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PV Integration and the Merit Order Effect

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Webinar Presenter

David Jacobs International Energy Transition

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David Jacobs Hello around the world, and welcome to the next session of the International Solar Alliance Expert Training Course. I am Dr. David Jacobs speaking here from Berlin. I'm very pleased to discuss with you today Session 28, which deals with PV Integration and the Merit Order Effect. So we're going to have a closer look at the impact of solar PV in wholesale electricity markets, which is a very interesting topic, and I'm very glad that you joined this webinar.

As you probably know, this is a webinar in cooperation of the International Solar Alliance and the Clean Energy Solutions Center. So thank you very much for providing this platform, and for teaching experts about solar policies and solar regulation. I am David Jacobs, founder and director of the consulting firm IET—International Energy Transition. Working for almost 15 years now in the renewable energy policy sector. Working in a lot of countries around the world, and having dealt with solar PV integration in a lot of cases. I'm very glad to discuss this topic with you today.

As you probably also know, this is part of a larger webinar series. We have a total of eight modules dealing with policies for distributed PV for largescale solar PV, technical integration, market integration, off-grid solar, and so on. This is part of module five, which deals with market integration. We have a total of four sessions on this topic. And if you're interested in additional information on these topics, related information, please also make sure you look at webinar 15, which deals with subsidy-free solar pathways forward. So what actually happens once you reach cost competitiveness of solar PV, either in wholesale electricity markets, or behind the grid, behind the meter.

And please also make sure you check out the previous and next webinar, which is 27, system integration of solar PV, and 29, dealing with a duck curve, where we take a closer look at the Californian electricity market, and how they deal with best practice strategies for integrating increasing amounts of solar PV. And, last but not least, there's two more sessions on storage, and also another one on power to X, so solar PV to transport, or solar PV to heating and cooling, which might also be of great interest to you if you're interested in PV system integration.

So here is an overview of this training session. First of all, we will discuss learning objectives, then go to the core part of the webinar—that is understanding the effects of increasing shares of solar PV in wholesale electricity markets, effects that they have on prices in these markets. Then, as always, we have some further reading, and, in the end, we have a very short multiple-choice knowledge check to see whether you actually captured the major takeaways of this webinar.

So let's start by looking at the learning objective. So after this one-hour webinar, it would be great if you would understand first of all the basic functioning of wholesale electricity markets, of competitive wholesale electricity markets. So you need to understand first of all what the merit order is, in order to then understand in the second step what the merit order effect is—that means the impact of solar PV or other renewable energy technologies on the price level in the wholesale electricity markets.

We're also going to have a short session on some case studies, where we look at some countries which have already built up a significant amount of solar PV, where you can analyze the impact that this has on wholesale electricity prices. And, last but not least, and from my point of view this is the most interesting part, we want to discuss as well with you some parameters that policymakers can apply in order to counterbalance this merit order effect. So, in other words, to stabilize _____ electricity markets once you move into markets which are more and more decarbonized, where more and more solar PV, wind energy, and other decarbonized technologies are integrated, how can you manage that _____ prices will not collapse, and there's still enough revenues to be earned for these power producers in the longer-term future.

So, let's first discuss the merit order in competitive wholesale electricity markets. So here on one slide I have summarized for you the last 40 years of electricity regulatory tradition in just a few bullet points. You have to understand that this is from a historic point of view a relatively new development. Until the 1970s, we had highly irregulated markets, mostly monopolistic markets, where power producers were all paid according to the different cost of their technologies. So we called this regulation the cost-plus regulation, because you were looking at the overall cost, including operation costs, but also finance costs, and also fixed cost—that's just building the coal-pipe power plant, building the gas turbine. And on top of this, you'd get a certain profit margin so you could actually also earn some money with your power generation project.

This has changed then in the late 1970s, where first of all in the United States marginal cost pricing was introduced. And this is what we now call wholesale electricity markets 101. Most of the liberalized electricity markets are now moving or have moved already towards this pricing, _____ _____, and it takes a little bit of time to understand this. So I want to make this very clear, at the start of this webinar, because otherwise you don't have any chance to understand the merit order effect. So how does it work in a wholesale electricity market today?

So you have buyers of electricity, and you have sellers of electricity. So the buyers of electricity are people like you and me who want to consume electricity at their home. Of course, I'm not bidding anything on the electricity market, but my supplier is doing that for me. So my supply company is going to the electricity market and indicating how much electricity is going to be needed, and what price they're willing to pay for that. Normally, this happens in day-ahead markets—that means for instance if it's noon, today, I'll have to submit my bids for the following day for each and every hour of each and every half hour of the following day, where I say I need this amount of electricity, and I'm willing to pay for that this amount of money.

And this is an aggregated—and by aggregating it you get an aggregated demand curve. Then you have the sellers of electricity. That is the power producers. And they are supposed to bid, to also submit bids on these competitive markets where they say okay, tomorrow from 2:00 to 3:00 in the afternoon, I have this amount of electricity to sell, and I want to get this price for this. And they are theoretically always offering their marginal costs. And this is now very important to understand—the marginal cost really just means the fuel cost that they have, or, to put it in a more theoretical framing, it means the cost that each power producer has for producing an additional unit of electricity. And producing an additional unit of electricity for gas-fired power producers, does not mean how much did I pay for my gas-fired power plant, it only means how much gas do I actually need to operate my power plant an additional hour, and how much money do I need for that?

So these marginal costs are then offered by each bidder, and then they are also stacked up in a supply curve. As you probably know, the marginal cost of different power plants differ from one _____ technology to the next. But I will show you this in more detail in the next couple of slides. Now, what is very important is the last power plant that is needed to meet the demand is actually setting the market price. So it's not that every power producer gets the price they offer. It is actually only the very last power plant that is needed in order to match demand, sets the price for all other power plants.

So maybe we move to the next slide, where I've visualized this for you, and where hopefully it gets a lot clearer. So let's look at this again. We have here already the aggregated demand curve. As you can see here, the power consumers have said I don't really care about the price of the electricity. This is why this red line is straight, and is not—doesn't have an angle to it, as you can see in some of the following slides. Meaning that I really need this electricity, and I don't care what it costs, five cents per kilowatt hour, 50 cents per kilowatt hour, I really need it, and I'm willing to pay any price for this. This is just to make things easier at the start, and we can go into more elaborated demand curves at a later stage of this webinar.

So we already know what the demand is. So it's a certain amount of capacity that is required. Now, what will happen in the next step is we see who is going to supply electricity. And now we understand what the merit order curve actually is. So let's see what happens. First of all, in the old electricity markets, you had nuclear power coming in first, because they had very low, or they still have very low operation and maintenance cost. They only need to buy some uranium, but all the other costs—the other operation costs are relatively low. So they come in first in the merit order. Then you normally have coal-fired power producers coming in second. This of course depends on the fuel cost for fossil fuels within your country. In the United States, for instance, this is different—over here, you see nowadays, gas-fired power plants coming in first, because of the very low cost of gas, due to the fracking boom in the last couple of years. But this is just one example of the merit order curve, so please be aware that this might look different in your country.

Then you also are stacking up the other technologies. Combined cycle gas turbines, normal gas turbines, and then last but not least to meet the final demand that is needed, we also see sometimes peaking power plants coming in, oil-fired power plants, for instance, which are normally quite expensive. But then what is very important, that in this case, in this hour, so this only depicts one hour or one 30-minute interval of the wholesale electricity market price, in this hour, oil will set the market price for all power producers in the market. This is what we call the market clearing price.

So what you need to understand is oil is setting the market price, and then you see the difference between the nuclear market price and the green line, the market clearing price—all that is above the nuclear, the blue nuclear bar, is actually rents or profit margins for the nuclear industry, and with these rents, they are able to pay off their fixed costs, for instance, for building the nuclear power plant in the first place. Or for building the lignite power plant in the first place. So they are making some additional money. So they're bidding their marginal cost, and then everything that is additional up to reaching the market clearing price can actually be used to make some revenues and pay off the fixed costs.

So by selling the electricity on the wholesale market, the power producers—almost all power producers, except for the market clearing plant, earn more money than they actually need to pay for just operating this power plant in this one hour. And, as I said before, this profit margin allows power plants to finance their fixed costs or their capital expenditure, CAPEX. So this is very important for you to keep in mind, that we have this—well, first of all, not very intuitive system where the last power plant needed in order to meet demand actually sets the price. And when this was first introduced in the 1970s, late 1970s in the United States, this was the latest economic theory, which was suggesting that this way, any kind of market would work in the most effective way, and also power markets—but as you can imagine, a lot of the folks from the electricity industry were rather skeptical of this.

They were quite used to the cost-plus regulation, where they were sure they could earn enough money, and also make a profit, by having irregulated prices, and now they were supposed to step into this relatively insecure market framework, where yes, they could make some quite significant additional profits, when you look at for instance the difference here between nuclear price that was bid and the market clearing price—but there was also the risk that you would not earn enough money in this market, because the market clearing price might also be relatively low, and then the rents that you're earning on top of your marginal cost might not be sufficient in order to finance your fixed costs.

So it was quite a dramatic shift in electricity market regulation that took place first at the end of the 1970s, and which was then introduced in all wholesale electricity markets, in all liberalized wholesale electricity markets, in many countries around the world. Now, this worked quite fine in the 1990s and in the 2000s. But then we had renewable energies coming into the system. But before we move to renewables, maybe just one more word on the actual merit order. Here I just show you one example of the actual merit order in a given day in Germany. You can see that it's actually not the fixed blocks. The marginal cost of lignite or of coal are not the same for all lignite or coal-fired power producers. But actually depending on the efficiency of these power plants, how old they are, they offer different prices.

So we don't have these blocks for technology, but you have a more—a less steep shape of the merit order. That's why we also call it a merit order curve, and not merit order blocks. As you can see here, for instance, even when you compare gas turbines and oil-fired power plants, you see that they are not even within one block, but some of them are so efficient, some of the gas turbines, that they even undercut some of the cost of the combined cycle gas turbines, and some of the oil-based power plants are even more efficient than some of the gas turbines as you can see from the orange bars in the very back. So it's not even that one technology follows the next, but that they are sometimes intermingled. And, as a policymaker, of course you'd like to have not so steep merit order curves, because steepness always means as well that you have quite dramatic changes when it comes to demand, and when it comes to differences in wholesale market prices.

So now let's look at the merit order effect of solar PV and other renewable energy technologies. This is our starting point. This is a market where we don't have any renewable energies in the systems. Anda you can see that the market clearing price here is set in this house by oil-fired power producers. And now the question is, what happens once we introduce solar PV or wind energy or other renewable energy technologies that don't have any marginal costs? Because, as you know, solar PV, what is your fuel cost here? The fuel cost is the sun. The sun comes in for free, and therefore you don't have to pay anything for this, and therefore the solar PV operators are normally putting forward bids at zero.

So when they go to the market, they say, for operating my solar PV power plant an additional hour, what I really need for this is no money at all. Of course, that doesn't mean solar PV systems are for free, that just means the operation costs of solar PV, once you finance the capital cost, are for free. So

I've indicated this here with a blue bar—wind and PV—at the very left corner of the graph. I indicated a certain price level in order for you to be able to see that wind and PV has been added. So this is actually zero or close to zero bid. I just made a blue bar here so you can see there's something additional to it. Now when you compare the two graphs—the first one where you have no renewables, with the one where you add a certain amount of wind energy and solar PV, you can actually see what happens to the merit order.

What happens is that solar PV and wind energy, which are technologies with no marginal costs, are actually pushing out the more expensive technologies that you can see on the right—in this case, oil-fired power producers. So they are shifting the entire merit order to the right, which means that the market clearing price that you see here is actually lowered. Once again, to show you the difference, this is the market clearing price without renewable energies, and then you add some solar PV and wind energy to the system, or you could also just add solar PV, and then the market clearing price goes down.

So this has two effects—one positive effect, and one not so positive effect. The positive effect is of course that lower wholesale electricity markets are beneficial for any buyer of electricity. So it's beneficial for households, it's also beneficial for industries, because in these marginal cost markets, that means that the cost of wholesale electricity is going down, and in the ideal case, this is also passed onto the final consumers. So you can see that in a lot of countries, energy-intensive industries are quite happy with adding more solar PV and wind energy to the system, because that actually reduces the wholesale electricity market price in general, and therefore they can buy electricity more cheaply, and therefore they can be more competitive in international markets.

So for the buyer of electricity, this is quite positive. However, for the sellers of electricity, this is not so positive. So first of all it's not very positive for the oil-fired power producers, because they are, in this hour, no longer part of the market. They can no longer sell their electricity. They are excluded from it, because they are offering prices which are not needed in order to meet demand. But it's also negative for all other power generation technologies, because you can see here that the rents, the profit margin that power producers can make above the marginal cost have been reduced, because the market clearing price has gone down.

So, in this hour, the nuclear guys, the lignite guys, the coal guys, and the combined cycle gas turbine folks are earning less money than in a situation where you wouldn't have wind and PV in the system. And of course, this continues when you add more PV to the system. This is then the topic of the next slides.

So I hope this simple effect is now relatively clear—why does wind and solar PV adding to the system cause reductions in the wholesale electricity market price? Because you're shifting the entire merit order to the right, and therefore the market clearing power plant in this case is no longer an oil-fired power plant, but a gas turbine, and therefore the profit margins for all power generators are reduced, and, at the same time, the wholesale electricity market price goes down, which is beneficial for the buyers of electricity.

Now let's take a look at some empirical evidence of the merit order effect in different countries around the world. Here, first of all, we have some analysis on the effect of solar PV and wind energy on the electricity market in California. This is a paper from Lopez Prol et al from 2017, which is called The Cannibalization Effect of Wind and Solar PV. This is also a term which is sometimes used for the merit order effect, or potential price reductions in wholesale electricity markets. I myself try to refrain from these really drastic vocabulary which is sometimes used. You have the cannibalization effect for solar PV and wind energy, which another word for the merit order effect. You also have in the case of rate design the death spiral.

All of this terminology is coming from the United States, where there seems to be an appetite for using really drastic words in order to describe relatively neutral effects. Maybe this is just a reflection of our time, but I'm always trying to stay away from these overly dramatic wordings. So let's stick to the merit order effect for this webinar series, and you can make the choice on your own.

However you call it, what you can really see here is with an increasing share of solar PV, that you can see here at the lower bar of the graph, with zero percent, five percent, 10 percent, 15 percent of market penetration—you can see the average market price, the value factor here, is going down quite steeply in the case of solar PV. So you can see here with very low shares of solar PV in the system at the left side of the graph, you can see that the value factor, the market value of solar PV, is actually above the average. So it's above 1.0. Because at these times, you still had a relatively interesting peak demand at daytime, and then by installing solar PV into the California electricity markets, you could earn quite a lot of money during these daytime hours, because there was a lot of demand, and you could then sell your electricity at market prices, which were above the average wholesale electricity market price.

But once you start adding more and more solar PV to the system, as you can see here from five percent to 10 percent to 15 percent, you see that the value factor, the market of value of solar PV, actually decreases quite considerably. When you move up to 20 percent here you can see that the value factor of solar PV is only 0.5. It's like 50 percent of the average wholesale electricity market price. That means in an hour that you sell your solar PV at a penetration level of 20 percent of solar PV, you would only earn half of the price that other non-solar power producers would usually earn in an average hour of the market. This is of course due to the fact that solar PV is producing electricity relatively simultaneously—so all solar PV systems within California will start producing on a sunny day solar PV at 7:00, 8:00 in the morning. They have their peak at noon or 1:00. And then they stop producing power again at 6:00, 7:00, 8:00 in the evening.

And this is same for all solar PV technologies. When you compare this with wind energy here on the righthand side, you can see that the effect of adding more wind to the systems are actually not that dramatic. They're actually quite the same, independent of the penetration level of wind energy. And this of course is due to the fact that not all wind power plants in California are producing at the same time—because sometimes it's windy in the southern part of California, sometimes it's windy in the northern part of California. So you have sometimes the wind is blowing in the evening, sometimes at daytime. So you don't have this simultaneous effect on the wholesale electricity market as you see it quite dramatically in the case of solar PV.

So what does it mean for the actual market price? You can see here the wholesale market price in California from 2013 until 2018. And as you can see, the average wholesale market price, by adding solar PV to the system, mostly has actually gone down quite considerably from an average of $42.00 per megawatt hour back in 2013 now to something like $28.00 per megawatt hour in 2018. And this is something we see in all markets, in all wholesale electricity markets, liberalized wholesale electricity markets, around the world, where we're adding substantial shares of solar PV.

Here, another example, from Germany. Same story. You can see here the typical operating hours of solar PV in yellow, in the summer month, in Germany, we're starting to produce power at 7:00, 8:00, 9:00 in the morning, having their peak at 1:00, 2:00, and then stopping to produce power at 6:00, 7:00, 8:00 in the evening. So this is a rather sharp increase of solar PV production, followed by a relatively sharp decrease of solar PV production. And this also had an impact on the relative spot market price. Once again, here, if you look at the year 2006, which is the darker line at the very top of it, you can see that you could still earn quite a lot of money by selling solar PV on the wholesale electricity market in Germany back in 2006, you could actually earn 1.8 times more than an average power producer in the wholesale electricity market during the noon hours.

So you also had a peak of electricity demand during noon, and therefore by producing electricity during this hour, you were actually able to make quite a lot of money. But once you add more solar PV to the system, you have more and more people offering electricity during these hours, and therefore your supply and demand changes, the prices go down, and you can see this quite clearly here—for instance, when you look at the line of 2013, where you no longer really have a mid-time peak. This has now become a mid-time down, mid-time off peak, of prices, because we have added so much solar PV to the system. I think in 2013 it was about 25 gigawatt—that this actually decreased wholesale electricity market prices during these hours.

Once again, what does this mean for the value factor of solar PV? Similar as the discussion already in California. You see depending on the market share of solar PV, which is the orange dots here, the value of solar PV actually goes down. So we were starting at a relatively high value of about 30 percent more than the average wholesale electricity market price you could earn with solar PV when you had very low shares of solar PV in the system, but this would then go down quite considerably already with a two percent and four percent market share of solar PV. We were then reaching more or less average wholesale electricity market. And this of course is going further down once you add more solar PV to the system.

Maybe just a quick look at other countries around the world. We have the same stories from Australia here. A newscast from last month, where the regulator said that electricity prices are expected to fall by 2.1 percent, wholesale electricity market prices. This means of course in the next two years due to additions of wind and solar PV. And it was communicated as well as this lower wholesale price will actually be beneficial for households, giving them savings of 55 Australian dollars over the next two years.

In Spain, same situation. Here we see an increase of renewable energy production by about 1 gigawatt hour reduces the daily average of the Spanish wholesale electricity market price by 2 euros per megawatt hour. And also a similar analysis was done in 2013 for the Austria-Germany interconnected market, where they concluded that adding an additional 1 gigawatt hour of renewables would actually reduce the daily average price on the wholesale market by roughly 1 euro per megawatt hour in this integrated market. So this just to tell you it doesn't really depend—well, it varies from one country to the next, but this is a phenomena that we've seen in all markets where we add substantial amounts of solar PV to the system.

This is why we now come to the most interesting part of this webinar, where we discuss factors that either reduce or increase the impact of the merit order effect. That also gives policymakers some ability to really deal with this issue, and to come up with solutions that also allow solar PV producers or any decarbonized technology to still earn some money in the future.

So first of all, here is an overview of the different aspects impacting the depths of the merit order effect. So as we've already discussed a little bit, of course the share of renewables or the share of solar PV you are adding to the system has a very substantial effect on the wholesale electricity market price, but also other factors like establishing CO2 price, a carbon price, and also the development of fuel costs for gas and for coal, has a very significant impact on the price levels in wholesale electricity markets. And what is very important to know for any future electricity market is of course by adding more flexibility to the demand side, you can actually compensate quite a lot of the factors, quite a lot of the effects that we have discussed previously.

And last but not least, I'll also touch a little on the effects of grid expansion and market coupling. And also the flexibility of fossil fuels and, well, less flexible power plants. Because we also saw some situation where adding more solar PV and wind energy to the system, we would see also some negative market prices. But this was actually not so much due to adding renewables, but that was due to the inflexibility of the fossil fuel powerplants, who, during these hours of negative market prices, preferred to pay a penalty—that is a negative market price—instead of just switching off their power plant for a couple of hours, because this would technically not be feasible, or would lead to higher additional losses than what you'd actually pay as a penalty in terms of negative market prices.

But this would require an additional hour of discussion. So I'm only going to touch upon these slightly. So the first three are going to be the topic for the next 20 minutes. So let's look at the share of renewable energies again. We discussed already a high share of solar PV will further decrease the wholesale market price, and that this is especially true for solar PV, because generation typically takes place simultaneously in one jurisdiction, and you don't have any variation as you can sometimes see in the case of wind energy.

What you can definitely do is market coupling. That means increasing interconnections with your neighboring countries, and then not having two separate wholesale electricity markets, but maybe coupling them, so that if you couple your market, which has a very high share of solar PV in the systems, with a market which doesn't have so much solar PV resources, or which has more wind energy in the systems, or less—more of other technologies, then you are actually also helping to reduce this merit order effect, because you are then overlaying your market with the other market, and you would get an average price, and no longer see these very dramatic effects that I've already shown you in the previous slides.

And of course, electricity storage can very much help to balance the variations in electricity supply. You can actually store the electricity in times of high solar PV penetration, and then you can discharge the batteries in times of low solar PV penetration. We're going to have one session on solar PV and storage. I think it's session 29 of this webinar series. So please check it out in order to learn more about this as well.

So let's look at some of the effects of increasing shares of solar PV in wholesale electricity markets again. Just a repetition again. So what happens here? We have a market without any solar PV in the system. Now we're adding a little bit. And now we see what happens when you add even more solar PV to the system. Price is going down further. As you can see here, we have pushed the merit order curve even further to the right, and now we no longer have the gas turbine here, as the market clearing plant, but instead we have a coal-fired power plant, and this reduces the electricity market price quite considerably.

And also the benefits of the profits, the profit margins for the other power producers, for the nuclear, lignite, and of course wind and solar themselves, have been reduced quite considerably. And you can spin this further, and say what does actually happen once we reach 100 percent renewable energy power markets? Which would require a discussion of its own. But you can imagine that we add more and more wind and solar PV to the system, and then of course what would happen is that the wholesale market price would go down to the price of wind and solar, once they cover the entire demand. This would mean then, at least for certain hours of the day, that the wholesale electricity market price will go down to zero.

However, there's a strong debate about this. First of all, you have to keep in mind that wind and solar PV will not produce 100 percent of electricity all the time. Because you have some hours or some month during the year where this is not going to be the case, and therefore you have other technologies which will then be setting the price in competitive wholesale markets. You could imagine that biomass and biogas will be the price setters in 100 percent renewable energy markets. Then they are quite—they have quite high operation costs as well. Similar to gas turbines. And therefore you'd still see quite a significant price, at least during those hours, in wholesale electricity market, even though you have 100 percent renewables in the system. You will also see storage coming into the system, in fully decarbonized systems, which will also be price setters in the merit order curve. And so on.

So this deserves a discussion on its own, and still needs to be a lot of research to be done. Just wanted to highlight this with a few sentences, that there is a lot of discussion about it. Because you have to keep in mind that the marginal cost pricing was actually introduced back in the late 1970s, in order to allow fossil fuel based power producers to refinance themselves on the market. It was actually when you look at the history, especially the electricity regulation in California, at the end of the 1970s, the whole intention of establishing marginal cost based pricing was to allow gas-fired power plants, which were newcomers to the market, to refinance themselves on the markets, via marginal cost pricing.

And if you keep in mind that the first intention of establishing marginal cost pricing was to allow fossil fuel based power generation, or it's not really fossil fuel based, it's about allowing power generators which have significant marginal costs—if you want to allow power generators with significant marginal costs to refinance themselves on these markets, this system worked quite well. But if you now think about an electricity market of the future, where most technologies don't have any marginal costs, then of course there's also some researchers, consultants, also thinking about potential differences to the market design, because operating in marginal cost markets when you have mostly technologies without marginal costs is going to become increasingly difficult. But this is beyond the scope of this webinar, therefore please also check out the webinars we have produced from the future of solar PV, in this webinar series.

To cut a long story short, what you have to keep in mind is that solar PV might reach competitiveness at a certain stage. But it might also lose it again at a later stage of the market development. And this is due to the fact that by adding more and more solar PV to the system, you are actually undercutting the potential revenues of solar PV that you were making in the first place. And this is what they—researchers from the 2017 paper showed in this graph really well. Meaning that you might not have any cost competitiveness of solar PVs in the first place. Then you might have a decade or a couple of years where yes, solar PV can earn a lot of money or can earn enough money on wholesale electricity market in order to also refinance the CAPEX.

But then with very high shares with penetration, we might re-enter a situation, again, where even though solar PV becomes less and less costly, it might not be able to refinance itself on wholesale electricity markets. This is very important for policymakers to understand. Currently, when I listen to discussions going on in a lot of countries, policymakers always assume, well, now we have reached cost competitiveness, and therefore we don't need this and this framework anymore, we don't need this and this anymore. Which might be true for a couple of years, but maybe a couple of years later, you might have to redesign your support frameworks, your market design again, in order to make solar PV cost competitive again. Because you might have this cannibalization effect, this merit order effect, where solar PV is undercutting its own economics by adding more and more solar PV to the system. So please keep this in mind, and please also highlight this in all the discussions that you have with policymakers in your country.

Now let's look at another very interesting aspect, and that is the effect that adding carbon prices has on the merit order effect. So let's take as a starting point a market where you already have a relatively large share of solar PV or wind energy in the system, and where you have a relatively low market clearing price. So what happens if I add a carbon price? Adding a carbon price actually means that you're increasing the fuel costs, depending on the carbon emissions from each technology. So once I add a relatively low carbon price, you can see here that the cost of lignite is going up quite significantly, because they're emitting quite a lot of carbon per kilowatt hour that they produce. Also increasing quite considerably for other coal-fired power plants. And then the effects on gas and oil are relatively lower.

So what you can see already here, by adding a relatively low carbon price, you can already see the market clearing price is going up. Because now you still have the coal-fired power plants, as a marginal power plant with _____ _____ _____ _____ setting the price. But _____ the fuel price, _____ just buying coal, _____ in the coal-fired power plants, they also have to pay the carbon price on top of this, which reduces the marginal cost of this power plant. What happens now if I introduce an even higher carbon price is shown in the next slide.

Here you can then see that we do not only have an increase of the technologies, of the carbon intensive technologies, you also see a fuel shift, because you're adding the carbon intensity of coal and lignite is much higher than those of gas, so you actually see now a shift in the merit order. First of all, you had here nuclear, lignite, coal, and then combined cycle. Now you're actually shifting it from nuclear, and then it goes to combined cycle gas turbines, and to coal and then to lignite and then to gas turbines. And this is also the intention of introducing carbon pricing, _____ _____ fuel shift that is intended that you move from more carbon intensive technologies to less carbon-intensive technologies, and then hopefully in the last stage to zero-carbon technologies.

So the impact that carbon pricing can have on wholesale electricity market is quite significantly—and this of course also has an effect on the merit order effect. Because what you then see is a relatively steep merit order. You start at zero, with wind and solar PV, then you have nuclear, also as a zero-carbon technology, coming in second. And then you have a steep increase in the merit order because you have all the fossil fuel based technologies, which are—which have to pay the actual fuel cost plus the carbon price on it.

So of course in the hours where then fossil fuel power plants are setting the market price, and this might also be the case in power systems, where you still have 80-90 percent of renewables in the systems, but you still have conventional power plants, fossil fuel based power plants, with a substantial CO2 price on top of it, which are setting then the market price. You can see that in those hours, the wind and PV producer could earn quite a substantial amount of money in wholesale electricity markets, which would also allow them maybe to compensate for the hours where they do not earn any money, because the wholesale electricity market is reduced to zero, because you're covering 100 percent of demand by wind and solar PV alone.

So I think many policymakers have still not understood these implications of setting a carbon price. And actually you're also allowing wholesale electricity markets to function better in a world where you're moving to low-carbon or zero-carbon technologies. Of course, this would then—once you move to a zero-carbon world, this would then collapse the system, because you'd no longer see any carbon price on any carbon-based technology, and therefore the effects that—there might be quite a dramatic change from a market where you still have 10 percent of fossil fuels in the system, towards a market where you have zero percent of fossil fuels in the systems. But once again, this is a whole different story, and cannot be covered within the next five minutes.

And you have also of course similar effects with fuel price variations, or fuel price increases, because effects are relatively the same. If you say my—the cost of gas and coal is going up, this has a similar effect, _____ adding a certain carbon price to a system. That means that the wholesale electricity market clearing price actually goes up.

Now, last but not least, let's look at the effects of more flexible demand. And as I've discussed already at the start of this webinar, we had assumed up to now that demand is inelastic, meaning that the consumer of electricity doesn't care about the price of electricity, just needs to have a certain amount of kilowatt hours. Of course, this is not true, because as an industry, but also as a household, you might say well I'm willing to pay 50 cent per kilowatt hour, but if it goes beyond that, I rather don't have any electricity instead of paying more for it.

This is then indicated by this demand curve, which is then no longer a straight line, but which is slightly inclined to the left, indicating that if prices go up, my willingness to buy this electricity is actually going down. And of course, there is a certain amount of elasticity to the market, but this only exists once the market prices—the hourly market prices that we see in the wholesale electricity market—actually reach the final consumer. This is still not the case in most electricity markets around the world. Because in most electricity markets, you pay the same amount of electricity for each and every unit that you buy during the daytime, nighttime, and so on.

So therefore, you really need to come up with a rate design, _____ electricity price rate design, which also reflects the actual generation cost in the wholesale market, _____ the final consumer prices. And therefore we had also produced two webinars on rate design. I think it's sessions eight and nine of this webinar series, where you can actually learn more about this _____. So this is now a market where you have slightly more elastic demand, but what I'm actually more interested in is also the ability of the buyers of electricity to say I need more electricity during these hours, and I can also buy less electricity during other hours. So, really, to have significant flexibility in the demand, which allows you to buy more electricity in times of lower wholesale electricity market prices.

So, for instance, here you have a market situation, an hour with a lot of PV and wind in the systems. So it would be great if for instance your industrial sector would say hey, during these hours we'll increase our production, we'll produce more copa-steel or whatever it is. So we buy more electricity during those hours, because the prices are relatively cheap. Whereas in hours where we have little PV in the system, and prices are relatively high, I'll try to decrease my demand, and therefore I'll also decrease my costs. So establishing demand-side flexibility is going to be very, very crucial for the electricity systems of the future. And it will also be one of the main intervention points for policymakers to really reach a more stable wholesale electricity market price, and to avoid some of the fluctuations that you could see in renewable energy based power systems without any demand-side flexibility.

So. Just a quick summary of our major findings here. Once again, it is clear that PV, adding PV to the system, actually reduces wholesale electricity market prices. This has an advantage for the consumers of electricity. They're normally quite happy with this, because they have to pay less for the electricity. But it also has some implications for refinancing power plants via wholesale electricity markets altogether. And it also undercuts the competitiveness of solar PV in wholesale electricity markets if you keep on adding more and more solar PV to the system.

Of course, what also helps, and this is also part of this webinar series, is allowing solar PV to be used as well in the other sectors, in the transport sector, with electric vehicles, but also in the heating and cooling sector. But this is going to be discussed in the next webinar. But this is also one of the parameters you have to keep in mind in order to stabilize wholesale electricity market prices.

And policymakers can apply additional measures to counteract these trends. As I mentioned before, you can engage more in market coupling, grid expansion with your neighboring jurisdictions, or—and this is probably the most effective one—is introduce a valid carbon price, which would then allow the profit margins for power producers to increase in wholesale electricity market prices. And, as I mentioned before, as well, what needs further investigation is really how the wholesale market could function in fully decarbonized electricity systems, where you no longer have fossil fuel power plants as price setting technologies, but alternative technologies, maybe biomass, maybe storage, maybe more flexible demand. And this definitely needs more investigation in different markets around the world, because the situation will be slightly different in all of the countries with different technology mixes, with different degrees of interconnection with neighboring countries, and so on, and so on. So this really needs some country-specific analysis.

So thank you very much for staying with me for the full hour. I hope this was interesting for you. I hope the graphical illustrations helped you to understand this relatively complex topic. Here is a list of further reading, as always. And I'm very grateful, again, for the International Solar Alliance and the Clean Energy Solutions Center for providing this platform. Looking forward to hearing you again in the next webinar session. Now, as always, just a few knowledge checkpoints, a few multiple-choice questions. Enjoy and have a very nice day.