the impacts of Hurricane Florence that made landfall in North Carolina back in 2018. They found that it affected properties that were owned by 94 US real estate investment trusts. Climatological shifts can have a lot of impacts not only on industrial infrastructure but on infrastructure, which is owned by people, by us.

We have tried to parse out some of our data to help people understand what their risks are in the real estate sector in the United States. We've done this recently with two different kinds of tools. We've developed a risk dashboard. This is an address-based climate and hazard analytics system. It's not live right now. But by the end of next week, it will be under HouseHazard.org. I'll show you what this looks like in just a second.

For people who are considering putting solar panels on their roofs, we've created a solar score and a sustainability score that allows them to understand how a solar system would perform at their location relative to the current cost of electricity and the current carbon signature of that electricity.

This is what this risk dashboard currently looks like. It allows you to see what your current risks are, how climate change is going to wind up impacting them? And then you can use these information to understand maybe whether you should be buying insurance or maybe not buying at that location at all.

This address, this is actually where I live in Boulder, Colorado. Hail is a really big deal in the Front Range region of Colorado. We have frequent hailstorms. They often drop hail that's greater than an inch in diameter, which can be very damaging not only to automobiles but to roofs. We had more than $1 billion worth of damage that was done in Denver due to a hailstorm just a few years ago.

I live on a hill. Flooding for me is a relatively low risk. Hurricane is very low risk because of where we are. For wildfire and drought, because of the way the data are aggregated, it's very difficult to project them into a simple category. Instead, what we do are show graphical data that allows people to better understand where wildfires sit relative to their property. And how many days per year that particular location sits in different categories of drought.

Heat index, Colorado is getting warmer. But at the moment relative to other places in the United States, the risk of heat is very low. This is not a seismically active area. Earthquake is relatively low. Because of the location of this property its susceptibility to landslides is low, but just a mile away, you're right up on the front range of the Rockies and landslide potential is actually quite high.

Relative to other places in the United States, Boulder has good air. It doesn't have very low risk, but it has low risk. And then, we actually threw internet in here as a category because of the need for it during the pandemic, and because it's becoming a tool, which is ever more important. Different locations in the United States have different levels of access to broadband. And so, we throw that in there as well. And then, we've got climate change impacts to the categories of risks that are affected by this.

Hailstorms are going to become even more frequent at this location in the future. It's a big deal now but that will increase. Flooding impacts from climate change will actually go down in this area because it's going to be drier in the future. Again, no impacts from hurricanes here. But wildfires, they're going to increase in frequency, unfortunately, and so is drought. Colorado or at least this region within Colorado is actually predicted to become much hotter in the future. While extreme heat isn't an issue now, it will likely be in the near term in the coming decades.

One of the things that extreme heat can impact is the need for cooling. The ability or the need to cool is going to become increasingly important in the future in Colorado. Flood risk is something that you have to worry about. But at my particular location, it’s not an issue, but I'll show you some data that allowed you to see in greater detail why we represent certain things graphically.

If you were to click one of these issues like here if you were to click on this, what would happen is it would pull up a map that shows your location. This actually isn't my house. It's the house of a former postdoc of mine. She was living right on a ridge line on this road. It was downhill in that direction and downhill in this direction. Her risk of flooding was low. But what you can see down here is that not far away that's about 300 meters the flood risk was very high. This was actually a flat area where you get a lot of drainage down from the slopes and water can accumulate. I actually drive on this road from my house down to the Colorado School of Mines every day.

The important thing to note here is flooding is extremely local. I mean literally one property over, you might have high flood risk even if there's no flood potential or low flood potential at your property. The reason that with certain kinds of data we give graphical information is so that you can see how things vary from one location to the next. That can be particularly important.

For solar sustainability, in Colorado, you drive around and solar panels are going on the roofs in many locations. We've developed a solar tool that can allow you to assess any particular address in the United States. It uses 10 years of historical hourly solar data, and it takes into consideration the pitch of the roof and the angle of the panels relative to the sun. And then, it computes payback period relative to the current cost of electricity in that location, the profit over the lifetime of the system, and then the rate of return on those investments and the amount of CO2 that you'd be avoiding relative to the local provider of electricity that you have.

I'll give you two examples, what data from this looked like. Here's a location in Houston where one of my postdocs used to live. And so, if you were to put solar panels on the entirety of this roof area over here, this system will compute for you how that will perform? How long will it take to pay back the cost of that system relative to the state average cost of the rooftop solar power facility? For Houston, it's 22 years. It's not that Houston isn't sunny, it is. It's that the cost of electricity in Houston is really low. As a result, given the relative cost of the system, it's going to take a long time to recoup those costs.

Over the course of 25 years system lifetime, you'd expect a profit of only $1000 for this, which gives you a Rate of Return or an annualized Rate of Return of 0.3%. That system from an economic point of view isn't doing particularly well. If you're just looking at economics, you'd probably want to put that money into something else investment wise.

There's a fairly high carbon signature, which is associated with electricity being produced in Texas. They still have a lot of coal-fired capacity in state and a lot of natural gas-fired capacity. You would be avoiding with this system 4.6 tons of CO2 per year in direct emissions. That's not nothing. If you're going to look at setting a solar power facility on your roof, from a carbon perspective that's a pretty good idea.

By contrast, things are very different in California. In California, if you were to put a solar panel on the entirety of this area of the roof, you'd pay back that system in only 7 years. The reason for that is because the cost of electricity in El Cajon, California is really high. Relatively speaking, this was a pretty decent investment from an economic perspective. Over a course of 25 years, you'd expect a $25,000 profit. That's an annualized Rate of Return of about 4.4%, not bad at all. The carbon signature for electricity that you would get at this location from the utilities and services is much better than it would be for that location in Houston. You'd expect to be saving 2.6 tons of CO2 per year with this system. From an environmental perspective, it's a plus. But from an economic perspective, it's quite good.

That's an overview of the kinds of geospatial analytics that we're able to do with the system that we've built and that we keep on evolving. Let me just take a moment to thank some of the people who have been really instrumental in allowing this work to happen.

In particular, Andrew Osborne, he was a postdoc of mine at UT Austin and also here at the Colorado School of Mines. He's now an assistant professor at the School of Mines in mechanical engineering. Guillaume L'Her and Robert Flanagan are research associates in my group, and all three are co-founders of Terra Analytics. I'd also like to thank Amy Schweikert. She was until this past year, a research assistant professor in my group, and she's now gone to Ernst Young, a consultancy in California where she is helping to advise them on climatological issues in their broader portfolios. I'd also like to thank B.P. Singh, who was really responsible for the initial NEUP work that made this work possible. And also, Temi Taiwo and Bo Feng, who administered that award [ph] afterwards. None of this would have happened if it weren't for these three, and they've just been super easy to work with.

The energy visualization tool, which we were originally contracted to build isn't currently live. The Terra Analytic system that came after it has been used to help advice the World Bank on the climatological and risk disclosure for electrification projects in 40 countries now all across Sub-Saharan Africa but also in Indonesia and South America. The system has really had a lot of benefits and impacts. I'm going to stop there. I'm going to hand this back over to Patricia.

Berta Oates
Thank you Mark. We appreciate you sharing this information and your expertise with us this morning, or this afternoon depending on where you're at. Before we go to the questions, there's a few things we want to share with you.

The upcoming webinars that we have scheduled in December, January, and February. In December, the Mechanisms Engineering Test Loop Facility at Argonne National Laboratory. In January, Molten Salt Reactors Taxonomy and Fuel Cycle Performance, and in February Safe Final Disposal of Spent Nuclear Fuel in Finland. And then, I talked a little bit when we started in the housekeeping, we have our information to share with you on the Pitch Your Gen IV Research. I'll hand this time over to Patricia.

Patricia Paviet
Yes, thank you very much Berta. Again, thank you very much Mark for this great presentation. I would like to bring your attention to the 2023 edition of the Pitch Your Gen IV Research Competition. I'm asking your help to really advertise this event, which you could find on the GIF portal, and also, I have the URL link below, and you will have access to the slides.

We are going to open the competition this Thursday, 1st of December where the current Ph.D. students or postdoc, early career scientists, and engineers who completed their Ph.D. after the 1st January 2021, they can compete. They can submit an extended summary abstract to the website. The website is open between the 1st of December to 15th of January 2023. The selected candidates will be asked to prepare a 4-minute video pitching their research. The first winner will participate to a fully sponsored GIF event in the future. The three first winners will present a GIF webinar. Thank you so much Berta. Back to you.

Berta Oates
Thank you. Okay, so we do have some questions that have come in. Mark, I have shared that question pane with you. The first one that I see on the top of the list is, if energy supply is increased in areas in energy poverty, will there a need to be a major investment in demand such as factories and consumer products?

Mark Deinert

Thank you for the question. There's a big literature on exactly this question, which comes first, the chicken or the egg? Does industry develop because power systems went into place or do power systems get developed because industry goes into place? The general consensus is that the two things co-evolved with one another. The desire of the people in the ESMAP program at the World Bank is to pull people out of electricity poverty up to at least a middle income level of electrification and that concomitantly with that what you'll have is economic development that will wind up making use of that electricity.

There are really two reasons they want to do this. One is for economic sustainability. The inability to have reliable access to electricity in many locations is simply a limitation for economic development. Industries will form as that power becomes available. But there are also equity issues that are associated with this. So, lack of access to electricity and to clean fuels in general has a disproportionate impact on women in developing regions of the world because they wind up being the ones who have to go and collect the fuel for fires. They're the ones who aren't able to stay in school because they don't have light at night with which to be able to read or do their work. There are equity issues and also economic issues that go into this, but the general view is that you got a co-evolution of industry and economics as power systems evolve in countries.

Berta Oates
Thank you. The next question reads, Fukushima was a major shock to the Japanese energy system. Has anyone tried to benchmark this modeling approach with what was actually done in Japan to restore the energy system?

Mark Deinert
To my knowledge, no. It might be being done in Japan, but I'm not aware of it. We actually just started a project with the Defense Threat Reduction Agency, DTRA, to take a look at the potential effect of radiological shocks on agricultural systems. How would an agricultural system be affected by a radiological shock? We actually are looking at Fukushima in that context, because there were economic fallouts from radioactive contamination, or the perception of contamination in different regions. Agricultural products were disproportionately affected. So, countries banned them initially, and even regions within Japan were unwilling to take agricultural projects from the Fukushima Prefecture and also prefectures in the vicinity of Fukushima. And so, we're trying to use those data to understand how fear and actual contamination would percolate into agricultural markets.

Berta Oates
Thank you. How can previous shocks and disruptions be used to benchmark the assumptions in the modeling?

Mark Deinert
They're not used to benchmark the assumptions in the modeling as much as they're used to understand what assumptions should go into the modeling. Natural hazard events occur all the time and they affect different regions of the world. You can use the data from post-disaster evaluations to understand what kinds of infrastructures were damaged, the frequency of that damage, and how that changed from location to location. That can be then used to inform the models themselves. That's the approach that we take in our group.

Berta Oates
Thank you. After 9/11, there were attempts to model disruptions in critical [ph] infrastructure and the cascading effects. How is this worth building on those previous efforts?

Mark Deinert
A lot of the work that was done there was synthetic. These were simulation based studies. There is an ongoing project within the Department of Energy called NAERM, the North American Energy Resilience Model, modeling project. This is a multi-lab project that is looking at how disruptions in energy infrastructure could wind up cascading through systems.

Invariably, a lot of it is done on the base of modeling of these systems. But you have to be able to benchmark these models so that you can use natural hazard events as a way of being able to test whether these models are giving you accurate predictions. I don't believe that the NAERM people have done that. But we've spoken to subgroups that are involved in those studies, particularly at NREL and suggested that using natural hazard events is a good way to be able to test whether their models are actually giving reasonable results.

Berta Oates
Thank you. Is sustainability of a home similar to a home with low maintenance?

Mark Deinert
They're not unrelated. Sustainability and operations and maintenance costs are coupled to one another. But sustainability, in general, refers to the ability to operate something in a fashion that is itself sustainable. Typically having a low environmental signature so that you don't change the surrounding environment through the operation of that facility, and you can operate it in perpetuity.

Berta Oates
Thank you. Can you speak to what the role of insurance in protecting the value of a home from natural threats?

Mark Deinert
Yes, I don't think the insurance necessarily protects the home from natural threats. But it allows you to rebuild the home or service the home if it were damaged in some fashion. Unfortunately, a lot of people live in areas where they are subject to risks for which they are not insured. Flood insurance is an important thing to carry. It's actually required for people to carry if they are within a floodplain, I mean, a 30-year floodplain, a 100-year floodplain. But there are a lot of regions where flooding can occur that aren't sitting in floodplains. And so, people may or may not carry home insurance for flooding in those regions, in particular, because they simply don't understand that flooding is a risk where they are.

The same thing is true for wildfires. Certain insurance companies will no longer insure homes that sit in regions with high wildfire potential. You can usually find insurance from other companies if you're willing to pay for it. If your home is burnt to the ground, and you don't have any insurance, then that's just a financial loss. The issue also comes up a lot in seismically active areas. Earthquake insurance isn't a given as part of a lot of policies. And so, it's something to pay attention to. If you're in seismically active areas, do carry insurance that would allow you to repair home if it's damaged.

One of the things that we've just recently built into the house hazard system are mitigation strategies. We try and give people sort of a list of bullet points of things that they can do to mitigate the risks of different kinds of natural hazards. For example, with earthquakes, it's making sure that your house is anchored to its foundation, it's really bolted down onto it. That's not always the case. Earthquakes can tip a house off of its foundation. Usually that causes catastrophic damage to the home. And it can be a real risk to anybody who's in the home as well. That's a simple thing that people can do particularly during construction. But then also point them to information usually out of FEMA or the US Geological Survey that gives them additional resources on how to deal with seismically active regions or regions that are prone to fire.

Berta Oates
Thank you. Mark, has there been any efforts to align specific nuclear reactor types with the various parts of the global your analytics have assessed? For example, you mentioned some African countries could use SMRs to meet grid demand considering comparable power

demands that did not necessarily tie them to other aspects of the analytics such as seismic design level.

Mark Deinert
So, we've just written a paper on this very subject taking a look at the global potential, market potential for microreactors and small modular reactors under US Nuclear Regulatory Commission siting constraints. What locations have the physical attributes that the US Nuclear Regulatory Commission would require for setting a nuclear reactor? But then, we've also looked at a whole lot of other things.

For example, regions with conflict, how climatological factors will affect access to cooling water, constraints in terms of institutional capacity within countries to be able to run organizations like the Nuclear Regulatory Commission. Do you have the institutional capacity to actually manage a nuclear power system in different countries? That actually varies quite a bit.

The International Atomic Energy Agency has a program called Milestones, which is designed to help countries with no nuclear institutional capacity develop that capacity and then develop the ability to site their first nuclear reactor. Different countries have different levels of ability to implement milestones effectively. I will say from a development perspective, just the process of going through a program like the IAEA's milestones has benefits associated with it. Because as you develop that kind of regulatory infrastructure, it has benefits within the broader governmental structures of many countries. They are building capacity of competence that has benefits outside of just the nuclear domain. But hopefully that study will be out sometime in the next few months. We're shopping it around to editors right now. It's a first of a kind effort.

Berta Oates
Thank you. There are a couple of related questions. Could your analytics be used to identify which reactor type; small, medium, or large, LWR, SMR, advanced reactor, microreactor, floating reactor, etcetera, is best suited for a region or country of all those being offered? And then a similar question that asks the role of SMRs technology in this context.

Mark Deinert
Yes, that kind of folds into the area of risk informed design. We haven't yet used the system for doing risk informed design. But there's no reason that you couldn't do that. I guess, in a broader sense, risk informed design and risk informed choice of reactors. We haven't tried to use it that way but that certainly is something that you could do with it.

Berta Oates
Thank you. Thank you again Mark for such a wonderful and informative presentation. That's all the questions that are in the Q&A field at this point. But you can see there's a lot of interest in the topic given the participation. If you still have questions, go ahead and type them in. Maybe, we'll just wait another minute to see if there's follow ups.

Mark Deinert
Sure. People are more than welcome to reach out to me as well by email. I'd be happy to answer any questions that I can.

Berta Oates
Excellent. Thank you for that. His email address is provided on his Meet the Presenter slide, his bio at the beginning of this presentation. We do have one more that has come in. Mark, it appears your analytics could also be supportive of consent-based siting facilities such as interim storage facilities for spent nuclear fuel and disposal facilities. Have you considered any of those activities?

Mark Deinert
Yeah, we have. In fact, one of my postdocs is using this system in conjunction with historical data on where large infrastructure projects have been successful, and the kind of demographics that were associated with that. But he has also developed a tool for being able to filter social media to be able to understand in a geospatial way people's perceptions to different kinds of energy technologies, and how those perceptions change as a result of political events or hazard events that have impacted those technologies. We're very, very keen on being able to couple different kinds of data sources from the geospatial data that I've shown you, social data, historical social data, and demographic data, and also the kind of information that you can now get from social media to understand where you would be likely to have successful siting.

Berta Oates
Thank you. Again, I really do appreciate your energy to present this information. I find it to be extremely interesting. You can tell again from the level of participation in the questions how much interest there is within the group. I think that's all I have. Patricia, do you have any last thoughts?

Patricia Paviet
No, I just would like again to thank Mark for this really great presentation and also the participants for being so active with the Q&A session. Thank you very much.

Berta Oates
Thank you.

Mark Deinert
I'll connect with you all offline. Thank you very much.

Patricia Paviet
Bye.

Berta Oates
Bye-bye.

END