[MUSIC PLAYING]

MIKE LIVERMORE: Hi. This is Mike Livermore. And with me today is Deborah Lawrence, a professor of environmental sciences and the director of the program in environmental thought and practice at the University of Virginia. Deborah's research focuses on forests and, in particular, the link between forests and climate change. It's really wonderful to have her as a colleague here at UVA, in part because she's always game to team up with folks in other disciplines across the sciences, humanities, and the social sciences, including law and lawyers like me. So, Deborah, thanks for chatting today.

DEBORAH LAWRENCE: It's good to be here Michael.

MIKE LIVERMORE: So just to get us started, I was curious about how you found your way to your research area. And one way I kind of thought of this question is, did you find your way to science through a love of forests, or did you find your way to forest through a love of science?

DEBORAH LAWRENCE: I think I found my way to science through a love of forests. I was really interested in rainforests. And I was looking for a way to save the rainforest. And I thought by the end of several years of work after my time as an undergraduate, I realized that, for me, science looked like a way to do it. Like, I wanted to study the ecology of rainforests and try to understand constraints on how they function and how people can use them without using them up. And I felt like science was the best way for me to do that.

MIKE LIVERMORE: So it's very kind of-- there's a practical policy component to your interest in the area then.

DEBORAH LAWRENCE: Definitely. And when I say that I came to science through the forest, it's because I thought I was going to run the World Bank. And I just thought I needed a PhD to do that.

MIKE LIVERMORE: In something.

DEBORAH LAWRENCE: Along the way, I became entranced with the science. So that's why I ended up being a professor.

MIKE LIVERMORE: Oh, that's really interesting. I mean, it would have been a good path to run the World Bank too. I would have been happy with you doing that job. But we have you and all the wonderful research you do. So one of your areas I think is really interesting and I believe the framing is really illuminating is the work that you've done discussing under the rubric of food fuels and forests. And we've talked a little bit about this project over the years.

And one of the things that I think is really illuminating about this framing is it clarifies that there are trade offs involved in land use decisions, and that these trade offs have really important implications for kind of governance in the face of climate change. So I was curious how you came to that framing or what it is, maybe just a little bit of background for folks who aren't familiar with it and why you think it's useful.

DEBORAH LAWRENCE: Sure. First, I'll just tell you the way I way I'm framing it is that we basically have one surface of the Earth. And that surface of the Earth can work for us in various ways. And really, fundamentally, you either leave it as nature-- and most of the land that's not already in agriculture is forested. There are also wild grasslands and things like that. But I tend to focus on the forests. And so you leave it be, you leave it as a forest, it actually works for climate mitigation as a forest. Or you can grow food for people. That's that other part, which we've already done and we've done for 10,000 years.

Or you can grow biofuels, which is a whole different approach to climate change, where you would actually take CO2 out of the atmosphere through photosynthesis, and then burn this biomass and, hopefully, sequester the carbon underground for long-term storage. So it's using sort of nature's potential to sequester carbon. And it takes a lot of land. So in terms of climate, those are the three big options you have-- well, food not really being an option. Food, we need food, so that's why it's in there, because we have to have food.

And I'll tell you that I first started thinking about this when I was working in the State Department in 2009 in the run up to Copenhagen. And I was working on the role of forests. And there was another fellow who was a scientist who was working on food security. And we would chat as we walked back and forth between the State Department and USAID, which is quite a long walk. And it just struck us that in the building-- we were both in the State Department. But no one in the building on the food security team was talking to the people who were talking about saving the forest and using forests to save the climate.

And they were kind of, it felt, in opposition. Like, this is two things coming out of the State Department, but no one in that building seemed to be talking to each other. So it was actually many conversations feeling like you can't have a food security framework without also having a forests and climate framework.

MIKE LIVERMORE: Yeah, because there's only one, as you said, there's only one land surface. And if we're using it for forests, that means we're not using it for food, at least some part of it. And part of the backdrop of this, too, again, for folks who aren't as deep into the literature on all of this is as you are, part of the backdrop is that bio-- at least under some scenarios, some kind of planning scenarios on climate change, biofuels and the biofuel carbon capture and storage idea that you've mentioned is a really important component for some folks of how the human societies could manage to keep temperature change at 1.5 and degrees or 2 degrees of change. So maybe we could just explain a little bit about how central that is to some of this modeling and some of this planning.

DEBORAH LAWRENCE: Oh, it is absolutely central. I've never seen a model that goes out to 2100 that doesn't include a lot of what we call negative emissions, meaning that we are actually taking CO2 out of the atmosphere and putting it below ground. So there are no models that I know of that get us there without this kind of sequestration and storage. And right now, because industrial processes are still rather uncertain or they're not really scaling up as much as we'd like, the only ones that the models put in are these biological mechanisms, like biomass burning.

And the idea there is grow a tree or you grow some kind of fuel. And you burn it and create electricity while you're burning it. And then you take the effluent and you capture the CO2 and pump it below ground, where it becomes some kind of cement or something that's inert. And so you get the electricity, which is a win. And you get carbon dioxide taken out of the atmosphere, which is a win. So it looks like a win-win.

The problem is as, I mentioned earlier, it takes a lot of land. So I've seen it in every model that gets us to 1.5. And that's a little bit worrisome to me.

MIKE LIVERMORE: Yeah. I mean, I find, personally, the model the, the whole BECCS idea, what I think is-- which always has struck me as troubling, in the sense that I feel that the scale of BECCS that are in some of the current models are unrealistic is just the economics behind it. Like, I know of a great way to store carbon underground. It's called coal. It's called oil. It's already there. If we just stop-- and we can't seem to stop digging that stuff up and burning it and putting CO2 into the atmosphere.

And so given that political and economic reality, the idea that we would then devote huge swaths of land, as you mentioned, and then somehow finance the refining of biofuels and then the indefinite storage of carbon underground in air form, it's kind of unstable, difficult to keep underground, and all that. It just has always struck me as radically implausible. And so that it's when we include it in a model of what the world what the world needs to do to get to 1.5 degrees or key below 1.5 degrees, it just strikes me as like, yeah, we could also put in the model that the fairy godmother will come and take all the carbon dioxide away. But it's just not realistic.

DEBORAH LAWRENCE: Yeah, exactly. And in fact, there is a fairy godmother out there. It's called DAC, which is Direct Air Capture. And that's the other fairy godmother that might come. And you know, funny, like in 200 years, it's going to be here, right? We are going to have DAC, maybe even in 30 or 40. I don't really know. I'm just not willing to bank on when it's going to arrive. And so, similarly, I feel like we have to push the conversation back towards mitigation, meaning just eliminating our emissions.

And I said before, I've never seen a model that doesn't include these negative emissions, meaning mostly BECCS. There is one, and it's a straight line down to 0. That's the one model. It's just that it's so hard that we tend to say, well, let's try something else. Let's go a little slower. And that's, yeah--

MIKE LIVERMORE: Let's imagine the fairy godmother. So even with the DAC-- and so I take it, like in a couple of years, we'll have the technology to do direct air capture. And this is what at least-- correct me if I'm wrong. This is where you've got like some big industrial facility. You're not growing plants and using the kind of natural photosynthesis process to suck carbon into the atmosphere. You're using a chemical or some industrial process to suck carbon out of the atmosphere and then stored underground.

But like, who pays to run these things? I still just don't understand the economics of them.

DEBORAH LAWRENCE: Well, yes. I mean, it's very, very, very expensive right now. The only work that I know of is something like $700 or $800 a ton. And that's a very high carbon price. So yeah, like later--

MIKE LIVERMORE: And who's going to pay for it? Who's going to pay for it? It's tricky. One thing I think is, again, like a little sciency back around here that I think is just fascinating is carbon dioxide, there's not all that much carbon dioxide in the atmosphere. I don't think people quite internalize this when we talk about 300 400 parts per million. I.E. parts per million, there's not a lot of them. It's tiny. And so it's amazing that a tree can actually soak such a tiny amount, such a scarce product in the atmosphere and then enrich it and enrich it and enrich it and turn it into a trunk. I mean, what a magical process.

DEBORAH LAWRENCE: It is absolutely magical. I'm so glad you used that word. Photosynthesis is amazing. And it's just amazing. And it means that this plant is taking the energy from the sun and using that energy to turn air into mass, like air into a thing. It's air. The CO_2 is in the air, and then it becomes a thing that you could knock your head on. That's just amazing. So it's miraculous. And we'll be really lucky if we can get something else that does something with such a very difficult starting point, which is 400 parts per million. The inertia there, when you're trying to capture that or scrape it out of the atmosphere is just very hard.

MIKE LIVERMORE: It's tough. And it just seems like the energy requirements would be vast.

DEBORAH LAWRENCE: They are, yeah.

MIKE LIVERMORE: And someone's going to-- I was just, again, think in terms of brass tacks, like, who's going to write the checks for these things? And it's a global public good. So whoever is running that these direct air capture devices, in some point in the future, is going to be producing a global public good. And so the political regime that's going to generate that just is, it doesn't seem obvious to me how that's going to come about.

DEBORAH LAWRENCE: I guess it's those of us who want to keep eating meat using steel. There's the possibility that we would-- but then it's not a real net gain, right? If we're actually using that process to offset things that we want to keep doing, that's one way it gets paid for, but then it's not moving us closer to our goal of reducing CO_2 in the atmosphere.

MIKE LIVERMORE: Right. And even then-- just to be not too much of a downer, which can happen easily in climate conversations. But someone would still have to tax those entities, so, say, a steel refiner or steel manufacturer or-- hopefully, we're not going to be using fossil fuels in 200 years. But whoever is putting out CO_2, some policy regime would have to be put in place that would require them to pay for these, essentially, what would amount to be offsets.

But yeah, moving on from the BECCS stuff-- I mean, we can return to that. I do think it's a hugely interesting kind of part of this conversation and will remain part of the conversation, likely for a number of years. But you've thought a lot about different ways of thinking about forests and climate change. And so one that I think many people are familiar with is forests as sinks basically. It's a mechanism to store CO_2. And so one of the concerns with deforestation is that we're releasing these carbon stores, which is increasing global CO_2 levels.

But you've done a lot of-- so that's like the big part of the conversation on forest and climate change. And then, of course, you've looked into this trade between forests and fuels and food. And that's another kind of part of the climate conversation. But it's even is richer and more nuanced than that. So there's a lot going on. Forests are complex things. So one of the things that you've looked at recently is the other effects that occur, other kind of feedback between climate and forests at a local or regional level. So what are some of the mechanisms for forests to interact with other climate variables like rainfall or temperature and that kind of thing?

DEBORAH LAWRENCE: Yeah, thanks for pushing us over in this direction because I think of forests as truly miraculous. They do so much for us. And they do so much for us on climate . And as you were saying, there's that whole piece that is the global mitigation piece. What are they doing to keep CO_2 levels in the atmosphere down? They take up a ton of carbon every year. In fact, they take up probably 25% to 30% of everything we put up goes into a forest somewhere and is stored away. Without forests, we would already be way, way hotter. So they are doing a huge service that way at the global scale.

And then in terms of the local scale, which turns out to have global ramifications, forests do so much to regulate climate without CO_2. So there's the whole CO_2 thing, which is a greenhouse effect that warms our planet. But then forests actually alter the energy balance right near them in a way that cools locally. And some of that cooling if it's big enough can actually cool globally.

So what am I talking about? I'm talking about, you think about a tropical forest. It's sitting right there at the equator. And it's absorbing so much solar radiation. And that's like the huge amount of energy coming into the Earth that should just warm it right up. So the forest can either turn it into heat that you would feel, and it would be hot. Or you turned it into latent heat, which is actually changing water into vapor, so that those photosynthesis leaves, the leaves that are doing all that magical photosynthesis, are also the site where liquid water becomes water vapor.

That process is a cooling reaction. So liquid to vapor is a cooling reaction, so you get an actual cooling of the air over the canopy of the forest. So that's amazing. It's like having an air conditioner right outside your back door. The other thing that forests do is that they are a rough surface. So they sort of stick up into the atmosphere, if you think of it as like a bunch of fingers sticking up, and that the wind, as it moves across that surface, bounces around and creates turbulence. and ends up shooting some of the air parcels up higher into the atmosphere.

So you can actually remove some of the heated air that what just happens at the surface. You push it up into the atmosphere, take it away from the surface. Well, if it's up there, it's not like it disappeared magically, that the heat is up there. But it's not where we live. It's not down on the surface. So roughness, evapotranspiration, these are physical things that the forests do that actually cool the planet. They cool locally and they can cool globally.

The last thing they do is, of course, when they're doing that business with cycling water, using all this energy to cycle water, they can promote their own cloud cover, which can change albedo, meaning that you suddenly are reflecting light back into space. And they can create clouds that will produce rainfall. So they have so many climate-- they do so much to climate. They're just really an amazing, amazing ecosystem.

MIKE LIVERMORE: Yeah, that's fascinating. And it shows you how complex and dynamic the climate the climate system is once you start to take into account some of these biological processes. Given that all of the forests that we have on the planet, how much of a cooling effect are we talking about from this kind of water vapor effect?

DEBORAH LAWRENCE: Well, I'm just like back of the envelope. If you added it all up, would you have a degree-- no, not a degree. I'm looking. I have some data in front of me that would suggest it could be half a degree. No, that's too much too. But it's some cooling. It's some cooling for sure.

MIKE LIVERMORE: That's a lot. And that's the other thing I think is important for folks who are maybe sometimes outside of the climate debate, is it's all about these slivers. And they all add up basically. There's a couple of big chunks, but then a lot of it is identifying. And a half a degree or quarter of a degree is huge in the scale of things.

DEBORAH LAWRENCE: Yeah. And that was just a couple of them, right? Evapotranspiration. Then if you add the roughness effect and you add these other weird stuff that happens with chemicals that are emitted by the trees, themselves, you could get up to a pretty significant amount of cooling for the planet, if it gets up beyond a half a degree, for sure.

MIKE LIVERMORE: Now, another question I had just about the second one, with the rough circumference and the wind turbulence and kind of shooting some of the hot air rises, but making it rise faster basically due to the turbulence--

DEBORAH LAWRENCE: Or making it leave the surface. Like, the idea of getting it away from where we live, and so it goes up to the top of the atmosphere.

MIKE LIVERMORE: Right. Now, is that a problem in any way, that the upper atmosphere would be-- I, mean it's not a problem in the sense that we have forests already. So we know then in equilibrium, it's worked out OK so far, right? But on a warming planet, is that--

DEBORAH LAWRENCE: So don't worry, because you know what happens at the end?

MIKE LIVERMORE: It's going to mix--

DEBORAH LAWRENCE: No, there's a rainstorm, so that then the air parcels move out away from the tropics slightly. They start to fall generally just because this is what happens, maybe because they're cooling, and rainfall happens. So then that transformation that we had earlier, where it was water to vapor, it goes vapor to water. And so it's your interest in free energy and stuff. There's an energy balance that occurs right. But it's spatially disparate right so that you can have a cooling at the surface, and then you'll have, later, it does warm up the atmosphere. But it's going to, eventually, the balance will be restored because rainfall happens.

MIKE LIVERMORE: Because you'll have this rainfall. And then and then that relates to the cloud cover as another kind of factor for forests. So maybe just, again, to explain for the audience the importance of clouds in climate models, which, again, are not obvious, but are hugely important.

DEBORAH LAWRENCE: Yeah, well here's-- you know how we have the surface of the Earth and I said there's three options, food, fuel, forest? There's also sort of two options for energy. One is to hit the planet and warm it up. And the other is to hit something else and be reflected back into space. And we are interested in things that would reflect back to space. And thew things we have to work with are ice, air pollution, sulfate aerosols, and clouds, and crops, and deserts. So those are the tools we have to send energy back into space, if we're trying to think about how do we manage our climate.

And clouds are really important and very hard to put into the models because they exist at smaller scales than our models work. So 100 kilometers across is maybe the grid cell in these global climate models. And yet, clouds occur on the scale of hundreds of meters or tens of meters. So it's very hard to get the clouds to work right. But if you just look at an image of the Earth from space, you can see how important clouds, like, you see them. They're there. They move around. But they're definitely there, and so they're definitely affecting our climate system.

And whether we have a way to-- well, there's two options for clouds, too, like there's good clouds and bad clouds. And for humans, we don't really want clouds that are low and giving us a cool day. But the fact is low clouds give us a cool day and a cool planet. High clouds actually don't help us too much. High clouds end up just trapping heat and not giving us a lot of-- they don't cool us very much. So good clouds, bad clouds, I'm not sure exactly what kind forests make except that they're down there close. So I'm assuming that they're making low clouds that will actually reflect back to space.

MIKE LIVERMORE: Yeah, the cloud thing is such an important part of the-- and water vapor in the atmosphere, in general, because that has greenhouse--

DEBORAH LAWRENCE: A huge greenhouse aspect, yeah.

MIKE LIVERMORE: Right. And these are just all things that are very difficult to model. I mean, one of the questions I wanted to get to at some point-- and maybe this would be a good time-- is the role of modeling in inclement but kind of, more specifically, the role of modeling in studying the dynamics of climate and forests. So a lot of your research, I take it, is working with these models. And what does that mean to work with a model? Sometimes we talk about-- I hear talk of experiments with models, which I think is interesting because I usually think of experiments as you do in a lab or maybe you get--

DEBORAH LAWRENCE: But imagine if the Earth is your study system. How else would you do the experiment? So it's pretty neat. In my world, I would never alter anything except the land surface. So if you think about a climate model, there's the land. There's oceans. There's, perhaps, ice dynamics. There's the atmosphere. So I've just given you maybe five big giant buckets. I'm trying to think if there's more. Each one of those has so much going on right, so many connections between-- they actually model a column of air that's from the surface of the ocean all the way up to the top of the atmosphere.

They also do the ocean and down. They do the land and down. So everything is very complicated. I would never change anything in my experiments except the land surface. My interest is saying something like, well, what if we actually avoided deforestation for the next 30 years? Or what if we actually added forests where they used to be? If we put them back, what kind of climate system would we get? How would that help locally and how would that help globally? And of course, deeper questions like, well, could we do that and still feed everybody?

So I only change the surface. There are other people who might want to understand dynamics in the atmosphere who would change the way the atmosphere works in order to understand it better. I just go with whatever the default atmosphere is. I don't ever adjust any of that.

MIKE LIVERMORE: Right. So that's and that's a lot of the work in this area where folks kind of take particular domains, and then they're going to-- and I think we could even maybe even explain this a little bit, what it means to manipulate or experiment on these models. So a model here, correct me if I'm wrong, but what I take those to be are essentially mathematical representations of physical quantities that we're interested in.

DEBORAH LAWRENCE: Yeah.

MIKE LIVERMORE: And so they're defined by sets of relationships. And in these models of the climate system that have all of the dynamics that you're describing between the land and the water and the atmosphere and the atmosphere at different altitudes and chemical mixtures happening and all of this, that you have an equation. Say, let's pick out one part of one equation in the model. But it would be the relationship between-- I don't know. I mean, a classic one would be CO_2 and the radiative forcing.

But what would be maybe a simpler one for us to understand that would be like one equation in the vast system of equations that is used to model the climate?

DEBORAH LAWRENCE: Well, for the ones that we were talking about, the one little specific equation that really, really matters, is how evapotranspiration responds to an increase in temperature, so like at the leaf surface. And in fact, I think, for the most part, these models, a lot of them model an entire grid cell, so like 100 kilometers, as one leaf. It's one giant leaf interacting with the atmosphere, which sounds strange, but that's just how they do it.

And that response, in terms of how much evapotranspiration is occurring, it's like the difference between heating up that grid cell on the surface or not heating it up, changing it. So that's very important for future climate. And that's a very-- like trying to figure out how to make that how to parameterize that equation, how much energy wil go into water vapor is just, that's an important part.

MIKE LIVERMORE: So again, just to ask the silly, naive questions to see if I'm understanding, so one is when we talk about these grid cells, right? So here we have, obviously, the Earth, and we could look at different resolutions of the Earth. So folks are familiar with latitude and longitude lines. And you can imagine dividing the whole planet into a bunch of little squares, and then they could be bigger or smaller. And the bigger they are, the simpler the model is and the more computationally intractable, presumably, it is. And the smaller the grids, the more difficult it gets.

And these grids-- again, just correct me if I'm measuring this incorrectly-- but they really are ultimately instantiated into a mathematical model. So we can say grid whatever, J, the inputs and outputs of grid J are going to be affected by the adjacent grids. It's all spatially realized.

DEBORAH LAWRENCE: And adjacent in three dimensions, yeah.

MIKE LIVERMORE: In three dimensions. OK, so it's cubes, actually.

DEBORAH LAWRENCE: Yep, it's cubes. And they keep track. They keep track of energy. They keep track of mass, so particles and gases, but also energy. Like, they actually track all of that.

MIKE LIVERMORE: And so what's happening is we define one of these formulas. And we say, OK, we're going to be looking at the evapotranspiration formula. And so what we say is, OK, the inputs into the formula are energy, water, whatever else goes in there.

DEBORAH LAWRENCE: Something about the leaf, what kind of leaf it is.

MIKE LIVERMORE: What kind of leaf it is, that's going to define the form. You're right. Yep, that's in there. That's going to tell us how this all relates. And then the outputs are going to be essentially energy, mass, or energy, mass, in terms of water, maybe some other things, right? And then what we have is this huge-- I mean, I don't know how many equations must be in these models, just fast--

DEBORAH LAWRENCE: Millions and millions of lines of code.

MIKE LIVERMORE: Millions and millions of lines of code where you have inputs, outputs, inputs outputs, inputs, outputs.

DEBORAH LAWRENCE: And you have to order it, like what goes first that sometimes matters. Which do which do we balance first, mass or energy? And do we do we transfer vertically first or horizontally? You know, it's mind boggling. And that's why I don't even-- I just ask someone else to change the land surface for me.

MIKE LIVERMORE: This is what graduate students are for.

DEBORAH LAWRENCE: But no, but even that, it's like even the land surface, you say I want to do this on the land, it's 1,000 decisions to how does that happen. What's the rate at which you would change the forest? How fast is it going to grow? What are the rules for where are you going to put the next piece of forest? It's really quite complicated to imagine how you put forests all over the globe.

MIKE LIVERMORE: Do this, right? Absolutely. And then we have-- and just to kind of close the loop on this. So the system of equations is so vast and so complex and so interwoven that you don't solve a question like, what are the consequences of changing the amount of surface area devoted to a particular kind of forest? You can't solve that analytically. You can't sit down and do the algebra to identify the meta relationship between forest cover and global average temperatures or something like that. Although, I guess, I don't even know if that's even theoretically possible. But it's not plausible as a strategy.

DEBORAH LAWRENCE: That's why you have the model.

MIKE LIVERMORE: Right. So then what you could do is you just test it in the model. So that's the experiment right is we've got this huge model of the planet, and it's essentially a toy version of the planet. And we're going to see what happens when we perturb this, that, or the other thing.

DEBORAH LAWRENCE: Yep. And you have to, of course, compare it to something. So you run some run the model in some state, and then you change the state. And so we never can actually say, well, how did it stack up to reality? I mean, we can a little bit, sometimes. We try to see how well the model can represent today, the current land, the current climate. And that's a big job is trying to figure out how well the models work. But when you're actually running experiments, you don't also check to see whether the model works. You assume it's working OK, and then you do your experiment.

MIKE LIVERMORE: Right. And then, ultimately, what we-- I guess the way we validate these models is, one, based on our best-- to the extent to which the models represent our best understanding of the underlying physical processes, which we can do real world experiments on.

DEBORAH LAWRENCE: Yeah. People contribute to the development of models by doing small scale experiments that give us some idea about what those numbers should be.

MIKE LIVERMORE: Right, some process. And then, yeah, we can compare what the model-- we could back predict, basically.

DEBORAH LAWRENCE: And we also have some great tools now with remote sensing, where you can remotely sense, say, net primary productivity. And you can do that for the entire globe for a year, and you can get a number from space. And then you can compare that to what you get from the model. And you can compare it in space. So you can see, did they get Africa right? Did we get South America? Did we get Asia? Did we get the US? So you can actually-- we have some pretty good tools that help us feel confident that the models are capturing what we want them to capture.

And in terms of sort of emergent properties, like the climate system or like the temperature of the planet, the models have been doing a very good job. If you think about James Hansen in 1988 predicting what would happen with his little, rudimentary model, one of the first, 22 years later, those predictions are looking very good. They were very good.

MIKE LIVERMORE: Yeah. And I think that it's one of this is one of the things that sometimes folks who are not enthusiastic about climate policy will say, well, these are just models, et cetera, et cetera. And I think that, well, a couple of things, like what would the alternative b4 if you're interested in studying this area and understanding it? And of course, we use models all the time in the sciences. This isn't unique to climate science. The world of science is all about models.

So yeah, so none of this is to-- I mean, my sense is that there's kind of a people go through a learning process when they learn about the role of models in our understanding of climate science, which is some folks, naively, are very confident in the enterprise, and others are naively skeptical. As folks learn more about it, they realize how difficult the challenge is and some of the limitations in our ability to understand some of these complex systems.

And then as you go further into it, you realize the enormous amount of intellectual energy that's been invested in this enterprise and the really serious science that goes into the kind of parameter-ization of the pieces of the model and how the models all fit together. And then you start to say, well, you know, this actually represents the aggregation of a huge amount of real knowledge about the world.

DEBORAH LAWRENCE: I think that's true. I mean, there are still some things that keep me up at night. And one of them is that the feedbacks are not always perfect. So for me, for forests, forests will do well in a world of high CO_2 because they love CO_2. That's their that's what they use to create their own food. So there's that reality. And if it's not tempered by the fact that it will be getting much hotter and, perhaps, drier and there will be disease outbreaks and fires, if it's not tempered by that, if those factors aren't in the model, we could get a rosy view of the future that's not very accurate.

So I worry about the ability to put in certain feedbacks that biologists have known about forever. And they're hard, like figuring out when pests are going to occur or diseases or fires. These are harder to get in our models, so I worry about them. The other thing I worry about in a big, big way is that-- and this is more of a problem for the integrated assessment models that provide the emissions trajectories that we include in our climate models. So the integrated assessment models give us a storyline. That gives us an energy future. That gives us emissions. And then we plug that into a climate model and it tells us what's going to happen.

But there's no feedback on the economy if the climate system gets out of whack. So that worries me because you can't imagine it just going forward based on some storyline if there's no feedback from a crazy climate in the future. So I worry about that. And of course, the other thing I really worry about is that these models assume kind of infinite economic growth. And that doesn't seem realistic to me either.

MIKE LIVERMORE: And it's interesting. I've done a couple of papers in this area. But the economic growth assumption, there's kind of two pieces to it. One is the kind of maybe standard interpretation as well, we can kind of grow our way out of any problem and technological development will continue indefinitely. And people in the future will be kind of arbitrarily wealthier than people today, that kind of idea. And that is kind of rosy, in a way, and maybe overly optimistic.

And then there's a kind of flip side to that, which I think is interesting as well, which is it's actually slightly optimistic, but in a less optimistic way. So if we imagine a future where we don't take serious steps to limit greenhouse gas emissions, we don't engage in negative emissions in any serious way, and it's all kind of lame and inadequate. And we get to 3.5, 4 degree, 4.5 degree temperature world, I find it extremely implausible.

Let's just say this. I think there are very good reasons to be concerned that, under such a world, economic growth will not continue at pace.

DEBORAH LAWRENCE: Exactly.

MIKE LIVERMORE: And now there's kind of two dynamics there. So one is that will have huge harmful consequences for human development if we slow down broadly understood economic growth. And of course, it's just because there's a question of economic growth and what are we growing in. Because economic growth can mean more fossil fuels that we're burning or it could mean more sophisticated video games that have lower energy draw. I mean, there's different things that we could do with our energies.

But if we get into a world where the temperature change is really substantial and we're having really severe climactic disruptions, then that's obviously going to feed back into the economy and the political systems. That's bad for human well-being. But it might actually mean that there's a kind of a limit on how bad the climate, itself, could get. Because, ultimately, the idea being that we kind of shut down the engine of the economy, and that means we shut down the engine of emissions over kind of a sufficiently long time scale. Now, that is terrible for human development, but maybe puts a limit on how bad we could actually make things in the climate.

DEBORAH LAWRENCE: I hate to tell you that actually that is not-- if it's going to be 3 or 4 degrees, that we have already put so much carbon dioxide in the atmosphere that we will not see a change in our climate system for thousands and thousands and thousands and thousands of years.

MIKE LIVERMORE: So there's a lag problem, that's right. That's a very important part of this.

DEBORAH LAWRENCE: And once it's in the atmosphere, it's there. It just doesn't go anywhere.

MIKE LIVERMORE: That's right. So this is huge right. So this is another thing that folks, to some degree, understand. But even if we stop emitting today or stop emitting suddenly in 50 years or 100 years, we will already have committed ourselves to a huge amount of warming. I think that the scenario that I'm kind of talking about is an extreme scenario where people are like 6, 7, 8 degrees of temperature change or something like that. And I just think, well, by that point, we will have destroyed our economy at 4 degrees.

And so 8 degrees we probably collectively lack the capacity to actually screw things up that badly. But 4 degrees, we should--

DEBORAH LAWRENCE: It's pretty bad.

MIKE LIVERMORE: Hasten to add is terrible. It's just beyond terrible.

DEBORAH LAWRENCE: Well, let's talk about what 1 degrees is. So 1 degree is not exactly a walk in the park. If you think about the number of billion disasters we've had this year, 1.5 degrees and the difference between 1.5 and 2, it's striking. So I don't even want to talk about 3.5 or 4.

MIKE LIVERMORE: Exactly.

DEBORAH LAWRENCE: It's overwhelming.

MIKE LIVERMORE: And I tell my students this in environmental law classes, when folks get kind of-- which can happen-- get frustrated with the reality political reality and what's being done. And I say, well, it's very important to avoid kind of non-marginal thinking in this. So the situation is not if we go over-- it's always lost if we go for 1.5. It's not a good idea to go for 1.5. But the difference between 1.5 and 2 is way bigger and more important than the difference between 1 and 1.5.

And the difference between 2 and 2.5 is way bigger and more important than the difference between 1.5 and 2 and the difference between 2.5 and 3. And it kind of keeps-- so it's this weird situation where the worse of a world that we find ourselves in, the more important, retroactively, all of the successful efforts at greenhouse gas emissions will have turned out to have been.

DEBORAH LAWRENCE: Yep, which means there's just, like, everyone has a role to play. There's so much to do. And every tenth of a degree matters. And so no one should think that any effort is not worth something.

MIKE LIVERMORE: Right. I completely agree with you. I think that's an important message. So on that front, you have another paper that I took a look at that has to do with land use measures to mitigate climate change, where you look at the country level. It looked like a really big study with a bunch of other co-authors. And you're looking at what can be done through land use changes to mitigate climate change. So what were some of the policies that you were looking at there, and how big of a bite were they? And what was interesting things that you learned in that work?

DEBORAH LAWRENCE: Well, if you think about what the land can do, there are a few buckets. But they really come down to there's a forest, a whole big bunch of forest operations you can do. There's a bunch of agricultural. So you either work in agriculture or you can work in forests and natural ecosystems. And within forests, there are forest and natural. There are three types of activities. You can either restore, you can protect, or you can manage. So protect means you keep it and you try to keep all the carbon that is stored in that forest or in that mangrove or in that peat swamp.

Restore means you've got an old converted piece of forest that's no longer forest. It maybe was crops, and it's now degraded. And you restore the forest on it. You grow it back. And then manages, we need to have wood products, so we take timber out of forests. Can we do that better? It turns out we can. So there is a manage component. And similarly, with agriculture, there is no restore. We don't undo agriculture. But you could manage. You can manage carbon storage. You could have more carbon going into the soil. You can manage the other non-CO2 gases that come with agriculture from fertilizers and from livestock. So livestock is methane. And fertilizers give us a nitrous oxide. And both of those are strong greenhouse gases. So those are the kind of big buckets, in agriculture, in forests.

And then there's also the weird, like BECCS. There's that Bioenergy Carbon Capture and Storage. Oh, but there's a whole other part I forgot. There's also the demand side, so meaning like what you and I do. And what if we all did things differently, in terms of our demand on the land? Particularly, it means eating a more sustainable diet, so less meat consumption, which translates to all that methane, and less food waste. And it's like something that everyone can do.

And it turns out that when you look at it, it's not trivial across the globe to eat differently and to avoid food waste. So when you look at all three of those things-- so the demand side, meaning what you and I do every day, and then the forest sector, and then agriculture-- together, you can get about somewhere between 8 and 13 gigatons of CO2. What does that mean? Well our current emissions are 40, maybe 35 gigatons of CO2 globally, plus about, I don't know, 10 more from the non-CO2 gases. So 8 to 13 divided by 40, it's not trivial. Yeah.

So that's kind of hopeful. It means that we can actually do something right now that doesn't require a lot of technology. Often, these are solutions that are troublesome in various ways because we have to make them happen. But it's not as if we don't know what to do.

MIKE LIVERMORE: Yeah, there's not a technological impediment.

DEBORAH LAWRENCE: Right. We're not waiting for some new technology like DAC or BECCS. So yeah, it's pretty interesting. And when you look at those big buckets, it turns out that the natural systems, dealing with natural systems, is a big chunk, the biggest chunk. And it's probably about 50% of what we can do. And then a third of it is in agriculture. And then the is the remaining 10% is what you and I can do with our demand.

MIKE LIVERMORE: So a lot of it is actually managing natural systems, forests and restoration. And one of the things I think is folks who, again, work in this space focused on, I think for good reason, is what are sometimes referred to as co-benefits. So a co-benefit of reducing coal consumption is that we're no longer producing particulate matter. Particulate matter causes all kinds of serious health problems, including death. And so we're saving lives at the same time as we're reducing greenhouse gas emissions.

And I would assume, at least with respect to the forests, that forest restoration, forest protection, and forest management, in addition to the climate benefits, would come with co-benefits as well.

DEBORAH LAWRENCE: Absolutely. So that first part of our conversation when we talked about all those physical things that the forests do to stabilize climate nearby-- the cooling, the air conditioner effect-- it's huge. Stabilizing your rainfall regime, that's a big deal. That's a big deal for agriculture is to have a stable climate and a stable rainfall regime. So there's climate effects that are local that would be easily considered part of-- well, they're like mitigating climate, so they're actually stabilizing climate. But they also could be in the bucket of adaptation because they're going to minimize all the extreme temperatures that those places would otherwise feel without the forest nearby.

The other thing forests are really good for is stabilizing water, like preventing flooding, keeping reservoirs at a stable level, keeping river levels stable, just making less variable, making our water flows less variable. So that's actually pretty important as well. I think the water benefits and the local climate benefits are huge. And of course, there's biodiversity, right? How about pollinators? Does agriculture want pollinators? Yes.

MIKE LIVERMORE: Right, water purification, that kind of thing. So one thing that I would be interested in-- and I don't know if you've done work on this or other people who are working on this is just exactly in what you were just saying. As climate change sets in and becomes more serious, which, again, we've already locked ourselves into some amount of it, local jurisdictions will have an incentive to use forests and other natural landscapes as an adaptation strategy, that part of what they will just naturally do based on their own self-interest, putting aside any global benefit, just for their own reasons, forests and other natural landscapes present adaptation advantages.

In the course of these local jurisdictions pursuing this type of adaptation, they will actually generate a global public good, in terms of greenhouse gas emissions.

DEBORAH LAWRENCE: Absolutely.

MIKE LIVERMORE: And so that's a hopeful story, in a way as a negative feedback loop, a dampening feedback loop in the system as human society is responding to climate change in a way that will actually reduce the ultimate downside of climate change going forward.

DEBORAH LAWRENCE: And there's also, I think, a positive cycle as well, which is that a good chunk of the places where we can put forests turn out to be in urban areas. And if you put forests in urban areas, you can also address some of the climate inequities that exist. So people who have a heavy energy burden, they are already in a city where it's hotter than it is outside of the city, so they face a steeper rise in temperatures and they have less capacity to pay. So putting trees in cities is really, really beneficial on so many levels.

MIKE LIVERMORE: Yeah. I mean, just as someone who's lived in cities and lived in places with lots of trees, certainly it is always such a wonderful thing to have trees in your direct physical environment. And that's something that has climate benefits and also psychological benefits.

DEBORAH LAWRENCE: Absolutely.

MIKE LIVERMORE: Final question for you-- and thanks so much for devoting the time to chat today. But I thought I would just take the opportunity to ask a broader question about the value of interdisciplinary study for an environmental scientists like yourself. This is something that I know that you've engaged in quite a bit. And I'd just be curious to hear your thoughts on what you benefit out of this as a scholar, and why do you think this is an important domain for interdisciplinary study, or what are some of the important links that can be made here that have either important policy payoffs or important intellectual payoffs?

DEBORAH LAWRENCE: If I may, I'd like to start with just a quick story sure, which is that when I started working on the edge of the rainforest trying to understand the causes and consequences of deforestation, I monitored the rate at which these farmers in Indonesia were cutting primary forest versus reusing secondary forest. So their whole system was a cyclical system where the forest grows, you cut it down, you burn it, you grow rice, then you let the forest come back. You cut it down, you burn it, you grow rice. So it's a many year cycle.

And they can do that pretty well if they've got 20 years. But then suddenly I noticed that people were cutting much more primary forest than they had been in the past. So it used to be 5% or 10% of the people were cutting primary forest and 90% were cutting secondary. And it ticked up incredibly. So suddenly, it's 40% or 50% cutting primary forest. And I asked them why they were cutting the forest down because I knew from my studies that the soils were fine. There was nothing that had changed. The rice yields were not going down.

So my ecologist head was very confused. But my interdisciplinary heart said, just ask them why they're cutting them down. And the answer was, oh, well, there's an oil palm plantation coming. And this is how we establish land tenure, we cut the forest and we plant rubber. We plant rubber trees. If we plant a tree, we get to have some rights. If we don't plant a tree, they do not acknowledge our rights. So how can I have understood that situation based only on the parameters that I measure, which was how much phosphorus was in the soil to support a rice crop?

My answer was inadequate to the question. And the only way I could really answer the question was to try to understand why they didn't have rights in the first place or how does a tree establish a right? And is that going to stand up in the long run? And I'll just finish the story by saying that it did stand up in the long run. That was all 20 years ago or more. Those people planted a lot of rubber. And they went from being rather poor, sort of [INAUDIBLE] agriculturalists who are just making enough to live on, to importing labor from other towns and villages because they have so much rubber that they don't know what to do with it.

And it completely changed the dynamic of their negotiations with the oil palm company. They were still in negotiations in 2011. They were going to get a much better deal because they had done what they did. So it's very interesting and the kind of thing you would only want to study with a bunch of people who a lot more than any one person can.

MIKE LIVERMORE: Yeah, that's a fascinating story. And there's so many interesting dynamics there, in terms of the interdisciplinary element and just the lesson about legal design, understanding human behavior and how rational people act and respond to incentives, even if they're initially hard to understand. And it's a story of development, which is a good story. And it's also a story about deforestation, which is a bad story. And so it really is a great microcosm of all the challenges.

DEBORAH LAWRENCE: And let me just tell you one more little thing. When I was there, they were there were people who were coming to the villages to try to talk to them about not selling to the oil palm plantations. And my feeling was-- and they were using arguments like either save the orangutan, which is not a very persuasive argument, or save your water, which is more persuasive.

But I just I ended up leaving feeling like what they really wanted was a bunch of lawyers. I think they all needed better representation and they needed better knowledge of their own laws. So I found myself saying things like, do you understand that the 25-year concession has an automatic renewal for another 25 years, and then a potential renewal for another 25 years? So this is a three generation decision you're about to make. And so I felt like they needed lawyers. They needed lawyers more than they needed ecologists. That's really what I ended up feeling, that they just needed to know better what was going on and what were the implications of these contracts they were getting into.

MIKE LIVERMORE: Right. I mean, I'm certainly a big advocate of people having more lawyers. And ultimately, there's a question of the design of the land tenure system and does it make any-- I mean, under some circumstances, it makes perfect sense to allocate land rights to people who make certain transformations to the land that we want to make. But then the problem is when those get locked in, it leads people to make transformations to the land that are not socially beneficial in order to acquire the same rights. And so we have to think very carefully and update those systems when circumstances change, which we're very bad at doing here and elsewhere around the world. And so that's another--

DEBORAH LAWRENCE: Oh, I wish they had just acknowledged that people had a right to that forest so they wouldn't have had to deforest it in the first place. That would have been great.

MIKE LIVERMORE: That would have been the first best, right.

DEBORAH LAWRENCE: Much better.

MIKE LIVERMORE: Yeah. So good, well Thanks so much for chatting with me. This has been a super interesting conversation.

DEBORAH LAWRENCE: Yes. Thank you. This is really fun.

[MUSIC PLAYING]