CLEAN ENERGY SOLUTIONS CENTER
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Greening the Grid: Best Practices in Conducting Grid Integration Studies

—Transcript of a webinar offered by the Clean Energy Solutions Center on 6 October 2015—
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This Transcript

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Tim Reber

Hello everyone. I'm Tim Reber with the National Renewable Energy Laboratory and I'd like to welcome everyone to today's webinar which is hosted by the Clean Energy Solution Center in partnership with USAID and the National Renewable Energy Laboratory. Today's webinar is focused on Best Practices in Conducting Grid Integration Studies. One important note of mention before we begin our presentation is that the Clean Energy Solution Center does not endorse or recommend specific products or services. Information provided in this webinar is featured in the Solutions Center's resource library as one of many best practice resources reviewed and selected by technical experts.

Before we begin I'll quickly go over some of the webinar features. For audio you have two options; you may either listen through your computer of over your telephone. If you choose to listen through your computer please select the "mic and speakers" option in the audio pane. Doing so will eliminate the possibility of feedback and echo. If you choose to dial in by phone please select the telephone option in a box on the right side of your screen. It will display the telephone and audio PIN you should use to dial in. If you are having technical difficulties with the webinar you may contact the GoToWebinar Helpdesk at 888-259-3826 for assistance.

If you would like to ask a question which we certainly encourage we ask that you use the "Questions" pane on the right side of your screen where you may type in your question. If you are having difficulty viewing the materials through the webinar portal you will find PDF copies of the presentations at cleanenergysolutions.org/training and you may follow along as our speakers present. Also an audio recording of the presentation will be posted to the Solution Center training page within a few weeks and will be added to the Solution Center YouTube channel where you also find other informative webinars as well as video interviews with thought leaders on clean energy policy topics.

Today's webinar agenda is centered around the presentations from our guest panelists, Jaquelin Cochran, Clayton Barrows and Jennifer Leash. These panelists have been kind enough to join us to discuss best practices in conducting grid integration studies including several case studies that highlight examples and lessons learned from grid integration studies that have been undertaken globally. Before our speakers begin their presentations I will provide a short and informative overview of the Clean Energy Solution Center initiative. Then following the presentations we'll have a question and answer session where the panelists will address questions submitted by the audience, closing remarks and a brief survey.

This slide provides a bit of background in terms of how the Solution Center came to be. The Solution Center is one of 13 initiatives of the Clean Energy Ministerial that was launched in April of 2011 and is primarily led by Australia, the United States and other Clean Energy Ministerial partners. Outcomes of this unique initiative include support of developing countries and emerging economies enhancement of resources on policies relating to energy access, no cost policy expert assistance, computer and peer learning and training tools such as the webinar you are attending today.

The Solution Center has four primary goals. It serves as a clearing house of clean energy policy resources; it serves to share policy best practices, data and analysis tools specific to clean energy policies and programs, delivers dynamic services that enable expert assistance, learning and peer-to-peer sharing of experiences and finally the Center fosters dialogue on emerging policy issues and innovation around the globe. Our primary audience is energy policy makers and analysts from governments and technical organizations from all countries though we also strive to engage with the private sector, NGOS and civil society.

A marquee feature of the Solution Center is the no cost policy expert assistance known as Ask-an-Expert. The Ask-an-Expert program has established a broad team of over 30 experts from around the globe who are available to provide remote policy advice and analysis to all countries at no cost. For example, in the area of regulatory and utility policies we are very pleased to have J. Riley Allen, Research Director with the Regulatory Assistance Project serving as one of our experts. If you have a need for policy assistance in regulatory and utility policies or any other clean energy sector we encourage you to use this valuable service.

Again, the assistance is provided free or charge. If you have a question for our experts please submit it through our simple online form at cleanenergysolutions.org/expert or to find out how the Ask-an-Expert service can benefit your work please contact Sean Esterly directly at Sean.Esterly@nrel.gov or call him at 303-384-7436. We also invite you to spread the word about this service to those in your networks and organizations.

Now I'd like to provide brief introductions for today's panelists. First up today is Dr. Jaquelin Cochran, a senior energy analyst with the National Renewable Energy Laboratory where she analyses system operations, policies and market designs that create an enabling framework for emerging energy technologies including renewable energy, demand response and distributed generation. Dr. Cochran has published on many topics related to integration of renewable electricity, including policy best practices, coal cycling, renewable energy curtailment, variability analysis, integration studies, system flexibility and market designs.

Following Dr. Cochran we will hear from Dr. Clayton Barrows. Dr. Barrows is a member of the Energy Forecasting and Modeling Group at the National Renewable Energy Laboratory. His research focus on improving the technical and economic efficiency of electrical systems through advanced computation and analysis. At NREL Clayton focuses on electric system planning and operations models.

Finally we will be joined by Jennifer Leisch who will be moderating the question and answer session. Jennifer is a climate change mitigation specialist in the USAID Office of Global Climate Change, where she supports the U.S. Enhancing Capacity for Low Emission Development Strategies program. Jennifer manages the USAID Greening the Grid partnerships, and she directs agency work to account for greenhouse gas emissions reductions as a result of USAID clean energy program. With those introductions I'd like to go ahead and welcome our three panelists to the webinar.

Jaquelin Cochran Thank you. This is Jaquelin speaking. Clayton and I are delighted to talk to you today about Best Practices in Grid Integration Studies. First we're going to have three parts to this. Part one – why conduct a grid integration study.

We'll be defining the concept and understanding why grid integration studies are important. Part two – what can a grid integration study address? We'll be looking at different types of grid integration studies. Then finally part three will be, "What is the process of conducting a grid integration study?" We will conclude with Q&A. So let's begin.

First, why conduct a grid integration study? Globally we have seen many countries establish ambitious renewable energy targets to add wind and solar to the grid. So for example, in India has established a target of 60 gigawatts of wind and 100 gigawatts of solar to be installed by 2022. What we found in other countries is as we add on significant amounts of renewable energy to the grid how we plan for and operate the power system may need to be changed. Why is this? Well wind and solar are variable and uncertain relatively speaking. So they're variable in that the generation output of the plants vary based on the quality of underlying wind and solar resource and they're uncertain in that we can't predict with perfect accuracy what that output will be.

As we have more variable and uncertain resources on the grid what we want them is to have a very flexible power system. By flexibility we mean a power system that can respond to changes in demand and supply. So typically we have found that at low variable penetration levels already most power systems are sufficiently flexible because they are designed to handle variability uncertainty from electricity demand and conventional power plants but as we scale up renewable energy we might find that we need to operate the system more efficiently so that the flexibility that's there in the system already can be accessed and as we scale up to even higher levels of renewable energy we might find the need for new physical sources of flexibility.

The flexibility – let me back up one slide. This was the topic of our previous webinar by Michael Milligan about how you – what are the sources of flexibility and what methods – how can that help you power system. So if you're interested in that webinar it is recorded at the Clean Energy Solution Center as well as on greeningthegrid.org on the training page.

But today we build from that point. We're looking at, "Okay, so we know there's a need for flexibility. How much flexibility? What types at what times?" That is the focus of the grid integration study.

The grid integration study is an analytical framework for evaluating a power system with high levels of renewable energy. It helps us establish what we might expect with renewable energy on this system and what changes we might want to make to accommodate that. So some of the outcomes include simulating the operation of a power system under different future scenarios, identifying reliability constraints, determining relative costs of actions to help integrate renewable energy and address system operator concerns that the system can work reliably and cost effectively.

Grid integration studies are one part of an overall part strategy to scale up renewable energy. We might find, for example, that we perform grid integration studies before or after establishing a renewable energy target. So a country might establish a target and use a grid integration study to determine what steps and what changes are needed in order to meet that target or we might do a grid integration first, figure out if this target is achievable and then establish from a policy maker perspective the grid integration study can inform the policy maker in setting a higher threshold.

So as an example, in California we've seen that integration studies have helped inform the establishment of renewable energy targets. So the initial renewable energy target was established without having a grid integration study but after that different studies were performed to assess, "Okay, what can we do to reach 20 percent on target, a 33 percent target?" Last year the company E3 conducted a study that shows, "How might the grid operate at a 50 percent renewable energy target?" Then this year the legislature passed a new target establishing a 50 percent goal for renewable energy.

So we have found that strong stakeholder engagement is key to building confidence in the conclusion of the studies. These studies are not done in a remote office without any input from others. We want to have industry concerns and expertise represented in the studies. We've also found that in practice system operators have been incredibly creative in solving challenges to meet each of these interim targets.

So part two; what can a grid integration study address? I want to start with focusing on the aspect that there are no two grid integration studies alike. Each study is customized to investigate a particular concern. On the right side of the screen we have 12 studies and each of these has addressed its own specific question. So when we start a grid integration study we're answering a particular question.

Then the methodology that the study takes will depend on what is of interest. So some examples; we might want to focus on what are the impacts of high renewable energy penetration levels on capacity expansion questions. Where should the generation be located? What new transmission lines might be needed? These studies are examples, on the right, of studies that looked at that capacity expansion question in a little more detail.

Many studies, grid integration studies do address hourly system balancing. So looking ahead at a given future year where is that renewable energy generated, at what times and how does the system balance that supply and demand throughout every hour of the year? With these kinds of questions we can ask, "What are the costs of operating the system? What are the emissions associated with that? What's fuel consumption in those years?"

Some studies don't look at – take it a step further and look at sub-hourly time frames. So not just hour to hour balancing but perhaps at 15 or even 5 minute scales, looking at how solar output changes over these timeframes, for example. These kinds of studies are also very helpful in looking at impacts to ancillary services. So on the right we have an example of ERCOT looking at how new wind generation has affected what types of ancillary services they need.

Another common feature is looking at the impact on the thermal fleet. So as we add more renewable energy the conventional power plants like coal and natural gas may operate differently. They might be cycling more so meaning that their power output changes more frequently or they're turned on and off more frequently. So these studies on the right have looked at, "What are the impacts of these renewable energy scenarios on the coal fleets?"

Another important question is, "What is the impact of renewable energy scenarios on grid stability following a disturbance?" So this is not looking at the hourly or minute time scales but really looking at the initial seconds after a disturbance on the grid and how does the system recover if there is a significant amount of renewable energy on the grid.

Then finally the study may be focusing on market design. So once we have all this renewable energy on the grid how do we want to operate markets balancing between different grid control areas to help improve the efficiency of the market operations and what changes to markets might we need, either ancillary services or capacity markets for example, in order to accommodate cost effectively the renewable energy.

Now I am going to turn the discussion to my colleague Clayton Barrows. He will take it.

Clayton Barrows Going from what Jaquelin – well good morning. This is Clayton. Going from what Jaquelin was saying about the variety of studies and how each study can address a different topic there's a variety of different solutions that can address needs in different ways. This figure here shows a variety of interventions and we call this the flexibility supply curve where each option here has a different intervention that can provide flexibility in a different way. So we have different interventions on the X axis and the cost of implementing or generalized cost of implementing those interventions on the Y axis.

As you can see here there are a variety of options that include everything from changing how the system would operate to introducing different market actions, leveraging the responsiveness of load resources, increasing the flexibility of generation resources, changing how the network is configured. So either adding more transmission or using transmission in a different way than it is traditionally. Then ultimately sort of everyone thinks of storage as the ultimate flexibility option. We find that that is, yes, very nice. We're adding flexibility to the system but is also a very expensive option traditionally.

So in the red circles in this figure we have some options that are typically very effective and most systems can increase their flexibility by implementing these options without a really in-depth study highlighting the need for some of these other options. So this is just a nice way of thinking about the ways to increase the flexibility of a system.

To identify that on the next slide we have sort of the steps or one way of thinking of the steps of going through a grid integration study and before and after a grid integration study and some things to think about before an agency would conduct this study. So we generally think about this in terms of there's a set of enablers that can be done before the analysis and then after the analysis there's really a lot of policy development that can use the results to generate actionable items. But before the study enablers include implementing some of those known effective solutions that we talked about on the previous slide.

So some of those are known effective solutions. There are others as well. The collection of data can be a multi-year very expensive process that may take longer than what most people would consider a reasonable timeframe for a grid integration study. So if you don't have data on renewable resources or historical data on how much the wind blows in a particular area that's something that can take many years to collect a rich data set for. So that's something that kind of needs to be done before considering just doing a study right away.

Then last is building the modeling capacity. That's everything from acquiring the software to acquiring the technical expertise and personnel to be able to run the models and understand the results. So these are sort of things that can be done before the study or need to be done before doing a study. Then the study itself in this analysis block can be broken down into what we consider three different studies. They're really looking at different timeframes.

So as Jaquelin kind of mentioned before we have capacity expansion studies, production cost studies and power flow studies. The capacity expansion studies are really looking at how the system will change in terms of what metal is in the ground and what resources are contributing to the system in the long term. So those studies usually look much further out in time. Production cost studies are really looking at more the cost of operating the system and not really playing with what's in the ground so much but more how does the market work and how do particular operators and particular generators operate. Then finally the power flow study is really looking at reliability, technical feasibility, contingency responses so that the very intricate electrical engineering response time type studies. So those are very useful for ensuring the reliability of the system.

Then ultimately all of these can be designed and executed and ultimately presented with an eye towards policy development. So with the eye towards generating really policy relevant results then the ultimate result can be very useful for developing realistic targets, new grid codes, new market design, things like that. So we really try and keep an eye towards that when designing each of these studies.

So to go into a little more detail on each study type and maybe an example of each one we'll talk about them individually. So when considering how the system might look in the future, so 5, 10, 20 years out we might consider doing a capacity expansion modeling study where we're optimizing resource planning and optimizing the capital expenditures and construction of new resources to minimize the cost of both capital investments and operations subject to a number of constraints. So usually we're looking at different policies so if you want to meet a certain renewable energy target or if you want to test the options that might – that your country might incur in terms of economic growth or technical advancement these are good things to use as scenarios in a capacity expansion modeling study that's really going to describe how particular policies might impact the expansion of the system through time.

So usually these studies are fairly long term horizons so they're looking at 20 to 50 years out. That gives the simulation time to consider the construction time for new resources, both transmission, generation and load expansion through time. So to do that of course you need good renewable energy resource data. Specifically one of the things that's really important is to know where renewable energy resources can and can't be built along with their quality. So understanding the topology of the countryside along with the land ownerships.

That is a very beneficial thing to understand where renewable energy development is even feasible. Then another key input to these is capital costs and understanding the cost of building new technologies. So one might consider a capacity expansion study that looks at development of nuclear generation which is a particularly difficult thing to assess the capital cost of nuclear. That's something that a lot of people have debated over the years and is very difficult to understand. So it's very difficult to capture in these models.

Ultimately these capacity expansion modeling exercises can both inform the effects of climate and energy policies. So you can test the effects of various different targets and things like that. But one of the key outcomes of capacity expansion modeling studies is that they can do a great job of setting up a production cost modeling study. So if you want to look at the detailed operation of some system that's 25 years in the future or something you can run a capacity expansion modeling study to figure out where generation might be built and then subsequently run a production cost modeling study that looks at the detailed operation of that hypothetical future system. Then you can do that with multiple scenarios with capacity expansion. So that's a useful case of how we often run our sequences of modeling studies.

So one example of a capacity expansion modeling study that has recently been conducted here at NREL looked at how much – to what extent the renewable energy supply can meet electricity demands in the U.S. in 2050. Really what we were looking at is how much or how high of a penetration can the U.S. feasibly achieve and what would be the price impacts, the emissions impacts, where would that generation expansion occur. That is the renewable energy future study. Ultimately what one of the key findings that it showed is that by 2050 renewable energy could supply up to about 80 percent of the U.S. load. That was a pretty groundbreaking study in that nobody had really shown such high penetrations and the effects of achieving that high penetration being relatively doable.

So onto production cost modeling studies. So really, like I said earlier, production cost modeling studies are focused on the impacts of operations. So, "How would a system operate when there already is more renewable energy than currently exist now," and questions along that line. So typically this is done by simulating a market or the operations of a market.

We often do this with some simplifying assumptions in that there's usually a centralized market and it's fairly perfect in comparison with real markets but ultimately what it does is it simulates unit commitment and economic dispatch through the course of an entire year and simulates the simultaneous fluctuations of wind, solar and load and how the system is able to respond to those changes. So we're really testing the flexibility of the system and we do that through looking at various different scenarios where there's different renewable energy penetrations, where there's different fuel costs, where there's different drought years, things like that. So the scenarios you can use are anything from weather years to forecasting methods to the addition of different technologies on the system.

Usually the modeling horizon is a single year so we would pick a future year and – yeah, we would pick a future year and model that future year in either hourly or sub-hourly resolution. That can also be one of the scenarios is testing the market dispatch on, "Does your market operate on an hourly resolution or 15 minute or 5 minute dispatch?" Those impacts can have a dramatic effect on ultimate production costs and the ability of the system to meet flexible load and things like that.

So the key inputs for these types of studies are really a detailed knowledge of the system, what the generation operating parameters and fleet characteristics of the existing system and the future system that you would like to test. Ultimately time synchronous renewable energy and load data. I'll get to a little bit more about that in a few slides.

Again, these operational flexibility type studies like these production cost modeling studies can really, again, test new policies. It can really highlight the need for new generation that maybe the capacity expansion modeling study didn't highlight. It can test the validity of some of the capacity expansion modeling results. Then again, where you see periods of high stress on the system, where the system is ramping particular hard or where the system has a particular low operating reserve those periods can inform a powerful study. You can really highlight the period that you'd like to test in a power flow study. So we'll see that in here in a minute.

One example of a production cost modeling study that has been recently conducted here at NREL is the ERGIS, the Eastern Renewable Generation Integration Study, where we looked at the operation of the entire Eastern Interconnect which is by some measures the largest power system in the world. We tested that system under high penetrations of renewables and showed that the Eastern Interconnection can handle a significant renewable energy penetration and no one had really tested that in the Eastern United States on a high penetration level and really showed the impacts of a lot of renewables in the Eastern U.S. before. So that was a very interesting study. Another thing that we did there is we ran these unit commitment and economic dispatch models on the system – an extremely large system with 60,000 lines and 7,500 generators at 5 minute dispatch. So a very high resolution study to really look at the intricate details of how that system would operate.

So the last type of study that we'll talk about is this load flow modeling where when you're looking at the reliability impacts and contingency responses in a system and assessing whether or not a particular unit commitment period is going to be reliable that this is the type of study you want to do. This is really looking at that sub one minute down to five second or less where you're looking at periods of system stress and trying to identify if the system will be feasible and then if not figuring out what needs to be done to make sure that you maintain reliability in the system because reliability is really an important thing in people's lives and the economics of the region you're serving.

So here one of the key inputs that the other studies don't require or at least dynamic generator modeling parameters such as the generator responses to contingencies you really need to calculate the system of differential equations to contingencies in the system whether it's a line outage or generation outage, things like that. So transmission line impedances and transformer tap settings. All those things are very important and they're from a research point of view particularly difficult to obtain however any grid operator typically has a good model of these things for the area that they serve.

So that highlights the need to, for researchers like us, to work closely with the real system operators and the system owners to be able to conduct this type of study and be able to get the accurate data to make it realistic. Ultimately these technical feasibility studies can sort of make or break some of the results from the production cost model studies and the capacity expansion modeling studies because this is really where a lot of the criticism comes in of renewable energy, that it's going to reduce the reliability of the system.

We've shown in a few studies that that is not usually the case or not always the case. One example of that is the Western Wind and Solar Integration Study Phase Three looked at how high penetrations of wind and solar would impact the large scale transient stability and frequency response of the Western Interconnect in the U.S. So what they showed was that there is really no barriers to achieving system stability and frequency response targets under high RE penetrations. There were some mitigation actions that could ensure a high level of reliability but there are no real technical barriers to achieving that.

This figure on the lower left shows over the course of about 60 seconds on the X axis the frequency response of this system under three different scenarios that were both generated through capacity expansion, tested in production cost modeling and ultimately implemented in a load flow study where these various different renewable penetrations and the specific periods that we were looking the frequency nadir and the frequency response of this system was well within acceptable terms. So these load flow studies really have shown that even with high penetrations of renewables you can operate a system reliably.

So in part three if you want to actually do one of these grid integration studies how would you conduct one of them? What is the process of conducting a grid integration study? So these steps highlighted here show steps that need to be taken not necessarily always in one after the other but steps that are necessary to conduct a grid integration study; collecting data, developing scenarios, simulating the system and analyzing the report are one way to break down the steps and something we have found to be very effective. One thing you need to note in this slide that is consistent throughout each one along the bottom is that stakeholder meetings are really a crucial part to conducting a successful grid integration study. Having a stakeholder engagement throughout each phase will ensure that people believe the results and that the results are something that can be relevant to policy makers and ultimately be useful in the real world.

We'll go through step one a little bit where data collection is a significant step, often something that might need to be started before one might consider a grid integration study. So wind and solar profile development what you're looking for is not just how much resource is available. So you want to look for land or sea area that is feasible for development of wind and solar but also the specific times at which and relative to each other you need to have time synchronous data which we'll talk about in the next slide, wind and solar load profile development. So that is really useful especially for production cost models where you're looking at how the system will respond to the various inputs at the same time.

So developing those wind load and solar profile – load is not on here but maybe should be – is very important. Then multiple years of each of those profiles is useful to understand whether you've had a high wind or low wind year but really when you're looking at production cost modeling studies you really look at those time synchronous periods.

The other thing that's very important is existing system data and understanding the system that you have in place. There's been a lot of work here in the U.S. that has shown that even some of our better models of the existing system is really not good enough. They're not representing reality and they don't show which generators have automatic generation control and things like that. That's a real problem because sometimes the studies are coming up with results that are not realistic because we don't have real system data and the proprietary nature of all the generators' operating data makes it a very difficult problem to collect system data which is something that's easy to overlook.

This next slide here shows the importance of time synchronous data. This is an example of the Texas system that's operated by ERCOT and unfortunately I don't have solar on here but we have a wind profile, a load profile and then if you subtract the wind from load you have a net load profile in green. It shows that the interaction between load and wind can create dramatically more ramping in the net load. So since wind is more or less a free resource once it's installed on the system you typically don't want to not use it if it's available. The net load is really what the rest of the system is going to have to respond to.

What was shown here was that the net load is requiring considerably more ramping of the conventional generation fleet. So that poses a challenge for operators, for conventional generator owners and for the market itself to compensate those resources for the additional stress and things that they're providing to the system. But this slide really shows the importance of making sure you have not TMY or Typical Meteorological Year with average profiles or anything like that but really the time synchronous wind and load in this case and then solar is also very important to add that on top of here. With that I'll turn it over to Jaquelin to talk about scenario development.

Oh sorry. I'll keep talking about scenario development. So here we have generation scenarios where we're looking at different wind, solar, conventional and demand response generation profiles. So in the case where you have more wind and solar developed through the system or you've added demand response or residential photovoltaics becomes a significant contributor to the system all these things can provide generation scenarios. Transmission scenarios are very useful because they're particularly hard to model in a way that a model would optimize transmission development.

So it's almost always easier to simply identify options for transmission expansion outside of a model and then just test them as scenarios. So one would say, "We would like to see about building a particular line," and you test the system with and without that transmission line. Other scenarios can include institutional changes such as changes in market rules and/or reliability rules where they really affect how the system is operated and not necessarily affect the physical capabilities of the system. But they can have a dramatic effect in the production cost or the reliability of a system.

Then once you develop all those scenarios and you can really design a study around scenario development and make sure that you have a range of scenarios that highlight what you're trying to study then you can compile all that data into a consolidated database and build out in some sense a matrix of testing a combination of these different scenarios. We do a lot of this in our production cost modeling studies where we're testing both the impacts of high transmission development and a lot of solar or something like that. There's just some really great examples of that in the ERGIS study where we tested various different levels of transmission and various different penetrations of wind, solar or both. So those are really interesting.

But all of that is important to test against a base case scenario or a scenario that either is business as usual in future year and even compares back to an existing year. So those are useful things to test no hypotheses. If we did nothing what would happen and if we were to try and achieve these various different penetrations what would happen?

So then in step three, the simulation step, this is really what people consider a grid integration study but there's a lot more that we've seen in steps one and two and then again in the next step where this step is focusing on the simulation. Depending on the type of simulation that you're conducting you can consider different modeling considerations. So the resolution and horizon of a simulation is very important. So understanding the period that you're trying to simulate and making sure that you're representing the capabilities of your market and you're not losing flexibility options by only considering multiple hours of dispatch instead of down to five minutes or something like that.

Other simulation considerations would be something like that need for additional ancillary services impact. Then whether or not you're doing everything to reflect market prices is a particularly difficult modeling consideration. Something that is very difficult is to reflect market prices in production cost models. So we have found that by not having perfect knowledge of how each resource operates it's difficult to recreate existing system prices. So knowing that, we would run simulations and expect that market prices are something we would present on an average basis or something like that.

So by simulating the system in these different ways you can ensure that you have a model that is both computationally feasible – it's very difficult to provide a detailed operations simulation in a capacity expansion modeling study and it's also very difficult to test the technical feasibility and the contingency response in a production cost model study. So understanding the types of questions you're trying to ask and the specific model you'd like to use and the assumptions going into that model is a very important step that shouldn't be overlooked and shouldn't – again, take into account the advisory committee's desire and knowledge as well as the modelers and their capabilities if they can actually simulate certain things and particular types of the model. With that I will turn it over to Jaquelin to talk about analyzing and reporting.

Jaquelin Cochran Thank you Clayton. So after we've done the model simulations this is where we can really continue to explore, put together a question. So as I was saying earlier the grid integration study is designed to answer a particular question but in the process of conducting this study we might develop 10, 15, 20 new questions. So some of these we can still answer based on the model. We might want to, as Clayton noted, look at some particularly challenging times more closely.

But in this step we can also summarize how the power system operates. What are the costs? What's the fuel consumption? Look at each generation, at each plant type in terms of what's the installed capacity and the generation during that year, what's the level of renewable energy curtailments. To the extent that's possible a cost benefit analysis of specific integration options. Then putting this together in a report and communicating the results to various audiences.

This slide shows a visual from IEA Test 25 which is a focus on wind grid integration and it's from their best practices document on how to conduct a wind grid integration study. But earlier we had pulled apart this visual into the different steps. Here you can see how they put all the steps together. The message being that these are very iterative processes. So for example, if we go to through the study and we find that it's not meeting reliability at the time scale that we're interested in we might need to go back and make adjustments to the resource scenarios or we might need better resolution data if we're not able to answer a particular question that we want to.

It's important to note that not every study is going to look like this. So when I was reviewing studies earlier I wanted to emphasize that studies will pick and choose which questions to answer and which analyzes are needed to answer that. This shows sort of the full suite of them but in reality the actual grid integration study might selectively choose from among these boxes.

However what is common across all these studies is stakeholder engagement. Stakeholder engagement is critical to ensure that the study is relevant to industry and technically accurate. A typical way that a lot of the studies have addressed this need is to develop a technical review committee. There are many purposes of a technical review committee. One is to assist the modelers in guiding the study objectives.

So what is the question that we're asking? Which future year are we looking at? What are the future scenarios that we want to address in the sense that what does that future system look like? What are the many different future systems that we want to analyze? How do those systems compare to today? So this is where the TRC, the review committee can speak with the modelers and say, "These are the questions that are really important to us. These are the questions that probably aren't as important."

The TRC also reviews study assumptions. So Clayton described a lot of the simplifications that need to be made so here the TRC can review those assumptions. Then also the TRC endorses the technical rigor of the study. This is why it's important to have a TRC that's well-represented by the industry. So on the right I show some example TRC members; system operators, utilities, renewable energy plant owners or operators or developers, similarly conventional plant owners, transmission developers, regulators, public advocates. If you've got a TRC that's well-represented then if this TRC then endorses the conclusion of the results that lends more credibility to the study for others to look at say, "Oh yes, these interests and expertise were all represented on the study."

On this slide I show you an example of some of the TRC members on our recent Western Wind and Solar Integration Study. So this is not a full list but it does give you a sense of who is on the committee. So we have system operators that included vertical utilities. Also some of the wholesale market operators. There are also other private sector companies on the TRC as well as the department of energy.

Then there are a number of research institutes and organizations, some that were looked at – like FRE is focused on reliability. We had a number of the DOE National Laboratories, the Utility Variable Integration Group, the Western Governors' Association to represent different state governor interests on the study. So this just gives you a flavor of the type of TRC and that these are also very large. They can be 15, 20, even 30 people and they'll meet maybe 4, 5 times over the course of the study sometimes in person, sometimes by phone meetings.

So here are some tips for conducting your own grid integration studies starting with crucially a clearly defined study question, "What is it that you want to learn?" So if you're interested in a system with high renewable energy reliability is measured at different time scales. We've talked about all the time scales today from the seconds after a grid disturbance to the long term adequacy of the system in meeting future demand growth. So picking which aspect of reliability and what metric you're going to use to measure that. Also you'll probably be looking for a cost efficient set of solutions for the grid integration future. So cost efficient for whom, at what time?

Do you have the tools to answer the question that you want? So Clayton described three different types of tools. Are you using the right tools to answer your question? Then importantly, do you have the data to use those tools and answer your questions? If no, where can you get the data?

We described earlier how time intensive and it can be multi-year. There are also ways to do this. There are a number of commercial data sources available for some types of renewable energy production. So time can be saved by purchasing some of these data but it is important to look into what the data options are and what – because data has very different characteristics depending on what your question is you want to get the right data.

Transparency is the process for developing methods and assumptions for your analysis transparent. Similarly, is it peer reviewed? Do you have impartial external experts reviewing the results?

So in conclusion we want to leave you with a few just key messages. A grid integration study provides a power system-specific assessment of the challenges and solutions associated with future RE scenarios. Grid integration studies evolve over time; each study frames the key questions for subsequence efforts. So we've described some of the studies here where we start a study with one question – so for example with our Western Wind and Solar Integration Study we start with a question of, "How do you balance a system with 35 percent renewable energy on the grid?"

The second study looked at, "Well can the coal plants actually operate under those conditions? What is the cost impact of that?" Then the third phase of the study looked at, "How can you maintain that system after a grid disturbance?" So once you establish a validated model you can use this model to answer many different questions in the future. Undoubtedly if you conduct a grid integration study you will be raising more questions than you want to answer.

Stakeholder input should inform the communication of results to ensure that the study outputs are actionable and policy relevant. Then the ultimate goal for the studies is to give the power sector stakeholders the information and confidence they need to take action to meet renewable energy targets.

I invite you to come to our website at greeningthegrid.org. We have a number of resources there and including this webinar and the previous webinar I mentioned and also some fact sheets, case studies and other resources on particular topics like forecasting or ancillary services. So please come to this website. We will now turn it over to question and answer. I'd like to introduce my colleague Jen Leisch from USAID.

Jennifer Leisch Great. Thank you Jaquelin and thank you Clayton and of course thank you to the Clean Energy Solution Center. I would like to encourage anyone who might have a question to please submit your question through the question box and we will try to answer it. We've already had a few questions come in. So I'd like to start by asking Jaquelin and Clayton something that a lot of people want to know really which is, "How long does a grid integration usually take and how much does doing a grid integration study cost?"

Jaquelin Cochran Okay, that is of course a very challenging question to answer because each study is unique. Some of the cost can – I mean the cost on data acquisition can – so for renewable energy data that can vary from – I don't know - $10,000.00, $20,000.00, $30,000.00 to purchase some solar data. Wind energy data is typically more. There's also time involved in collecting generator data.

Now if you have data available through some of your industry colleagues, so for example the system operator might have power flow models that where they already have generator characteristics in there that can save some time in collecting the data. So there's a broad range in terms of the price of the data collection. Then the labor cost is specific to the source of labor. But let's say it could be low hundreds of thousands for a small system and you know a few million for really large complicated systems and anywhere in between depending on the level of detail you want. The time it takes to conduct this also depends on how – like data acquisition can be time consuming but once you have the data it then depends on what are the questions that you're answering.

So if you're only asking a basic set of questions like you're looking ahead at one or two scenarios and then you're running the model, you're validating the results with your TRC that can go fairly quickly if you're not asking too many questions off of it. But if you really want to get into the details let's – so let's say that's several months. But if you really want to look at a variety of future scenarios that takes time to build out in your model each of the scenarios. Then if you want to look at really hard to answer questions – so like, "What if instead of two separate balancing areas we had one larger balancing area," or, "Instead of two separate balancing areas we had these two balancing areas then establish a market in between themselves. What if that market is day ahead or what if the market is real time?"

I mean all of these can be time consuming to incorporate into the model. So just like the cost is highly variable the time could be anywhere from months to a couple years depending on the level of complexity and the rigor in which you're bringing to the study.

Jennifer Leisch Great. So maybe a little bit of a follow on question to that is, "To what extent can these studies be conducted using commercially available models or commercially available software versus custom built or system specific models?" To follow on with that, "What are some of the examples of these commercially available models that could be used that already exist that are out there?"

Clayton Barrows So I'll take this one. So for each of our three categories of models, capacity expansion models, production cost models and power flow models there are commercially available modeling software for each one. That said, capacity expansion models are the one I'll say are most frequently developed on an ad hoc or in-house basis. That's due to a number of things. A lot of them consider different options when looking at a capacity expansion.

Some of them do more consideration of economic development. Some of them do more consideration of renewable resources. So we at NREL we do a lot of developing our own capacity expansion models. We don't do a lot of development of production cost models or power flow models. So an example of our most widely known in-house developed model is called REEDS. I won't go through the label of the acronym because I'll probably get it wrong but there are commercially available capacity expansion models from Energy Exemplar, from a few other entities. There are several but I can't go through a comprehensive list.

For production cost modeling software this is one where commercially available software is sort of king and that's due to the complexity of considering all of the variables in a capacity expansion model and a lot of times to get industry accepted results it's important to use a software that is widely accepted in the industry. So there are a number of those from sources such as GE, Energy Exemplar, Ventex and then there are several others. I won't go through a comprehensive list. But those are widely available commercial models. They're very expensive generally. Something to consider. Then in terms of power flow models that are really too that jump out that are from GE and Siemens and they are typically not an ad hoc self-developed model but more often they're – you would use a commercially available software.

Jennifer Leisch

Great. So we had a question come in about different experience and different approaches in countries outside of the U.S. So what type of approaches or experience can you speak to working on these studies in countries that are perhaps island nations or in countries where there is not a lot of data availability or poor data quality or in countries, for example, that instead of having a market are a more vertically integrated system?

Jaquelin Cochran

Okay, so a number of questions there. Let me start with a few of the easier to answer ones. If a country does not have much data the grid integration study – let's assume that country doesn't have significant renewable energy. I would approach grid integration thinking about other actions that the country could take where they don't need that integration study to prove that that is a cost efficient action form.

So for example, forecasting. What are some methods that they can use to improve forecasting? The country could start with that. They don't need the grid integration for that. Moving from hourly to sub-hourly dispatch is another known effective mechanism that can improve the integration of renewables. Again, starting there. Then I would save the renewable – if there is limited data then we can – take time to build up that data and not rush into the grid integration study right away if there are other actions that the country can take.

On the markets question, our presentation really applies to wholesale power markets or vertically integrated areas. So for example, the Western Wind and Solar Integration Study. Most of the West in the United States are vertically integrated utilities. A lot of – Colorado where we live is a vertically integrated utility, has a vertically integrated utility. They've done integration.

Xcel Energy has done integration studies specific to this area that can inform decisions to make. So for example, the need for expanded natural gas storage to be able to handle wind ramps or uncertainty of wind production. So it's not important whether it's a market or not. It'll affect how you run your study but this is applicable to any type of environment.

Then in terms of islands we've done a lot of work at NREL on islands. So for example, Hawaii we've worked with Hawaii to conduct a grid integration study there but I don't know as much about the island integration studies.

Jennifer Leisch Great. Another question is, "Can you just really quickly explain the difference between a grid impact study and a grid integration study?"

Clayton Barrows Yeah. So I think that when people refer to a grid impact study they're typically referring to the impacts of integrating a specific plant or specific development on the system. They're often looking more from a developer perspective on, "If I'm a wind developer and I build my new wind site how is that going to affect electricity prices or how is that going to affect supply?" Really a grid integration study is looking at more of the system effects and a system wide development towards higher renewable penetrations.

So we're looking at developing the best resources from a cost effective standpoint in the model and then looking at how the system is going to respond to that increased penetration of renewables, how the emissions of the entire system is going to be reduced, things like that. So really the grid integration studies are more of a system wide study. A grid impact study is more of plant specific type impact study.

Jennifer Leisch Great. So you guys did show us some great examples of a lot of grid integrations of these _____ _____ _____. Are there any kind of common conclusions across all of those major grid integration studies that have been done to date?

Jaquelin Cochran I'd say the most common one is that it is feasible. We've seen it in the studies and we've seen this in practice that grids with high penetrations of renewable energy is feasible to achieve and there are a lot of kind of low capital cost but challenging changes that could be made at the institutional level. So for example, to improve the efficiency of operating the system. So for example, like in the West there's a lot of small balancing areas that operate independently and the more that they are coordinating and sharing resources and balancing resources the cheaper it is to integrate renewable energy. We've also found I would say another broad conclusion is that electrical storage is not necessary until you get to much higher penetration levels.

Clayton Barrows I'd say from a general rule of thumb a lot of what we've found is up to small or medium levels of grid integration and those percentages vary by system a lot but oftentimes they're around 30 percent renewables on an annual basis. There's really no new technology investment that needs to happen. This is specific to studies that we've done here in the U.S. and lots of other caveats to that number. But then really the adjustments that need to be made are more institutional in the way the system's operated.

Beyond that low to medium penetration level some new investments need to be made in terms of increasing the physical flexibility of system resources.

But at the beginning for most countries that is something that is usually fairly easily addressed, to address those institutional changes. Then the more difficult part is making the capital investment in flexibility.

Jennifer Leisch So, speaking of countries of very high renewable energy targets can you talk a little bit about the process that India is currently going through to evaluate the opportunity to integrate high penetrations of both solar and wind into their system?

Jaquelin Cochran Yes. The Ministry of Power and the system operators and the transition companies are working together with assistance from the NREL and also our partner DOE lab, Lawrence Berkeley National Laboratory. We are working together to look at three types of grid integration studies. One is at the national level, so looking at that hourly system balancing. If India were to achieve the 175 gigawatt renewable energy target which includes 160 gigawatts of variable renewable energy how does the system balance?

What are the transmission lines that are needed to achieve that? What is the cost of operating a system like that? Then we're also looking at two regional grid integration studies; one in the West and one in the South. These are much more in-depth and looking at transmission at the sub – within the state and how the transmission lines are used. What are the impacts of solar parks? These are large one to two gigawatt solar parks that have plans to be installed.

Then also looking at what are the changes they could make in terms of better coordination between states? What are some market rules that could be done? This is still pretty early in the process so the first technical review committee meeting will be coming up soon for each of these studies but I would expect to see results for the national study next summer and for the regional integrations studies next October/November. Feel free to check in with me if you want updates.

Jennifer Leisch So in a place not only in India but in the U.S. and through your experience in doing these studies can you talk a little bit about how a grid integration study relates to integrated resource planning or that process in itself? Do these happen simultaneously? Does one come after the other?

Clayton Barrows Yeah, so the IRP process is something that is usually taken on by the system owner, system operator. So a utility is usually the person doing or the entity that's conducting an IRP. That really reflects more of the capacity expansion modeling type studies that we've been talking about. Capacity expansion modeling studies can really take the shape of IRPs or more of a national type study.

So a lot of times capacity expansion modeling studies that are looking specifically at renewables are looking at maybe even longer than an IRP type process. So they're looking at maybe 50 years out and they're really trying to understand the effects of some renewable energy target on emissions in the really long term or prices or how the build out of the country might look in the long term. So those are sort of outside of the IRP process.

Then there are capacity expansion modeling studies that are more akin to the IRP type process that are looking at, "Okay, we are a utility and we have a target we need to meet and so in our capacity expansion modeling type study we are going to look at various different technologies and the resources available to us and the specific targets and needs that the system has." So those can really be integrated into – I mean they really can be the same process if needed.

We have been presenting them as more grid integration studies than IRPs because typically it's not the government that's doing and IRP and it's not a research institution doing an IRP but rather the utility. We want to make sure that these types of studies can be conducted by those other entities or third parties like ourselves and can consider things outside of just what the utility is considering or trying to consider, not just the profitability of a utility but also the best option for the society of the country as a whole.

Jennifer Leisch So IRPs, grid integration studies, a lot of this is very, very technical work. What type of capabilities are really needed in a country to be able to run these models, collect and gather the data? Then obviously, most importantly, what type of capabilities are needed to be able to translate this into policy recommendations and actions moving forward? [Laughter] Hard question.

Jaquelin Cochran Well some of the vendors of the software offer commercial training. It doesn't mean that you necessarily know how to do everything you – all the questions you want from going through a few trainings. Our approach at NREL when working with our collaborators in other countries is to kind of walk through each of the steps of the grid integration study to be able to show – discuss with them like, "Why are we going to take this methodology? Why are we picking scenarios that look like this and not that?"

I mean a lot of – there's a lot of – all countries – a lot of the power system folks in all these countries have a lot of the capabilities of knowing how their system operates. They know their generators really well, what are they capable of doing or not. It's usually just a matter of translating that knowledge into the modeling inputs. So that knowledge is there in many cases. Just the modeling inputs and how to put the whole structure together.

Clayton Barrows It's not to be overlooked the translation of the results into something that's useful. A lot of times the people that are the most knowledgeable about how the system works and the existing resources on the system they also have the most trouble presenting those results or new results into a policy relevant format. So that's a critical phase that's very difficult to make sure that the results that you get can be translated into a document or a set of recommendations or policy relevance. So it's something that needs to be considered and something that can be considered when creating the team that will be doing the study is making sure that you have a good communications plan in place to make sure your results are widely accepted and usable.

Jennifer Leisch So we've had a lot of questions come in and I think this is going to be the last one. Really to tie everything together, what are the recommendations that you would have for making sure that these studies are actionable and credible to policy makers because ideally that's the aim in what we're going for? To that end there is a disconnect, for example, between four-year legislation terms and 10 to 20 year planning timelines. So are there things that can be done to bridge that gap? Are there recommendations that you have for making sure that these things are actionable?

Jaquelin Cochran Well I mean fundamentally having this granted in the technical review committee and the stakeholder concerns so if the study is conducted without that then the study will just go on a shelf and will be dismissed as not answering the specific concerns that that system operator has. To get the results to translation you need to have the industry also agree with the results. So that industry engagement is critical.

Then it's also important to work with policy makers to sort of make sure that the questions you're asking are the questions that they're interested in or maybe they don't know that they're interested in it yet but will be informative for what kinds of decisions they need to make. A policy maker might be on a four-year legislative cycle but that doesn't preclude taking action on things. So for example, setting a policy, a renewable energy target or establishing – authorizing the regulator to explore different mechanisms for balancing between balancing areas.

I mean there's a number of things. A rooftop solar program might be a legislative concern, "How can we support rooftop solar?" The grid study could be looking at what is the effect – you could have a grid study that's very specific to the distribution grid and looking at what are the impacts of that and being able to show that you can have higher renewable energy targets without a threat to the distribution grid or to the transmission grid.

Clayton Barrows Yeah, I was going to just add that the – to ensure some of the long term relevance of grid integration studies although a study might be commissioned to answer a very specific question on a specific policy that is being considered or something like that those types of studies at some point could also include new technologies that aren't necessarily widely deployed at the particular moment. But including these options that aren't necessarily in the ground now or aren't necessarily on the horizon but may be very soon. Those things can help maintain the relevance of a study through time.

So for example, in the U.S. we haven't really faced a whole lot of regulation on carbon emissions until very recently but for a long time our studies have been considering that as one of the scenarios as a – we know that carbon regulation is something that's going to come eventually or we think that carbon legislation is something that's going to come eventually. So we've been testing various different implementations of carbon legislation in a lot of our grid integration studies for a long time. Similarly with demand response. We don't necessarily know how demand response is going to participate in the markets but we've been trying different ways and trying to add that into our grid integration studies for a while in hopes that although a study might be trying to look at penetrations of solar adding demand response might be one way that our study kind of continues its relevance into the future.

Jennifer Leisch Great. Thank you both Jaquelin and Clayton. I just want to remind folks that if you do have any lingering questions Greening the Grid does have a website with a lot of additional information, greeningthegrid.org, as well as an email addressed, greeningthegrid@NREL.gov. Now I'd like to turn it back over to the Clean Energy Solutions Center to wrap up.

Tim Reber Thank you Jennifer and thank you again to both Jaquelin and Clayton for a wonderful presentation. I think we certainly learned quite a bit and we had some great questions submitted by the audience. It spurred some interesting discussions. So thank you to all those in the audience who asked questions. Again, just to reiterate what Jennifer said, please feel free to reach out to our wonderful panelists here if there's any other follow-up.

So with that before we close we'd like to do a quick survey here. Getting feedback from you, the audience really helps us improve our webinars and lets us know how we're doing and how we can improve. So if you go ahead and take a moment to please answer the first question you see there on your screen we would appreciate it. Okay; and second question coming up here. And one final question for you.

Great. Thank you so much to everyone for answering those questions. Once again, on behalf of the Clean Energy Solutions Center I'd like to thank all of our panelists as well as the audience for joining us today. We very much appreciate everyone's time. We invite all of our attendees to check the Solutions Center website if you'd like to view the slides or listen to a recording of today's presentation as well as previously held webinars.

You'll find the information on upcoming webinars and other training events as well. Additionally we're also posting webinar recordings to the Clean Energy Solutions Center YouTube channel which should be up there within about a week or so. We invite you to inform your colleagues and those in your networks about the Solutions Center resources and services including our no cost expert policy assistant known as Ask-An-Expert. So with that I'd like to thank everybody once again and invite everybody to enjoy the rest of their day or evening as the case may be. We hope to see everybody at a future Solutions Center event. So, thank you very much.