Energy Resources, Economics and Environment
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Lecture 15
Revision Paper-1 (Party 2)

I hope you have been successful in solving the paper. It is a fairly simple paper which just revises all the things that we have touched upon. We will go through the paper, question by question. So, let us start with the first question.

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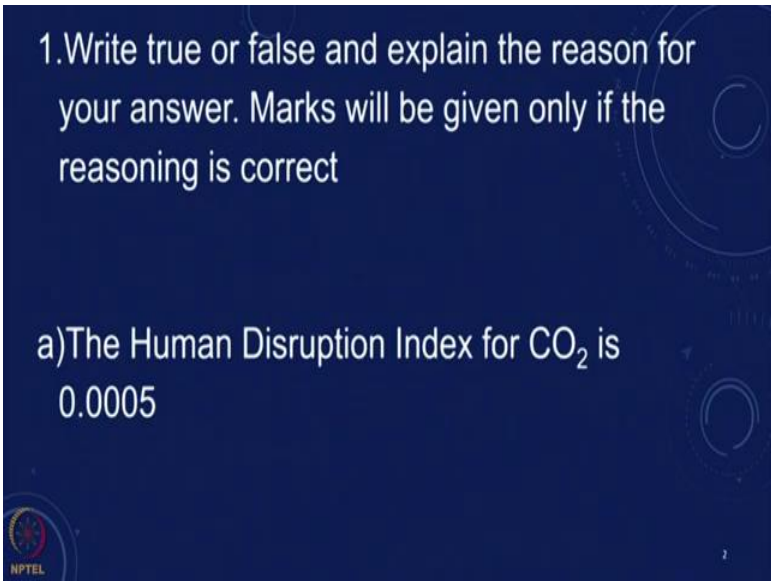

The first question was where we have to write true or false and explain the reason for the answer and of course, you should give yourself marks only if your reasoning is correct. So, the first part of this one, A says, the human disruption index for CO_2 is 0.0005. Now look at what is the definition of the human disruption index.

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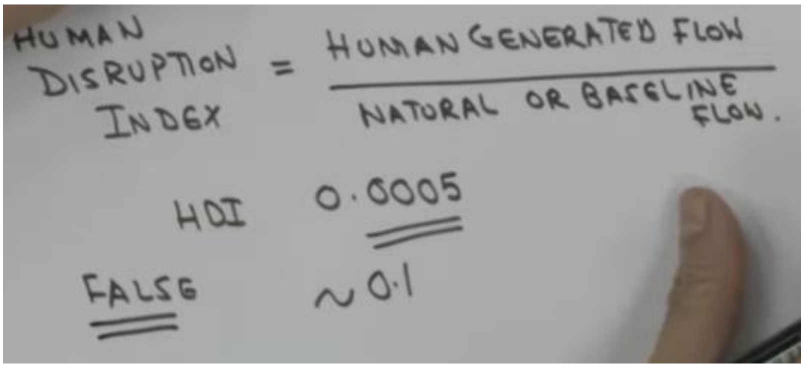

Human disrupt index which if you remember was proposed by John Holdren is the ratio of the human generated flow of a particular global pollutant, human generated flow annually divided by the natural or the baseline flow. Now, what happens is that, this would mean and we said that if the human generated flow is 1 or more than 1 then we have a problem. HDI suppose this HDI for CO_2 was 0.0005 then nature would be able to take care of the CO_2 emissions very easily.

It is small as compared to the natural or baseline flow and then there would not be a CO_2 problem. So, this statement is false, the HDI for CO_2 is much higher. It is approximately 0.1 and since the concentration of CO_2 is increasing, and its, it is not possible for nature now to take care of it and that is why there is a global warming problem. So, the answer as we said is false because if the HDI was so small, then there would not have been a CO_2 problem. If the CO_2 flows, the human generated flows would be much lower than what is generated by nature and what nature can actually sustain. So, this was the first question.

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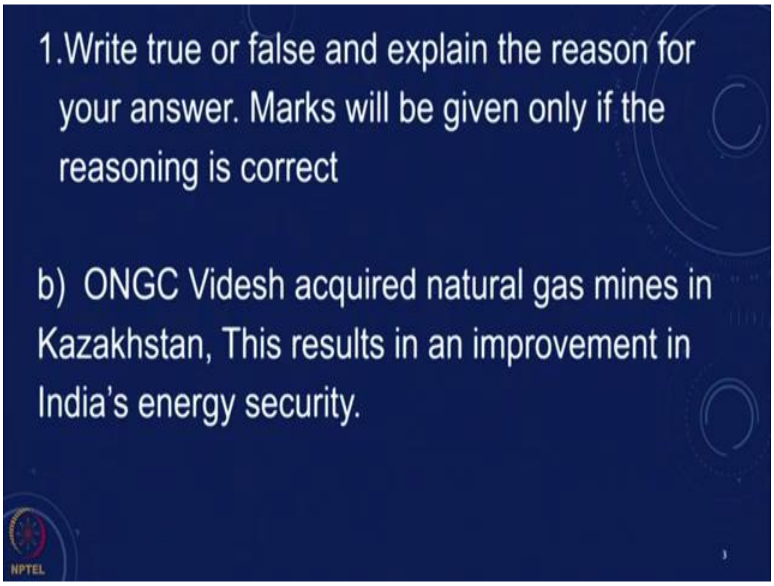

Let us go to 1b. 1b is saying ONGC Videsh acquired natural gas mines in Kazakhstan. This results in an improvement in India's energy security. So, as we said, energy security, the definition of energy security is where we would like to see that our energy sources will not get disrupted and we can have uninterrupted supply of energy that is required for the society. If we add natural gas mines in Kazakhstan, which will increase the control and sovereignty over gas supplies in India, and then this will increase our energy security.

So, the answer to this is that this is true and this will increase our energy security because we have control over additional gas resources, which will be under the sovereign, under the ownership of the company ONGC Videsh and so that is, this is going to be, this answer is true.

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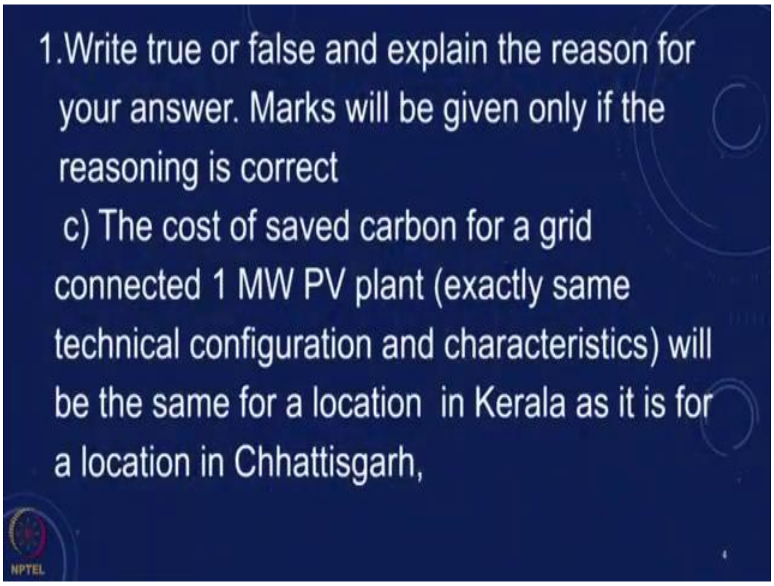

Let us look at the third question. The third question says, the cost of saved carbon for a grid connected 1 megawatt PV plant, the same plant, exactly the same technical configuration and characteristics will be the same for a location in Kerala as it is for a location in Chhattisgarh. Now, what is the cost of saved carbon?

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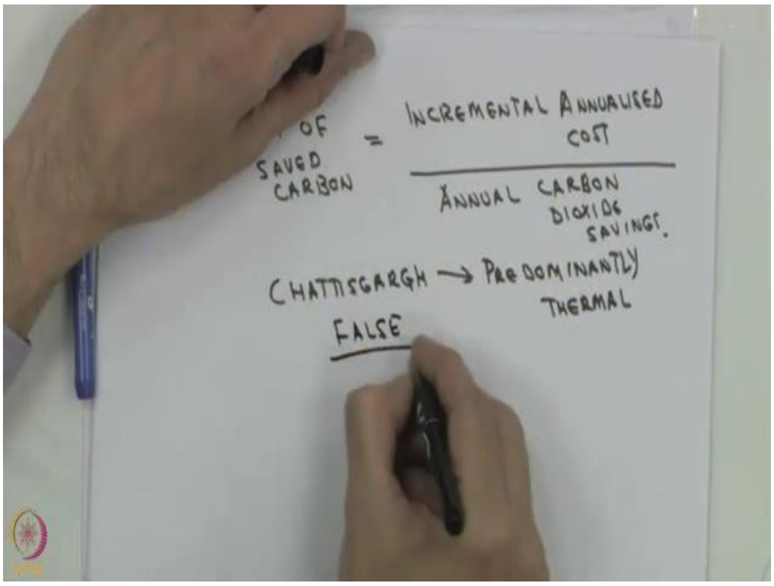

Cost of saved carbon is the incremental annualized cost of that measure. So, that would mean what is the capital cost of that PV plant and when we annualize it, and then divide that by the annual carbon dioxide savings. So, couple of things, the first thing is that in two locations in Kerala and Chattisgarh, the solar insulation may be different. So even though the plant is the same, the outputs may be different. Of course, this may not be drastically different.

The second thing is that when you look at the supply mix, in Chhattisgarh, the grid is predominantly thermal. Chhattisgarh grid, predominantly thermal which means that when we put a PV plant there we are actually replacing coal-based power and the amount of CO_2 savings would be much higher than the CO_2 per kilowatt hour. In Kerala, it is a predominantly hydro grid.

So, the CO_2 per kilowatt hour would be much lower and hence, these two would be quite different, solar installation may also be different. So, the answer is that this is going to be false, it is not going to be the same. The answer to this is false.

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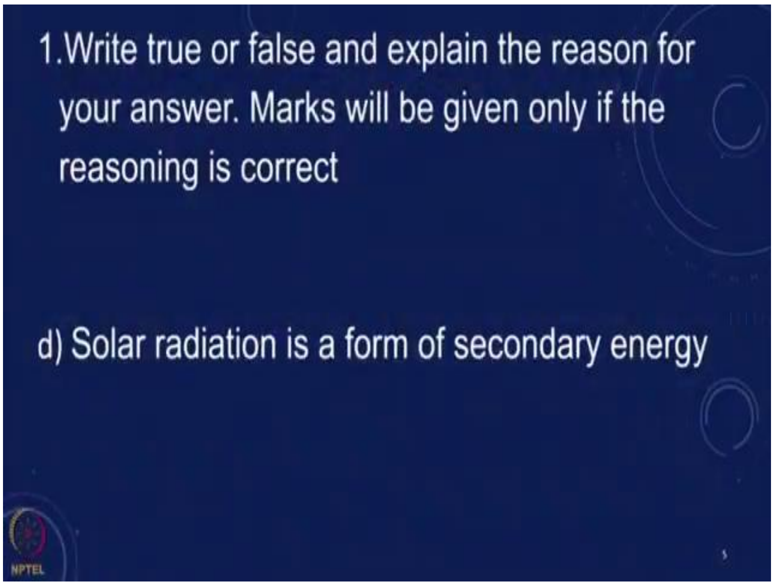

Let us look at the next part. 1d. 1d says solar radiation is a form of secondary energy. Remember what was our definition of primary and secondary energy stopped primary energy is the energy that is available in nature, goes through a sequence of conversion steps to get secondary energy. So, this is false because obviously solar radiation is available in nature. It is a primary energy and not a form of secondary energy. So, the answer to this is clearly false.

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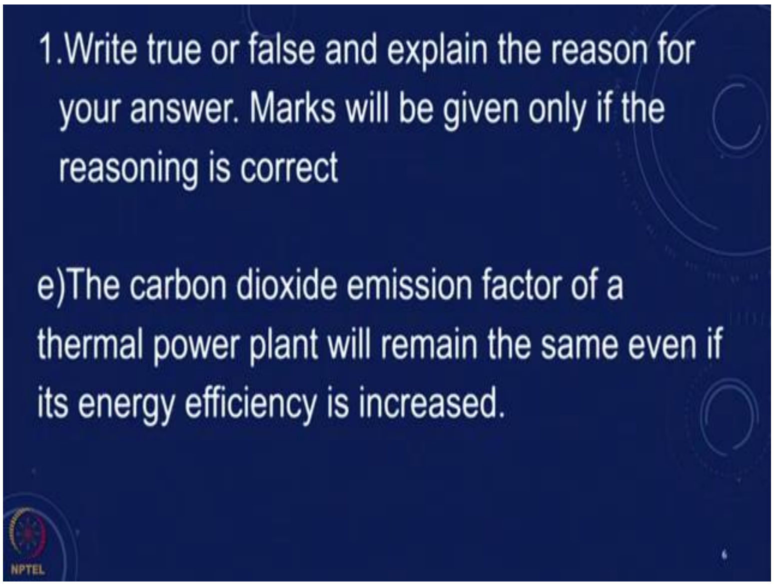

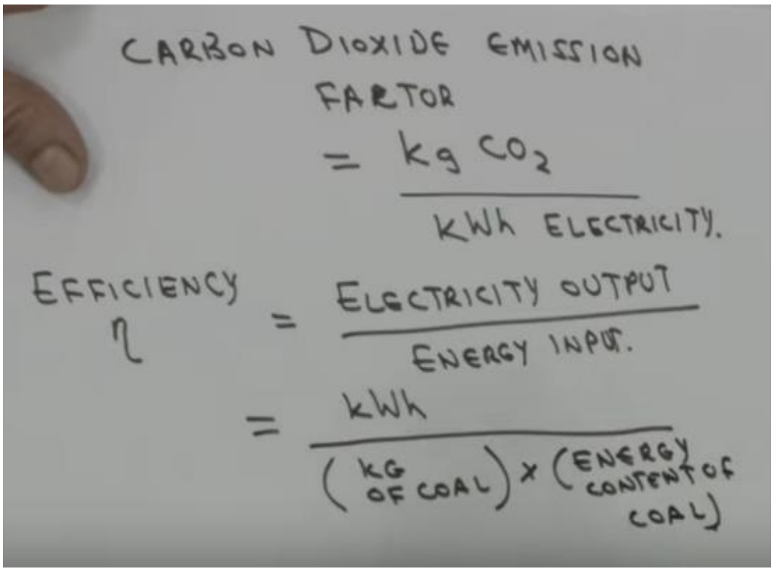

Let us look at 1e. 1e says the carbon dioxide emission factor of a thermal power plant will remain the same even if its energy efficiency is increased. So, let us look at what is the carbon dioxide emission factor, carbon dioxide emission factor. Carbon dioxide emission factor will be the kg of CO_2 per kilowatt hour of electricity. That is the carbon dioxide emission factor.

Let us see what is the efficiency, efficiency, this is going to be the electricity output in kilowatt hours divided by the energy input. So, we can write this as kilowatt hour of electricity divided by kg of coal into the energy content of coal.

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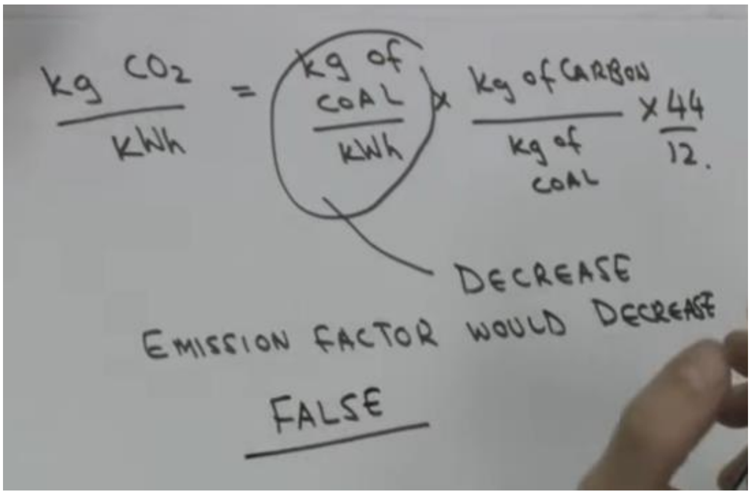

Now, if the coal composition remains the same, what would happen is that if we look at kg CO_2 per kilowatt hour, that will be equal to kg of coal per kilowatt hour into kg of carbon per kg of coal, that is the percentage of carbon in the fuel into 44 by 12. Now, if the efficiency increases, for the same amount of electricity generated, we would be using less coal. So, this would decrease and if the composition of the coal remains the same, this would mean that the emission factor would decrease.

Emission factor would decrease if the efficiency increases, would decrease and the statement here says that if the carbon emission factor of a thermal power plant will remain the same, even if the energy efficiency is increased, so the statement is clearly false. If the efficiency increases, and it is the same coal that we are talking about, the emission factor would decrease.

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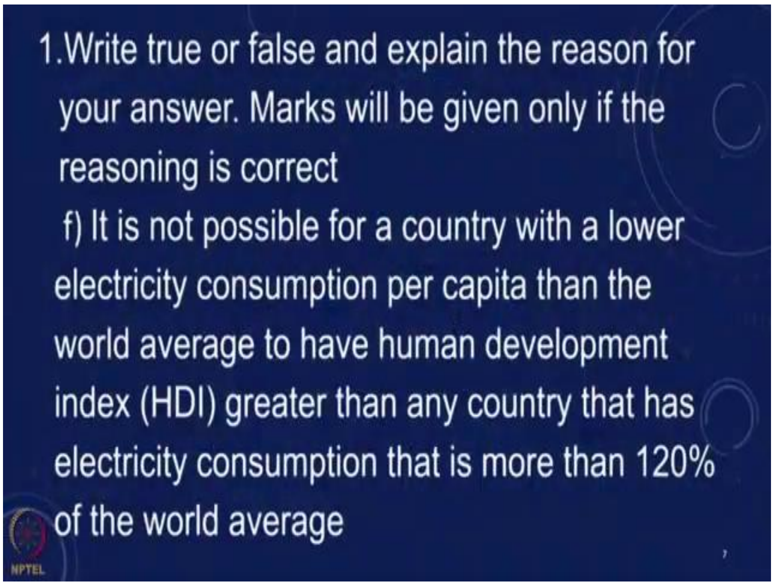

So, let us look at the 1f, the next statement. It says that it is not possible for a country with a lower electricity consumption per capita than the world average, to have a human development index greater than any country that has an electricity consumption that is more than 120 percent of the world average.

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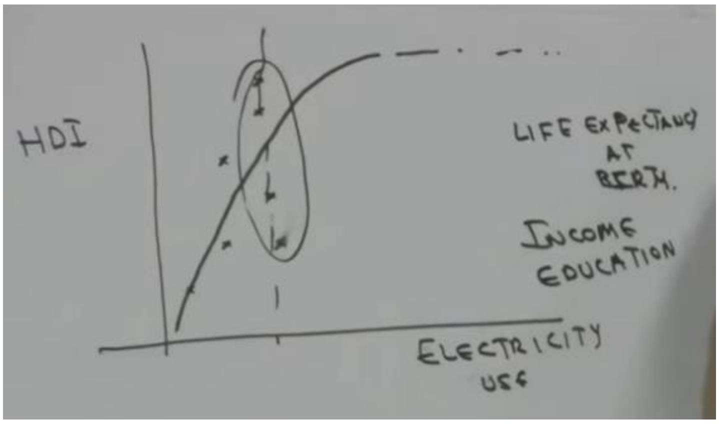

So, now if you remember the plot that we had showed, where we showed the HDI, if you show HDI versus electricity use and the Human Development Index, you clearly see there is a pattern. But there is also a scatter in the data and you have a curve something like this, which saturates beyond the point. But at any electricity use, there are a large number of countries where there could be a variety of human development indexes.

So HDI, as we saw is a composite index of a set of things. The life expectancy at birth, life expectancy at birth, income and education. So, it is possible there are countries which are using less energy services, but which have developed better quality of health and education. So, many countries have focused on health and education and they can have a better quality of life, even though they have not increased their electricity use.

So, it is possible that there are countries where, it is not possible with a lower electricity than the world average. It is possible that there are countries which have lower consumption than world average to have a better quality of life. There are countries which have significant, high electricity consumption and which is inefficient, there is much more inequality and the health and education is not that good.

So, this statement is essentially it is false, because it is possible for a country to have a higher HDI. In general, there is a minimum amount of electricity required for improving the quality of life. But within when you make the comparison, there are many other factors apart from the electricity use, which affect the AGI. So, these are the six statements and if you have got the answer, true or false correct and your reasoning is correct, then you can give yourself the full 2 marks for each of these sections. So now let us look at the second question.

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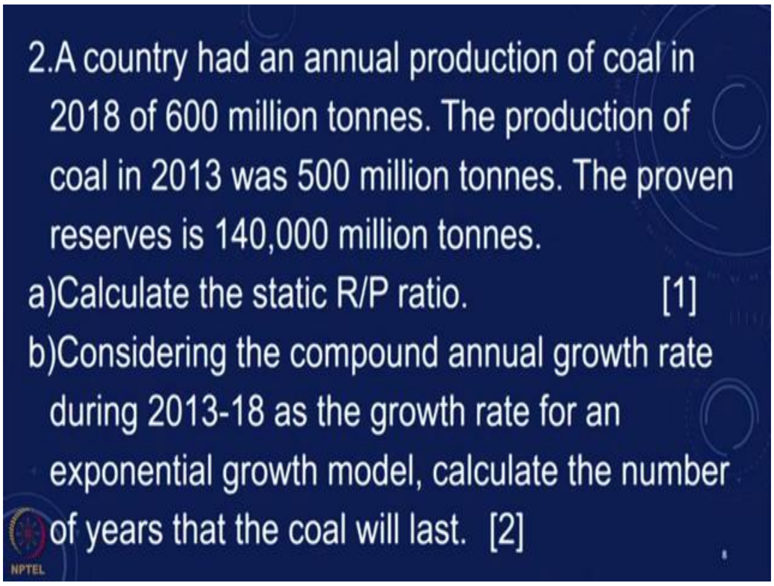

The second question is on the resources it is a country had an annual production of coal in 2018 of 600 million tons and the production of coal in 2013 was 500 million tons. The proven reserves is 140 thousand million tons. Calculate the static R by P ratio. So, the static R by P ratio that we calculate should be for the most recent year.

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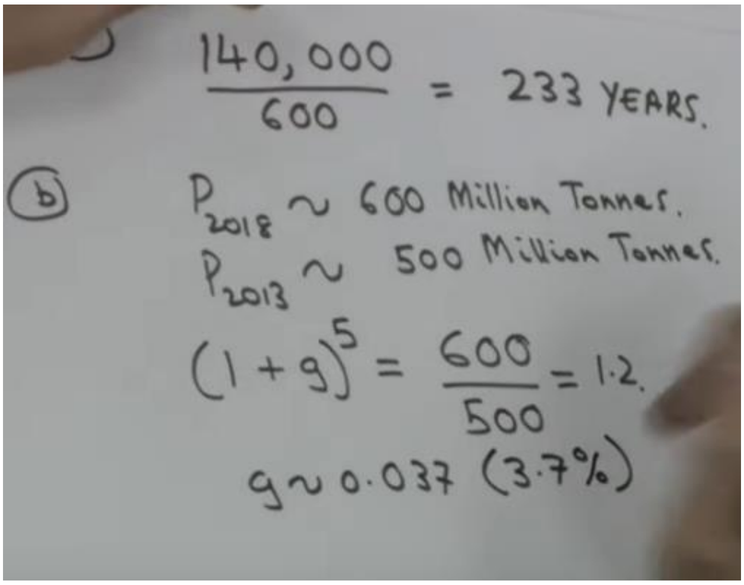

So, let us take 600 million tons, all that we have to do is divide 140 thousand million tons by 600 million tons and we get 233 years. This is the static r by P ratio. The second part of the question is considering the compound annual growth rate during 2013 to 18 as the growth rate for an exponential growth model, calculate the number of years that the coal will last and obviously that is going to be less than this 233 because we are talking of an exponential growth model.

So, let us, see P 2018 is 600 million tons and P 2013 is 500 million tons. These are similar to the numbers for India actually for coal. So, if we want to find the growth rate, it will be 1 plus g, 2013 to 18 is 5 years, 1 plus g raised to 5 is equal to 600 by 500, 1.2 and so g comes out to be 0.037 or 3.7 percent. Compound annual growth rate of 3.7% during these 5 years.

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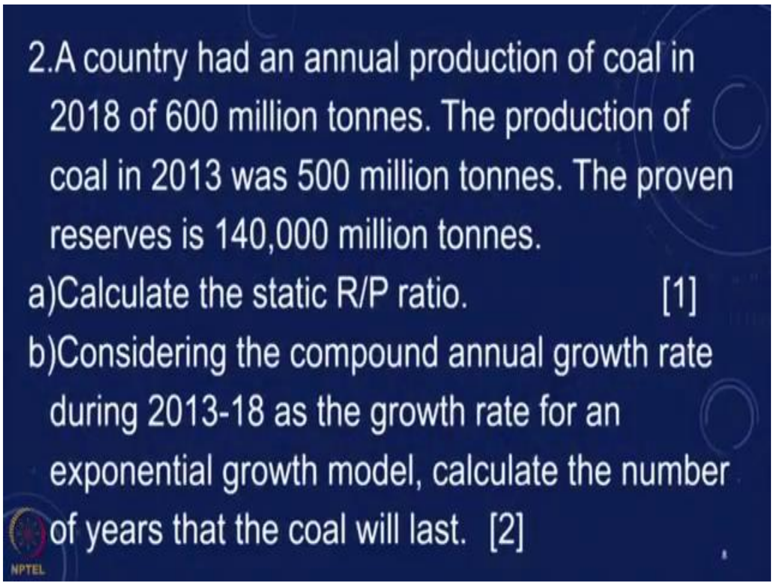

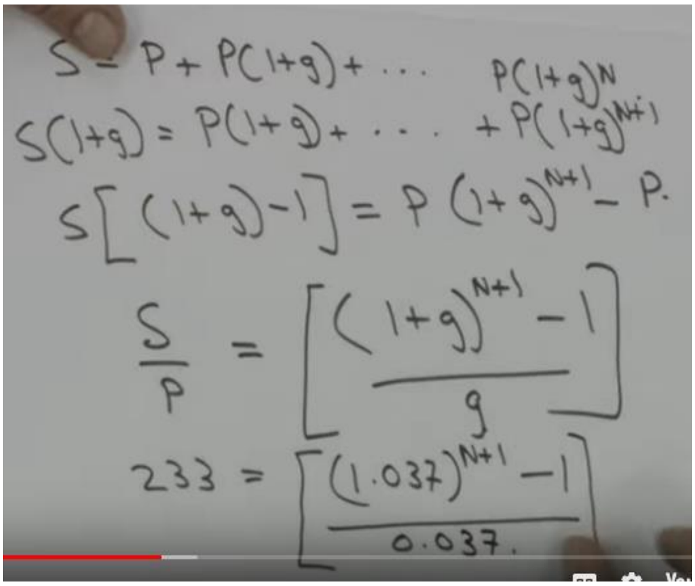

Now, let us see how do we calculate the number of years for which the coal will last. So, we can just take this. We just derived this earlier, P plus P into 1 plus G and so on, P into 1 plus g raised to n, you can of course, if you remember the formula that is also fine, but you can just derive it in one or two steps.

So, this gives us S into 1 plus g minus 1 is P into 1 plus g raised to n plus 1 minus P. So, S by P and this is the, S by P is the total that we were looking at, is the static r by P ratio. This should be 1 plus g raised to n plus 1 minus 1 by G. Substitute this, we get 233 is equal to 1.037 raised to n plus 1 minus 1 by 0.037.

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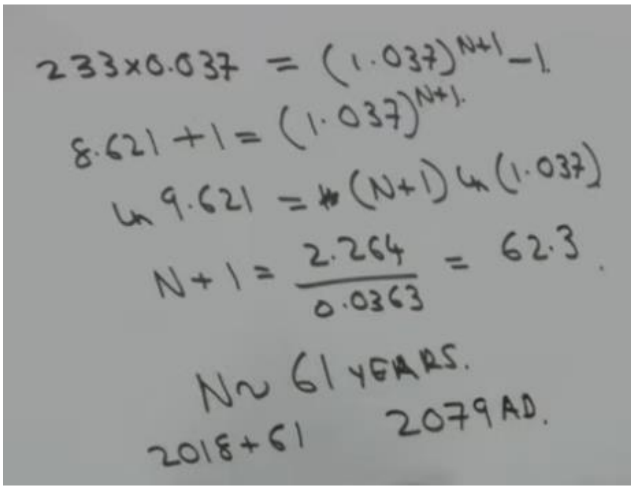

So, what we can then do is we can just you can see that this is going to be equal to 233 into 0.037 is equal to 1.037 raised to N plus 1 minus 1. This comes out to be 8.621, you can take the 1 on this side, this comes to 1.037 raised to n plus 1. You can just take ln on both sides and you get ln of 9.621 is equal to n plus 1 into ln 1.037 and you get N plus 1 is equal to 2.264 by 0.0363 and you get this as 62.3.

N plus 1 is 62.3. So, N approximately equal to 61 years and so that means the date will last from 2018 plus 61 year in which it gets completed will be 2079 AD, so that is the model, earlier we got R by P ratio as 233 years, now we have got it as 61 years. So that is the question part B.

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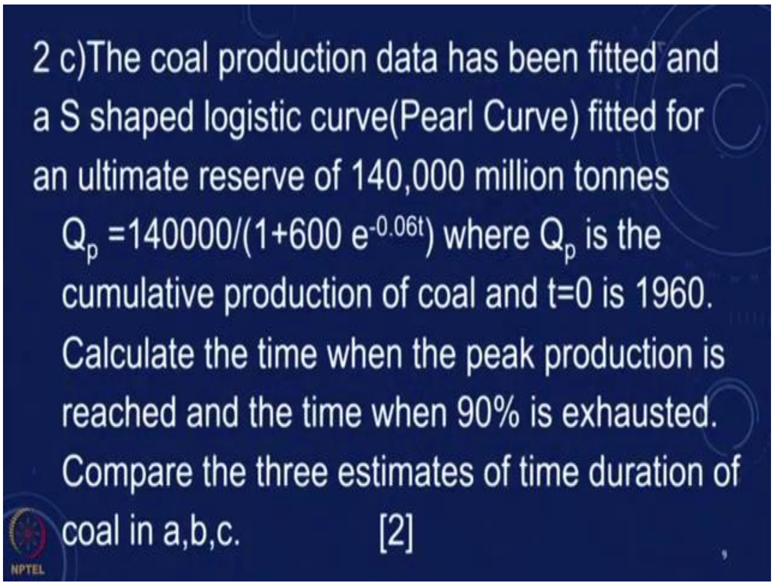

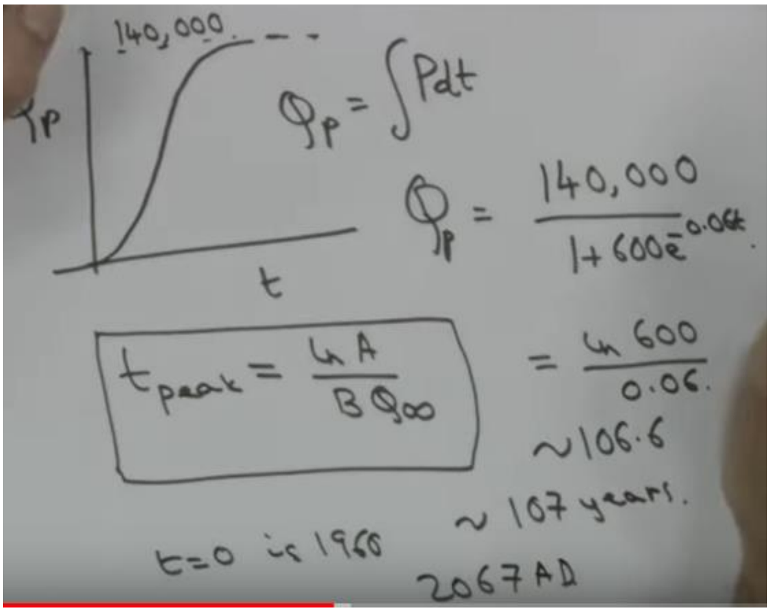

Let us look at Part C, the coal production data has been fitted. So, you have a data set and it has been fitted to the data set and an S shaped curve, logistic curve, that means this is production S, this is QP by t, QP is integral Pdt, that is what has been done and this has been fitted for an ultimate reserve of 140 thousand million tons.

And this is the equation that we got, QP, this has been given to you. 140 thousand divided by 1 plus 600 e raised to minus 0.06 t where QP is the cumulative production and that starts from t is equal to 0 is 1960. So, the question that has been asked is calculate the time when the peak production is reached.

Now, if you remember when we had derived this we had derived the, you can differentiate this and find the point at which we are getting the peak that is going to be the differentiation of this gives you dQP by dt will be the production and second differential of that and set that equal to 0, that will be when the production is maximum, you can check, this will give you tQP by is lnA by BQ infinity.

This was the formula that we had derived and we can substitute the values. This is going to be ln 600 by 0.06. 0.06 is BQ infinity and this is your A. So, this turns out to be approximately 106.6. So, it is about 107 years. That is when the peak will occur and if t is equal to 0 is 1960, so peak will occur in 2067 AD. Remember, we found in the exponential growth case that it will last get depleted in 2079, here it will, the peak will occur in 2067.

So, if we want to calculate the second thing which has been asked is calculate the time when the peak production is reached, and that we have just done and when 90 percent is exhausted.

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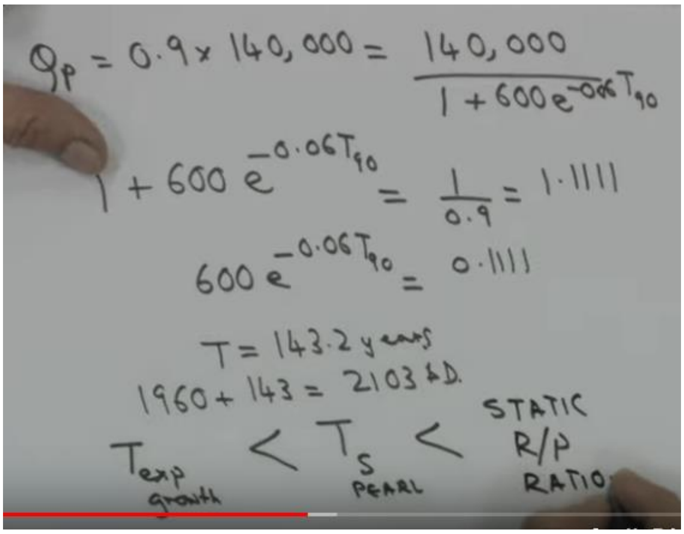

So, when 90 percent is exhausted, we want to put QP is point nine into 140 thousand, this is equal to 140 thousand by 1 plus 600 e raised to minus 0.6 T 90. T90 is what we want to find out. So, then this becomes 1 plus 600 e raised to minus point, 0.06. 0.06 T90 is equal to 1 by 0.9, this is 1.11. So, we get 600 e raised to minus 0.06 T90 point and we can take logs and you get T is 143.2 years.

So, 1960 plus 143 comes out to be 2103 AD. Then you asked, compare the three estimates of time duration of coal in A, B, C. So, obviously, the smallest value comes out to be with exponential growth. T exponential growth less than T pearl curve or s shaped or the Herbert's model S shaped curve or pearl curve and this will be less than the static R by P ratio. These are three different ways in which we get estimates of time for which the resources will last.

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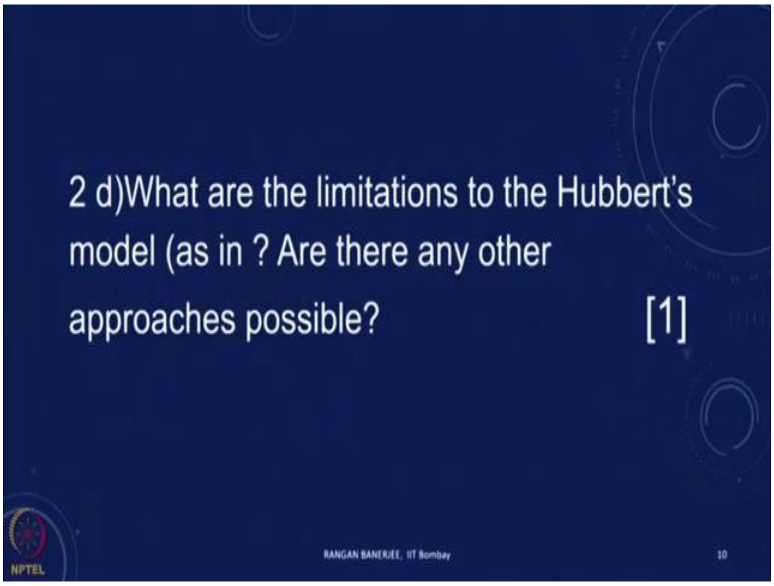

So, the last part of this question says what are the limitations to the Herbert's model and are there any other approaches possible. So, there are in all of this, the technology, in Herbert's model, technology is assumed to be static. So, what happens is that with time resources which are not considered to be minable based on improvements in technology and economics, many of these now become mineable and so the estimate of the results changes.

So, that is one that is one problem with the model. The second problem with the model is that the curve considered is symmetric about the point of inflection, but in actual practice, when you reach the peak beyond that, that will not remain symmetric. Also, there are other substitutes and so that is not considered in this model.

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Another approach or other approaches possible, there are approaches where you have, do you create a cost of supply and you can see this, this was there in the global energy assessment chapter on resources. If you look at the quantity that you can get or the reserves which are there, at different costs of supply, we can actually create a supply curve in terms of cost of supply and the quantity of the reserve.

That means today we may get it at some costs, then may be other reserves which are relatively more difficult to mine, where they can have, so we can have basically different things and these could be, these need not be deterministic, these could also be probabilistic. So, let us look at now the next question.

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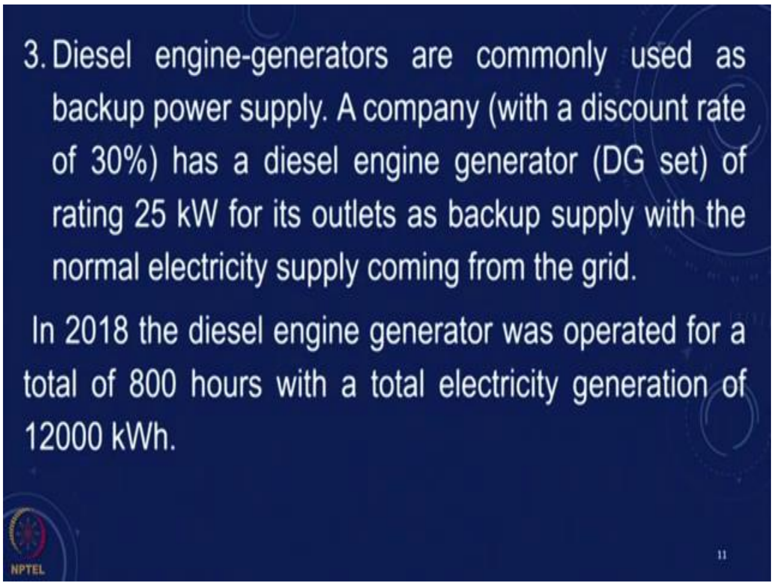

The question three is a question on economics we are talking of, let me just read out and explain the question to then we will go over it step by step. Diesel engine generators and you may see this all over the country wherever there is problem with power supply, we usually have what is known as a Genset. It is a diesel engine cum generator. They are commonly used as backup power supply.

And we want to look at a company with a discount rate of 30 percent, which has a diesel engine generator dg set of rating 25 kilowatt for its outlets as backup supply with the normal electricity supply coming from the grid. And in 2018 we are told that the diesel engine generator was operated for a total of 800 hours with a total electricity generation of 12,000 kilowatt hours.

So, the details of the generator are given. Capital costs of the diesel engine generator is 4 lakhs, life of the dg set is 10 years, then there is an operating cost, there is a fuel and the non-fuel.

Non-fuel operating maintenance costs annually is given to us as 25,000 rupees, the efficiency is given as 35 percent, fuel used is light diesel oil. The energy content and the price and the carbon percentage is given.

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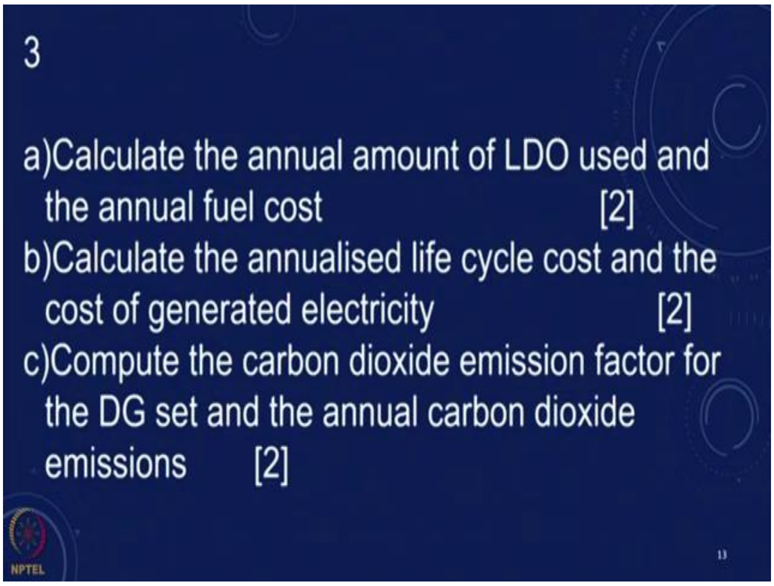

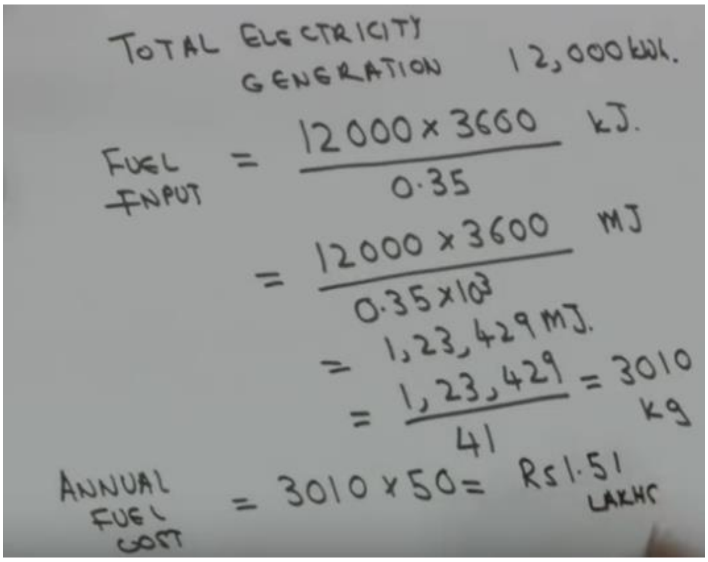

So, let us see what else we are asked to determine. The first thing is calculate the annual amount of LDO used, light diesel oil used and the annual fuel cost. So, first let us see we the total electricity generation annually is given as, total electricity generation is 12,000 kilowatt hours and we want to find out how much fuel is being used.

So, we have the fuel input will be the generation divided by the efficiency, 12,000 kilowatt hours, 1 kilowatt hour is 1 kilojoules per second into 60 seconds per minute into 60 minutes per hour. So, this is going to be 3600 kilojoules per kilowatt hour.

So now this numerator is in kilojoules divided by the efficiency, 35 percent. Fuel input in kilojoules is this and if we want to find out, so this is the fuel input in kilojoules. If you want to find out in mega joules, this is going to be 12,000 into 3600 by 0.35 divided by 10 raised to 3, this is in mega joules and this comes out to be 123429 mega joules.

If you want to find out how many kgs of fuel is used, we know what is the energy content of 1 kg of coal, 1kg of a LDO, diesel oil is 41 mega joules as given in the question. So, we just divide this by 41 and we get approximately 3000 kgs, 3010 kgs of LDO in one year. So, what is the annual fuel cost? Annual fuel cost is taken this and multiply it by the price. So, 3010 into rupees 50 per kg comes out to be rupees 1.51 lakhs.

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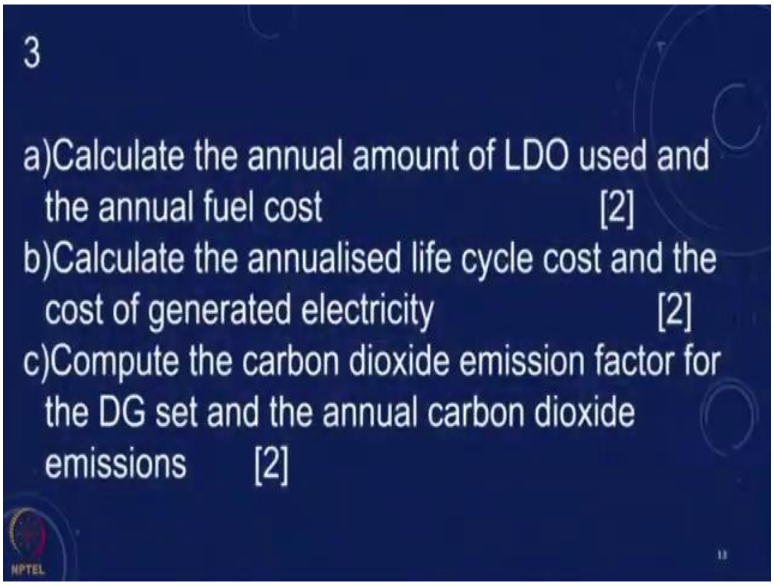

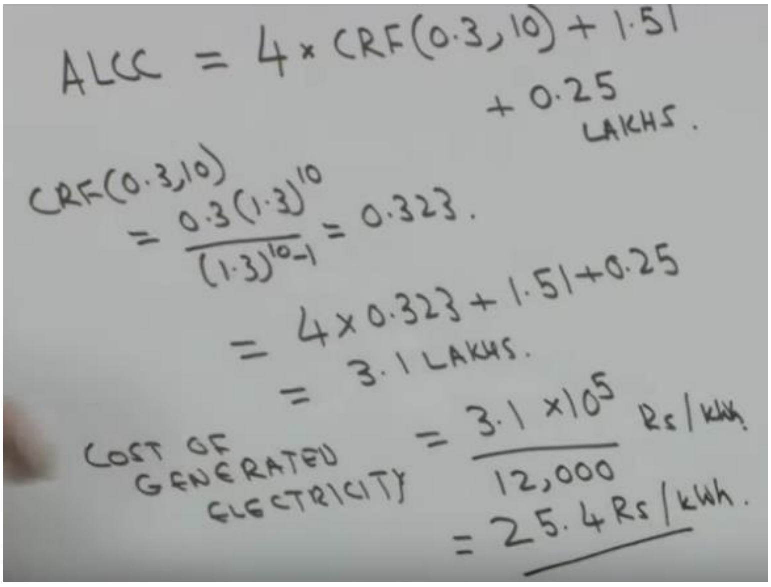

The next part is to calculate the annualized life cycle costs and the cost of generated electricity for the LDO system. So, if we look at the cost, we have the annualized lifecycle cost will be the annualized capital cost. Let us calculate this in lakhs. So, we have the dg set has been told that it costs 4 lakhs. 4 lakhs into the capital recovery factor.

So, that we annualize it, discount rate is 30 percent, life is 10 years plus the fuel costs which we just now calculated, which was 1.51 lakhs plus the nonfuel O&M which was 25,000 rupees, which is in lakhs which is 0.25. So, this is in lakhs, CRF 0.310, we have already calculated, this is 1.3 raised to 10.

This is 0.323. So ALCC is 4 into 0.323 plus 1.51 plus 0.25. So, this comes out to be 3.1 lakhs. Cost of generated electricity if you want to calculate, cost of generated electricity, we divide this by the total amount that we are generating annually. So, it is 3.1 into 10 raises to 5 divided by 12,000 and this will be rupees per kilowatt hour and if you calculate this it comes out to be 25.4 rupees per kilowatt hour. Done some rounding off, so if you get something which is similar off by a decimal place or so, it is all right. So, this is the amount of, you keep this number in mind we will compare it with the new.

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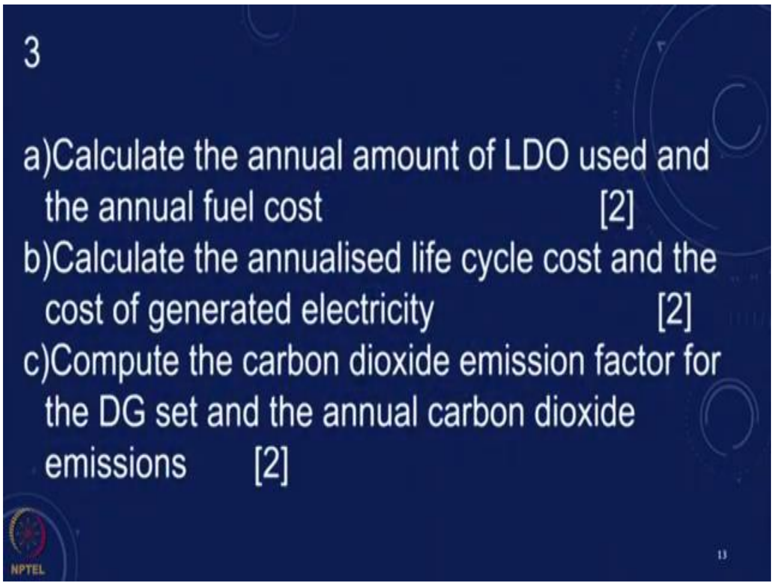

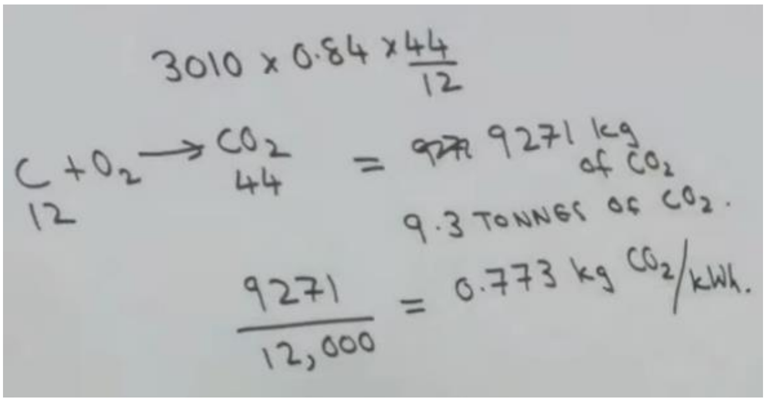

The next part is compute the carbon dioxide emission factor for the dg set and the annual carbon dioxide emitted. So, annual kg of CO_2, we said 3010 kgs of diesel, we are also told that the diesel has 84 percent carbon. So, this will be 3010 in 0.84 This is the kg of carbon which is emitted. Now, C plus O_2 giving you CO_2, this is 12, this is 44. So, kg of CO_2 per kg of carbon is into 44 by 12. We have done this a number of times. So, you probably just remember this factor but so this way we can get this.

This will give us 9271 kgs of CO_2 annually or if we just talked about carbon it would have been 2500 kgs of… So, this is 9.3 tons of CO_2 being emitted. Now, let us see what was the emission factor, emission factor is the amount that we are emitting 9271 kgs divided by the output which is in kilowatt hour. So, this will be kg per kilowatt hour and if you do this number you will find that this is 0.773 kg of CO_2 per kilowatt hour. So, this is if you look at the numbers that are there in our power sector, you will find that this is a reasonable number it is within that kind of range and the power sector is sector which is responsible for significant CO_2 emissions. Let us look at the next part of the question.

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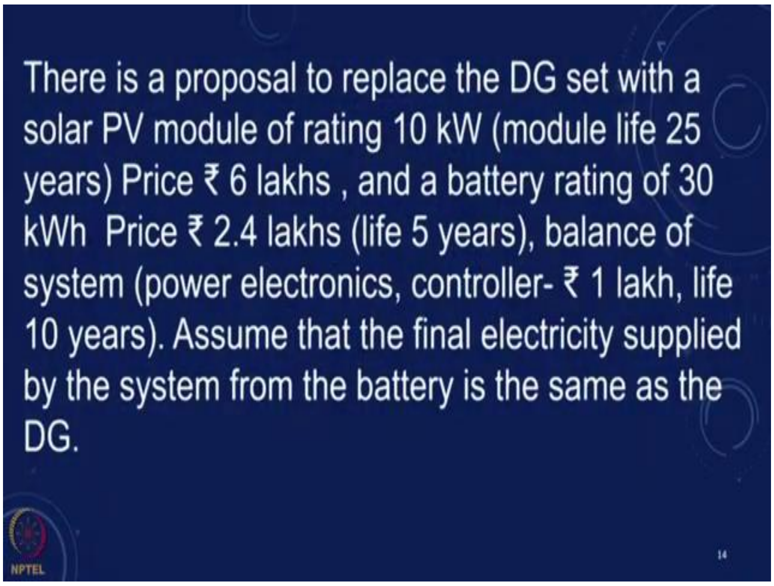

Next part of the question is that there is a proposal to replace the DG set with a solar PV module. Why are we trying to do this? Well, we have DG has emissions, both local emissions as well as CO_2 emissions and we replace this with solar. Then these emissions would be avoided and there is an annual cost of fuel. If you replace it with solar there will be no annual cost of fuel.

So, in this case, the solar PV module rating is 10 kilowatt, module life of 25 years, price 6 lakhs and battery rating of 30 kilowatt hour, price 2.4 lakhs, life five years and balance of system power electronics controller is 1 lakh, life 10 years. So, assume that the final the electricity supplied by the system from the battery is the same as that of the DG. So, if we look at this, we can just take this as total capital cost.

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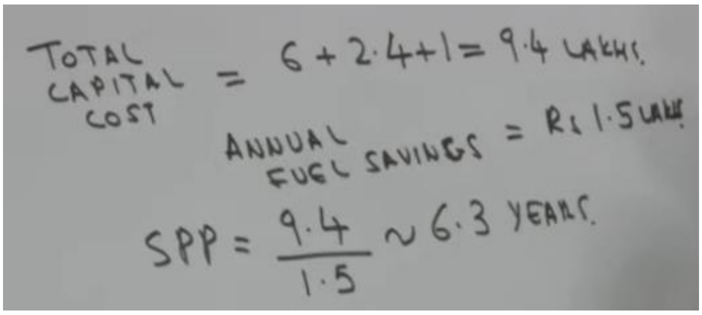

This is very similar to the example that we had done. 6 plus 2.4 plus 1, this is 9.4 lakhs. What is the annual saving? The annual saving is essentially the difference in the fuel price, the O&M is almost similar. So, the annual fuel saving is 1.5 lakhs. 1.5 lakhs and what is then the simple payback period? It is just going to be 9.4 lakhs which is the investment divided by 1.5 is approximately 6.3 years.

Now, the point in this is that this is, this considers the entire capital because we are saying that the DG is already there. We could also take in some cases, if we, if it is a Greenfield project, we can take the initial cost, we can subtract from these 4 lakhs and then the payback periods would be much lower. If we consider and if we neglect the non-fuel O&M in the case of PV then the annual savings could be slightly higher. So, this is the in terms of the simple payback period.

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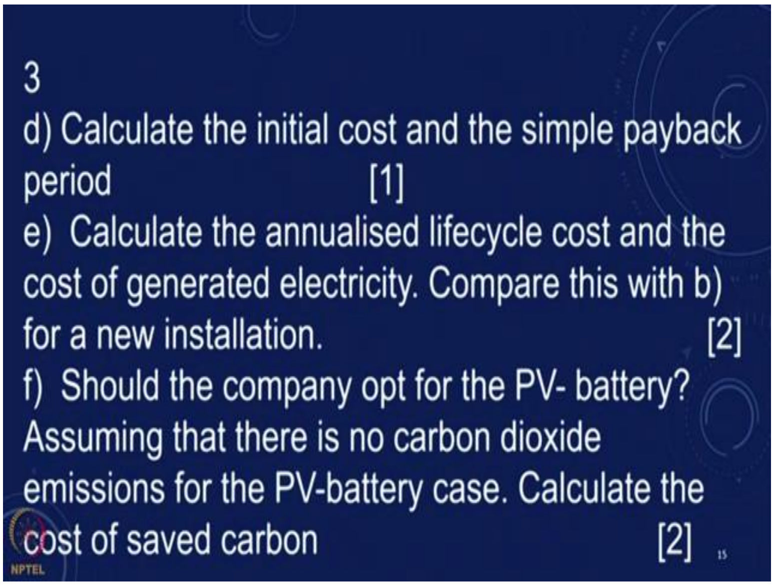

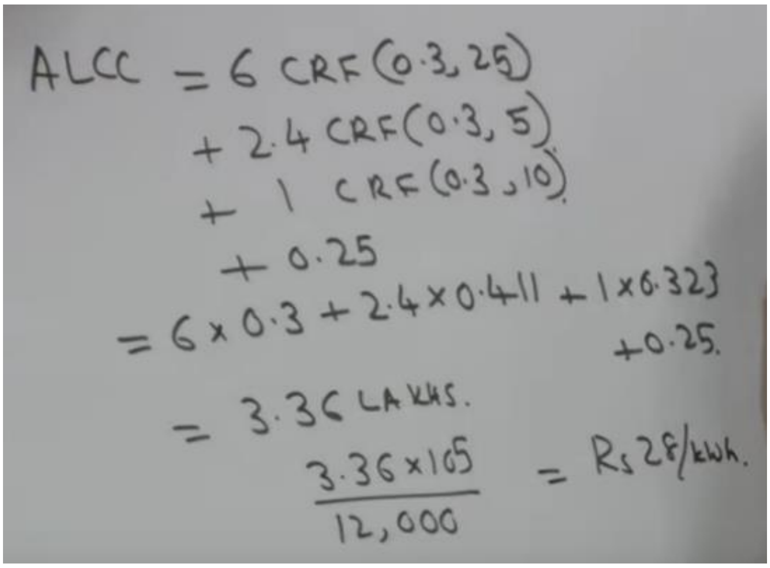

Now let us calculate what is the initial cost and simple payback period. We have done this. Calculate annualized life cycle cost. So annualized life cycle cost for the PV system is going to be 6 into CRF 0.325 PV modules have a higher life, the battery 2.4 lakhs, capital recovery factor, discount rate is the same, life is five years plus balance of system 1, CRF 0.3, 10 years plus let us say 0.25 lakhs is the if we say that the non-fuel O&M is almost the same, then this is going to be 6 into the CRF 0.325 turns out to be approximately 0.3 itself, 0.301 or something. This is 2.4 into 0.411, please check these numbers.

And this is 1 into 0.323 plus 0.25, when we add this up this turns out to be 3.36 lakhs and the cost of generated electricity then becomes 3.36 into 10 raised to 5 divided by 12,000, turns out to be 28 rupees per kilo watt hour. Just compare this with the earlier number that we had, that number was 25.4. So, this looks to be a costlier option. Of course, it depends on the discount rate and what is the scarcity of capital. If you do the same numbers with a discount rate of 10 percent, you might find that the PV seems to be viable.

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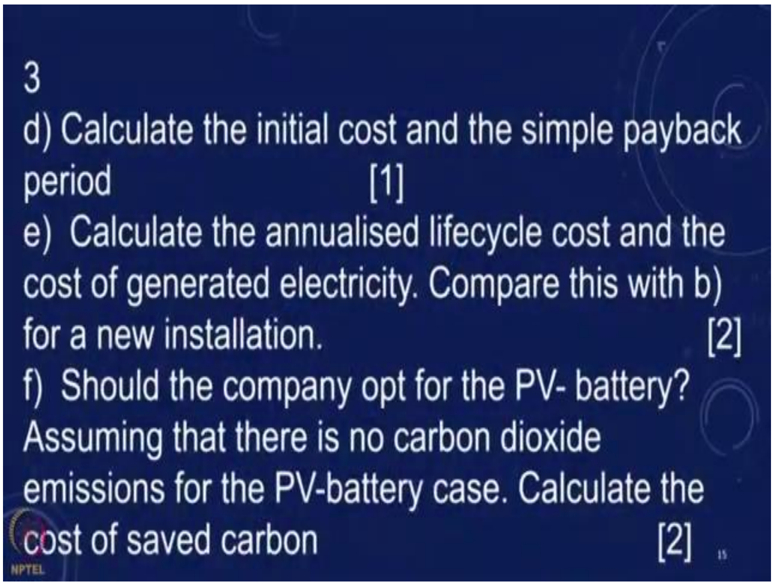

In this case, let us the last part is should the company opt for the PV battery? Well, based on the economic calculations and the discount rate, the company would not opt for the PV battery system because the LCC is going to be less for the DG system. However, if we look at the cost of saved carbon and if there is an incentive based on the carbon and you have a carbon credit, then the test might make it viable. So, let us calculate the cost of saved carbon.

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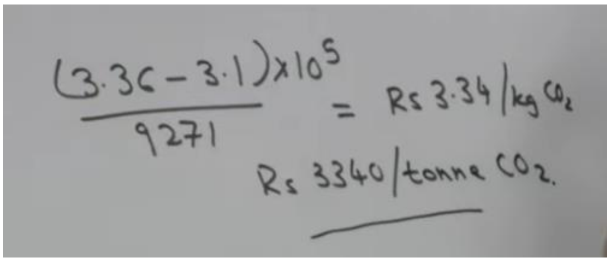

This is going to be 3.36 minus 3.1 divided by 9271. This is the annualized life cycle costs in the case of PV, annualized lifecycle costs in the case of dg, the difference in that divided by the tons of carbon the cages of carbon saved and this turns out to be rupees 3.34 per kg of CO_2 or rupees 3340 per ton of CO_2 then you can compare it with the carbon price for a CER, CER is one ton of CO_2 and so you can see this and compare it with that.

So, if the CERS are sold at a price which is greater than 3340, then of course this will become viable. So, we have seen this option, it is essentially various simple in terms of, it is a simple application of what we had learned in the energy economics and the emission factor. Now let us look at the fourth question.

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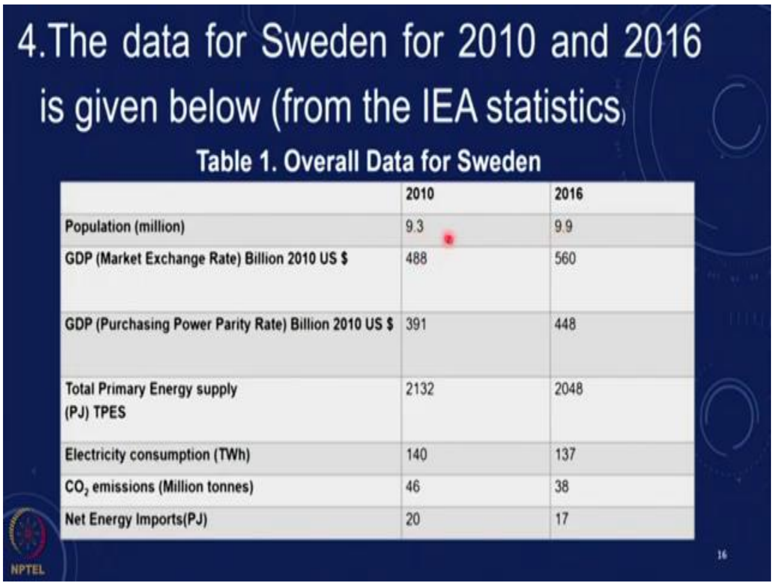

	2010	2016
Population (million)	9.3	9.9
GDP (Market Exchange Rate) Billion 2010 US $	488	560
GDP (Purchasing Power Parity Rate) Billion 2010 US $	391	448
Total Primary Energy supply (PJ) TPES	2132	2048
Electricity consumption (TWh)	140	137
CO_2 emissions (Million tonnes)	46	38
Net Energy Imports(PJ)	20	17

And the fourth question talks, so this is data for Sweden for two different years, 2010 and 2016 and you can see the populations growing but not much. 9.3 million and 9.9 million and look at the GDP in market exchange rate.

It is been growing and interestingly GDP and purchasing power parity, less than the GDP in the market exchange rate and the total primary energy supply you can see it, it has declined the electricity consumption, CO_2 emissions and the energy imports. So, based on this, these are all available for IEA statistics.

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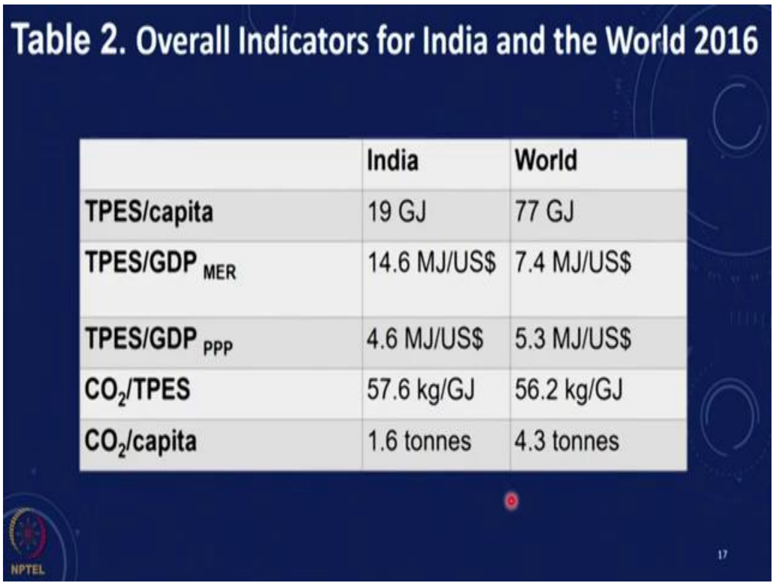
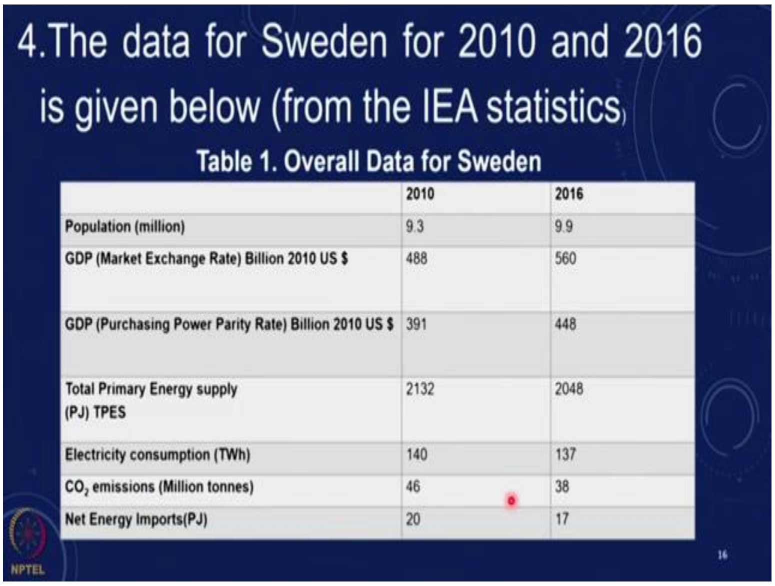


Table 2. Overall Indicators for India and the World 2016

	India	World
TPES/capita	19 GJ	77 GJ
TPES/GDP $_{MER}$	14.6 MJ/US$	7.4 MJ/US$
TPES/GDP $_{PPP}$	4.6 MJ/US$	5.3 MJ/US$
CO_2/TPES	57.6 kg/GJ	56.2 kg/GJ
CO_2/capita	1.6 tonnes	4.3 tonnes



4.The data for Sweden for 2010 and 2016 is given below (from the IEA statistics)

Table 1. Overall Data for Sweden

	2010	2016
Population (million)	9.3	9.9
GDP (Market Exchange Rate) Billion 2010 US $	488	560
GDP (Purchasing Power Parity Rate) Billion 2010 US $	391	448
Total Primary Energy supply (PJ) TPES	2132	2048
Electricity consumption (TWh)	140	137
CO_2 emissions (Million tonnes)	46	38
Net Energy Imports(PJ)	20	17

And the aggregate data is also given to you for India and the world in terms of and this is for snapshot in time in 2016. Here we have both 2010 and 2016. We have the similar numbers now, the overall indicators for India and the world. And the question which is involved is a comparison of the Swedish energy sector and the economy with India and the world.

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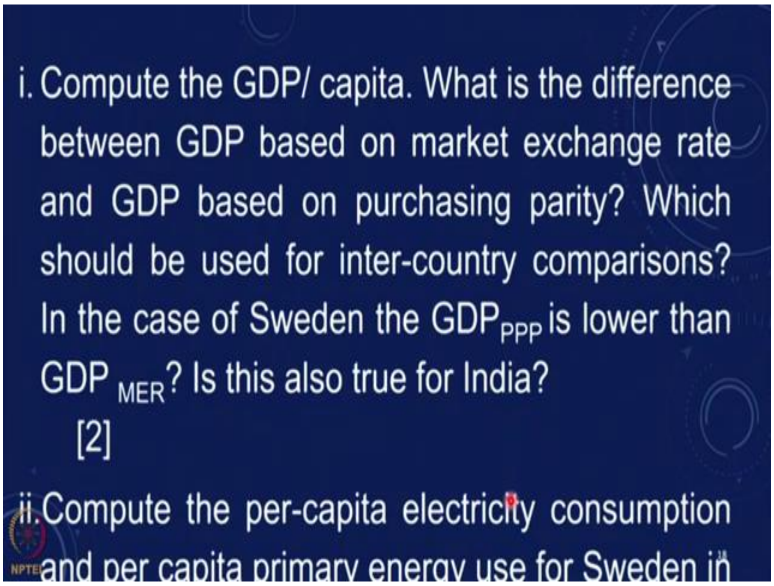

So, the first thing which has been asked is what is the GDP per capita? What is the difference between the GDP based on market exchange rate and GDP based on purchasing power parity? Which one should be used for inter country comparisons? And in the case of Sweden the GDP, purchasing power parity is lower than GDP market exchange rate. Is this also true for India?

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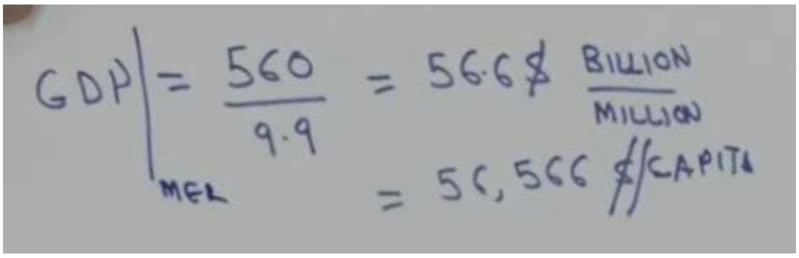

So, this is straightforward calculations. First GDP per capita we just take the GDP and divide it by the population, 560 by 9.9, turns out to be 56.6 billion dollars, this will be billion by million. So, this turns out to be 56,566 dollars per capita and if you see the India, India's numbers will of course be lower and this is based on the market exchange rate, 2016 GDP market exchange rate.

Similar thing if we did base on purchasing power parity we find that this is 45,252 dollars per capita. Generally, GDP purchasing power parity is used for inter country comparisons and that is to adjust for the fact that in different economies there are different types of when you look at the exchange rate, it does not always reflect the purchasing power. So, the cost of living and prices in Sweden is high, higher than the basis. So, the actual GDP is overstated.

When you correct it for GDP by purchasing power parity, that amount which is there turns out to be lower and so in the case of Sweden even the GDP per capita is lower. Is this also true for India? This is not true for India. For India, on the other hand, the GDP in the market exchange rate in US dollars is much lower than the actual value of that money. So, the GDP by purchasing power parity is higher than the GDP market exchange rate.