**TRANSCRIPT**
**Environmental Insights**
**Guest:** Daniel Jacob
**Record Date:** August 22, 2022
**Posting Date:** September 8, 2022

LINK to podcast: https://tinyurl.com/3z2ks4vh

Daniel Jacob: Methane is responsible more for near term climate change, but also it means that acting on methane can give us a short-term response to climate. So, if we are trying to address climate change over the next decade or two, methane is a very powerful lever.

Robert Stavins: Welcome to Environmental Insights, a podcast from the Harvard Environmental Economics Program. I'm your host, Rob Stavins, a professor here at the Harvard Kennedy School and director of the program. In this podcast series of conversations on policy and practice, nearly all of my guests over the time we've been doing it have been economists, political scientists, legal scholars, policy makers, or industry leaders. As I recall, only one guest before has come from the academic world of the natural sciences, and that was David Keith, a professor of applied physics in the Harvard School of Engineering and Applied Sciences. But perhaps he doesn't even count because he's also a professor of public policy here at the Harvard Kennedy School. So today I am finally breaking the mold, and I'm pleased to be doing that, because today we're fortunate to have with us Daniel Jacob, the Vasco McCoy Professor of Atmospheric Chemistry and Environmental Engineering at Harvard, and an expert and a world leader in the development of powerful inverse methods to infer methane emissions from satellite observations of concentrations. Now, we'll get into that later, but for now let me just start by saying, welcome Daniel.

Daniel Jacob: Thank you, Rob. Happy to be here.

Rob Stavins: So, before we talk about your research and its implications, let's go back to how you came to be where you are, which I think will be of tremendous interest to our listeners. So where did you grow up?

Daniel Jacob: I grew up in Geneva, Switzerland.

Rob Stavins: And does that mean that you went to high school and primary school there?

Daniel Jacob: Yes.

Rob Stavins: And where was that, in specific, in Geneva?

Daniel Jacob: In Geneva, yes.

Rob Stavins: And then you went on to college immediately after secondary school?

Daniel Jacob: Yes, I went to a chemical engineering school in Paris.

Rob Stavins: And you graduated from there in?

Daniel Jacob: 1981.

Rob Stavins: In 1981. And then did you immediately go on to graduate school for the PhD?

Daniel Jacob: Yes, I did. It was somehow brought together with my military service that I had to do. But yes, I went straight to graduate school at Caltech.

Rob Stavins: So, you immediately went to graduate school partly for the same reasons that when I graduated from college, I immediately joined the Peace Corps, it sounds like. Now, you went to Caltech a long way away from Geneva and from Paris. Other than the fact that Caltech is known as one of the greatest universities in the world, in particular in the natural sciences, how did you go about choosing Caltech? How did that happen?

Daniel Jacob: Well, there was some history with this. I am a US citizen, and my dad actually had done a postdoc at Caltech. He had very fond memories of the place, and I wanted to do environmental research, and they had a very strong environmental engineering program at the time. And so I viewed this as an opportunity to study air pollution in a pretty unique environment for that.

Rob Stavins: And then what was your dissertation on?

Daniel Jacob: My dissertation was on acid fog, which was a wrinkle, an air pollution problem that California experienced at the time and was somewhat linked to acid rain.

Rob Stavins: So acid fog was a huge issue as I recall in London decades ago.

Daniel Jacob: Yes, that's correct. But we were in a position at the time at Caltech to try to understand the mechanisms driving acid formation in the fog. And we were hoping that in that way we would be able to make a connection to acid formation in rain and better understand acid rain.

Rob Stavins: And was that indeed the case, that you were able to make that connection?

Daniel Jacob: Yes, that was indeed the case. And we were able... I mean, not just us, but the community in the 1980s developed a very good understanding of how acid rain is formed, to the point that now acid rain has become more of a policy issue than a scientific issue. And we've been doing much better now with the problem.

Rob Stavins: I mean, completing your work at Caltech in 1985 I believe, that was a fortuitous time because it was in 1988 that the process started of developing what were the Clean Air Act Amendments of 1990 including the very important and pathbreaking Allowance Trading System to reduce $SO_2$ emissions as a precursor of acid rain in the United States and Canada.

Daniel Jacob: Yes, that's correct. So, during the 1980s, when we had Ronald Reagan as president, the mantra coming out from the White House was that more research was needed on acid rain before any policy action was taken. And then when George H. W. Bush got elected in 1988, you may recall that he said he would be the environmental president. And to make good on these promises he pushed through a revision of a Clean Air Act that included provisions to address acid rain.

Rob Stavins: Right. And that's something we've talked about in previous podcast conversations. For example, with Dick Schmalensee, Professor Emeritus at MIT, who was at the Council of Economic Advisors in the George H. W. Bush Administration and played a key role in getting that legislation through the US Senate, actually. So, tell me, what was your first position out of graduate school?

Daniel Jacob: So out of graduate school I went to Harvard as a postdoc, I wanted to do more global atmospheric chemistry research. I thought that was something more for the future than looking at traditional air pollution issues.

Rob Stavins: So your path sounds beautifully linear. So many times it seems people sort of bounce around from one topic to another, then there's some serendipity that they get into something else. But it seems like you've been targeted, and that one can understand very well why you're doing now what you're doing.

Daniel Jacob: Yeah, somewhat distressingly so. I mean, the only zag that I did was that when I was at Caltech, I was mainly doing experimental research, and I discovered that I was absolutely no good at this. So, I had to go more into theory and modeling, and so this is what I went to at Harvard and do it as a postdoc.

Rob Stavins: And the postdoc, was that in a specific department?

Daniel Jacob: Yes. It was in what was then the Division of Applied Sciences, working with Mike McElroy, who's still a professor at Harvard.

Rob Stavins: Absolutely. Speaking of that, Mike is someone that I haven't had on this podcast series, but it would be interesting. And years past I worked with him a great deal. There was a time at which, as you probably recall, that he was running the environmental programs at Harvard, university wide, before I think Dan Schrag sort of took over that role. So your postdoc was a couple of years long, is that right?

Daniel Jacob: That's correct. Yeah, I joined the faculty at Harvard in 1987.

Rob Stavins: So this is quite remarkable. You come to Harvard as a postdoc in ’85; you become an assistant professor in ‘87; you become an untenured associate professor at some point; and then you become a tenured full professor in 1994. Do I have those years correct?

Daniel Jacob: That's correct, yes.

Rob Stavins: That's a very impressive path.

Daniel Jacob: Thank you.

Rob Stavins: So before we turn to your research on satellite measurements of methane concentrations, and inference of methane emissions, let's talk more broadly about the importance of methane. And I say this because nearly all of our conversations in this podcast series, whenever we've talked about climate change, and climate change policy, have focused on carbon dioxide emissions. But there are other greenhouse gases, an important one of which is methane. So tell me, how should we think about the relative importance of methane as a greenhouse gas?

Daniel Jacob: Oh, that's an excellent question, Rob. So, methane has very much of the same kind of climate effect as $CO_2$. I mean, it's a greenhouse gas, and as you pointed out, there's a number of those greenhouse gases, and they all tend to have the same behavior as $CO_2$. But a big difference is that methane has a shorter lifetime, so methane has a 10-year lifetime in the atmosphere because it gets oxidized. Whereas $CO_2$ it's complicated, but you can think of it as having about a 200-year lifetime. And so what that means is that methane is responsible more for near term climate change, but also it means that acting on methane can give us a short-term response to climate. So, if we are trying to address climate change over the next decade or two, methane is a very powerful lever.

Rob Stavins: So, when you say it has a 10-year lifetime, you're not referring to a half-life, but to rather virtually none of the methane still being in the atmosphere after 10 years?

Daniel Jacob: It's what we call technically an e-folding lifetime. If you want to call it a half-life, it's seven years.

Rob Stavins: Okay. And then this is essentially asymptotic to going to zero, and it just drags out over time, or does it not?

Daniel Jacob: That's right. Yeah, it's an exponential decrease. So it drags out to zero, but over a very long time.

Rob Stavins: So in other words, if that's the case, then if one were to use as many studies and graphs for that matter in the policy world, and in the policy literature tend to do, and that is to compare greenhouse gases in terms of $CO_2$ equivalent, but on a hundred year basis. I've seen this over and over again. What's the result of that in terms of possibly distorting the relative importance of methane?

Daniel Jacob: Yes, that's again, a very, very good question. So, the standard metric by which we compare $CO_2$ and methane is with a 100-year global warming potential. And this is a very artificial metric, it basically calculates the integral of radiative forcing on climate for over a hundred years, from methane versus CO2. And so when you do this, you find that methane has about the same climate effect as 25 $CO_2$s.

So, it's a 25 $CO_2$ equivalent, which means that if you control one kilogram of methane emissions, it's the same thing as controlling 25 kilograms of $CO_2$ emissions. But it's very misleading, because the time scales are so different. So, if you were to use a 20-year horizon instead of a 100 year horizon, then methane would be 80 $CO_2$ equivalence, instead of 25. And even if you were to say, "Well, I care about climate change over a hundred-year time horizon," this global warming potential is not the right way to do it, because if I emit methane today in the atmosphere, then after about 10 years it's gone. Which means that a hundred years from now there will be no memory of the climate effect from that methane that I emitted today. Whereas if I emit $CO_2$ today, the effect will linger on for a few centuries. So it's very, very different.

Rob Stavins: Now, everyone knows about the sources. At least everyone listening to this podcast knows about the sources of $CO_2$ emissions, principally from the generation and use of fossil fuels. What are the major sources of methane emissions?

Daniel Jacob: Well, there's a natural source from wetlands. That's about one third of the total source of methane right now. Two thirds are sources from human activity, and those sources include livestock, and in particular cattle, landfills, wastewater treatment plants, coal mines, as you know methane is generated in coal mines, oil and gas operations, and rice paddies. Those are the principal sources of methane.

Rob Stavins: And what's the relationship between methane and what we regularly to as natural gas?

Daniel Jacob: Natural gas is mainly methane; it's about 95 percent methane typically.

Rob Stavins: Okay, and what's the other 5 percent?

Daniel Jacob: Oh, it's got a little bit of ethane, a little bit of higher hydrocarbons.

Rob Stavins: So technologies for detecting methane concentrations via satellites have been improving over time. Can you say briefly something about the history of these improvements?

Daniel Jacob: We have been able to observe methane from satellite for about 20 years. The first instrument was a European instrument called SCIAMACHY, and that operated for about five years in the early 2000s. And then we've had a Japanese instrument called GOSAT that was launched in 2010 and has been providing very high-quality data since then. Very high quality, but relatively sparse data, the kind of data with which we can look at trying to understand methane emissions on maybe continental scales, but we have a hard time resolving individual countries or individual oil and gas fields, individual landfills, if you get my drift. And then in 2017, another European instrument called TROPOMI was launched, and that instrument is still going on, and it provides a global daily observation map of methane. And so that provides a tremendous resource for understanding the sources of methane globally.

Rob Stavins: Now, so with the satellites then, methane concentrations are being observed. But of course, what we care about for policy are methane emissions during particular periods of time and from specific geographic locations, if not particular sectors. So, can you explain to us how it is you go from satellite-based measurements of concentrations to estimates of emissions?

Daniel Jacob: That's a very complicated problem, and something in which my research group has made important contributions. Is that between the time when you emit methane and the time when you observe it there is transport taking place in the atmosphere. And as you know, transport is relatively rapid. I mean, we experience pretty strong winds. And so what you need to do is to be able to interpret the concentrations that you observe from satellite, in terms of the sources upwind at various previous times. And this is what we call technically an inverse problem. And there's quite a bit of intricacies associated with this. Part of this has to do with the uncertainty in the transport. Part of this has to do with noise in the satellite observations. Satellite observations are difficult to work with, but ultimately we are getting some very powerful results.

Rob Stavins: So is it fair to characterize this, that you have measurements of concentrations, you combine that with some additional information historically about concentrations and emissions, and from this you statistically infer what those specific concentrations you measured tell us about emissions?

Daniel Jacob: Yes, that's correct. So what I do is I start off with what we technically call a prior estimate. That I say, “this is what I think the emissions are.” Basically the EPA is telling me how much methane the United States put out, other countries tell us how much methane they put out.

Okay, I'm going to take those at face value, and then I'm going to transport them in the atmosphere with my model. And so I'm going to simulate methane concentrations in this manner, and then I'm going to confront those to what I actually observe from the satellite. And I will try to interpret the differences in terms of errors in the emissions, and so the emissions may have to be changed. But you see, I have to be very careful, because when I see differences with what I observe, it could be that the observations might not be very good or it could be that my atmospheric transport model may not be very good. So I have to be very careful, but this is where the intricacies come in. But ultimately what we can get from that is an improved understanding of the emissions.

Rob Stavins: And then how can you validate then whether or not your estimates of emissions, to what degree [are they] accurate or what the uncertainty bounds are around them?

Daniel Jacob: That's another excellent question. I will never take what comes out of these inversions of satellite data at face value. What I will do, is I will then take some very accurate, but sparse observations taken from the surface. NOAA, for example, has a network of stations around the world taking methane observations. And then I will simulate those observations with my model using the older methane sources, my prior estimate that I was referring to. And then my new estimates of emissions that I obtained from the satellite. And then I will see which one is better, and whether the satellite is providing a better representation of those very accurate observations.

Rob Stavins: So how would you compare then the uncertainty that surrounds your emission estimates from concentrations to the uncertainty of what I'll call conventional estimates of methane emissions, sort of adding up all the different engineering estimates from this source, and that source, et cetera?

Daniel Jacob: Well, my uncertainties will always be smaller than the uncertainties that are coming out of those bottom-up prior inventories. And that's because I'm very careful before I bring in the satellite information. So in other words, I have some uncertainty estimates associated with those prior emissions. And then I'm going to say, "Well, can I reduce those uncertainties with the information I get from the satellite?" So these are not two independent ways of estimating emissions. Instead, what I'm trying to do is seeing whether the atmospheric observations can play a role in narrowing down the uncertainty.

Rob Stavins: And I should emphasize that this is extremely important, these estimates of methane emissions, differentiated spatially and temporally, because under the Paris Agreement, there is a need to assess the national inventories that are reported. And then in addition to that, of course there's now the Global Methane Pledge among 119 countries to cut global emissions 30 percent by 2030. And the challenge in both cases is the tremendous uncertainty regarding methane emissions, and you are addressing those challenges directly.

Daniel Jacob: Precisely. And then the other thing that we can do uniquely from satellite is to be able to look at recent changes in emissions, because the emission inventories that are coming out of individual countries are based on statistics that will typically be two or three years old. But if we're going to try to change the emissions rapidly, and to verify those changes in emissions, the only way that I can think of is to do it from satellites.

Rob Stavins: So what do you see as the future of this line of research? I'm thinking of this marvelous set of postdocs, who I've had the pleasure of meeting, who are working with you. But not just them, but then future postdocs you'll have, and then they're all going to go off and they're going to become researchers in various locations. What do you see as the future line of this research? Where is it leading?

Daniel Jacob: Well, from a policy standpoint, what I would like to see is that we can contribute to continuous monitoring of emissions, to be able to detect changes in emissions, particularly if those are correctable, and point to the need for action. Say for example, if you have a flare that goes off, we should be able to see it from space, and then be able to take action on that. Some industrial accident, be able to observe that, but also to verify that individual countries are meeting their obligations under the Paris Agreement, or collectively under the Global Methane Pledge.

Rob Stavins: Indeed. So, since I brought up about your post-doctoral fellows, who from my point of view anyway are extremely young people, I want to bring this to a close by asking you a much broader question about young people. Because as a professor, you have an opportunity to be around such people all the time, but I'm thinking of even younger people than that. Something that we've observed over the last few years is really what I'd call a youth movement of climate activism, most prominently with Greta Thunberg in Europe, but for that matter it's students in the United States and throughout Europe, and probably in many other parts of the world. What's your reaction to these youth movements of climate activism?

Daniel Jacob: Well, I'm glad to see young people engaged. It's kind of heartwarming because you and I, I think, come from a generation where we were politically engaged. And sometimes we are distressed to see the youth of today being somehow less active. But there definitely seems to have been something about the climate movement that has taken a hold of young people. It's difficult for me as a scientist to get really involved in the advocacy, because there's a credibility issue that you're trying to maintain.

Rob Stavins: And that's important that you're able to draw that distinction, of doing your rigorous scientific research, maintain your credibility, while at the same time, possibly on a personal level, admiring the advocacy of some of these young people, both in Europe and the United States and around the world. So listen, thank you very much, Daniel, for taking time to join us today.

Daniel Jacob: Rob, it's been a pleasure.

Rob Stavins: Our guest today has been Daniel Jacob, who is the Vasco McCoy Family Professor of Atmospheric Chemistry and Environmental Engineering at Harvard University. Please join us again for the next episode of Environmental Insights: Conversations on Policy and Practice from the Harvard Environmental Economics Program. I'm your host, Rob Stavins. Thanks for listening.

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