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The Role of Rate Design, Part 2: Time-varying Rates, Locational Pricing, Cost-benefit Analysis, Two-way Rate Design

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Webinar Presenter

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David Jacobs Welcome, everyone around the world, to this next training session from the International Solar Alliance Expert Training Course. Today's session is going to be on rate design. That's actually the follow-up of the first rate design session 8A. As already mentioned, this is a combined training course from the International Solar Alliance and the Clean Energy Solutions Center, and we're dealing with large variety of subjects related to solar policies. I'm David Jacobs, founder and director of the consulting firm IET, and I'm very pleased to guide you through this lecture today.

So, first of all, let's look where we are. As you know, there's eight different training modules. Here, this training on rate design, is still part of module one. You're looking at the second of two sessions on rate design. And please, keep in mind that there's also other relevant related training units, which might be interesting for you—namely, session two on the introduction of solar policies, in case you haven't really dealt with solar policies before.

Then, an index training session on compensation mechanisms—sessions three—and then, also, a deep dive on net billing and net metering and other self-consumption policies which are dealt with in our session six. So, please, also check out the other training material available in this course. Here, just a quick overview of this training session. So, first of all, we'll define the learning objective, then, come to the core content of this webinar, which is understanding smart rate design. Last time, we looked at traditional rate design; now, we look at some of the more innovative rate design, which have been experienced in many jurisdictions around the world for the last couple of years.

Then, you will, as always, get some further reading material so you can continue your research, and, at the end, there will also be a quick knowledge check with multiple choice questions. So, first of all, let's look at the learning objective. First of all, we will recapitulate the various objectives which are related to rate design. We already discussed them in depth in the last session. Then, we will move on to time-varying rates, which is an important part of smart rate design.

Later, also look at some innovative approaches regarding locational pricings, some differentiated pricing incentives—pricing as depending on the location of the prosumer, of the PV system on the rooftop. And what is very crucial—we already discussed this also in the last session—is a more in depth understanding of the costs and benefits of distributed generation in general and roof-mounted solar PV in particular, because this will then also inform how you should structure your rate design in your country. And, last but not least, we will also have an outlook on two-way rates, but there will be a set of other training sessions in this training course which will particularly deal with this subject. First of all, let's have a quick recapitulation of what we discussed in the previous session. First of all, it became clear that future power systems will require a lot of flexibility, not only from the power generation side, but also, from the demand side.

And this is primarily due to an increasing share area of very renewable energy sources—that being solar PV and wind energy—and since we cannot control the output—or not in the same way—control the output as for conventional power plants because they're weather dependent, we then have to increase the flexibility of the remaining conventional power plants, and also of the demand side. And, as you can see here, from this graph, there will be periods where we need to have an incentives of less electricity demand, but there might also be periods where we might want to have an incentive of more electricity demand. And these—well, time-varying and also space-varying incentives are very crucial, and they will be discussed today in our session on smart rate design. Here, again, an overview of the traditional objectives related to rate design—so, cost recovery. The utility or the network operator needs to recover all the costs defined in the system.

Cost efficiency is, of course, the overarching objectives that you have, not an over-billed system—that you don't have too many transmission and distribution lines, but you're creating just the right amount of all components of the electricity systems in order to come to the least cost scenario. We discussed, also, the cost causation principle—that's the people or the customers who are responsible for using the electricity grid. Many times, during peak hours, they should also pay the fair share for maintaining and upgrading the existing grid infrastructure. And we also discussed cost allocation and affordability—that maybe, for certain consumer groups, certain exemptions are needed 'cause they're not able to afford higher rates. And also, in some developing countries, we see cross-subsidies from the industrial and commercial sector to the residential sector as a matter of cost allocation in these countries.

And then, we discussed—in more in depth than now—newly emerging objectives—namely demand side flexibility as just mentioned before with this slide; enabling innovations and integrating new technologies, including rooftop solar PV. We need to come to a design where we balance utility interest and prosumer interest by rate design. Also, incentivizing energy efficiency, customer empowerment, calculating the fixed cost based on the long-term perspective, and also, we said that we should deploy any changes to rate design very gradually in order not to have such a too strong impact on certain customer groups by changing the rate design. Now, this is just a recapitulation. Keep this in mind when we also discuss now more in-depth smart rate design options.

We also looked, last time, already at potential effects of prosumerism—so, that means someone who was previously a consumer, now becoming also a producer of electricity. [Break in audio] effects, of course, on how network costs are share, and, as we have explained in more depth in the last session. This might actually lead to affect where costs for network upgrades, network maintenance, network investments—I actually shifted from prosumers to non-prosumers as it is, again, indicated in this graph. However, always keep in mind that usually, in most jurisdictions around the world, the share of residential rooftop installations is still very small. So, the effects of these small-scale systems on the few households have a very limited effect on the overall cost recovery and rate design in the countries.

Only when you reach higher shares of penetration of distributed generation—let's say one-and-a-half-two-three per cent, then, you might have to look at rate design changes. And we also said that it's crucial to also look at the benefits of distributed generation because they should also be taken into account. So, we will have a closer look at the cost benefit analysis of distributed generation in a couple of minutes from now. And, as I mentioned before, other policy objectives which are not directly related to the cost causation—for instance, energy efficiency measures, customer protection, transparency—they should always also be taken into account, so you find the right balance of the various objectives that are related to rate design. Here, again—the glossary we already presented at the last session, so in case some of the acronyms or abbreviations are used, you always know what we're talking about.

So, in the last session, we talked about primarily these three components of traditional rate design—volumetric charges, fixed charges, and demand charges—which can be implemented based on the old school existing metering infrastructure. And in today's session, we will look a bit further into smart rate design, looking at time of use rates, critical peak pricing, real-time pricing, and locational pricing. And this is the first important takeaway is that these smart rates can only be implemented when advanced metering and infrastructure—AMI—is implemented and rolled out in the respective jurisdictions. And, as I said, before, last but not least, we'll have a short outlook into prosumer rates—so, that means two-way designs or one rate for purchasing electricity from the utility, from the supply company, and the other rate for feeding in electricity into the grid—the excess electricity from a prosumer-oriented system or the entire electricity on the feed-in tariffs for total electricity generated by roof-mounted PV. So, first of all, let's look at some of the technical requirements.

As I said that AMI is required for this advanced metering structure. You can do a certain amount of time use tariffs with a normal metering infrastructure; however, you would need—this would need to require a meter that is capable of tracking at least two billing periods. So, if you have a very basic meter who is at least able to track off-peak and peak electricity consumption at different times of the day, you could also work with this for a start. However, if you want to become more granular, go into real-time pricing or locational pricing, then, you would need to implement even more advanced meters. As you probably know, many jurisdictions around the world are currently rolling out smart meters.

This, of course, [Break in Audio] especially in the first place when you're replacing meter increases the metering costs, because a smart meter's more expensive than a traditional meter, and also, 'cause someone has to come to your house or replace the meter and this, of course, increases the metering cost for the final consumer. So, it's always a big question who is actually paying for this rollout. Sometimes it is only the utility that pays for it; sometimes, it is a combination of payments by the customer, who pays maybe a monthly fee over a certain period, and then, the utility pays the rest. There's different cost sharing arrangements between customers and utilities. And last, but not least, we should also mention that not only the metering infrastructure might have to become digital and smarter, but also, the appliances that are used in a household or in a small scale commercial business will have to become smarter, because many researchers have found that even though we might be able to implement policies in order to give consumers certain price signals, they might not react to it because they have different things to do over the day than to well, manage all of their hundred appliances in the household and only run the washing machine at night time when electricity's the cheapest.

So, automated systems will definitely play a huge role of increasing the level of demand flexibility in the residential, commercial, but also, of course, industrial sector. We already have quite a lot of automated demand response in the industrial sector, but now, with technology advances, we'll probably see more and more of this also coming to the commercial and residential sector. Here, just a few findings on who's currently leading smart meter rollout. It's actually China, with more than 408 million smart meters already rolled out. We also see other jurisdictions in North America and Europe which made quite far advances.

For instance, Ontario—a province in Canada—has already 100 per cent smart meter penetration for all sectors—so, that means residential, commercial, and industrial. Japan, we also have aggressive targets for rolling out smart meters. Also, in the European Union—currently 40 per cent of the citizens have smart meters. And by 2020, this is expected to increase to 72 per cent. Italy is a key jurisdiction who started at an early stage with smart meter rollout.

Also, Sweden has set quite aggressive targets at an early stage. And, by legislation—by European Legislation—the other countries will now also follow in the next 5 to 10 years. So, we will see a new way for smart meter rollouts in the European Union as well. To summarize this, again, you see most of the smart meters are currently installed in China, then, followed by the United States, Italy, Japan, Spain, and the rest of the world. So, this is not only developed countries—so-called developed countries—that are rolling out smart meters, but also, some emerging economies in developing countries are making progress on this because this is simply a pre-requisite, especially, in the commercial and industrial sector for coming to more flexible, smarter, power systems in the 21st century.

So, first of all, let's look at time-varying rates—namely, time of use rates. "Time of use" means that depending on the hour that you use your electricity, the electricity price—or the network tariffs that you're paying—will change. And this is, of course—the primary incentives for this is to shift consumption from peak periods—where producing electricity is relatively expensive—to off-peak periods where you already have a lot of power generation in the system, low-cost power generation in the system, and where also, you don't have any grid constraints, and therefore, the system—it's much cheaper to generate electricity at those times. Higher prices are designed to deter the consumption, then, from peak times and you normally have like, stepped rates. So, you have periods and shorter periods and then off-peak periods where you have lower rate payments or electricity prices. And this has already been used for larger scale electricity consumers—industrial and commercial—for many decades.

So, this is something new—what is new that these rates are also being tested out in the residential sector and residential customers will have to get used to it, and policy makes have to figure out to what extent this time of rate design are actually feasible and also necessary for the residential sector. I already mentioned that we normally have peak, shorter, and off-peak periods. We need to have the granularity, then. The time-based granularity can vary, and some jurisdictions, you only have two different rates. For instance, one normal payment show the payment over the full day, and then, maybe just one hour of peak electricity prices from 6:00 to 7:00 in the evening.

However, you can also make this much more granular and have more granular intervals—15 minutes, 30 minutes, one hour—and, of course, a wide range of time—varying options, as you can see from some of the slides in a couple of minutes. What is very crucial when using time of use rates, is the ratio that you set between off peak and peak rates. If you really want to incentives customers to shift their consumption—primarily in the residential sector—then it is quite important to have quite a bigger ratio between off-peak and peak rates. For instance—some research in the United States has shown that when you have a ratio of five to one, then, you have a much higher incentive for customers to switch off electricity consumptions during peaking hours and move towards off-peak hours than when you just have, for instance, a two to one ratio. What is also very crucial is the peak period duration and the peaking frequency.

Once again, here, for the residential sector, it is important that the peaking periods do not occur too often or that they are not too long, because otherwise, there might be a dis-incentive for consumers to move into these time-based rates. Because you need to keep in mind that currently, in most jurisdictions around the world, these time of use rates are still optional. So, you can either remain in your off _____ rate tariff or move to a time of use tariff. In some jurisdictions—like, Hawaii, for instance, or California—for prosumers—so, small scale PV system owners—these time of use rates are no longer optional, but they have become mandatory. However, for the general consumers, in most cases, they're still optional. So, by making the peak periods too long or making them appear too frequently, you might actually scare consumers off, and they might not be willing to move to these rates on their own.

Here's just a few examples from Hawaii, from Colorado, and from Minnesota. Don't be surprised that you see a lot of examples here from the United States. They have been actually the front runner in experimenting with smart rate design in the last couple of years much more than other jurisdictions—for instance, Germany, where also one could expect that this is happening. We see here the difference between off peak and peak periods. You can see a large variation in Hawaii—it's only attracted 2.8, whereas in Minnesota, during the summer, you see quite a big difference here, which is partly due to the fact that during the summer months, of course, you have a lot of electricity consumption that is used for air conditioning.

So, there has been quite a sharp increase of electricity prices in time of use rates during these periods in order to give customers a signal that they should reduce electricity consumption during those rates. And this is why you see rather a bigger ratio here. Now, we come to one variation of time of use rates, which is critical peak pricing, and this is actually introduced for normally just certain hours of the year or very few days of the year where you might have certain emergencies in the grid or where the grid is so much under stress that these emergency critical peak pricing is necessary to give the necessary pricing to customers to reduce the electricity demand. These critical peaks are normally several times higher than under normal conditions, so, even compared with normal peak pricing, and what is important to notice—that prices are usually predetermined. So, it is clear that the critical peak price is, for instance, 10 times higher than the shorter price or the off-peak price.

However, what is not predetermined is normally when it happens. So, the customer needs to inform a couple of hours or a couple of days in advance when such a critical grid situation will occur and when these critical peak prices will have effect. Here's just one example from South Africa, where Eskom is offering critical peak pricing under the rural flex and tariff. So, you see on the right-hand side that these critical peak days have occurred 17 times in 2015, whereas, in the other 248 days, there were no such critical peak prices available. And what you can also see when you compare the normal tariffs in the left-hand columns with the critical peak prices on the right, you see there's quite a huge difference in the prices in order to really give the incentive for customers to significantly reduce their demand, thus stabilizing the grids and thus also avoiding blackouts of the system or brownouts—rolling brownouts—altogether.

Yet another variation of time-varying rates—peak time rebates. This is actually used also in many jurisdictions around the world, and instead of penalizing participants of this programs, they actually get a karat. So, they are being remunerate for this, so the participants actually paid for the load reductions, which they contribute to during critical hours of the grid. So, customers just pay the regular rates at all hours, but, they receive a proportional rebate when they reduce their consumption against the baseline, which you need to calculate in advance when the grid is under stress. So, there's a financial reward and no penalty, and what you have to keep in mind is that these peak time rebates are frequently considered a training wheel—so, a starting point—for jurisdictions, which might want to move to critical peak pricing, which is the option which we will discuss afterwards.

Here, just one example from Baltimore and the United States. You saw that the utility, BGE in Baltimore, was very successful in enrolling customers in peak time rebate program—over one million customers participating. And these customers are notified with a phone call or an e-mail or a text message from their mobile phone a day before these energy saving days, and then, the customers gets a reward on their bill for reducing their electricity demand during those hours. And this has actually resulted in a system where 290 megawatt of peak demand reduction could be achieved. And this is frequently very important for utilities to reduce this peak demand, because this is normally what is most expensive for them, where power generation is most expensive and where also, additional grid upgrades might be necessary in order to meet traditional peak demands.

Now, another option that I wanted to discuss with you is real-time pricing. So, instead of determining different prices just for a few hours of the day as we normally see this in time of use rates, in real-time pricing, we're normally trying to follow more closely the real-time costs of the system—that means hourly or even half hourly or 15-minute changes that we also see on the wholesale electricity markets. So, what we do in this case, is really linking the retail electricity price to the wholesale electricity price, and this way, the customer gets, well, a large part of the price signals that you would get from wholesale market prices who will also be included in the retail market price. And depending on the customer class, the participants are made aware of hourly prices either a day ahead or hour ahead basis, depending on how your wholesale electricity market is structured. Normally, in the past, we only see—so, large customers—commercial and industrial—participating in these real-time pricing programs, however, as I said before, due to an increase of renewable energy—so, _____ prosumerism.

There's more and more jurisdictions considering these smarter rate designs also for the residential sector. So, here's just a comparison where you see, for instance, the difference between a flat or numeric rate here with a dotted green line, then, a normal or typical time of use pricing rate, and then, what you would see in jurisdiction—in specific jurisdictions—as hourly market prices. So, you can see there might even be negative market prices at the nighttime, and then, you have very high electricity prices on the outside market during the late afternoon. So, this would also be embedded in your retail electricity price. And then, the argument is that if you have—if you confront residential customers and prosumers with these type of price incentives, then, there will be a much greater incentive to actually install solar PV, because if these peak prices actually coincide with generation periods of solar PV systems, you're actually able to cut off these peaks via your own self-generation of solar PV on your rooftop.

Or, if it's maybe an hour later or two than your peak output of your solar PV plan, we might actually combine the solar PV system with a small battery, and this way, avoid a lot of the usual electricity payments that you would have during the day. So, this would be the argument for such real-time pricing. However, there is, of course, advantages and disadvantages of time-varying rates. Here, just to give you a quick summary again, what we have actually discussed so far—so, time of use rates—you can see here the price varies from certain hours during the day—that you have slightly higher prices during the period—and critical peak pricing is here. Quite significant price increase over normally just a couple of hours or couple of days in the year.

Peak amount rebates is actually the reverse, so, you can actually reduce your electricity bill if you switch off some of your consumption during certain hours of the day. And last, but not least, we discussed real-time pricing—so, the time varies according to the price signals that it's given from the wholesale market rate. This is then handed over directly also to the retail electricity price. So, the advantages of these time of use rates is they encourage more efficient timing of electricity use. They reduce the need for expensive peaking power plans so that customers can save money by shaving the peaks overall system—will become less expensive on the one hand, and, on the other hand, you also have more financial incentives for installing solar PV or other distributed generation technologies in order to cap your own peak demand during these hours of PV generation, in case that they coincide.

This will then lead to an incentive for PV and distributed generation, but, as mentioned before, they could also help to reduce power outages, because you have a much clearer signal for the consumer when electricity demand needs to be reduced and when power can be consumed without any problems for the system. What many people argue, many experts argue is also that they educate consumers and they will increase the awareness on when electricity generation's actually more expensive, and when it is less expensive, because this is normally reflected in the tariffs and, of course, in the end, could also trigger demands on flexibility and thus help integration of _____ renewable energy technologies into the system. The disadvantages of time-varying rates are the increasing complexity. This can be easily handled by commercial—larger scale commercial and industrial customers. However, some experts say that it will be increasingly difficult to understand the electricity bills for them—for these residential customers—so, we should definitely keep this in mind and not make the system overly complex.

What they typically require, as mentioned at the start, is advanced metering infrastructure, smart meters. This, of course, comes with a cost for the society as a whole, so, it is important to check whether actually the money that you have to invest in upgrading the infrastructure, the money that you need, is actually lower than the money that you would save by increasing flexibility and by, also, meeting the other objectives related to time based tariffs. They can also, in some cases, increase the customer bill, which is very sensitive, of course, for policy makers. So, this why we normally start with certain tries in certain areas to see how customer groups are actually being affected, that you don't roll it out, maybe, for the entire population altogether—that you make them voluntary and not mandatory at the start. And they also may penalize certain customers or custom classes—for instance, small scale businesses, small scale commercial customers—who cannot easily shift the power usage that they have, because when you run a store, you simply have to consume electricity for certain appliances when your store is open, and you cannot just switch off the light or decrease air conditioning from 5:00 to 6:00 in the evening just because electricity prices are higher.

So, it's always a question, as well, which customers can react to what price signals. Looking more closely at the advantages and disadvantages of peak time rebates—the advantages, of course—that they provide a certain level of bill protection, 'cause electricity bill cannot increase but only decrease. So, this is, of course, very beneficial for the customers, and it is also normally seen as positive by policy makers, so that the impact on the customers is reduced. And this can then, of course, also lead to greater acceptance among these stakeholders. The disadvantages, of course—the true cost of the electricity during these peaking periods are not reflected.

There's no price signal that will encourage distributed generation like rooftop solar PV, so, there will be no incentive for you to install a solar PV system during these periods, as you would get it, for instance, on the time of use for critical peak rates, time of use rates, or real-time pricing where you're able then to cut off your electricity demand during these periods. And what it is very difficult regarding peak time rebates is that you always have to calculate the baseline consumptions for every consumer, for every customer group first, and if you have inaccuracies in this, then, this can mean quite significant and unnecessary cost increases for the utility. So, this, of course, make the implementation of the system quite complex. Critical peak pricing is a further incentive for load shifting, mainly to stabilize grids. So, when you come from a jurisdiction where you frequently are facing brownouts or blackouts where you're always behind *[Break in audio]* expansion in order to meet a new demand, this might actually be a very useful pricing methodology to avoid blackouts, because this way, you can get very clear price signals on when the electricity grid is very unstable.

Of course, you always have to contact all the customers that are supposed to react, but with today's communication technologies—smartphone's SMS that you can send—that should actually no longer be the biggest problem. The disadvantage is, of course, that critical peak pricing does not reflect the real system cost during critical events, because you might have one very critical event and one less critical event, but you have the same price, because prices are predetermined. That's one reason why real-time pricing might be more effective from this point of view. And peak prices can also increase electricity bill quite significantly, which could, if you have an unbundled market, actually favor the supply companies who simply get an increased electricity bill, even though they might actually procure electricity for less money themselves, and thus just take the revenues on their own. Now, let's take a look at the advantages and disadvantages of real-time pricing.

They, of course, provide the best available price signal—about marginal value of the power system—to the customer, because, well, it is real-time, and it is not just a proxy as we see it on the time of use rates or even peak pricing rates. And this way, these real-time pricing cannot unleash innovations and distributed generation, of course, always depending on whether the peak electricity demand or the peak prices actually coincide with the generation of solar PV. This is still the case in many jurisdictions around the world, however, please keep in mind that with an increasing share of solar PV, once you get to 5-10-15 per cent, actually, wholesale electricity market prices will be depleted during these periods of the day, which has caused the Merit Order Effect. We're actually going to have one session on the Merit Order Effect in this training. So, that means that once you reach higher shares of solar PV, then, of course, real-time pricing can also be a disadvantage for installing solar PV, because wholesale market prices will go down and this will then directly pass on to the final consumer, to the retail electricity price.

So, this is always a changing picture. The disadvantages is, once again, the need to automating technologies, advanced metering infrastructure, in order to allow customers to respond. As mentioned before, these are primarily available now. They're large scale commercial and industrial sector; not so much in the residential sector. And what is very important to note as well—that there's quite as uncertainty about the electricity price and quite a large degree of volatility in the electricity bills that customers may face, and there's still doubts whether customers will actually accept such a high degree of uncertainty and volatility in their bills.

So, these were the four major design options when it comes to time-varying rates. Now, I want to spend five minutes to talk with you about locational pricing. So, time is one variable you can change when it comes to smaller grid design, and location is the other one. And the reason for this is, of course, that in power systems, you might have grid constraints at certain part of the grids where power generation then becomes more expensive or where you would need additional generation capacity, and you might also have zones where this is not the case. So, this is why many jurisdictions are now also experimenting with geographically differentiated price signals.

We have already seen this in many countries around the world with regards to the power generation and the transmission grid. What we're not seeing so far in many jurisdictions is also price differentiation by location for the distribution grid. So, this still uncharted territory to a large extent. What you have to keep in mind is that usually, electricity networks are either zonal or nodal. As you can see here in this depiction, that means in nodal networks, each node of the electricity network would get a different price, and in zonal networks, you're actually defining certain zones, and within these zones, every customer would actually have to pay the same price.

As I said before, on the wholesale market level, this has already been implemented in many parts of the world. Most frequently cited case study, when it comes to nodal pricing, is usually in Texas in the _____ system in the United States where each and every node of the electricity system, you will get a different price for power that is generated. And this reflects the scarcity of generation capacity at this specific node. So, for instance, when you're in an area where you have huge grid constraints, where electricity cannot flow easily and where there's little generation capacity, then, you would receive higher prices—here indicated in this red zone—for the power that is generated, then in other parts of the jurisdiction. And this is, of course, an incentive to increase power generation in zones where you have grid congestions and where you have limited power generation capacity.

Zonal pricing, as I mentioned before, means that you have uniform, marginal prices within each of the zones. So, for instance, in Norway or in Italy, we have five different zones ranging from North to South of the country, but, within these zones, you actually get same price for each kilowatt hour that is produced. So, you just have to keep in mind that this already exists for power generation in wholesale markets. Now, we're looking into a future where these kind of locational price differentiations might also happen in the distribution network. And one option which is currently tested and discussed, once again, in the United States, is so-called "hotspot pricing" where you identify certain hotspots within your distribution network, where you have a lack of power generation, where you have frequently congestions within the grid.

And then, of course, you want to set locational price incentives within these regions that distributed generation or other power generation sources—PV generation—will be installed. Then, you need to have the right price signal, and the question is whether you actually get a credit or a rebate on your electricity bill, or whether these price incentives will then be structured differently. So, by doing this—for instance, you have grid congestion in one of these hotspots. You can actually avoid a lot of costs which might be necessary for upgrading the existing grid infrastructure and therefore, rather have incentives for distributed generation. As I said before, this is only just tested in a few cities/jurisdictions around the world.

Here's just one example from New York—from Brooklyn—where we saw some hotspot pricing which was tested. There was a so-called Con-Edison Demand Management Plan, which tried to incentivize distributed generation technologies, including solar PV, to actually avoid upgrade costs for the substations within the area. And the upgrade of the substations alone could have amounted into total costs of up to $1 billion. So, in these areas, you actually had specific incentives for customers to deploy solar PV on their rooftop in order to avoid these costly upgrades of the distribution grid.

Another option is distribution locational marginal pricing, and this is very similar to the nodal pricing that we had previously discussed based on the case study in Texas—the _____ system.

So, you would also then define several nodal points within your distribution market and then sub-hourly or hourly, pricing nodes at each node of the distribution system so that you really come to a very granular price differentiation that you have within the distribution system, and this way, you would then, hopefully, get the right price signals. Of course, as you can already see from this graphical illustration, this is quite complex, assigning different values, different prices, to each of the nodes. This is normally why most jurisdictions start with zonal pricing and then, move down to nodal pricing *[Break in Audio].* An interesting example here, once again, from the United States is that you should actually publish maps for everyone available on the internet to indicate in which part of the distribution network you're facing constraints—here, highlighted in the red areas—and in which part of the distribution network you're not facing constraints. And here, the recommendation from the Solar Industry Association of the United States was then to say, "Okay. When we publish these maps, we should indicate how much distributed generation capacity's actually needed, and also, what is the value of the avoided investment per megawatt installed"—so, what would be of the value for the utility to upgrade the grid and put new generation capacity there.

And this could then also be used as a proxy for the price signal that a distributed generation producer—a solar PV producer—could get to see to know whether investment in solar PV actually would be positive or negative for the society as a whole in this region. Locational rates, as you've seen from this discussion, are quite complex, however, they have very important advantages, because they can help to overcome distribution network constraints, which will most likely occur more and more frequently as we move to more and more complex power system with small scale generation, also, with electrification of the transport sector—so, additional loads within the distribution networks, with also a sector couplings—or coupling the electricity and the heating sector. So, as we move towards more complex power systems of the future, the distribution network will play a more and more important part—so, also making the distribution network more intelligent, smarter, will require that at least some of the elements of the locational incentives that we just discussed will probably have to be implemented, because it can also help to avoid very expensive investment in grid upgrades, grid expansions.

Of course, what you always have to keep in mind, is that locational constraints can appear and also disappear again. Once you upgrade the grid, for instance, your constraint will no longer be there. And then, on the locational pricing, then also, your price signal will be gone. So, this can be very difficult, of course, for someone who's buying a solar PV system with an amortization period of 10 years. So, as an investor, as a private household, you somehow need to foresee at least a period of 5 to 10 years in order to make an investment.

And since these locational price incentives can appear or disappear depending on grid upgrades and also, the development of the electricity system as a whole—also, depending on the demand—this might create a certain uncertainty, and it is not clearly whether these pricing signals alone will actually trigger investment in distributed generation and solar PV in particular. And there might also be a lack of acceptance that, for instance, I pay a higher electricity price than my friend who lives 100 meters down the road, who is then in a different nodal point on a different electricity zone. So, from an acceptance perspective, it is not quite clear whether these systems will actually work for the residential sector as well. Talking about all of the smart rates that we just discussed—so, time-varying rates and also locational rates—let's keep in mind some of the implementation options.

First of all, as already mentioned, you should probably start with pilot projects for specific customer groups and not roll out time of use rates or critical peak pricing for all customers straight away. So, you, first of all, start with a pilot. You analyze the effects. You analyze the impact on the rate payers, and then, you can still make some minor modifications and roll out the rate design to all customers. It is also important to make this new rate optional at the start, and then, maybe move to mandatory implementation at a later stage.

We also saw that some jurisdictions have opted to making rate design changes only for prosumers—so, only for people who have a solar PV system on their rooftop and not yet for all electricity consumers. However, this might also only be the first step, and rate design for all customers will be necessary at a certain stage. And the gradual rollout of advanced metering infrastructure should, of course, also be planned in order to make these tariff options feasible. And, as most of you already know, you should, of course, start with industrial and commercial sector, because here, you have most of the technical equipment available already to actually react to price signals, and later on, you can still consider rolling it also out to the residential sector where most studies have shown that demand flexibility's actually the lowest. So, this was just an overview of the smart rate design.

Now, let's look again at the interest that different actors had. We discussed this already in the last session—what are the interests of different actors? What are the interests of the power system altogether? So, when you come to change with rate design, you have the utilities who always argue for more certain cost recovery and revenue security. So, they will probably come to you and argue for more fixed charges and more demand charges, because this will allow them to refinance their system.

And then, you have the prosumers—the PV generators—that come to you and they say, "How? But, well, you need to have incentives for solar PV on our rooftops. We need to have customer empowerment, and also, incentives for enabling new technologies into the system." And then, of course, you, as a policy maker, need to say, "Oh. Well, there's also overarching general interest on the power system, of the society altogether, which are related to fairness, to affordability, gradualism—most of all, cost efficiency of the overall system, and then, of course, also, the flexibility that you need for modern power system—decarbonization of the power system, energy efficiency."

So, balancing these interests if very crucial when you come up with new rate design. And I just wanted to highlight this, again, with these three slides. In order to come out with a balanced and also fair rate design, it is very important for policy makers to understand the costs and the benefits of distributed generation. And in the last 30 minutes but also in the previous session, we have primarily talked about the costs that may occur due to solar PV generation, because these are normally the most obvious. And here are some of the costs for the prosumer or customer by installing the solar PV system on their rooftop, et cetera, then, also, cost for the system; system integration costs; lost revenue for the utility; lost for the system in terms of additional billing and metering; administrative costs.

We've discussed, also, the cost shift which may occur in prosumer-based power systems where some of the network costs are actually shifted from prosumers to non-prosumers. And, what you also have to keep in mind when you consider the costs, of course—the potentially reduced value of solar PV in high penetration scenarios. So, once you move to 10-20-30 per cent of solar PV in system, you no longer have the same assumptions for the benefits of solar PV than when you have in systems with only one or two per cent of solar PV penetration. However, to finalize these two sessions on rate design, I also wanted to take a look with you at the benefits of distributed generation, because they are frequently overlooked when discussing rate design. So, there's, of course, a benefit of avoided energy, because by having solar PV on your rooftop and then, coinciding PV generation with system electricity peak demand, you can, of course, have peak shaving.

You can avoid investment into new power generation, marginal generation displacement. Normally, as you know, the most expensive power plans are the marginal power plans that you need for meeting the last unit of electricity demand within the system. You can also avoid line losses and system losses by having distributed generation installed closer to the demand—closer to the load centers. So, not connecting larger scale power plans to the transition grid, but instead, connecting distributed generation directly to the distribution grid. You can also, of course—if you get the right signals via locational pricing as discussed before—have incentives to avoid upper grid costs of the distribution and transmission grid by avoiding congestions in the grid.

And there's a whole range of other benefits related to solar PV deployment. Grid support—you have to keep in mind that more than PV inverters are able to provide important ancillary services to the power system, including reactive power, voltage control, frequency response. We also have certain financial services of distributed generation and PV—for instance, fuel price hedges, because you're avoiding risk of the utility, of the off-taker, to buy fossil fuels on the world market where the prices vary quite significantly. Financial services, security services in terms of the more resilient and the more reliable power system—avoiding blackouts, like we've discussed before. Environmental services related to carbon reduction—carbon emission reductions—also important. Microeconomic benefits, job creation, less watt consumption and so on.

And what is also very important for many developing countries is that the deployment of solar PV is usually met faster than running a larger scale system. So, when it comes to grid constraints, power _____ constraints, and power generation capacity in certain areas, it is much faster to install a small-scale solar PV system on the rooftop than planning a large-scale centralized power system. And last, but not least, this is also more and more stressed aspect in energy policy making. It's part of the democratization of the energy system that more and more people will be able to invest in power generation, and hopefully, it will not only be the rich people, as it is sometimes, but forward, you could also think about special programs for allowing lower income households to invest in roof mounted solar PV. We will still have a few examples of this in our sessions on new business models as well within this training course.

Those are just a few of the benefits related to distributed generation and solar PV in particular, so, you have to keep them into account. When you do the rate design, you cannot just look at the cost which are associated with deploying distributed generation. Here, a quick summary, again, from an IEART report, summarizing, to a large extent, what I just said. I just wanted to show you some calculations that were done, once again, in the United States, on the costs and benefits of solar PV and distributed generation in different markets around the world. So, what you can see here quite easily is that the benefits are outweighing the costs by far based on the parameters that we just discussed a minute ago.

So, especially for power systems where we still have a small volume of distributed generation of solar PV, the benefits are by far outweighing the cost. And this is also why, in many jurisdictions, you avoid to introduce fixed charges and other restricting components of the electricity price and rather continue working with volumetric rates until you reach a certain share of distributed generation, and then, of course, you will have to take action. So, this was a discussion of the smart rate design. Now, I just wanted to give you an outlook on some of the two-way rate design, as we call it. So, one rate that you pay for consuming the electricity that is fed in that you get from the grid, and then, the other way is then feeding in electricity that you produce from the solar PV system on your rooftop.

We're talking about classic net metering, net metering 2.0, feed in tariffs, net feed in tariffs, and also other compensation mechanisms for distributed generation and new business models. So, this is why I wanted to highlight session two, again, on the introduction of solar PV policy, session three on compensation mechanisms, session five on feed in tariffs and premium feed in tariffs, session six on net billing and net metering, seven on net FITs, and last, but not least, two very interesting sessions on new business models within the solar PV sector. So, all of them will be interesting for you if you like this webinar. There's, of course, a lot of reading material available here. Some are reading on smart rate design and already, in the last session, I gave you quite a lot of reading on general rate design and rate design for distributed generation futures.

So, thank you very much for your attention. It was a very big pleasure to present for you. I hope to hear you again in next training session and have a good rest of the day. Thanks a lot.