Energy Resources, Economics, and Sustainability

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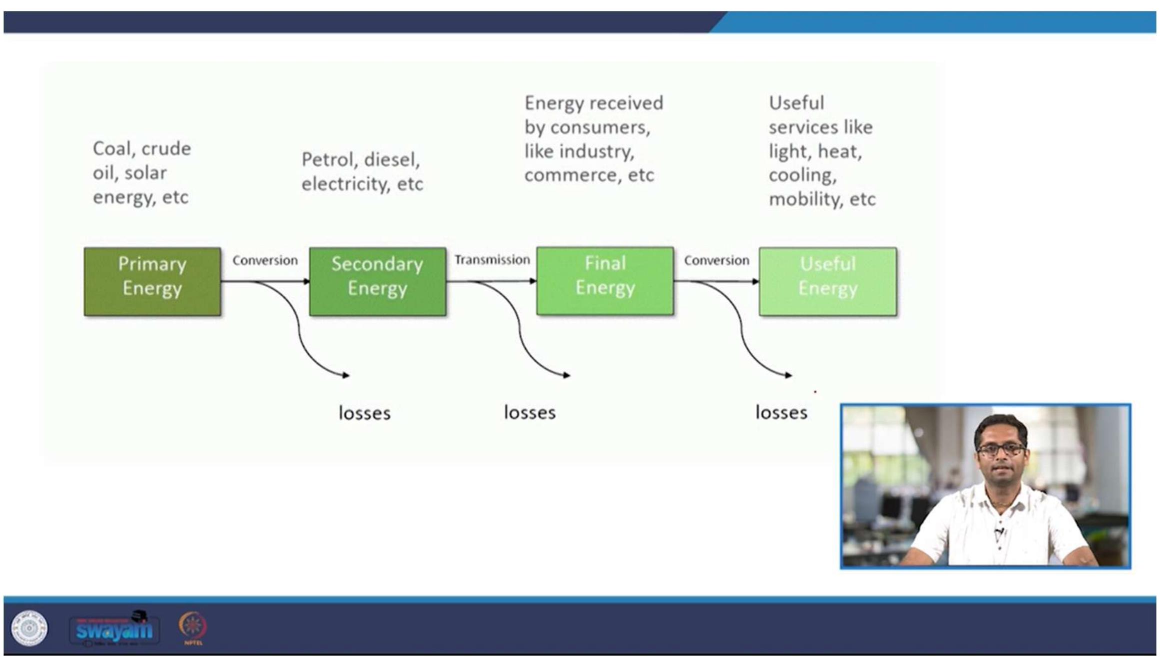
Week – 02

Lecture – 02

Lecture 07 - Energy Flow Diagram-I

Hello everyone, welcome back to the course. So in the previous classes, we have been discussing the different issues with respect to the energy consumption. And in the last class, we have been discussing how the kaya identity basically regulates the CO2 emissions. In today's class, we are going to understand the net energy or net primary energy consumption with the help of energy flow diagrams. You have been maybe coming across discussions which might say that an EV is much more efficient as compared to an IC engine vehicle. Or if we go towards an electricity based system that is expected to be much more efficient than a diesel based system. Or similarly now there have been saying a fuel cell electric vehicle is much more efficient as compared to an IC engine vehicle. So this is something and these are some of the answers that you can get from an analysis that we are going to learn in today's class and in the future classes. So let us start with the basics. So energy that you would come across across different sectors could basically be divided into different terms.



First one could be the primary energy that is the energy that is available in the raw form. It could be the source coming directly from the coal or the raw crude. It could be the solar irradiance that falls on the concentrated solar or solar PV systems. This could be the oil. Then these sources of energy need to be converted into something that could be stored and transported for longer distances.

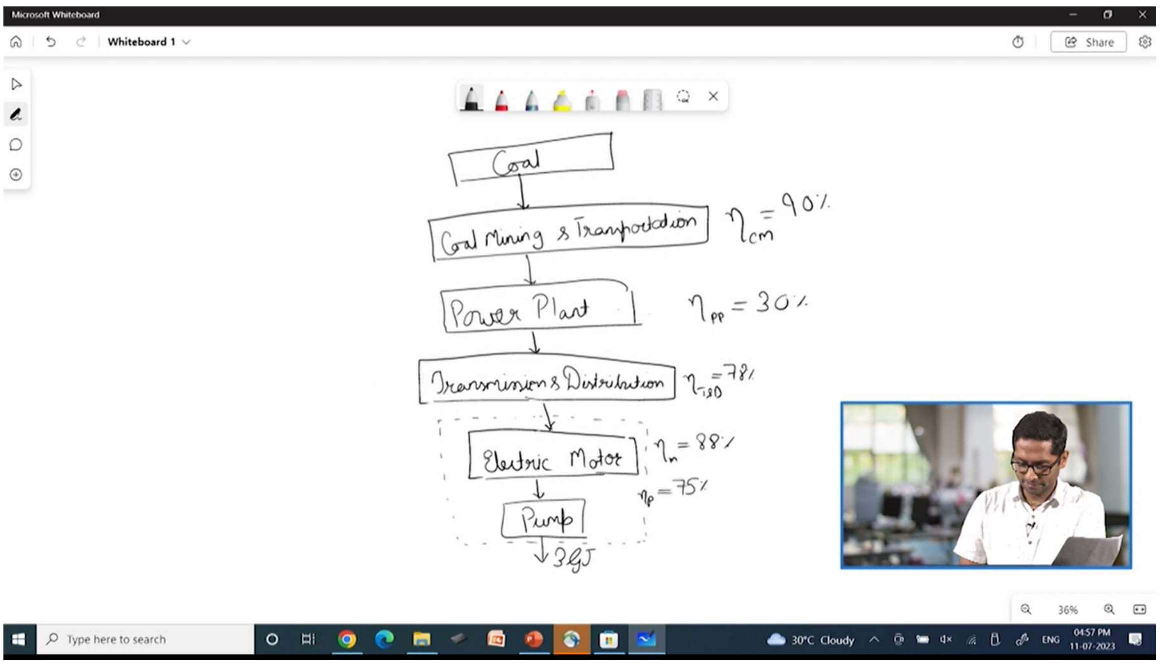
And of course there would be losses involved. Like if you have coal that needs to be extracted from the mines. If you have the crude oil that needs to be refined in a fractional distillation column giving in the different fractions which could be used for different applications. The solar energy needs to be converted either through concentrated solars or solar PV. And this has its own conversion losses as well as the transportation losses.

Then what you get is a secondary energy which could be used in different kinds of energy systems which an example could be petrol that you use or the diesel that you use in your cars, your two wheelers and other applications. The electricity that you use in your homes. And this secondary energy also then needs to be finally transmitted to the end users like you and me. So what I mean I am talking about this secondary energy. This is basically a bulk energy storage that is either stored in the oil tanks, the oil bunkers or the electricity that is available at the conversion centers.

Finally this reaches our homes, our industries where we make use of this final energy. The use could be travel in that form of the vehicles. It could be light energy. It could be the different kinds of equipments like laptops or mobiles that we use. And the useful services that we get is the useful energy.

It could be mobility, cooling, lighting, heating and all these steps among itself have different kinds of losses. So there could be some processes which could have very low losses and other processes which could have very high losses. And these are some things or these are some of the aspects we will try to understand as with the help of a few examples. We will take typical examples which would help us relate it to our day to day life and also come up with an understanding and answers to some of the popular discussion that we come across like which processes are much more efficient, which processes have much lesser CO_2 emissions, which are much more economical and we will try to understand the trade-off that lies between them. So let's try to go towards that analysis.

So the example that we are going to take to start with is a typical solar pumping system. So if you go towards any agricultural farms that would need water for the harvesting and in many of these cases the water is pumped by digging borewells. We would have the agricultural pumps using different kinds of energy pumping water and this water is used for the irrigation purposes and these kinds of systems are used quite abundantly in a country like ours which is a primarily agricultural based economy. So let's take the example of different ways in which a pumping water system could be designed. So what we are going to understand is energy requirements of a water pumping system.



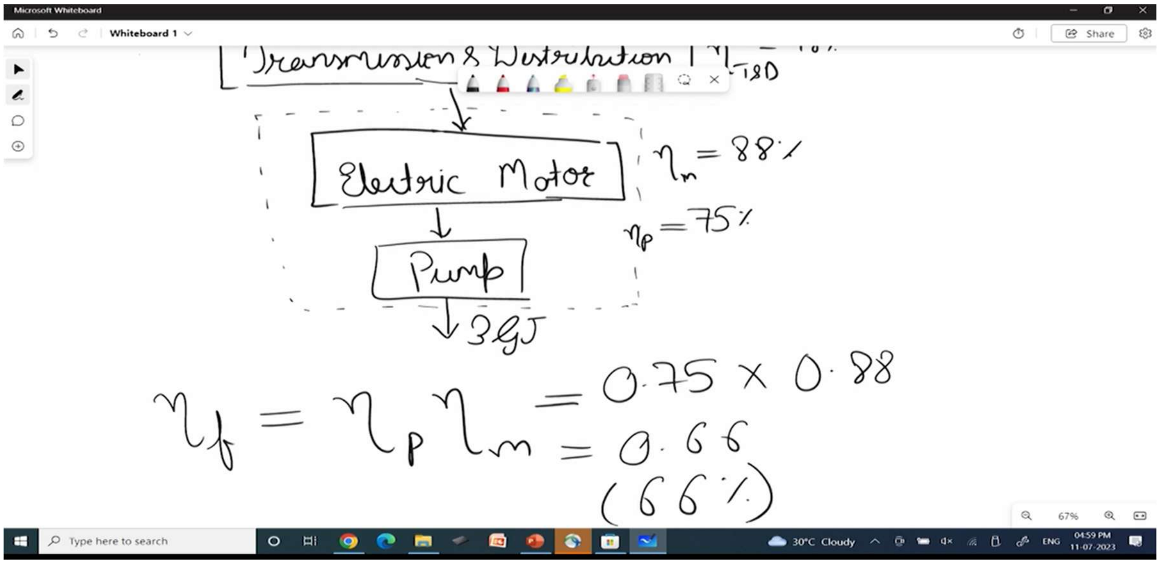
So we will go with assumption that this pumping system has an end requirement of around 3 gigajoules of final energy. Now this energy could come from different sources. One of the source could be used electricity that is available in the grid. This grid could be used to power the pumps and the water could be pumped out. The other option could be we could have the diesel powered gensets which many of you would have seen or you would have utilized in your day to day activities as well.

What if I use a DG set and use that to run a motor and a pump and we try to see which of them consumes more energy or which of them is expected to be much more efficient or economical. So let's start with an electrical system which is based on electricity. So the basic system would be a pump. Let me start from here. And this pump would have an output energy of 3 gigajoules.

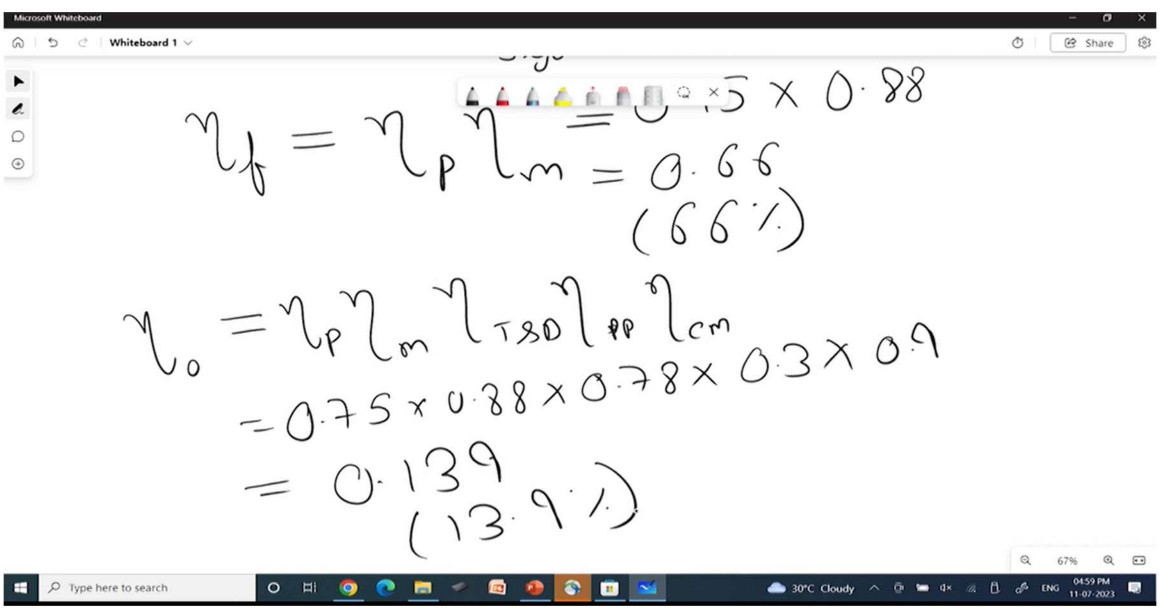
So this pump would basically be linked to an electric motor. And this electric motor was basically be consuming electricity that is coming from the grid. So if I talk about the typical efficiency of a pump maybe goes by eta pump this would be of the range if I go with the maximum possible efficiency around 75%. It would vary basically depend upon like what is the load on which the motor is or the pump is being operated. And the typical motor would which I give by eta m would have an efficiency of 88%.

So this is the type of typical efficiency that a farmer would see. If I look towards the farmer this is the system boundary from a farmer's point of view. He is taking electricity from the grid. The electricity is used to run a motor. The motor is linked to a pump and this pump is used to basically bring out water.

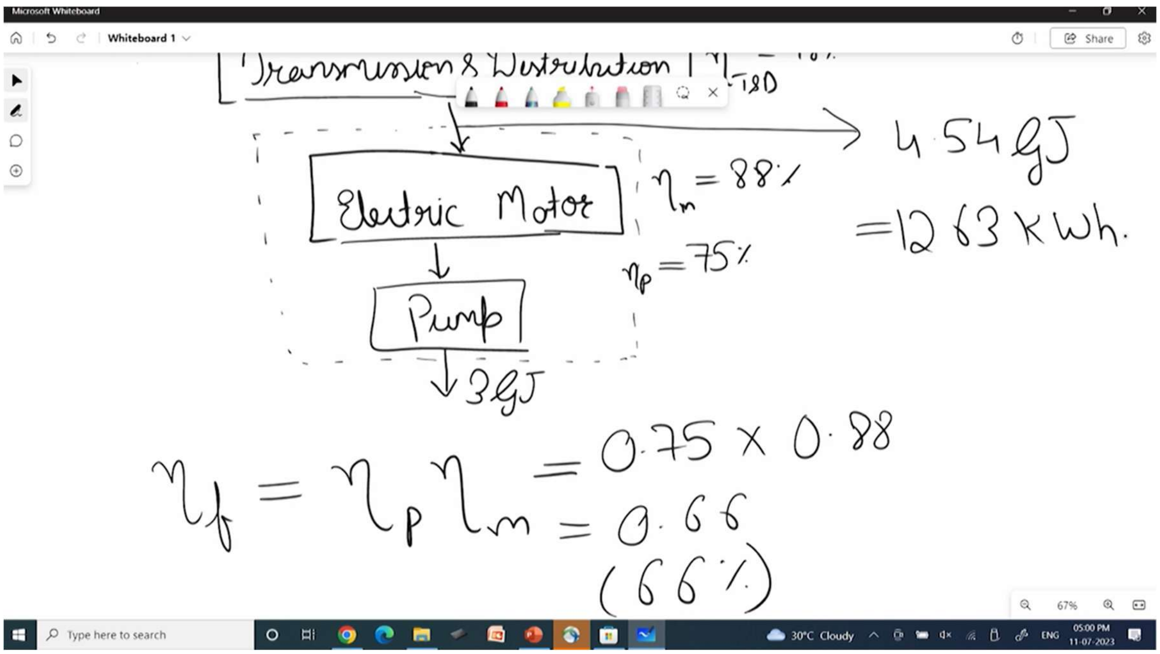
But this electricity if we consider would be using the electricity that is coming after transmission and distribution. And if we consider a country like India the transmission and distribution losses could be huge. The typical efficiency of the transmission and distribution which is eta transmission for India would be around 78%. Beyond this transmission and distribution losses would be a power plant that would be generating this electricity. And this power plant can be expected to have a typical efficiency of around 30%. And this power plant if in a country like India would normally be operating on coal. So we would have the coal mining and of course the transportation. And beyond that would be the source of energy which is the primary source which is coal itself. Now this mining and transportation could be assumed to have an efficiency of almost 90%. So how do I come at this number? This basically gives us like what is the energy consumed in digging up the mines and then taking the coal out of the mines which includes like different kind of fuels being used. And in terms of energy value that basically ends up being around 10% of the energy content of the fuel. And that is how I would arrive at a number around 90% for the mining of and transportation of coal. And so if I look at the complete supply chain this is how this would look like. You would have the coal, coal mining and transportation, power plant, transmission and distribution, the electric motor, the pump and finally what I get is around 3 gigajoules of energy. So if I look at the efficiency from a farmer's point of view, so if I say from this would be only the efficiency of the two elements which is that of the pump and that of the electric motor.



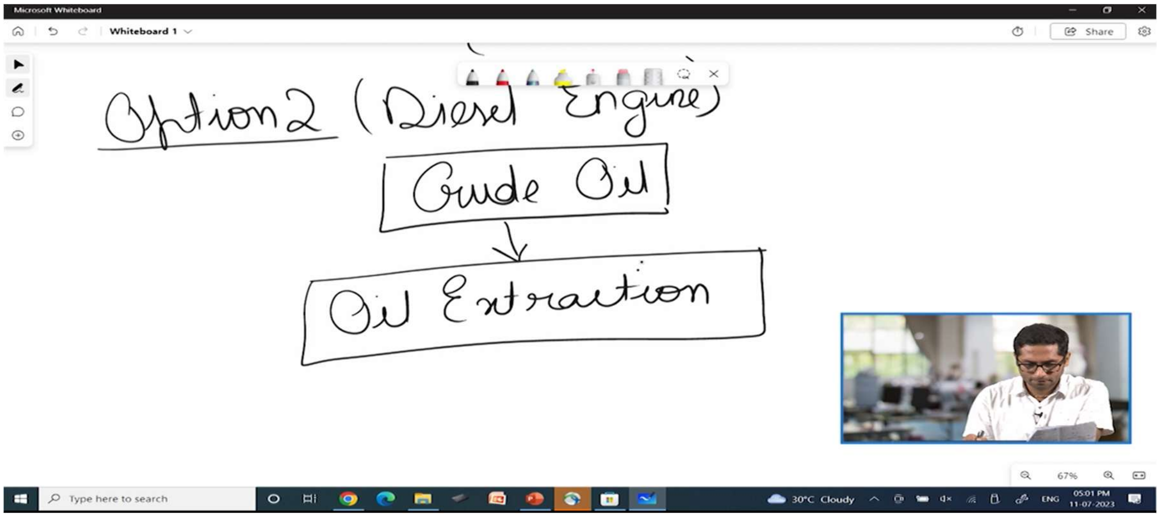
You multiply the two things and like 0.75 into 0.88 and you should get a value of around .66 or 66% as the over efficiency from a farmer's point of view which appears to be quite good like based upon the electricity that you are getting or you can make use or a good use or you can convert that into useful energy around 66% which happens to be very nice. But if you look at the overall efficiency of this process which is eta overall this would basically include all the different factors which is eta pump, eta motor.



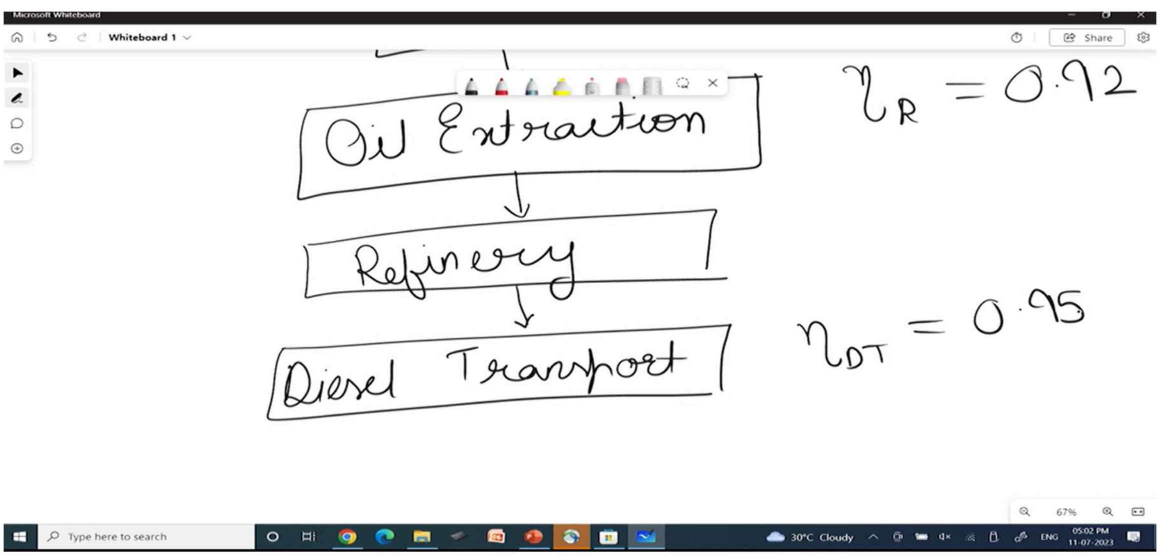
I multiply that with the transmission and distribution. Then I also have this power plant and then the coal mining. If I multiply all these factors which would let me write down those factors for you. It would be 0.75 into 0.88, 0.78 then the next factor would be around 0.3 for the power plant and then 0.9. You multiply these factors the final number that you get is around 0.139 or 13.9% overall efficiency. So if I see from an overall systems point of view the efficiency seems not to be very great almost of the order of 14%.



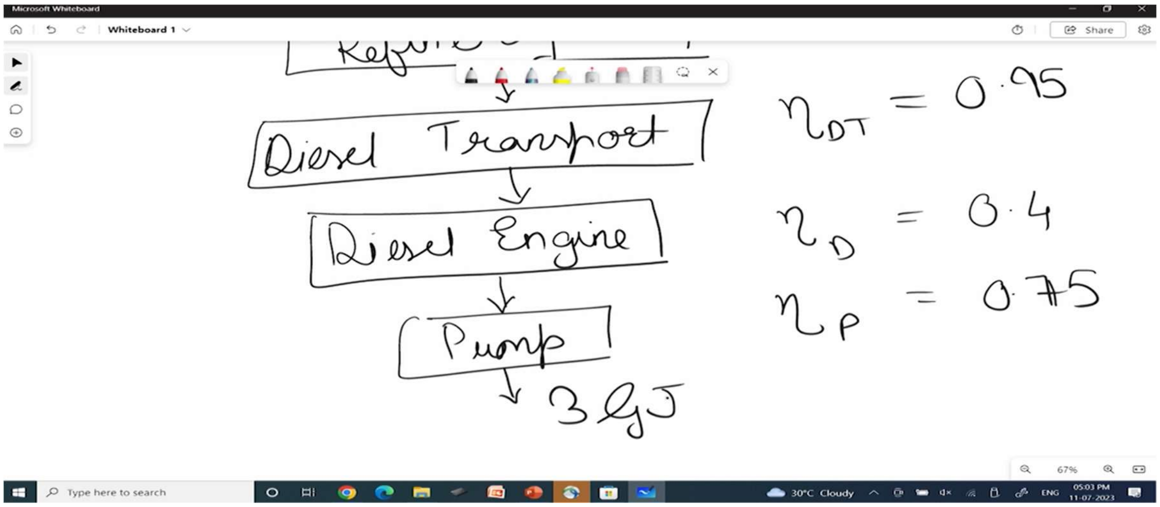
Further I can see that like if I see from the farmer's point of view like if he is inputting around 3 gigajoules or like he wants a 3 giga joules of energy at the output the amount of electricity that he would need you can convert that like would be around at this point divide that with efficiency would be roughly around 4.54 giga joules and you can convert that into kilowatt hours by using simple conversion units and this would come around to be roughly equal to 1263 kilowatt hour. So if you see any urban house the normal electricity bill usage is normally like 200 to 300 units a month of course that would depend on your personal usage and that gives you like what is the usage in terms of electricity and that gives you an idea but from a farmer's point of view like this is a fairly efficient system but if I see the overall efficiency does not turns out to be very great. Now let us move towards the other alternative which is a DG set and let us try to analyse that system how the efficiency would appear for a system like that.



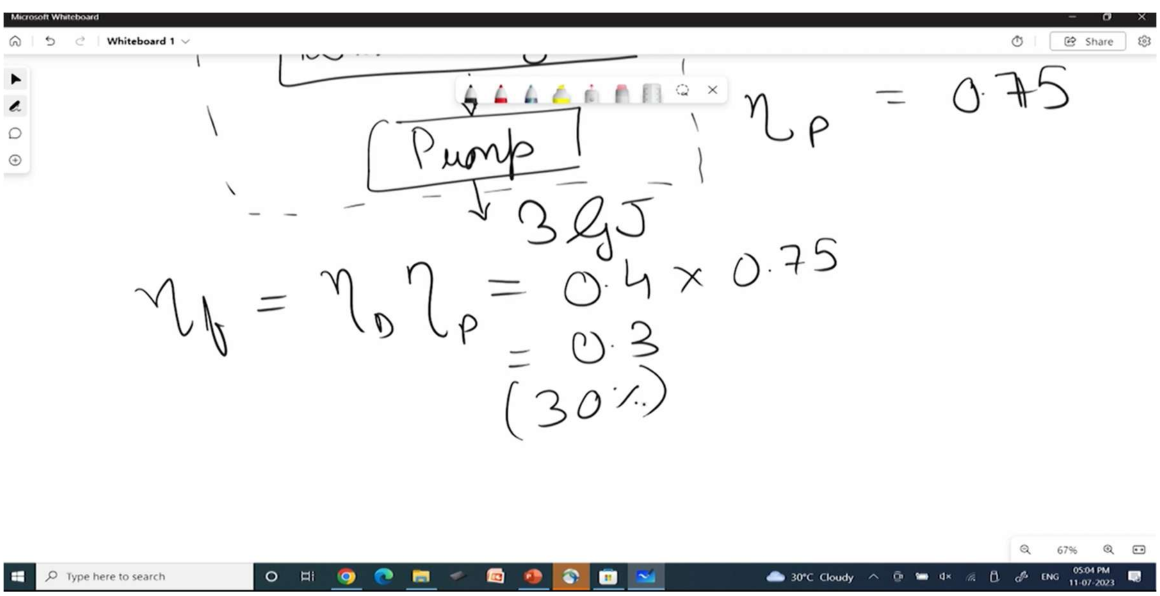
So let me go to the second option and this would be a diesel engine. So for this particular case let me start from the top. So normally for a diesel engine you would operate that on diesel and diesel as all of us understand comes from crude oil and this crude oil is normally refined before that. So the original source of this energy would be crude oil. Crude oil would go for oil extraction there would be oil extraction rigs and then there would be refinery which would convert the oil into the different components.



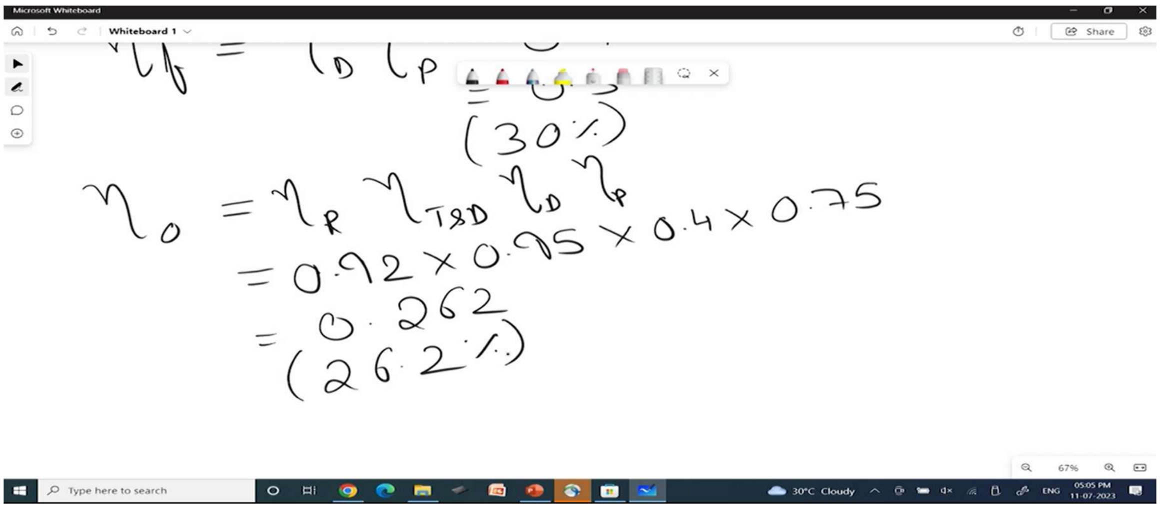
So if I consider the total efficiency from crude oil till the diesel production in a refinery I can take a cumulative efficiency of eta r to be roughly around 92% or 0.92. Then we would need to transport this diesel till the end location which would involve the diesel transportation and this consumes a good amount of fuel. So we can have this efficiency to of around 0.95% for this diesel transportation and finally this diesel ends up in a diesel engine.



This diesel engine would have a typical efficiency of somewhere around 40% and finally we would have the pump operating from this diesel engine and the pump has a similar efficiency of around 75%. And the final energy that I am looking towards is 3 gigajoules of energy per annum. So now if again I would want to look from a farmer's point of view so this is the system boundary what a farmer would be interested in. He would bring in the diesel put that diesel into the engine and use that the power from the diesel engine to pump the water.

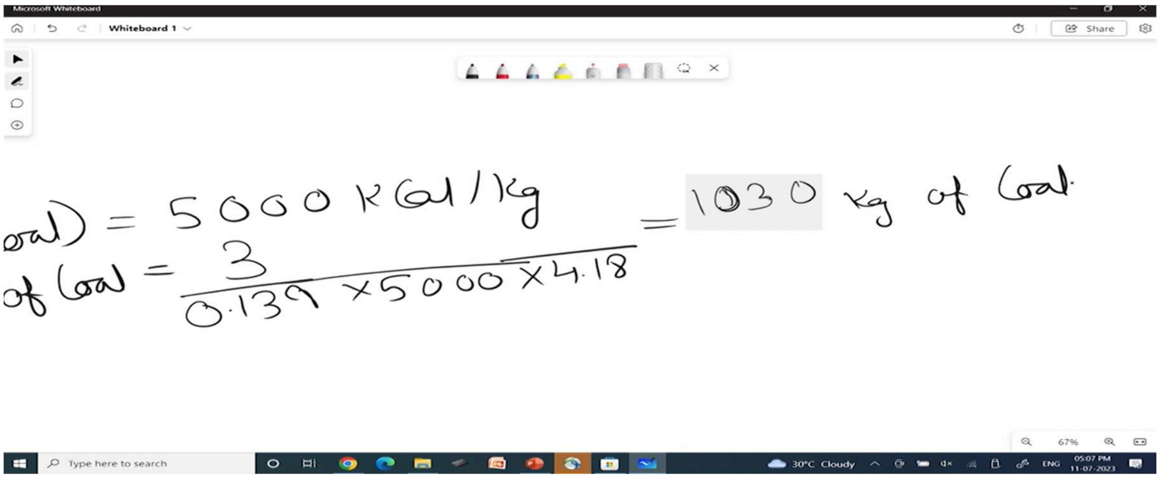


And if I see the efficiency from a farmer's point of view which is eta f which would be a function of eta d into eta pump the multiplication of 0.4 into 0.75 this value would come around to be 0.3 or 30%. So a farmer would see an efficiency of almost 30% for a system like this. Now this seems to bit on a lower end as we compare that with the earlier case where we saw an efficiency of 66%. So for the end case for a system that is based on diesel the efficiency is almost half.

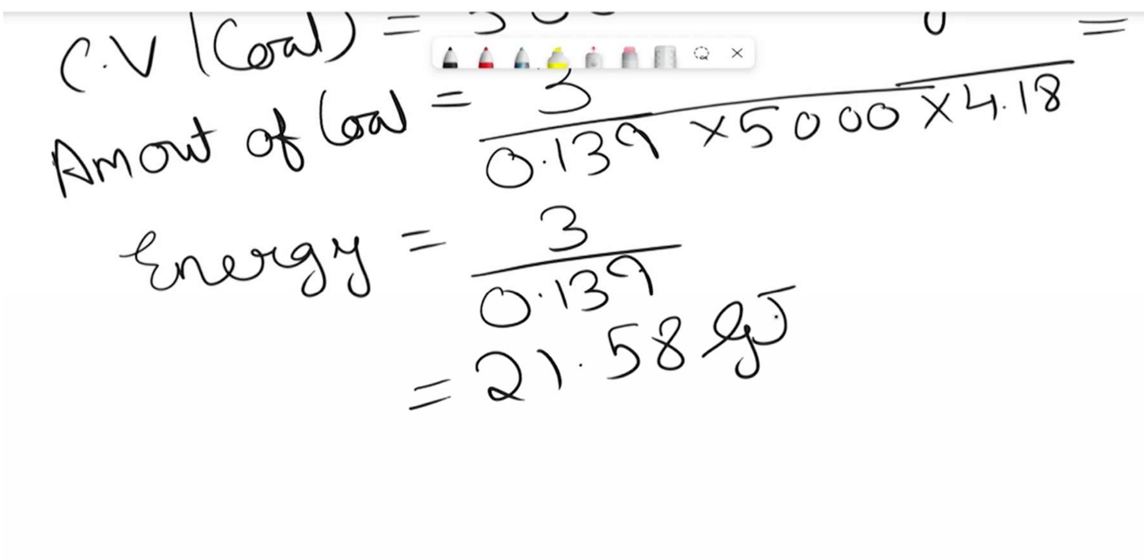


Now if we try to see for a system like this the overall efficiency which is eta overall which would include multiplication of the eta r which is from the refinery eta transportation and distribution eta of the diesel engine and eta of the pump and if I put in all this values which is 0.92 into 0.95 into 0.4 and into 0.75 the final value that I would derive is around 0.262 or 26.2% of the total efficiency. Now what you see here is all the form of farmers point of view the efficiency is almost half from a total systems point of view it has almost doubled. In the earlier case the efficiency that I got for electricity based system was around 13.9 whereas it has now become very close to double in the terms of 26.2%. So we can also calculate the amount of fuel that would have been required for producing this energy.

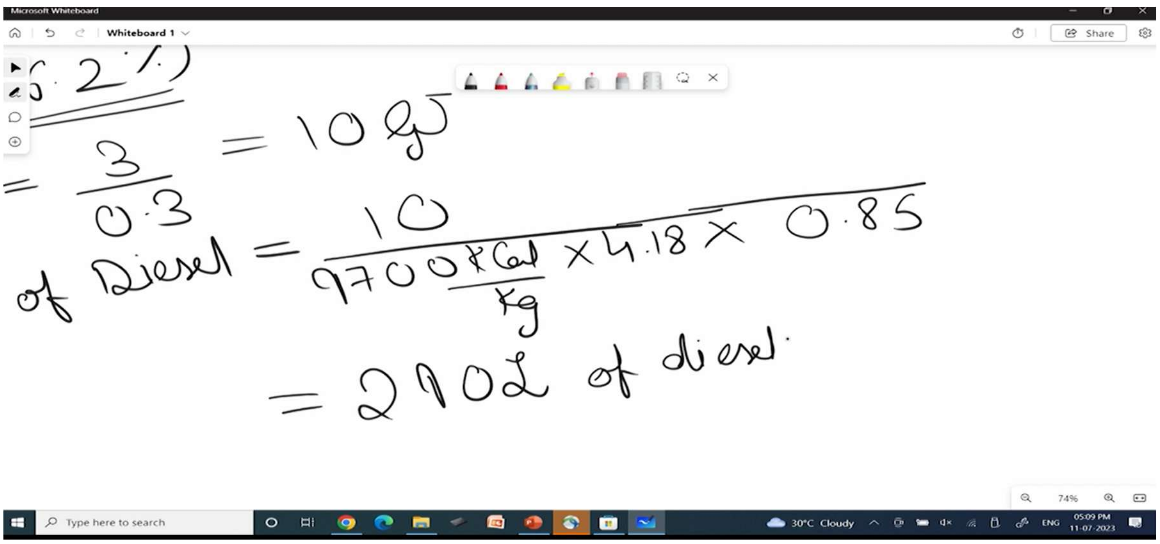
So in the earlier case what I can do is like maybe I can go a bit here like we can assume a typical calorific value for coal which would be like CV of coal and this could be of the range of 5000 kilocalories per kg of coal and I can use this to calculate the amount of coal. So they for producing this energy which is 3 gigajoules per year and this would come around to be the total energy was 3 I divide that with the efficiency which was 139 this gives me total amount of energy that is required and then I divide that with the calorific value of coal which is 5000 and I also need to convert the kilocalories into kilojoule which will come around to be 4.18 factor and this result would roughly come out to be around 1030 kg of coal that would be required.



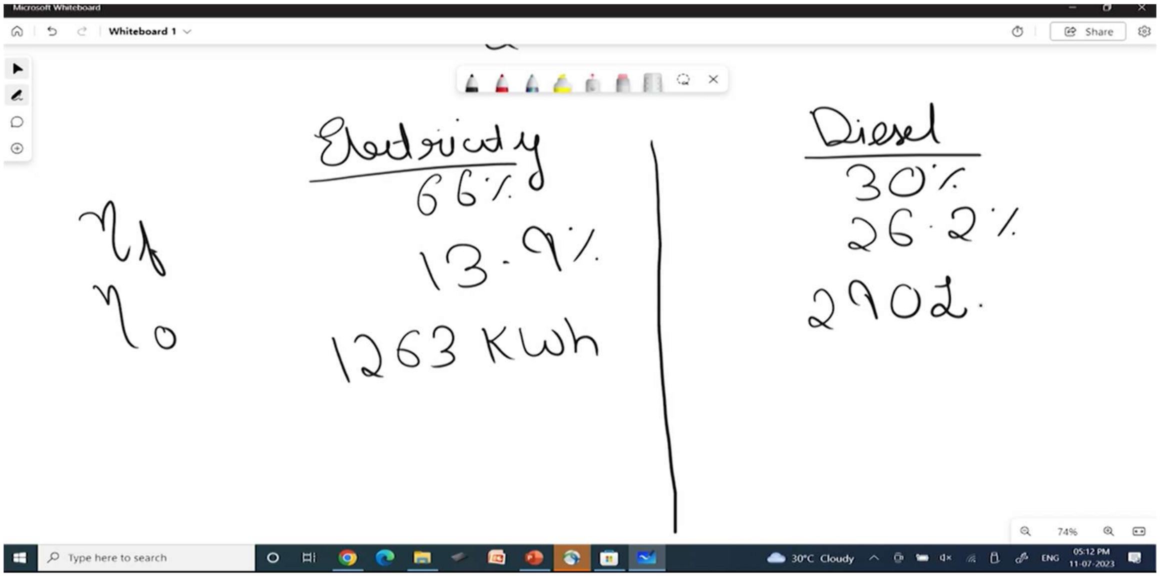
If I talk about in terms of the energy terms it would be simply 3 divided by the efficiency and the total energy that would be going in on the system would be around 21.58 gigajoules. So you would need around 1030 kg of coal around 21.5 gigajoules of energy per year.



Compare that with the next case which was the diesel energy so again in this case I am having an efficiency of around 26.2% and if I go with the amount of diesel that would be required so I am not going towards the crude but the diesel. So for the diesel like the efficiency would be 0.3 like 3 divided by 0.3 that is the efficiency that are farmers saw and the amount of energy that would be required in terms of diesel would be 10 gigajoules and the amount of diesel if I go with that this would be the 10 gigajoules divided by the calorific value of diesel so in this case I have assumed to be 9700 kilocalories per kg multiply that with 4.18 as a conversion factor for kilocalories to joules and finally I multiply with the density of diesel which is assumed to be 0.85 and what I get is around 290 liters of diesel. So if I talk from a weight or a volume point of view like 290 liters of diesel appears to be way lesser as compared to 1300 kgs of coal.

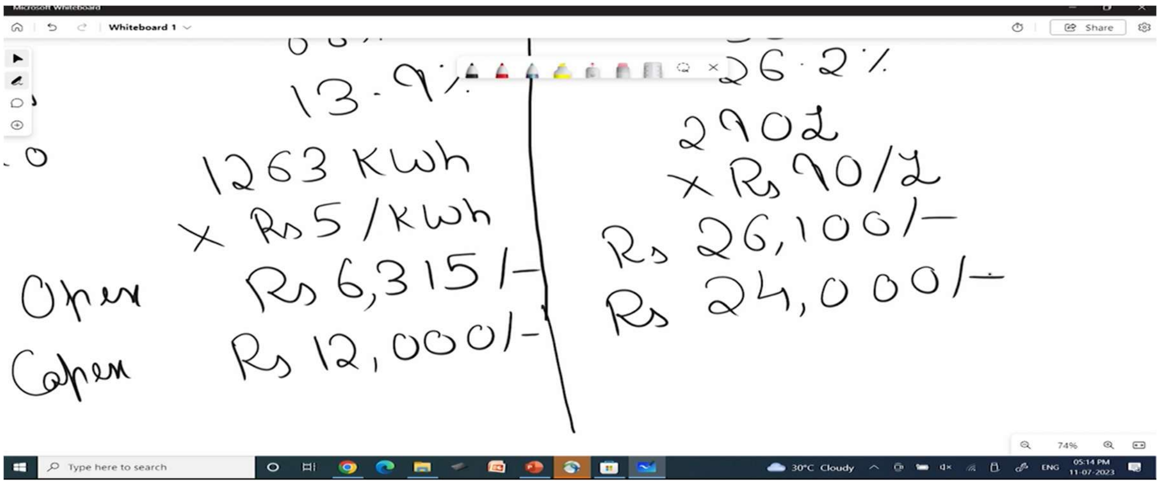


For the total primary energy that would be consumed would also be somewhat lesser because the efficiency of the system is vastly high. Okay so now we have been discussing the two systems and let us try to understand them in more detail. So let me divide the systems into two so we have the electricity based system on the left and we have the diesel based system on the right. So let us first start with efficiency so efficiency from the farmers point of view we saw that the electricity based system would have almost 66% efficiency and that for a diesel based system would be almost 30%. If I go with the overall efficiency from like from a systems point of view the efficiency is reduced in the case of an electricity based system comes down to almost 14% and whereas for a diesel system this is quite high at around 26.2%. Now let us also try to understand in terms of the total energy that would be used. So in terms of like the electricity that would be used would be around 1263 kilowatt hour and whereas in the case of diesel the diesel fuel that would be used would be around 290 liters of fuel.

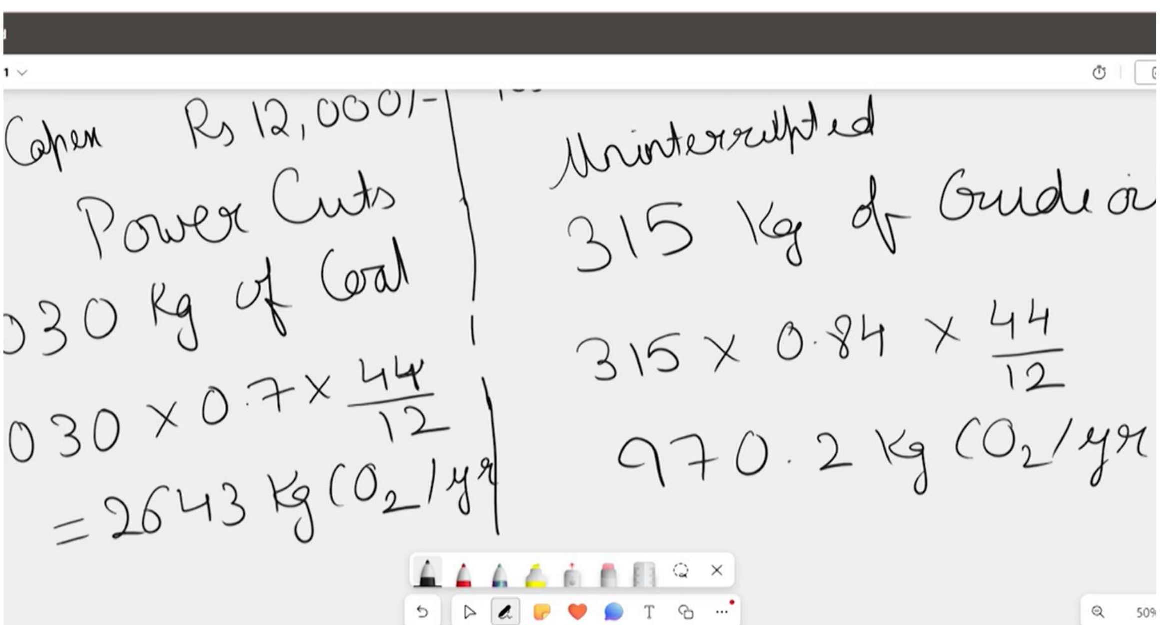


We could also estimate the price or the operating cost of the systems so we know that the typical electricity is available at around 5 rupees a unit of course these rates are quite different for agricultural producers but let us go with the same figure. So if I am using the like if electricity is available I multiply that with rupees 5 per kilowatt hour which might be the average price of electricity so the operating cost for a system like this or if I say the OPEX would come around to be rupees 6315. We can do the similar for the diesel based system so typically diesel would be available at around 90 rupees a liter so I am taking a conventional figure of 90 rupees a liter so depending upon the time period you are referring to these numbers would be changing and given this if you multiply these two things you would get around you will get an operating cost of around 26100 rupees. So we see that like the operating cost is almost four times for a diesel based system as compared to a coal or electricity based system so although the system for like a diesel based system is much more efficient from a systems point of view if you observe that from an economics point of view like this is almost four times higher based upon the OPEX. We also need to understand like the cost is all dependent on both the CAPEX and OPEX so capital is a one time investment that would bring in so if I talk about the CAPEX the typical system which is based on electricity would cost you around rupees 12000 rupees and of course this would number would be widely different for the brand and the efficiency that you are looking for but I am just taking a typical cost and the typical cost for a diesel based system would somewhere be almost double this number.

Of course there could be a system which are available at much higher the cost what I am suggesting now but I am just taking few representative values. So even in this way we can see both in terms of the operating cost and the capital cost the diesel based system happens to be much on a higher side as compared to a diesel based system. So if I talk about economics if I look from an economics point of view it is quite intuitive that a person would go for an electricity based system which is based on coal based electricity but there is another catch to it.



In a country like India and up till recently we have had major power cuts that could last for many hours. So in case of the farming if you need to pump water and electricity is not available that might have some harm done to your business.



So one of the aspects that we have in the case of an electricity based system that it would be prone to power cuts although that is reducing with time. Whereas the diesel based system is something that you have that could be running uninterrupted till the point you have like diesel available in the market. So in that case you have that liberty that you could have a system that is not dictated by the policies of a particular DISCOM where the power is available when the power is not available.

So then in case you are looking towards an uninterrupted supply of power you might want to go towards a diesel based system if that is more important to you. Besides the availability of uninterrupted power or the power that is available power cuts we also need to be concerned about the primary energy that would be used. And as we have done the calculation previously that for electricity powered pump it would roughly require around 1030 kgs of coal as a primary energy. Comparing that to the requirement of crude that would roughly come out to be around 315 kgs of crude oil.

Now here I am talking about the crude oil. So you can see there could be a vast difference in the absolute amount or the gravimetric amount of a different amount of primary energy that is being used. But again we need to be concerned here because coal is available in a country in plenty and we can be using coal quite freely for the coming few decades. Whereas for crude we would have to depend upon the foreign nations and the relationship with those nations might not be good all the time. So we might have to bear the circumstances for importing something. So the trade off that lies here in it should be go ahead with something that is available in plenty but again it is also utilization is on a larger level or maybe we should depend upon the import of a particular feedstock or a raw material.

Another aspect that becomes prominent nowadays is the emissions particularly that of the CO2. And based upon the primary energy that we are utilizing we can also estimate or try to estimate the amount of CO2 that is going to end up in the atmosphere. So if I take the calculation of coal we are using around a 1030 kgs of coal and assuming that on 70% of the coal is made up of carbon. So I am taking a lower percentage whereas if I am considering a good quality coal that might also have around 90% of carbon. And giving that like the underline equation is 1 mole of C combines with 1 molecule of oxygen or to giving me 1 mole of CO2.

So probably every kg of carbon in the coal is going to end up around 44 divided by 12 which is the molecular weight of CO2 divided by that of the carbon leading into the atmosphere. And if I do that probably I am emitting around a 2643 kgs of CO2 into the atmosphere on an yearly basis. If I am using an electric pump that is powered by electricity that is coming from primarily from coal. Now if I want to compare that with a system that is run by diesel I would have like 315 kgs of crude going in and I multiply that with the carbon content which I am assuming here to be 84% of course this would be varying how where the crude is source form. And again multiplying by a factor of 44 by 12 which is the molecular weight of CO2 divided by the molecular weight of carbon.

And this would typically result in a CO2 emission of 970.2 kgs of CO2 per year. So here we can see another tradeoff that coal if we are using has emissions almost 3 times of that of using diesel as fuel. So here is something again we should be concerned about. So here we have tried to see in different tradeoffs that lies basically in terms of the efficiencies, the economics, the supply, the interrupted or uninterrupted supply of energy further should be depending upon import or do we have internal resources and finally the amount of CO2 that a particular pathway might lead into the atmosphere. So again this problem was brought in to show you the complexity that is involved in a simple system like a farming irrigation system.

If you see from a farmer's point of view there we could see very different efficiencies. From overall systems point of view there could be again very different efficiencies. From the economics point of view you can make one decision but from a policy maker point of view where you would want to minimize the imports and maximize the use of inherent resources there could be other decision. If you are taking a decision from an environmentalist point of view you would want to prefer one system over the other. So and these are some of the tradeoffs that we will try to discuss and understand as we move in this course in the future.

And we will take a similar analysis in the future classes as well. And this particular analysis is coming from the teachings of Professor Rangan Banerjee from IIT Bombay.

So this is an example adopted from one of his lessons. So with this we end today's class. Thank you.