Energy Resources< Economics and Environment
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Lecture 6 Part 2
Energy Economics- Tutorial

So, today we were going to revise the concepts that we have already discussed in the energy economics course, we will apply these to an example.

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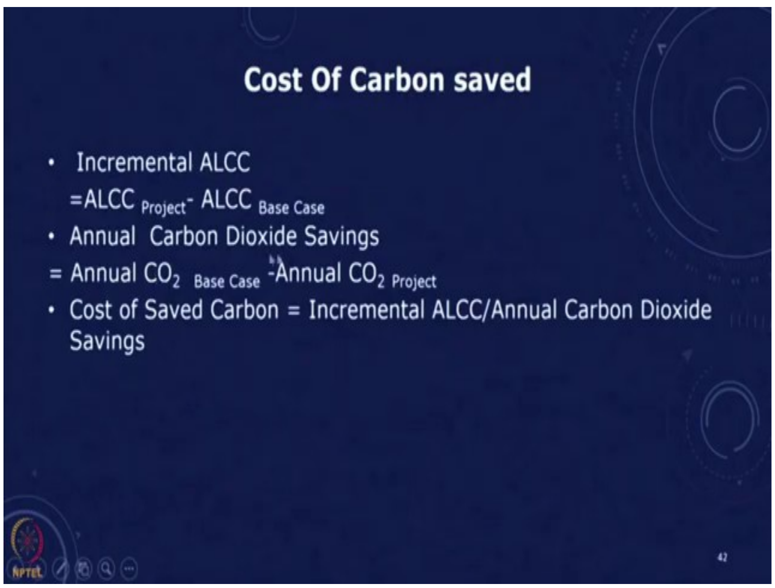

So we have already discussed the cost of saved carbon and the cost of saved carbon, we said that when we look at a renewable option, we will take the incremental annualized lifecycle costs. That means that annualized lifecycle cost of the project minus the annualized lifecycle costs of the base case.

Also, we will calculate the annual carbon dioxide savings, which will be the CO_2, which will be there in the base case. If you did not have any intervention and in the project we have some CO_2 savings. So, the incremental annualized lifecycle cost, divided by the annual carbon dioxide savings will be the cost of saved carbon. So let us take an example and calculate this for this example.

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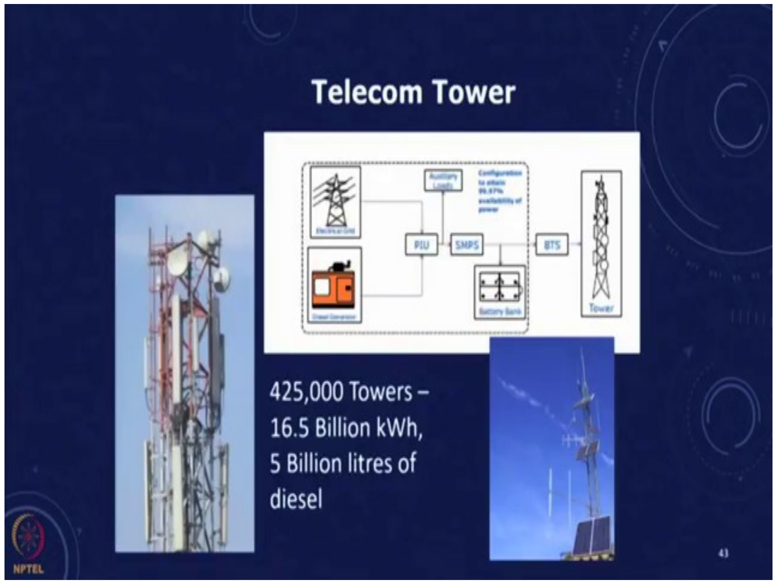

So we all across the country, we have a large number of telecom towers and the cell phones and mobile phones are available in all areas, including several remote areas. Amongst these telecom towers, there are many locations where the electricity supply is not there. There is no electricity grid or even if the electricity grid is there, there are many disruptions or there is load shedding, so several of the telecom towers have a provision for backup power.

So this is slightly old number, like about five or six years back, we had about 425000 towers, which made a which in which we had 16.5 billion kilowatt hours of electricity and 5 billion liters of diesel being used. These numbers would have increased. But just to give you a sense that this is an important induce where a reasonable amount of electricity and for the backup power, diesel is being used.

So we will try and take an example of particular telecom tower with a peak requirement of 5 kW and an average requirement of 2 kW. Average requirement of 2 kW means throughout the day if we look at the average it will be a power rating will be 2 kW and we are looking at continuous operation of the telecom tower.

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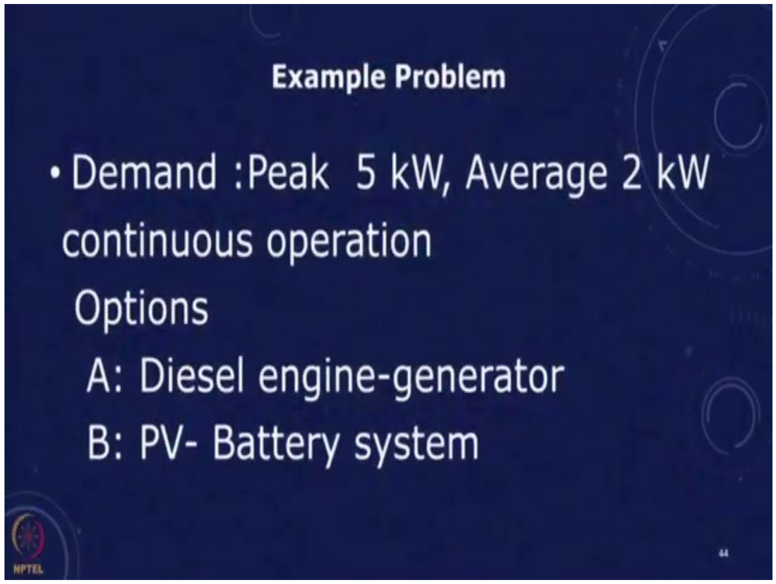

We want to consider the economics of two options. The first one is where we have a diesel engine generator and the second one is where do we have a P.V. battery system. In both these cases, we will presume that there is no grid supply and this is a standalone supply where it is going to meet the requirement. So this will be designed to meet the requirement of an average amount of 2 kW. Now we are given the following data for both these options.

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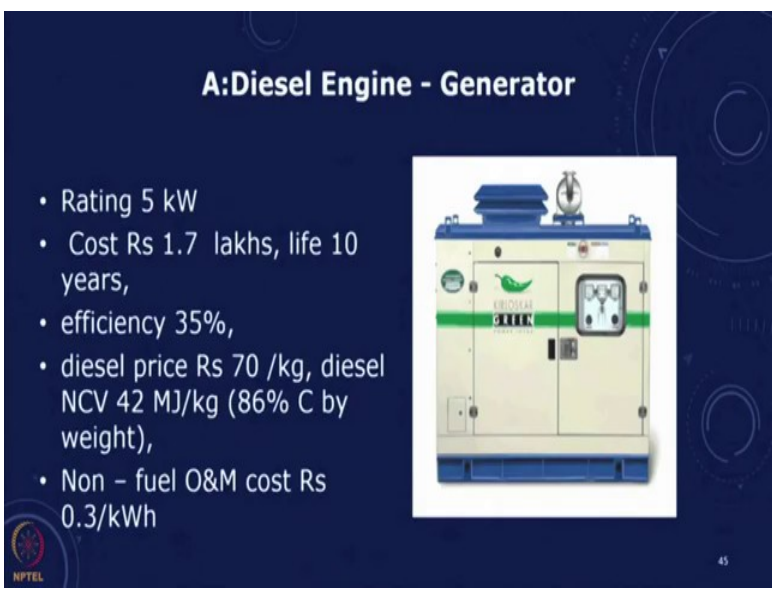

Option A, if you have a diesel engine with a rating of 5 kW, the capital cost is ₹ 1.7 lakhs; this is there in your tutorial sheet, problem number 4. The life is 10 years, efficiency is 35% and the diesel price today is about 70 ₹/kg, we have the net calorific value of diesel roughly around 40 mega joules, 42 mega joules per kg and the composition of diesel has 86% carbon by weight.

So, all of this we will use and then there is a operational and maintenance cost in addition to the fuel cost which is a non-fuel O and M cost which is 30 paisa per kWh generated. So we will again use this in terms of making the calculation this is for option A, which is diesel engine generator and so the engine generator will be using diesel and depending on the load, it will be operating at a particular rating.

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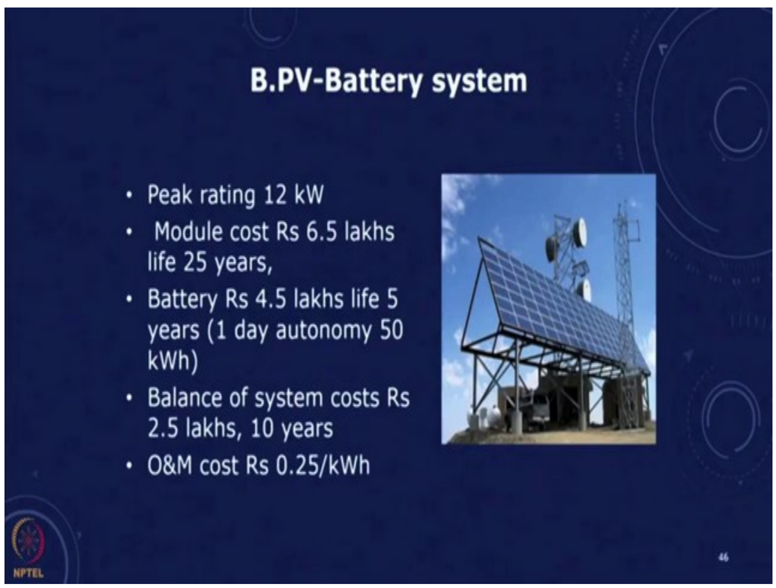

And the second option is where we have a PV battery system, so we have a PV system and please note here that the peak rating of the PV system is 12 kW when we actually need an average of 2 kW. Please remember that we are using 2 kW on an average for 24 hours. The for the solar the solar energy and the generation is going to be only available during the sunshine hours so that is why you have this kind of a rating.

The cost of twelve kilowatts of modules at present prices is of the order of about 6.5 lakhs. We will take the module life at 25 years. We have also planned to have in order to provide the requirement of the telecom towers throughout the day, we are going to provide our batteries and we have said that 2 kW in to 24 hours means 48 kWh.

So we planned for one day autonomy, that means for one day if there is no sunshine and no generation, the battery should be able to provide the requirement. So we are looking at a battery rating of about 50 kilowatt hour and an average cost of about 4.5 lakhs with a life of 5 years. We also have a balance of system and that balance of system is this, this will be like your maximum power point tracker, your power electronics and your controllers, and the balance of system life is typically of the order of about 10 years.

We are taking a cost of about rupees 2.5 lakhs and the O & M cost for the PV. system and there is no fuel cost for PV because the solar is free, solar installation is available and we are looking at an O & M cost of about 25 paisa per kilowatt hour, slightly lower than the non-fuel O & M for the diesel, but almost of a similar nature.

So for this, what has been asked is we are supposed to first calculate, what is the simple payback period for the incremental investment in B and then using a discount rate of 30% compute the cost of electricity generated in both cases.

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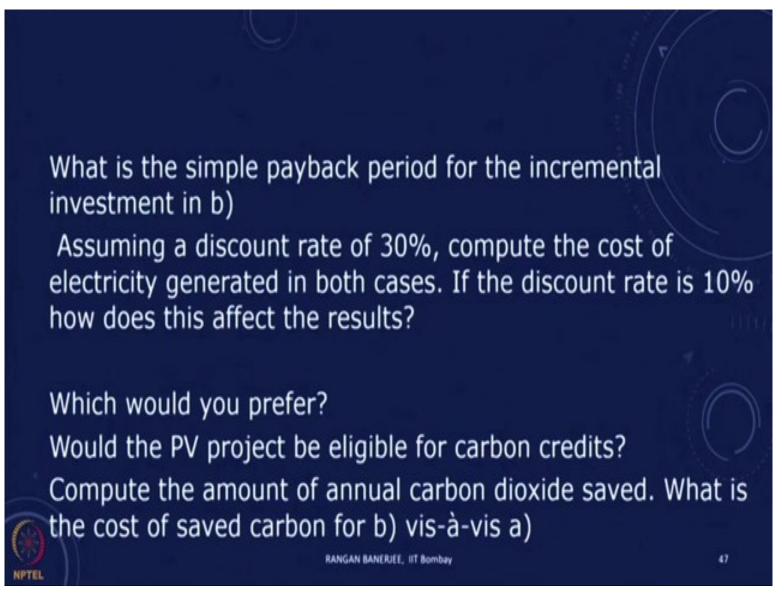

Which one would we prefer? Would the PV project be eligible for carbon credits and then compute the amount of annual carbon dioxide saved? What is the cost of saved carbon for B compared to A? And if the discount rate is instead of 30%, if it is 10%, how does it affect the results?

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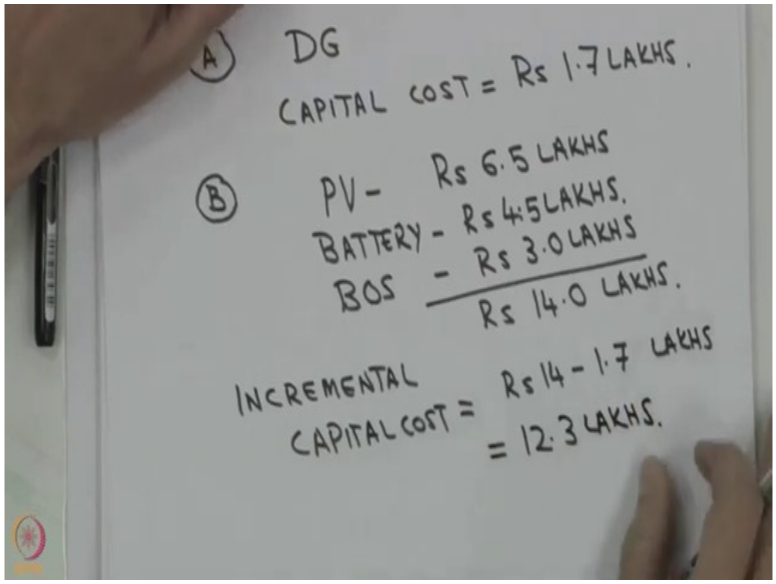

So, let us start with this problem. Let us start with option A. Option A is a diesel engine generator, DG., and it is given to you that the capital cost is, capital cost is ₹ 1.7 lakhs. So, the capital cost is 1.7 lakhs for the diesel engine generator as compared to this. Let us look at the capital cost for option B.

So option B has three components. There are the PV modules with a capital cost of ₹ 6.5 lakhs. We have the battery and in most of the PV battery systems, you will find lead acid batteries, some of the recent ones, you may find that we are using lithium ion batteries. So in the case of batteries, we are talking of rupee's 4.5 lakhs for the batteries.

And the balance of system, all the power electronics we are seeing, this is rupees 3 lakhs. So, let us just add this up. This is coming to rupees 14 lakhs. So you should note that the capital cost in case B is 14 lakhs as compared to 1.7 lakhs for the case A. So what is the difference? What is the incremental investment, incremental capital cost? Incremental capital cost, this is going to be rupees 14 minus 1.7 lakhs and that is nothing but 12.3 lakhs. So, keep this in mind and let us now calculate what is the difference in the annual cost?

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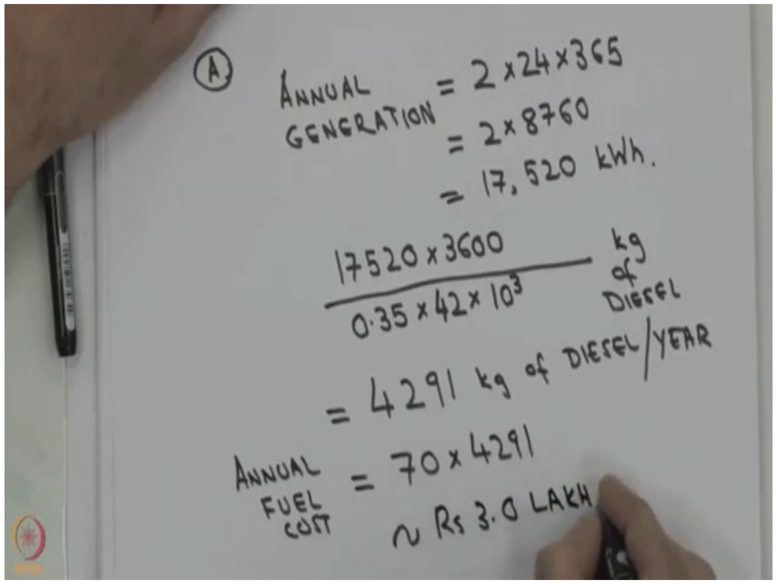

So in the case of A for the DG system, let us first find out for both these cases what is the kind of annual generation? So, annual generation is 2 kw/hour that means in an hour, 2 kilowatt hour into 24 hours in a day into 365, since this is the average and this is nothing but 2 into 8760 is 17520 kWh.

Now in order to meet 17520 kWh in the case of the diesel engine, we are using diesel. We are firing diesel in the engine. We want to find out how much diesel are we using. So the output that we have is 17520 kWh. 1 kWh is one kilowatt is kilo joules per second into 60 seconds per minute into 60 minutes per hour, which means in to 3600. That is 3600 kJ. This is the required output in kilojoules; divide this by the efficiency of the diesel engine which is given to us as 35%, so 0.35.

Now this is the energy input in kilojoules. Remember every kg of diesel that we are talking of has a net calorific value of 42 mega joules, 42 mega joules means 42 in to 10 raise to 3, 42000 kilojoules. So now this is in kg of diesel. You can calculate this and you will find that this turns out to be 4291 kg of diesel per year. So, once we get this, now we know how much we have given that the price of diesel is 70 rupees, so we just take the annual fuel cost is 70 in to 4291 approximately equal to rupees, 3 lakhs. So, if we now look at this in terms of the in the case of what was the annual O and M cost?

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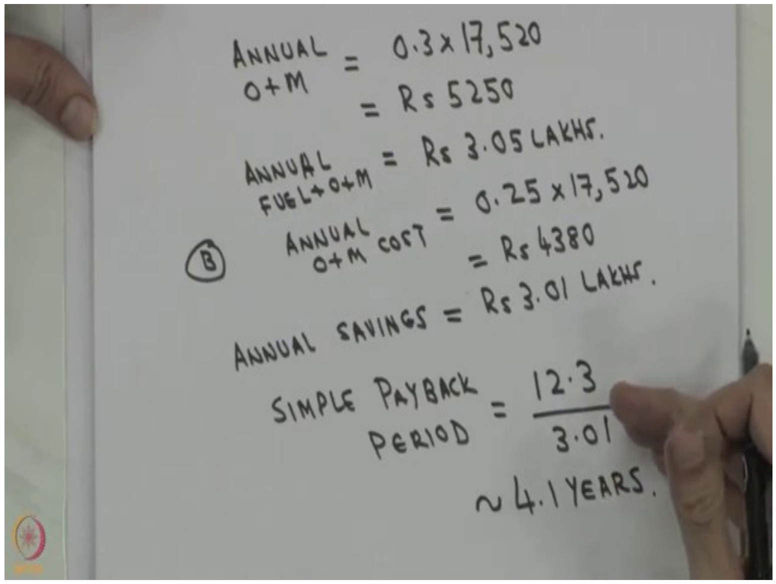

We said the annual O and M, non-fuel O and M is 30 paisa per kilowatt water. So this is 0.3 in to total of 17520 kWh, which is generated. And this turns out to be ₹ 5250. So it is actually very small. The total annual cost, annual fuel plus O and M, total annual cost is just instead of 3 lakhs now it becomes rupees 3.05 lakhs.

In the case of in the second case, where we are looking at the PV, what is the fuel cost? The fuel cost is zero because we do not have to pay for the solar insolation. So that entire annual fuel cost is saved. There is an annual O & M cost in case of B and that we can calculate annual O & M cost is nothing but 0.25 rupees per kilowatt hour in to 17520 and this turns out to be rupees 4380.

So the annual savings, which we have if we opt for P.V battery, is the difference in this two cost. That is difference between 3.05 lakhs and this is 0.04 lakhs. So, the annual savings is rupees 3.01 lakhs. So now we can calculate straight away, what is the simple payback period and this is just going to be the incremental investment which was 12.3 lakhs divided by 3.01 lakhs, which turns out to be approximately 4.1 year.

Now, depending on the company, as we had said, if you look at the company which has a payback period of 3 years or so, then this is not viable. Of course, in such a case, we will not just look at the simple payback period. We will look at the other indices. We have also been asked to now calculate what is the cost of electricity generated in both the cases. So let us for this cost of the electricity generated we will use the annualized lifecycle cost.

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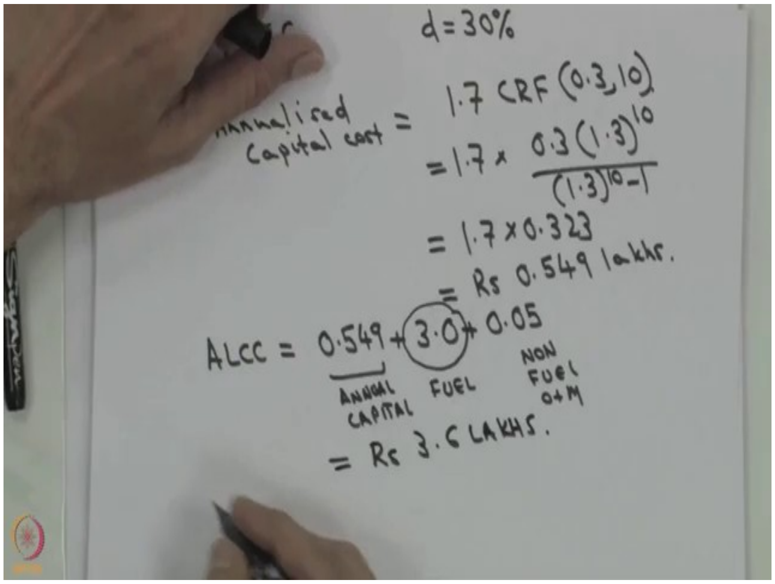

So when we look at annualized lifecycle cost, let us first calculate annualized lifecycle cost for option A, we are given that discount rate is 30 percent. So let us first see what is the annualized capital cost for the diesel engine, this is going to be 1.7 into CRF, discount rate is 30 percent, life is 10 years. So this is 1.7 as per the formula that we had, 1.3 raise to 10 minus 1, 1.7 in to 0.323, this comes out to be rupees 0.549 lakhs.

This is the annualized capital cost, and we have already calculated what is the annual fuel cost, and annual O & M cost that turns out to be 3.05. So, the total annualized lifecycle cost is 0.549 plus 3, we had seen this one it was 3.0 plus 0.05. So you see these components, you can see the relative magnitude. This is the annualized capital cost. This is the annualized, this is the annualized fuel cost. This is the annual fuel cost. This is the non-fuel O & M cost.

And this is the annualized capital cost, so you can see in the case of the diesel engine, it is the fuel cost, the diesel cost which is predominating, the capital is relatively low and overall we are looking at the total cost that we are now looking at is 3.6 lakhs. This is the annualized life lifecycle cost.

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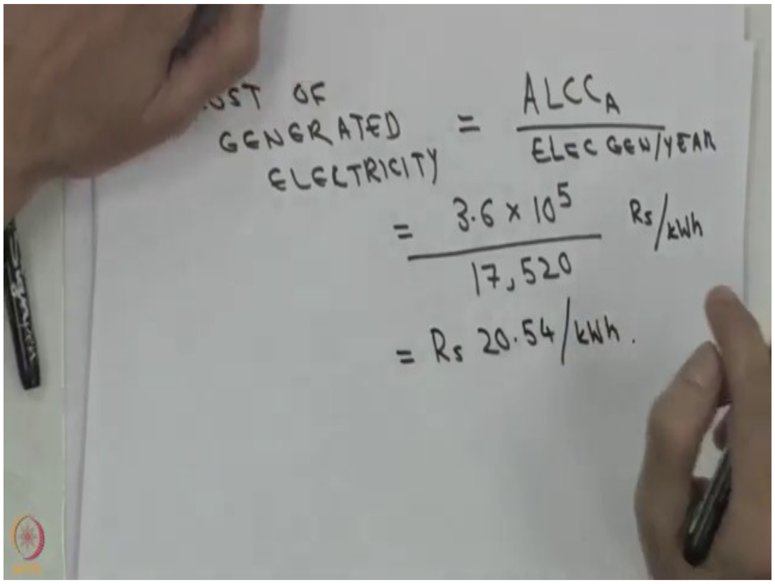

Now the cost of generated electricity that we have will be taking cost of generating electricity. We take the annualized lifecycle cost ALCCA by the annual electricity generation. Electricity generated per year. So, this is going to be 3.6 lakhs. 3.6 into 10 raise to 5 divided by 17520 and what will be the units? This is going to be rupees per kilowatt hour. When you put this and calculate, you will find that this is ₹ 20.54 /kWh, this is the cost that we are getting for generating electricity from diesel. Now, is this reasonable? We can try and see.

This is higher than the price at which we get electricity from the grid, which is reasonable, because otherwise, instead of your power plant, we would actually just have diesel engines and we have a rating of a diesel engine, the diesel prices high. So this is higher than the price at which you get grid electricity. And that is why you prefer greed electricity to diesel power. But if you have no other option and you have an isolated system, then this is a system which has low capital cost but high running costs because of the diesel price. So now let us keep this in mind and go ahead and calculate for case B.

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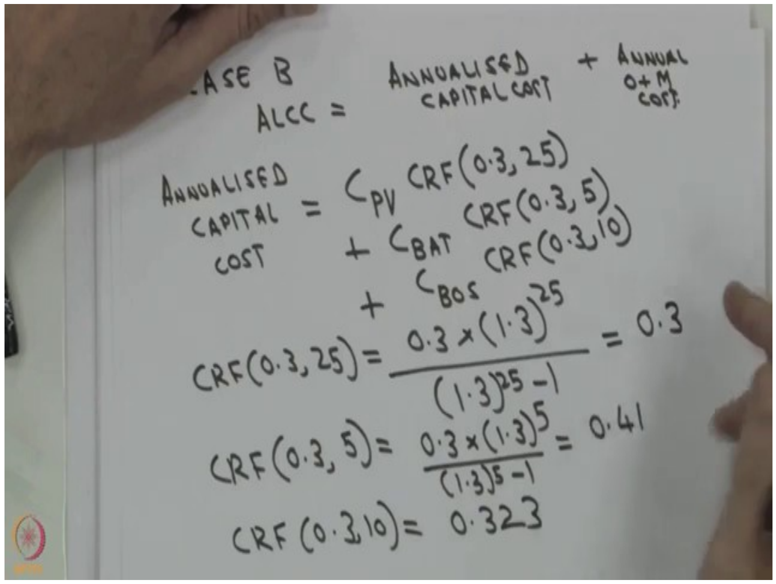

In case B, we have when we talk about the ALCC, again this ALCC will have here two components annualized capital cost plus annual O&M cost. There is no fuel cost here. So, in the case of annualized capital cost, we have three components here and remember, these three components have different lives. So because of that, when we take the capital and annualize it, they will have different capital recovery factors that we are going to use.

So this will be equal to CPV, which is the capital cost for the PV into capital recovery factor, discount rate is 0.3 and the P.V module life is 25 years. So this is this plus C battery CRF 0.3 but battery life is less than the life of the panel or the life of the power electronics. So this is B, 5years. And see this is the advantage that we have when we use an annualized lifecycle cost method because we can actually just simply add up the annualized capital costs for different components which have different lives.

And then it just means that the capital recovery factors we use are going to be different and then the third component, which is C balance of system in to capital recovery factor, 0.3 and 10. So, now let us calculate these capital recovery factors. CRF 0.3, 25 is 0.3 into 1.3 raise to 25 divided by 1.3 raise to 25 minus 1 and this turns out to be approximately 0.3. Then CRF 0.35, this is going to be the highest value, this is going to be 0.3 into 1.3 raise to 5 divided by 1.3 raise to 5 minus 1 and that turns out to be 0.41.

And CRF 0.3, 10 is something we have already calculated in the earlier examples. This is 0.323 So you see the lowest value is where the life is highest, 0.3 in 10 years is 0.323 it is only 5 years, it means the capital recovery factor is higher. Now let us use these and plug in the values to get the final value of the annualized capital cost.

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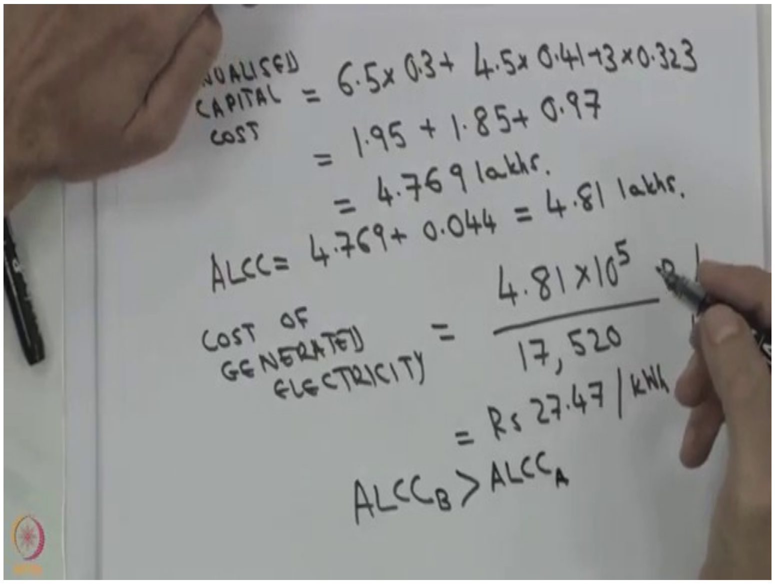

So, the annualized capital cost, annualized capital cost is going to be calculates, calculate this in lakhs 6.5 lakhs in to 0.3 plus 4.5 lakhs in to 0.41 plus 3 lakhs in to 0.323. Ok So, this comes out to be 1.95 plus 1. you can check these numbers. There may be some rounding of this 0.97. And this turns out to be 4.769 lakhs. To this, so when we look at the ALCC we will add 4.769 plus what we had calculated, which was 4400 something of that sort, 4380 but we can just take it as 0.044. So it comes out to be 4.81 rupees lakhs. That is the ALCC. Now let us calculate the cost of generated electricity.

So just similar to cost of generated electricity for of case B generated electricity. Let us calculate this will be 4.81 in to 10 raise to 5 because it is lakhs divided by 17520 and the units, as we said, was rupees per kilowatt hour. When we do this, we get ₹ 27.47 /kWh. $ALCC_B$ turns out to be greater than $ALCC_A$, cost of electricity for B turns out to be greater than that for A. So with a discount rate of 30 percent, this means that the company will not opt for solar PV.

Now let us calculate what happens when we look at, if we have, do we get it? Do we get carbon dioxide savings? And if we get carbon dioxide savings, would it be eligible for carbon credits?

So generally what happens is in the case of PV there is some CO_2 emissions because of the embodied materials. If you look at the silicon or you look at the glass and you look at the kind of energy used and the kind of CO_2 which has come in, in making that material, we can make that calculation.

But typically these values are relatively less. So it turns out to be 20, 30 grams per kilowatt hour for our purpose, for our calculation. We can neglect it and say that all the CO_2 there is, it is like negligible. And we will just take whatever is the CO_2 that is being saved because we are not using diesel is the kind of CO_2 saving which is obtained. So, let us calculate now how much CO_2 we are saving.

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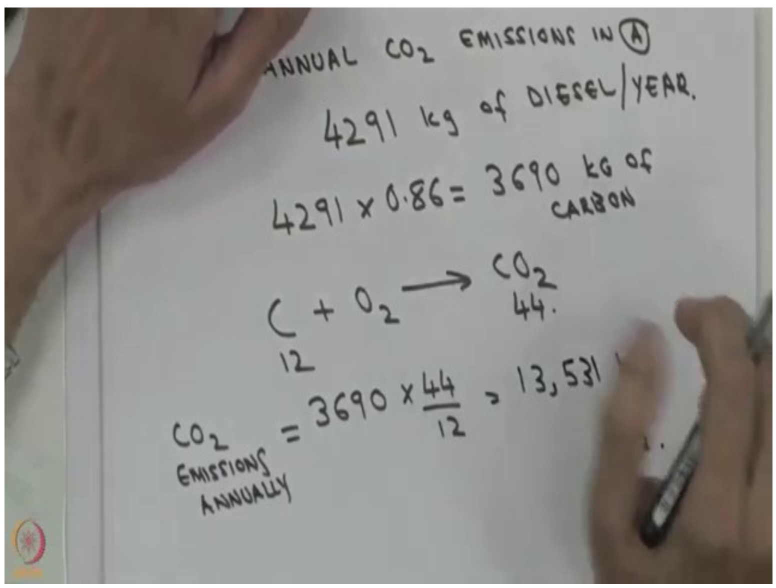

So, we have we want to calculate what is the annual CO_2 emissions in A. In case A, case A uses diesel, and we have calculated already the amount of diesel that we are using, we are using 4291 kg of diesel per year. Ok So, this will involve we know also that 4291 kg, each kg of diesel has 86 percent carbon. So this is point A into 0.86.

You get 3690 kg of carbon annually are being burnt. Now we know that see the basic psychometric, C plus O_2 giving us CO_2, which means 12 kg gives 44 kg. So if you want to calculate how much CO_2 we are getting by annually from the diesel, we can see that this will be 3690 into 44 by 12 is the, CO_2 emission annually in option A. So this turns out to be if we do the calculation, you will find that, this is 13531 kg's of CO_2. In option B, we are saving this much amount of CO_2.

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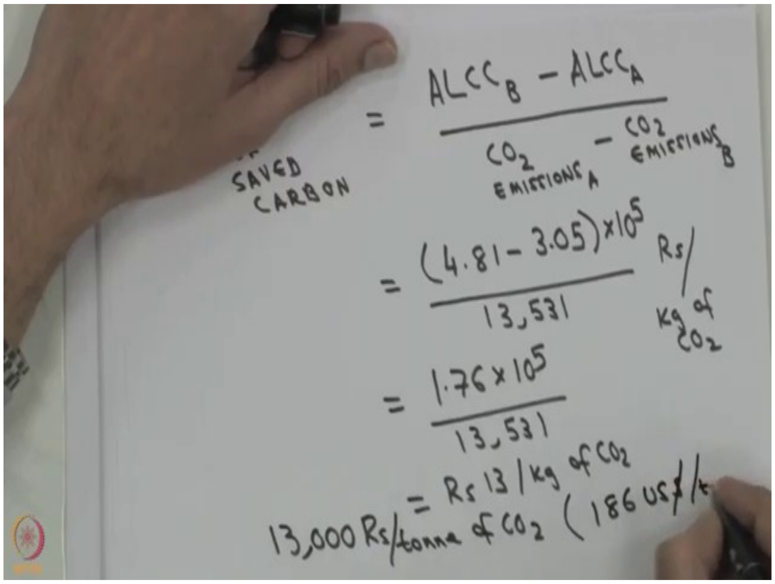

So the incremental costs that we have now if we are looking at the cost of saved carbon. If you remember, we talked of that as the ALCC with the project that means ALCC of B minus ALCC of A divided by the CO_2 emissions of A minus CO_2 emissions of B. We will presume that the CO_2 emission of B is negligible. If we have that value, we can add it up.

This would be typically of the order of 20, 30 grams per kilowatt hour. So it is relatively small. So, this is going to be now 4.81 minus 3.05 that is the incremental capital cost into 10 raise to 5 divided by 13531. And what are units? This is rupees per kg of CO_2 saved. That is why it is called the cost of saved carbon. And if you see this, this comes out to be 1.76 lakhs is incremental divided by 13531 and that comes to rupees 13 per kg of CO_2.

Often when we talk in terms of carbon savings and carbon, the cost of saved carbon, we usually talk in terms of certified emission reduction. One certified emission reduction or CER is one ton of CO_2 saved. So let us calculate we can just take this, this is per kg. We can make it per ton. It will be 13000 ₹/ton of CO_2 saved annually and if you convert this to US. dollars, that is, divided by 70 you will get this as about 186 $/ton.

And you can compare that with the carbon credits or the carbon price. You find the carbon price is actually much, much lower. This is a relatively high value. So this gives us an idea that at these costs with the cost number that we said, if the company has a discount rate of 30%, it would not be viable. It would not prefer to go for the PV option. Of course, if it has an incentive in terms of a carbon credit and that carbon credit is priced. Then it might happen.

And let us also do we had also said that what if the, it is a public sector company or it has an access to fund, green fund where the interest rate is lower and we can look at it as a situation where we are talking of a discount rate, not of 30 %, but a much lower discount rate of 10 %. So if the discount rate is 10 %, case A economics remains the case A also, the economics will change.

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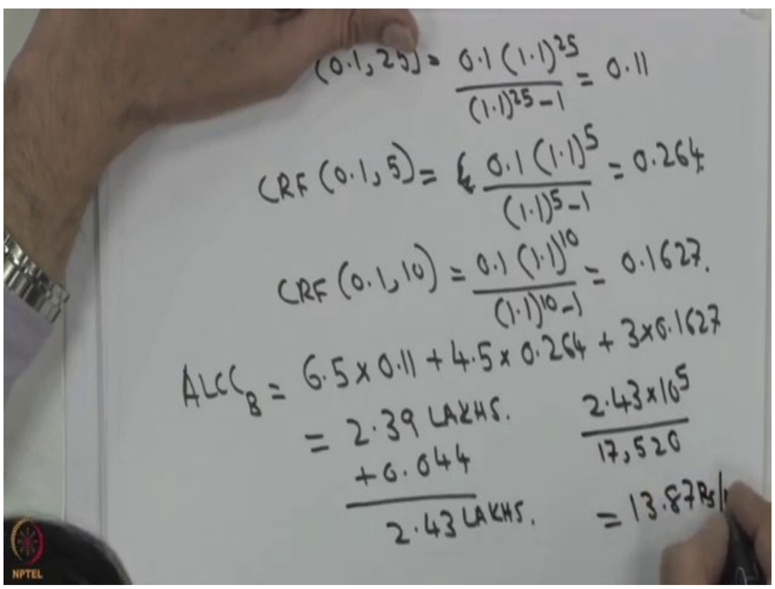

But let us look at what will happen in terms of case B. Case B will have the CRF, will change CRF 0.125 is, you can calculate this and this will turn out to be 0.1 in to 1.1 raise to 25 by 1.1 is to 25 minus 1. This is just about 0.11 CRF 0.15. Again, in a similar fashion we can make, the calculation is 0.1, 1.1 raise to 5 minus 1 if you calculate to get to this 0.264, CRF 0.10 and this comes out to be 0.1627.

So, now you are ALCC for B turns out to be 6.5 in to 0.11 plus 4.5 in to 0.264 plus 3 into 0.1627 and this turns out to be 2.39 lakhs and to add to that, the O and M of, which is 0.44 so we are talking of 2.43 lakhs. The cost of generated electricity now is 2.43 in to 10 raise to 5 by 17520 and this turns out to be 13.87 ₹/kwh. This is, of course, much cheaper than the option B when we calculated for 30 %.

It also happens to be cheaper than option A, but of course, please remember that option A economics also changes because now the discount rate is 10 %. So, the capital costs that we had calculated earlier for the diesel engine that will also change.

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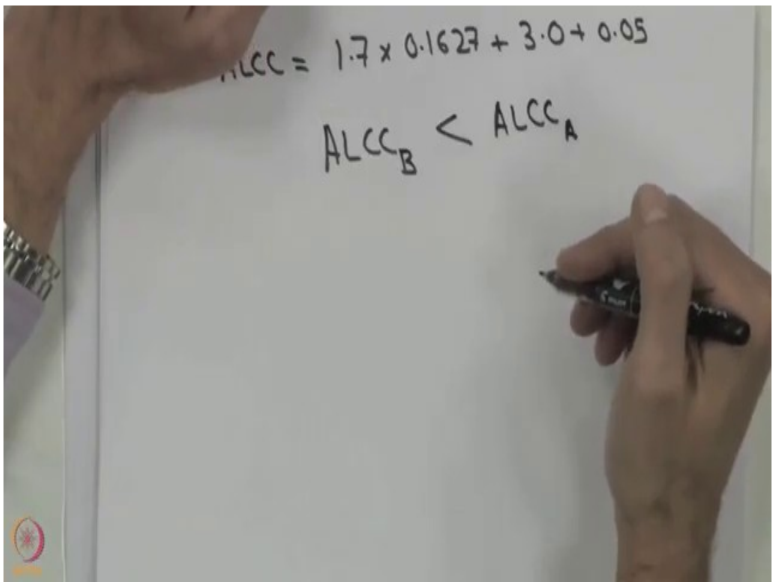

So now the ALCC for option A will become 1.7 in to CRF 0.110, which is 0.1627 plus the other values that we had 3 plus 0.05. So, instead the value here, we will get a lower value but even then, this ALCC now, $ALCC_B$ turns out to be less than $ALCC_A$. So the interesting thing is that now in this particular case, PV is more viable than the diesel engine generator and this is because we have a lower cost of capital. We have a lower discount rate and so this.

So with this, we can sum up. We have looked at the way in which we can do the economic calculations and we have then also taken an example by which we have shown how we can calculate the annualized lifecycle cost and the effect we can compare both the options and select that option, which has a lower ALCC.

This decision for the telecom towers. We found that at a discount rate of 30 %, it is preferable to go for diesel engine generators and that is why you see mostly diesel engine generators across the country, relatively low in terms of capital, convenient in terms of usage, but not good in terms of emissions. We then also calculated what are the CO_2 emissions which are coming based on that option and then seen the difference in that cost divided it by the emissions and calculated the cost of saved carbon.

So with this, we can actually get the curve that we showed for different options. How much what is the cost per ton of CO_2 that we are saving. We also saw that if the discount rate is lower, then it is possible the company would be interested in making that additional investment and it is viable to go for the PV battery systems.

So you can try out the other tutorial problems and see that you can use the different kinds of indices when you have different components in a system with different lives, annualized lifecycle cost is a convenient way of doing the calculation. Thank you.