Jill Engel-Cox: Hello, everyone. And welcome to our webinar on Spatial and Temporal Considerations of Energy Decisions. I'm Jill Engel-Cox, the deputy director of the Joint Institute for Strategic Energy Analysis. The Joint Institute conducts in-depth analysis of energy systems, specifically at the nexus of energy finance in society. Our natural gas and energy decision analysis is part of our analysis looking at the evolving power sector away from coal and towards renewables and natural gas resources. So, today is the third of a three-part webinar series that we've conducted on these types of analyses that we have completed over the past year. Recordings and the slides of the previous two webinars related to power market trends and methane abatement are available on the JISEA website, which is on your screen at the bottom of the slide.

So, our speaker today is Dr. Sarah Jordaan, assistant professor of energy politics and policy at the University of Calgary. And she is going to talk on spatiotemporal considerations for energy decision for about 45 minutes, and then we will have time for questions at the end. You can ask questions at any time during the presentation. You just type them in the question box on your screen, and then at the end of the presentation, we will get to all the questions. So, feel free to type a question as we go along, or you can also ask the question at the end of the presentation. Now, I'm going to go ahead and turn it over to Sarah then.

Sarah Jordaan: Hello, thank you. So, first I just want to say thanks to JISEA for inviting me to give this presentation. I'm very much looking forward to hearing your questions and getting your feedback. Again, a lot of this information is in development, so it's a great time to be able to present to you and get some feedback on direction as well as thoughts on future work.

Oops – apologies. So, the focus of my talk today is going to be on the importance of space and time for energy decisions, and really a lot of – this is the cusp of the very idea of where a lot of my research lies. The main reason why is if you end up walking into the area of interdisciplinary research related to energy, you'll find quickly that a lot of the ways in which we've used space and time across disciplines is actually different. So, a lot of my research really focuses on this having worked with a lot of different groups – having had the opportunity to work with a lot of different groups in the past. Starting off, technology assessments typically focus on inputs and outputs, so more so in engineering-type approach where you look – where you determine impacts in that way. But we know that energy projects occur across regions, so face different

environmental variables across scales, and certainly scales matter for what the impacts are, but are also for governance levels and with different timelines or different assumed project lifetimes. So, project lifetimes can refer to the economic life of a project, or the amount of time that a project impact might take to reclaim on land, for example, which is viewed differently from an ecological perspective.

The assessments of impacts often focus on snapshots in time in a particular region, but we know that certainly the interregional impacts differ. So, the outside environment also evolves, not only by region, but also over time. So, economic influences, political influences, and even broader on the international geopolitical influences, and also the natural environment. Ultimately, while we know very well the broad inputs and outputs for mass/energy balances and, more specifically, for specific projects, technology assessments over time that include regional variability are not well developed. So, this poses a gap and a challenge for decision-makers in trying to determine what exactly these technology assessments mean for their regions or for the specific projects being developed in their regions or across regions.

So, then we come with a question, "How can environmental costs and benefits of energy projects be evaluated across regions, skills, and time?" The most exciting thing about these types of questions is that we now have software tools and we are increasingly having access to data sets that can be combined and utilized with methods – with new methods and methods yet to be developed to address some of these questions. And this is happening at quite a rapid pace, so our ability to do so will only improve over time.

So, the focus of the talk today is going to be on three impact categories – water, land, and climate. So, first I'll discuss water consumption. And so what happens with water consumption is that what happens at the water shed level is not necessarily what we see happen at the technology assessment level, so – and even farther up, if we look at government decisions at the highest level. So, at the federal level, they don't necessarily transcend to those regional impacts, and vice versa. So, what we really need to do is start thinking through methods that will translate these government decisions to local and regional effects, and vice versa, because water is one of those impact categories where scarcity can create limits to operations, not even accounting for local ecological sensitivities.

The second impact category I'll be addressing is land, where I'll be discussing the spatial requirements of energy technologies. What is to be noted from the present status of research is that there is not very much that's been done to compare systematically the land required for energy developments and technologies across regions. So, this is an area where a lot of work is needed to come to some form of agreement, and this is further confounded by the fact that it's very challenging to compare consistently renewable energy and non-renewable energy over time. And this is because geological resources deplete, where renewable resources may – we may require an additional wind turbine or operations and maintenance, but it's a very different type of energy with similar products.

And the last impact category to be addressed will be climate, and this isn't more broadly on the impacts of climate change, but certainly the impacts of climate change are really important for this particular area. But the focus will more so be on emissions and policies. So, the key examples being with globalization and the extension of trade and the potential for growth in global greenhouse gas emissions associated with this trade, the decision support tools that we use, such as life cycle assessment, need to better recognize this intraregional variability and international variability, but also to recognize the importance and the influence of regional policies in greenhouse gas reduction.

Starting off with water use, any conversation about water use should start off with an understanding about what the difference between water consumption and withdrawal are. So, consumption is typically viewed as that water which is used and not returned to the water shed or the water body from which it was withdrawn, and withdrawal is that which is withdrawn or taken out of the system and includes that which is consumed, but also that which is put back into the water shed. So, these two pie charts essentially show water use in the United States. On the withdrawal side, the thermoelectric power generation in green is 49 percent. I believe this data is from – it's between 2009 and 2010. So, the green is thermoelectric power generation, and the orange is irrigation – so, the two largest contributing factors. But when we account for what is put back into the system, the thermoelectric power generation decreases to three percent and irrigation has a much larger component, showing that – the definition of consumption under that definition, a lot of the water is put back into the system for thermoelectric power generation. So, when we start to think through these conversations on impacts, it's necessary to make the difference – recognize the difference between the two.

In terms of associating these broader federal policies with what actually happens in regions, I'll start off by a case study looking at the renewable standard and alternatives to that. So, we know federal energy policies can and will impact water consumption nationally and regionally. But again, there's not – we don't have a lot of methods that are incorporated within these decisions to actually examine how – what those impacts might be. The Environmental Protection Agency, we know, is responsible for ensuring transportation fuel sold in the U.S. contains a minimum volume of renewable fuel. So, the current standard mandates an increase from nine billion gallons in 2008 to 36 billion gallons by 2022 – no more than 15 billion from corn, grain, and the rest from advanced biofuels.

In order to better understand what this might translate to in terms of impacts, what we did was we developed a methodology to try to understand this. So, we developed seven scenarios, and those – and used those scenarios to estimate what the potential water increase might be associated with those scenarios. And then we took these scenarios and translated them to what water consumption might look like at the state level. And again, this is more the development of a methodological approach, okay? More of a first step in understanding how we can necessarily start to define what the potential impacts of these questions – of these policies are.

So, the seven scenarios that we looked at are baseline policy, where biofuels maintain 10 percent of what gasoline is distributed, and that will increase proportionally to the demand growth. Now, we also looked at a shale oil scenario, so you can imagine how this could be looked at as a "business as usual" case to fill that additional amount it required to meet the RFS fuel volume by 2022. Then we looked at the renewable fuel standard as it was currently developed at the time of this paper, so 2013. We included a complete switchgrass scenario, so assuming cellulosic ethanol is commercially available, and again, meeting the same volume, a full corn scenario where cellulosic ethanol was not deemed commercially available, and two other options – coal to liquids, and gas to liquids.

And this figure demonstrates our overall results from the federal standpoint. So, you'll see that the increase based on demand growth is the first in 10 percent corn. Then we have the renewable fuel standard, the switchgrass alternatives, corn, shale oil, coal to

liquids, and gas to liquids. And where there are a number of different options, those are different configurations to achieve the final fuel – different configurations, i.e. using mass energy balances to estimate what those might look like. The gray is conversion, and the black is extraction for each option. So, results show what we would expect the first generation corn ethanol will require a significantly larger amount of water than the other options, and in many respects, explaining why is a challenging option. And in comparison to the other options, you'll see that the switchgrass particularly and the fossil fuels use much less water.

The purpose of the analysis was not necessarily however to estimate to the total of the demand, but was rather to develop a method by which we can actually understand what that might mean at the regional level. So, what we then did was we said, "Okay, well how can we necessarily portray what water availability looks like?" There presently is not a lot of data availability on water budgets, so in lieu of an actual water budget, we did drought incidence as a metric to understand what the availability might look like. So, extracted ten years of drought incidence data and translated that to the state level. So, the darker colored states are those which experience higher levels of drought incidence. We then compared the consumption to withdrawals, and that's the USGS data. Now, the withdrawal data was used specifically because the consumption data is no longer made available and in addition it does provide value because it is a conservative estimate for what the incremental growth might look like.

We compared it to irrigation withdrawals because that aligns well with the comparison of biofuels, but again, for those fuels which are not biofuels, it makes more sense to compare to industrial withdrawals, so we compared to both to get a better understanding of what the growth in water use might look like – water consumption. So, the key results being if you look at the irrigation – so, there might be some areas where you'll see a very large increase – for example, in West Virginia. That's driven by the fact that there is low irrigation demand in comparison to other places. You'll see the change between industrial and irrigation. But you'll note that for the corn examples, you'll see an increase certainly in the corn belt and there is spatial weighting towards those states which are drought-prone. Again, a much less overall water increase for the switchgrass and fossil fuel options, but not as much impact towards the drought-prone states, with the exception of coal to liquids. Again, if you imagine where the coal reserves are – for example, in Powder River, Wyoming, you can imagine

why that is because, again, that's where many of the assumptions are derived.

In terms of water consumption comparison to withdrawals, you'll see the same types of trends in terms of how spatially the water use for the corn options are weighted towards drought-prone states, but certainly increasing in those that are less drought-prone as well. But if we're – again less of a water increase for the other options, with the exception of coal to liquids.

So, what are the policy implications? Well, first of all, we did come up with the key finding that fossil options and cellulosic ethanol requires significantly less water and are weighted towards less drought-prone states – with the exception of coal to liquids – for a resource availability options. The first-generation corn scenario is the most water intense, and spatially, has more weight relative to the others towards the drought-prone states, but the reason why this matters for policy is because it provides a core-scale, first-order estimate that can help with integrating federal policies with regional planning. So, this again is to help integrate the – or increase the federal regional policy coherence. So, in essence, there's a need to develop these strategic planning tools such that as these decisions are made, we can understand what the water impacts are, and it does emphasize the need for coordination amongst agencies, so, i.e. federal and state. The water implications of U.S. energy policy can be significant and they are not going to be uniform across states, so again these are more thought exercises to understand how we can potentially plan for these. And what it can also do is highlight areas where more fine-grain analysis is needed in order to better understand what happens at a sub-state level.

The second case that I'll discuss is the coal to gas transition. So, natural gas – so again, this is an example of federal policies and federal decisions translating down to the local level. Natural gas is a cleaner burning fuel than coal, and we know it results in fewer stack emissions, greenhouse gas emissions than coal. But when we think about the water implications, they're complex spatially and temporally. So, what this figure shows is the broader technology assessment type of perspective, and what you'll note is that the natural gas options are less than those of coal. But if we look at the shale gas, versus the conventional natural gas, you do not see a very large difference between the two. So, what this ends up translating into is that a lot of analysts will then say, "Well, the water implications of this coal to gas transition is in that benefit,"

and that is true in many respects. But we also hear that the expansion of hydraulic fracturing does cause local stress in some cases. So, from this we can start to see some of the policy conflicts that might start to arise from simply relying on technology assessments or relying on water shed level analyses.

So, there's two main contributions that come out of this exercise. The first is the development of a method to estimate water consumption associated with fuel extraction and power generation at higher spatial and temporal resolutions than has been done before, but also to gain a comprehensive picture of the changing water consumption patterns associated with the coal to gas transition. So, what this figure shows is the changes that have occurred in Pennsylvania from the retirements of coal and increase in capacity and generation from natural gas, and that is one of the primary reasons why Pennsylvania was chosen as the study area. The second being that the state is considered to be water-rich, but we know that there already have been reports of water limits placed on shale gas operators. So, it's a prime example of where these policy confusions can occur. Our analysis focused specifically on the change in water consumption from 2009 to 2012, so from now on, that will be the temporal focus. And this was a data-driven exercise, so for shale gas we used FracFocus and PADP. We used coal data from the Mine Safety and Health Administration, and also from prior work from the ETIP group at Harvard – Energy Technology Innovation Policy at Harvard. For power generation, we included Energy Information Administration data, NREL data, and also – data from the ETIP group again, and the Union of Concerned Scientists to get to exactly what the spatial distribution might look like – or does look like.

So, what we did was we looked again from 2009 to 2012 at what the changes in water consumption look like. And the first figure – the percent of water consumed by sector in the coal to gas transition, you'll see what we expect – an increase in percentage to natural gas extraction and natural gas power. What we also came up with – I won't focus on it here exactly, but I wanted to point out this – these figures were completed by Lauren Paterson at Duke University, also in collaboration with Laura Diaz Anadon from the Harvard Kennedy School. We also developed these finer temporal scale figures at the basin level, so if you're interested in looking at any of the particular basins, you can go onto the Duke website and look at our visualization tool and find all the different basin level results. The annual water consumed – so the table up on the right-hand side – shows the changes in water consumption from 2009 to

2012. For gas extraction, as expected, it would increase, coal extraction would decrease – did decrease, coal power did decrease, while natural gas power increased. Interestingly, the total overall has increased, but also keeping in mind that the operative practice will evolve and also if there's a large expansion of the drilling that occurred at once, that can drive higher water use on the short-term. We also did include water reuse for shale gas consumption, so again these types of policies will make a large difference over time.

Now, what Figure Three shows is a net change in water consumption from 2009 to 2012, and in this case, the red actually implies a net water benefit, okay? So, that's where water will decrease, and the blue indicates where water use is increasing. So, what again we found was the importance of the spatial heterogeneity and the changes caused by federal decisions, and again highlighting the need for us to actually develop these tools such that we can start to understand where the local impacts might happen. So, if you look up in Susquehanna area where we know a lot of drilling happens, we have net increases in those specific areas. But if you look to other regions where there have been decreases in coal generation, or a decrease in coal generation and increase in natural gas generation, there can actually still be a net water benefit.

So, the key findings, again, from an overall perspective – for shale gas extraction from 2009 to 2012, water consumption for the fuel increased within each sub-basin with hydraulic fracturing activity – okay, so also identifying the fact that certainly there is water consumption associated with this activity. But at the same time, we do see the alternative argument for power generation – the water consumed by coal decreased by 13 percent. That for natural gas increased by 67 percent, but we see a net decrease of six percent for the total water consumed for electricity generation in the area. And again, highlighting the fact that the overall generation may still on the long-term be a decrease, but there is a need to realize the spatial heterogeneity. Overall, we do see the change in water consumption patterns does vary by sub-basin, and recognizing this in many respects is an important path forward in understanding and translating what these – the energy policy and impacts means from different governance levels. The basins of hydraulic fracturing increase the water consumption, unless there's an opportunity to transition from coal to natural gas power plants, in which case that will offset those increases. And basins where coal-fired power plants transition to natural gas may decrease in

their overall consumption, depending on what's happening with the other sectors.

So, what are the policy implications? First of all, it gives a good understanding for broad transitions and it explains the differences in these governance levels, where we see decision-makers approving and not approving permits, but it allows for an understanding between the two and also to craft policies to manage these impacts. Government from the broadest level to highlight the importance of water shed level management. The Susquehanna River Basin Commission has been a strongpoint in that region in terms of identifying potential risks to that specific water shed, so that type of management is really important from a governmental level. We may also see an increased need for water markets and pricing in certain regions. Regulations – there are regulations that can and do require new technologies or performance, and that might be something that we see in terms of water reuse in some regions, as well as produce water treatment. And certainly there may be times of the year, for example, where withdrawal and consumption restrictions are required, specifically, for the protection of sensitive ecosystems.

From the utilities perspective, it highlights the importance of technology innovation and the utilization of best-in-class cooling technologies, and in addition, considering alternative water sources. So, there are a lot of creative ways in which industrial ecology can be used. For shale operators, water reuse has become an important factor in Pennsylvania – certainly decreasing overall water use in the shale gas industry over time. Technology innovation is another in terms of determining creative ways in which produced water can be treated and reused. The use of water sources other than surface water or other materials to inject – i.e. propane gel fracking, certainly can become predominant in some areas where there are different risks. And the timing of consumption and withdrawal is quite a significant question to keep in mind.

Before carrying on to the other impact categories, I just wanted to highlight – so this is EPRI work. I don't know if you can see there was actually an EPRI logo at the bottom of this, but I worked with the Electric Power Research Institute for a year while I was in the United States, and part of that was determining the costs associated with – the incremental costs associated with produced water treatment, and this also includes well completion as well as the profits derived from capturing a natural gas. And the reason why I

wanted to bring this up is because it doesn't only – these restrictions or these differences do not only pertain specifically to water consumption, which may also be a limiting factor, but also to the costs associated with environmental mitigation. They can, and do vary over time.

So, solutions may be cost-competitive in some regions versus others. So, you'll see here the Marcellus, for example, injection was much more costly than the Barnett, in terms of the incremental costs compared to drilling. So, to keep it – and that's primarily due to the abundance and availability of disposal wells. So, really, these results highlight the importance of better understanding the regional variability for cost and solution, but as well as for impact. So, again, there's a lot of areas in which there can be additional investigation.

The next impact category I'll discuss is a land energy nexus. So, two key areas where space and time matters for the land energy nexus will be covered. First of all, the comparisons between renewable and non-renewable energy – just spatial requirements are actually often very criticized because of the lack of agreement or – and the lack of systematic methodology and data. And in my perspective, this is an area that we really need to address, not only because we do make these broad comparisons, but also because even to get to the point where we compare impact, this is in essence where we start – is developing a first way to actually compare the technologies. The choice of metrics and assumptions about time do have a very large impact on the results, however, so this really needs to be highlighted and recognized.

The next component – well, this is actually confounded by the fact that interregional variability of specific energy types have not really been well investigated. Because of this, we really need to recognize that this can also have an influence on the results – even comparing renewable and non-renewable – but even farther than that, we need to recognize what types of things influence this variability. So, it can certainly be geology – so what is the productivity of wells, operator practice, regulation, existing infrastructure. So, keeping these questions in mind, there are quite a few challenges with this type of work. First of all, the choice of metric – are you looking at a land use intensity? So, a meter squared per megawatt hour, or meter squared per megajoule? Power density – so, this is a method that was – that has really been popularized by Vaclav Smil. This is a watts per square meter. But, we really need to think through the timeframes of the analysis

and the lifespan. So again, the economic lifetime does not necessarily reflect the amount of time that a piece of land requires to actually restore it to the equivalent or reclaim to equivalent capability – so, keeping that in mind. And land quality is certainly different, so these projects are developed across very different landscapes. So again, we need to recognize that and also think through ways we can even start off by defining these spatial requirements and then moving further, to actually start to incorporate the impact. So, this is an area where a lot of work can be done.

My Ph.D. thesis focused on looking specifically at Alberta in the spatial requirements. So, highlighting again the assumptions about lifetime remain a challenge. So, a lot of the time project lifetime is used, but I wanted to again highlight that this is perceived differently by different disciplines. So, Table One shows estimated restoration times. This is mostly illustrative just to make the point. So, if we consider mature peat bogs, for example, they can take on the order of thousands to tens of thousands of years to restore, and again, we don't know how to reclaim them – and the all the way down to agricultural land, where it can take less than five years for such vegetation to regrow. So, these assumptions – and this is not even taking into account that again we quite often use economic lifetime and there's not necessarily anything wrong with either approach – but we do need to recognize the different perspectives from these different disciplines.

Power density is again more a method that was popularized by Vaclav Smil at the University of Manitoba, and so what I did as part of my thesis was to estimate the power density for different energy types based on available data in Alberta. So, in this case – so higher numbers are actually better. So, you want to extract more energy from a square area of land, okay? So, in essence, it with taking all of the different energy types – and that's not necessarily generating electricity, it's more looking at watts as joules per unit time, so it's more of the extraction or the – the extraction of energy. And, what was interesting about the results is that when I included both conventional oil and natural gas, I actually found that some renewables for these specific data were actually found on par with these fossil fuels, which is quite different than what a lot of the previous assessments have shown where renewable energies are actually considered to be much larger, and a lot of this is driven by assumption, so a lot of the time wind power, for example, the whole wind farm is considered rather than the explicit well sites. Again, keep in mind this is a

logarithmic axis, so the size of the bars is reflective of that as well.

So, then we get to the question of, "Well, how do we even start to compare renewable energy in a systematic way that's meaningful?" And the way in which I approached it in my thesis was this notion of equivalency time. So, this is the time for a hectare of land – so, the time that a hectare of land would take to produce the equivalent amount of energy as a hectare producing a finite amount of fossil fuels. And so the proof of concept here is what I developed for my thesis based on Alberta data. But what you'll see here is that renewable energies can become equivalent to fossil energies at time scales of below 50, but certainly below 20 in certain cases – 20 years. So, this again is a proof of concept, okay? So, it's developed specifically based on Alberta data, but certainly data availability and regional variability remain a challenge to get broader conclusions and get a better understanding of what the uncertainty looks like. And keep in mind the natural gas values, for example, reflect conventional gas with a large contribution of low-productivity shallow gas wells. But on the other hand, what I did for this was because it was specifically for Alberta, I included the different transmission options – transmission expansion options that are required to connect the additional wind to the grid. So, certainly a lot of work that still needs to be done to ensure that this can be done – these types of concepts can be developed more broadly for systematic comparison.

So, confounding the factor is the fact that we still don't have a good idea for interregional variability, okay? So, land requirements and intensities vary across regions for some energy categories or technologies, but we don't really understand exactly how or how much. And these are really great questions because it can help inform how to decrease land impacts. Influencing factors can include historical development patterns – so what exists on the landscape, current land use and population settlement patterns, land use lots and regulations, geology – so relating to the productivity of wells, operator practice – how operators may already work towards reducing land impacts, or even increasing productivity, so drilling multiple wells per site, and certainly maturity of the gas development in the region. So, you can imagine that the incremental addition of infilling wells – so, if you're just infilling, it will require less additional infrastructure than an area where you require long access roads to access those areas where wells are to be drilled.

So, we're already observing some of the variability and the factors

across regions in the United States, so this Energy Information Administration cumulative well production shows how the well productivity varies across plays. And this will certainly apply to regions globally, so the other EIA figure shows the regions across the globe where we have assessed the resource estimates and where we have not, but we know that there are a lot of resources – shale resources available, and certainly these types of variabilities will apply to all these different regions – so again, opening up for a lot of questions from a global standpoint.

Of key importance – this is of key importance not only to land, but also to the methods that we discussed with water, and also with emissions – so, what Garvin Heath and the NREL group was talking about in the last webinar. So, this also applies to solutions – to mitigation and control. And the most exciting part of it is that methods are still in their development, so we're still trying to figure out how to do these comparisons based on what data that we have available to us.

So, why does this matter? Well, first of all, it will assist decision-makers in a number of ways. First, to develop ways in which spatial requirements can be compared of renewable and non-renewable energy, and there's a lot of debate around this right now, so it's a great topic to be thinking about. It will also improve the way in which we compare interregional estimates and this can help inform decisions and policies in the future, such that we're not applying results from one area to another and we can actually recognize what the differences are. For firms, better comparisons can inform the public, so we can start debunking some of the myths of what we've developed based on prior data. Spatial – and the data is only improving and becoming more spatial resolved, so this is really exciting for improving these types of analyses. The spatial databases that are developed can actually inform other areas where infrastructure is related to impact, so methane emission, but there's also areas related to pipeline risk assessment. This has become more prominent in the news, looking at areas where there might be risks associated with natural gas pipelines, and from this we can actually start to answer some of these questions. And then also using these results to develop more efficient land use plans, with the other land users in the region.

For governments, we really need some support in terms of determining where – how exactly to form agreement on developing systematic methods, but also meaningful metrics that can lead towards better scenario modeling for multiple land uses in a

region. This can really help inform policy on how to reduce impacts. There are also meaningful links that are formed between policy and impacts, and interregional variability can inform regional land use policies, and then also it provides an understanding for the overall land requirements of infrastructure, and again this is an infrastructure question, so it can lead to more efficient infrastructure planning for the broader levels – cost-savings, for example.

And finally, the last impact category is the climate energy nexus. So, there are two areas where regional variability really matters for mitigation that I will cover. Clearly, there are a lot more, but I will focus on these two specific areas. Greenhouse gas emissions we know very geographically, according to a number of factors, such as available resources, the technology and the use, the vintage of the existing infrastructure, and local environmental variables. The present lifecycle assessment models really need to start to be – to consider these types of questions, particularly as global trade starts to grow from an international perspective. And second, we need to recognize the interregional policy variability and how important it is for our overall ability to achieve emissions reductions from a global, national, and regional perspectives. Climate policies are developed according to a region's political influences particularly, but also resource availability, which is strongly tied to economic development, but then there's also economic development status – so, what are the political priorities of that nation, amongst other factors.

So, liquefied natural gas, export, and greenhouse gas emissions. So, in recent years, we know there's been a large expansion of liquefied natural gas from a trade perspective, and this is in response to market demand. Three natural gas markets have emerged – Asia, Europe, and the Americas, but they have really been evolving, so it's going to be interesting to see what happens. So, this figure was developed by my graduate student, Jeanne Liendo, who compiled all the FERC data over time, but with the recent drops, you can see in 2015, but this has dropped even farther. So, I went on the FERC website yesterday or the day before, and – to show that even the Asian prices have dropped even more. The purpose of this work – this has been led by Adebola Kasumu and we're also working with Vivian Li, who is with me at EPRI, but is now a graduate student at MIT. So, the purpose of our work is to assess the greenhouse gas implications of liquefied natural gas export. In this work, we've included a review of markets, a compilation of U.S. and Canadian lifecycle studies,

and country level – and we've looked at a country level assessment of greenhouse gas emissions per unit electricity delivered, but also emissions displacement scenarios.

And also, when we start to think through these regional effects, it's important to recognize the resource endowments of regions, as well as nations, and these political influences. So, I'm just going to give an example here just of Canada to highlight the importance. So, this is work that I'm doing with several students from the University of Calgary – Elizabeth Romo-Robago, Romaine McLeary, Luke Reidy, but also with Jamal Nazari from Fraser University, and Irene Herremans. It's broader work on energy technology innovation, but I wanted to highlight our review of policies.

So, what this shows in essence – and the emissions reductions are those between 2005 and 2012 – is that the leaders in emissions reductions have applied renewable portfolio standards and coal phase-out, and those have been found to be with a driver – much of the reason of the drive behind these transitions. So, policy matters a lot from a regional perspective, particularly in areas where you have federalism, so there's a large role for the sub-national level to develop and influence policies, and emissions grow, so Alberta – while we have a legislated carbon pricing system, it is based on emissions intensity targets, so we've seen exactly that in terms of the outcome, there is a gross in overall emissions, but a nice decrease in the carbon intensities of development, for example. So, also to recognize that that doesn't necessarily – as expected, it doesn't achieve those emissions reductions, or with the other provinces, it might be too early in the policy implementation to tell exactly what is going to happen with the policies or the success in meeting the renewable targets was not achieved or reported, so it's hard to tell exactly what's happening in some places.

But overall, to highlight, so we still have the same time for Alberta. Alberta does have the climate leadership plan that's proposed in which – and in this plan, they are actually including the reduction policies that have been applied in the leaders in emission reduction. So, certainly this is something that we know also changes over time.

So, policy implications – so, we have a couple of slides left, and then I'm excited to open up for questions. So, policy implications – so, in trade, we know that national and sub-national policies of nations play a large role in emissions reductions. To take a step

back and say, "Okay, at the national level, what should the focus of emissions reductions be?" I just wanted to raise that question again because we certainly know that there are some places where transmission distribution plays a large role in overall emissions of the electric sector, for example. So, I think it's something that we certainly need to discuss, highlight, and think about. At the sub-national level, we know that the governments play a very large role, particularly in aspects or in nations where there is power placed in the sub-national level in developing policy, like we have in Canada, and that's written into our constitution and, of course, plays a large role in terms of what can be done at the sub-national level.

There is a lot of work left to do on methane emissions and natural gas production systems, okay? So, in those results – in those box slots – what we're really seeing is there's a lot of differences that we don't yet understand, confirming the published studies. And there's a large role for regulation and policy in improving that, but also in consistent availability across regions, and that becomes – that became very apparent working with the Canadian data, so there are differences in the emission thresholds for reporting. So, 10 kilotons in British Columbia versus 50 here in Alberta, and 25 for the EPA. So, there's a lot that can be done in terms of making those consistent, and also providing equal levels of aggregation or standardizing the aggregation, or disaggregation that's available in the data.

So, priority areas for government, for example, should include a careful examination of the infrastructure, but we know that we can't apply policies to other countries, and it really matters for the – to remain within the country context and understand the competing political objectives – so economic development versus greenhouse gas reductions, which is a really big challenge in terms of developing overall effective climate policy. We certainly need increased transparency and operational data, and standardization of reporting. For firms, I just want to highlight again that importance for increased transparency and participating in improving this operational data, because having that available to us allows for us analysts externally to actually provide helpful recommendations to you.

The common thread – so, I just gave a pretty broad explanation of the research that I'm covering, and again bringing back to the fact that this is really a presentation about the importance of recognizing interregional variability and differences. So, again

these differences exist in not only the productivity, but also the impacts of energy products – projects, and this includes the effects of federal policies and regional policies, as well as available resources. So, it's on the impact side, but it's also on the opportunity side. The technology assessments that we use – for example, lifecycle assessment and these policies on the broadest level, which are really important in initiating change – they don't transfer very easily to these interregional results, so we need to start thinking through new and mixed methods to actually do this. And this can help translate that information across government levels.

Methods are actually becoming advanced in some areas – for example, water – but certainly there still are some large data gaps, but less so in others – for example, land. And a lot of that is derived from these fundamental disagreements and how necessarily we should approach these questions. But in many respects, that makes it a very relevant area to be working in and to be questioning. The integration of technology assessment with spatiotemporal analysis really opens up these very large, new areas for research, which is very exciting. But we have to recognize, too, that this is only going to improve and become better with software and new datasets, okay? So, as we start to do this, every time I turn around, there's this new dataset that I can use and incorporate within my work where in a collaboration with someone else and answering a new question. So, in many respects, we're – this is a kind of new way to start looking at the world, but there's a lot more that we're going to be able to do as we improve these two aspects. And what I've been finding is that these new methods really uncover a lot of the reason why policy-makers and decision-makers face these different opinions, and this creates challenges, but when we start to uncover the answers through these methods, we can come up with new solutions.

And so, what next? This is the last slide and if you don't get a chance to ask a question, please feel free to follow up with me because I'm looking forward to feedback from all of you who attended. But the path forward – so, from the broadest perspective? We need to start thinking through how to apply these new methods to regions globally, and that way we can understand where scarcity exists, where there are constraints, how operations might be restricted, and to help inform different decisions. We really need to start redefining the conventional approaches we've been applying and being more specific to certain regions – for example, lifecycle assessment – and this way, we can better

examine the temporal and spatial effects. Also, we need to think through how to increase the resolution and the accuracy of current metrics because data in that respect is only improving, so again we're going to start getting more well-defined questions over time. And this evolution of data and the integration of these different mixed methods really helps us develop more robust planning tools so that we can integrate international, federal, state, and provincial policies with what actual impacts occur. Most importantly, I think that we need to embrace so – the rule of parsimony is still really important, so I don't want anyone to think that I don't think that the rule of parsimony is important, but in these cases we really need to embrace the uncertainty, but also the complexity, okay? So, we need to start thinking through how broader policy uncertainty models apply, and how to embrace the complexity and the fact that these questions are not – they do not come out with one number. We need to start thinking through how they do not come up with one number, and how we can better understand why they aren't, and how that can actually help improve our decisions.

So, thank you very much for your time, and I really appreciate your thoughts. I have – I had an acknowledgement slide. I just want to put that up here. This is a series of work with a lot of different collaborators and from a variety of different funding sources, so I just want to give a minute to highlight these, but not to take up too much time because I'm very much looking forward to your questions.

Jill Engel-Cox: Thank you so much for the presentation. So now, we'd like to go to questions. We don't have a whole lot of time, but we do have a few questions already. And please type your questions in the question text box. And even if we don't get to your question, we can go a few minutes over, but if we don't get to your question, we do have a record of that, and Sarah can follow up with you, if the answer is too brief or we don't have time to get these questions. So actually, the first two questions are actually on Slide 8, so Carolyn is going to go to Slide 8. And the simple question is, "What are the dots on Slide 8 conveying?"

Sarah Jordaan: Ha ha. That's a good question. So, thank you for asking that. It's again – to go through this amount of information in a small amount of time is a bit challenging, so I'm really glad that you asked that question. So, the dots refer to the increase in – of water consumption compared to irrigation withdrawals, okay? So, it's a ratio of consumption to withdrawals.

Jill Engel-Cox: Great. The second –

Sarah Jordaan: Or the change. It is not necessarily an increase, but it's a ratio, to show the difference. And it's 2022 with the new estimates compare to the 2005.

Jill Engel-Cox: Excellent. So, the other question related to this slide is, "Why is the consumption data no longer available? And what is the next best alternative source of data for the consumption side?"

Sarah Jordaan: You know, I actually also really appreciate that question. So, the U.S. – yes, I believe it was in 1995 that they stopped actually publishing that data. So, we were quite disappointed because that would have been the best data to use, and now they publish withdrawals. I don't know if that's changed – if there's been a new release. It's 2016 now, so conceivably there could be a new release. But in many respects, these whole notions of water budgets – in my personal perspective – are the most important area that needs to be improved within the water realm, and with that come the availability of data. So, my biggest recommendation in that realm would be for the U.S. government to work to where it's providing that consumption data as well as with the withdrawals. And I also think we need to start working towards the – having these water budget data because again in the case of this analysis, you can see it's an attempt with limited data, and so if we had perfect data, we would be looking specifically at what the impacts are to the actual water budgets. And I like to think that over time, with this – the work that we're doing on data methods with the new satellite imagery that coming on and all these new tools that we have to communicate information, that we might get to the point that we can actually work with better datasets in the future. So, in terms of what is the best substitute, we used what we thought was the best substitute, but again I think in many respects we need to – the best would be to actually have that data available.

Jill Engel-Cox: Great. So speaking with water – the water side of this, we have a question related to that other question. "Are there any plans to include water quality as well as consumption and withdrawal on these analyses? Intensive agriculture has been shown to degrade water quality, nitrate, and other fertilizer runoff at the water shed scale, and shale oil and fracking have their own water quality issues. So, are there any plans to include water quality in these studies?"

Sarah Jordaan: So, right now, I don't – I personally don't have the time and resources, but I'm assuming that question is coming from someone who works in the area, and I certainly would be happy to start working on proposals and ideas with people to do that because again, the – this is one of those areas that if we can actually start to apply some of these regional methods to different impact categories, I think there is so much room to develop methods and new proposals based on these very questions. So, I presently don't have any plans, but one never knows what might happen with funding. *[Laughs]*

Jill Engel-Cox: Great. And I think we have time for one more question. And so, this is on a different topic. "Have you or anyone you know compared to biochar versus BECCS on both time and spatial scales for carbon dioxide removal?

Sarah Jordaan: BECCS? Can you clarify, please?

Jill Engel-Cox: It's not written out in the question. *[Laughs]*

Sarah Jordaan: So, can you ask the question again and I –

Jill Engel-Cox: So, have you or anyone you know compared biochar versus BECCS on both time or spatial scales for carbon dioxide removal?

Sarah Jordaan: So, maybe the idea in that respect is CCS – anyway, so when – so I have not seen such a study. That is the – *[Crosstalk]*

Jill Engel-Cox: BECCS is bio-energy with carbon capture and storage.

Sarah Jordaan: Aha – there we go. I figured it – this must be carbon capture and storage in there somewhere. No, I have not seen such a study, but it does not mean it hasn't exists because I haven't actively researched it, so not to my knowledge.

Jill Engel-Cox: Great. Well, that's all the time we have. And we have an offline question for you, but we'll take that offline. So, thanks to everyone who could attend. A version of these slides – a slightly modified version of these slides will be available on the JISEA website, which is www.JISEA.org – it was also at the beginning – probably in about one to two weeks. So, thanks again for everyone attending, and thanks to Sarah. And then this concludes are webinar. Thank you.

[End of Audio]