Energy Resources< Economics and Environment
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Lecture 8 Part 1
Renewable Energy Sources- Part 1

We are carrying on with the course on energy resources, economics and environment. We have been looking at energy resources in the previous lecture. We looked at, the fossil fuels and the depletable resources. So, in the characteristic of those resources were that there were stocks and that means that you can have if you talk about coal or you talk about oil or you talk about natural gas you can store it. There is a fixed amount of reserve that is there and we saw methods by which we can quantify, how much time that resource will be lost. We now want to look at a different set of resources and these are renewable resources.

So, as we discussed earlier even fossil fuels are also renewable in the sense that they have been formed by natural processes which occurred over thousands of years. But the rate at which we are using them is much faster than the rate at which it gets renewed. So, for all practical purposes they are depletable.

We now look at another category of resources which are renewable which means that the rate at which they are being renewed is much faster than the rate at which we are using them and so for all practical purposes they are inexhaustible and renewable and in such cases the rules or the way in which we analyse these resources will be different because unlike the earlier case most of these are actually flows not stocks.

Of course, in the case of biomass there are flows which have been converted into stocks. So, biomass is a little different. But for all other resources that we are considering renewables these are actually flows. So, then there will be different ways in which we will characterize them. So, for this you may look at the Global Energy Assessment which was done by IIASA and published by the Cambridge University Press. It is available in the public domain. So, Chapter 7 of that has the listing of different kinds of energy resources and the potential and we will cover some of those things from that chapter.

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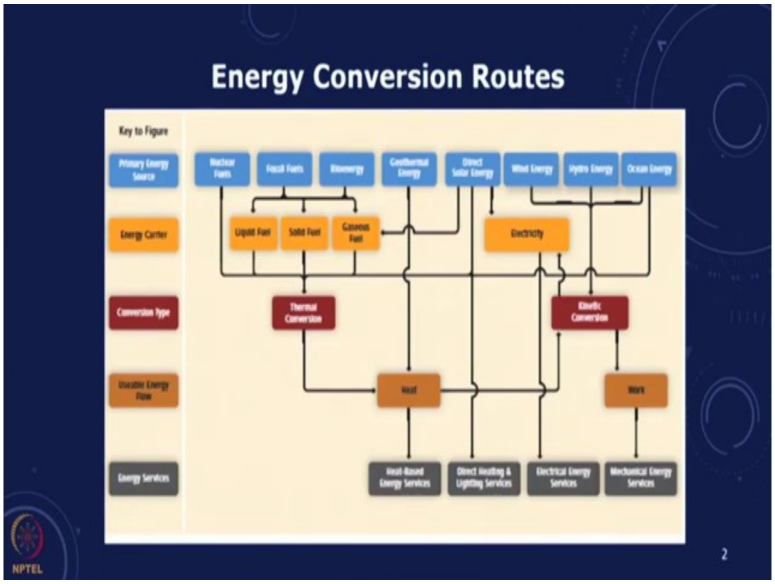

So, if you look at it first is if you look at the different kinds of options that we have, we have a whole set of primary energy options and from the primary energy options as we saw there is a there are different kinds of conversion steps with to get our final end use. And in all of this electricity is one of the major roots.

So, we take electricity either it could be from, we talked about earlier about fossil fuels. But even if you look at renewables we can look at solar giving us electricity, we can look at wind, we can look at hydro, we can look at ocean, we can look at bio energy are could be nuclear and that electricity then can go and the used in different end uses.

We can also look at directly hydro giving us kinetic energy or hydro giving us electricity and in the case of fossil one of the intermediate step is thermal heat which gives you power and then that power is being used, in some cases you are using heat directly for cooking or we are using heat directly in the industrial processes. So, let us take a look at the in the global energy use. What is the current share of renewables?

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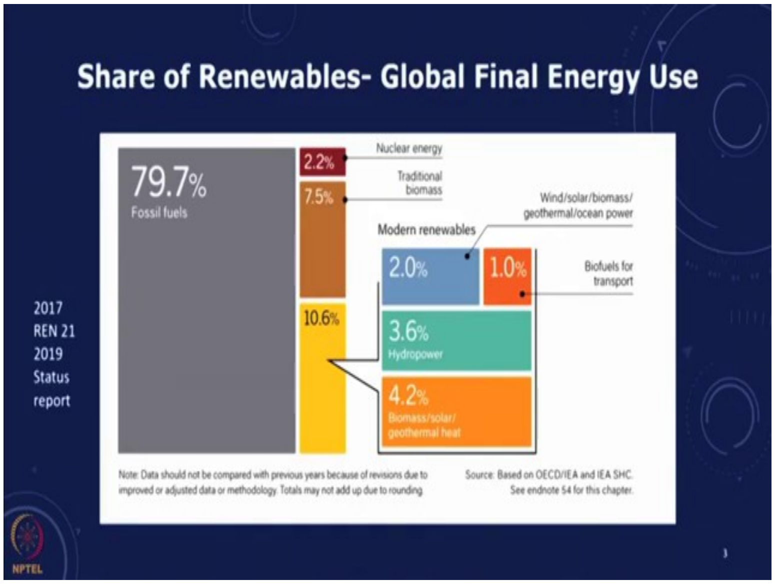

So, if we look at this figure this is from the renewable energy update of 2019. This dataset is for the year 2017. You find that almost 80% of the primary of the final energy use is actually coming from fossil fuels, off the remaining its traditional biomass which accounts for a large part and nuclear, traditional biomass almost 7.5% and nuclear about 2%. Of the 10% or 11% which is coming from renewables a reasonably large amount is from hydro power and some coming from modern renewables which is accounts for about 2%. 1% is biofuels for transport.

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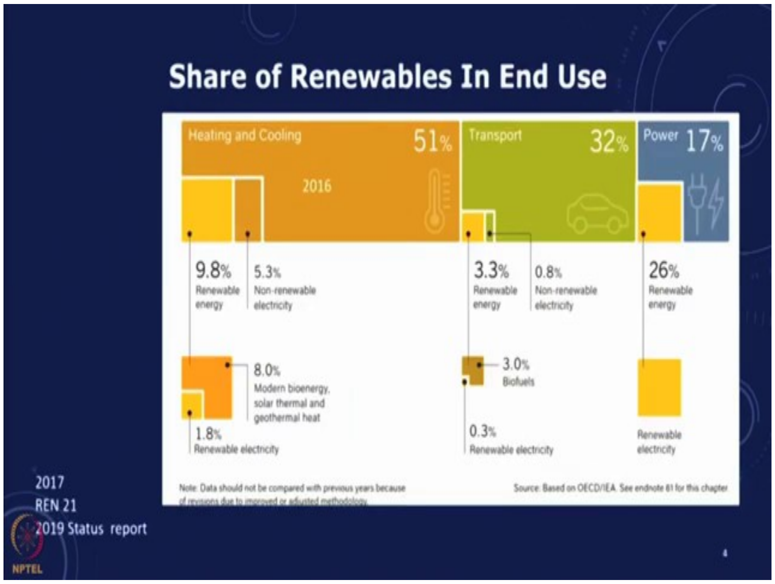

If we look at this a little more in detail by the sectors and the end uses, if you look at the end uses and transport is about one third of the total and in transport we have 3.3% just from renewables of which 3% comes from biofuels. So, currently the penetration of renewables in the transport sector is relatively low.

In the power sector we have 26% of renewable energy of which large hydro is also considered and then we have wind which is the largest chunk. And then you have solar PV and bio. In the heating and cooling there is a lot of 9.8% coming from renewable energy and some of it most of it is from traditional biomass and some of it coming from renewables.

So, as we see overall the renewables account for a relatively small percentage but we expect this to grow. So, we would like to first of all see what is the potential? What is the technical and economic potential for renewables and the how is that potential distributed amongst the different sources?

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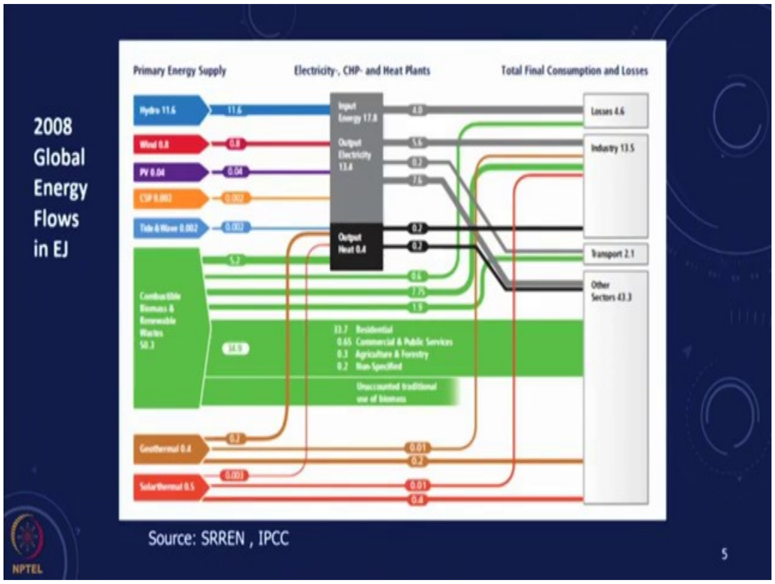

So, this figure is a global energy source of renewables, which is for the year 2008. And this is from IPCC special report on renewables. You may want to look at this and download this. This gives you overview of all the renewables either status of that in 2008. It is a slightly old but the relative magnitudes remain the same.

So, if you look at this figure you can clearly see that the largest chunk continues to be biomass a most of it is still being traditionally used. Most of it is being used in the domestic and cooking sector. For all of the other renewables and largest chunk goes into electricity, CHP and combined heat and power and geothermal both use for electricity as well as directly.

And solar thermals small percentage. A large hydro is a very large percentage and the total. If we see this total we are looking at something of the order of fifth, of the order of 50 EJ. And if you look at this in terms of the global, we talked of 450 to 500 EJ. So, it is a relatively small percentage but it is already sort of getting into the main stream and it also has significant amount of growth and it is growing at a faster rate than the fossil. So, we expect future energy mixes to be much more renewable.

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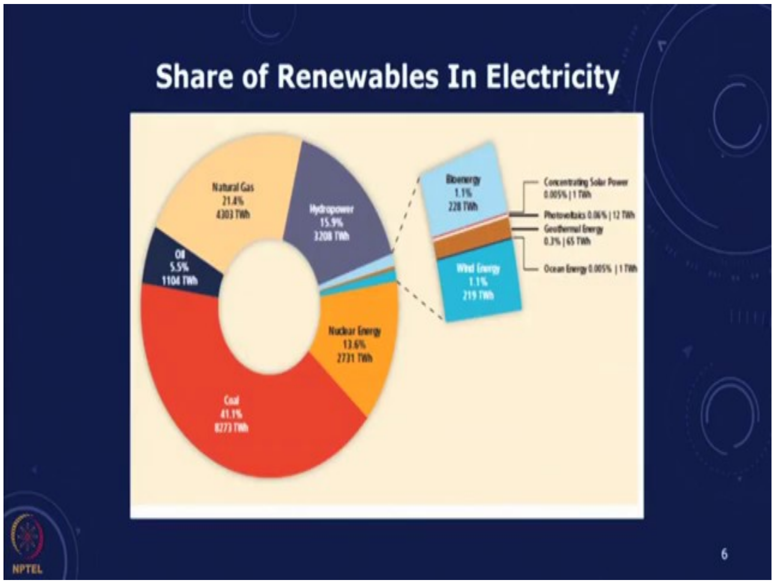

So, if we look at the electricity sector, as we as I told you the renewables in the electricity sector the largest chunk for electricity is coal, followed by natural gas and then hydro and some amount of nuclear. Nuclear globally is a reasonable amount. It is about 13, 14 % and then, as we said, this is the renewables of which wind is the largest chunk and then bioenergy is also reasonably high.

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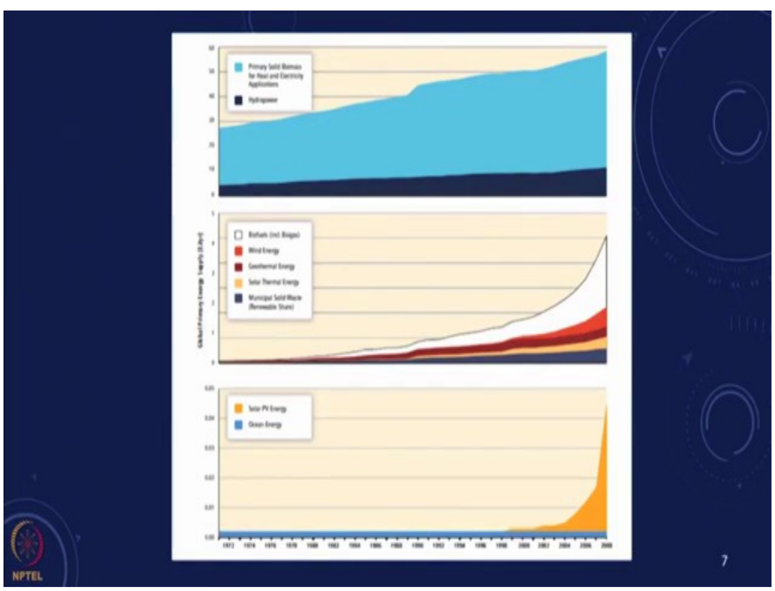

Solar photovoltaics growing relatively small but growing fast and you can see this growth in terms of these numbers. And you can we can see in this case if you look at the graph at the bottom you see that solar PV starting from a small base but growing at a much, much faster rate and overall if you see its wind and PV and renewable which is growing at a reasonably fast rate and that is the a that is the signal that is there that the renewables is growing at a much faster rate than fossil and the share of renewables in our mix is going to be higher in the future. So, now let us look at each one of these in terms of the potential.

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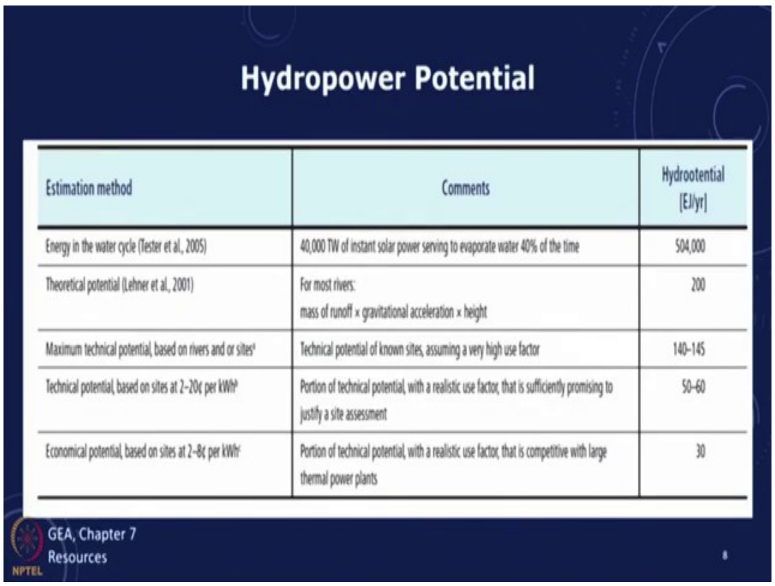

Estimation method	Comments	Hydrootential [EJ/yr]
Energy in the water cycle (Tester et al., 2005)	40,000 TW of instant solar power serving to evaporate water 40% of the time	504,000
Theoretical potential (Lehner et al., 2001)	For most rivers: mass of runoff × gravitational acceleration × height	200
Maximum technical potential, based on rivers and or sites[a]	Technical potential of known sites, assuming a very high use factor	140–145
Technical potential, based on sites at 2–20¢ per kWh[b]	Portion of technical potential, with a realistic use factor, that is sufficiently promising to justify a site assessment	50–60
Economical potential, based on sites at 2–8¢ per kWh[c]	Portion of technical potential, with a realistic use factor, that is competitive with large thermal power plants	30

Let us look at first hydro. So hydro for a long time we have been having these large hydro power plants. And if we look at this assessment, this is from the global energy assessment you will find that if you look at solar power which is evaporating the water and causing the flows of hydro and the energy in the water cycle you find that this is a very large percentage.

We are talking of 504,000 EJ/year which is orders of magnitude higher than what is required in terms of energy, theoretical potential, if we look at from this, what percentages, what is a potential which can be actually taken off in terms of the runoff and the flows and converted into energy, you get off the order of about 200 EJ/year which is again orders of magnitude similar to the kind of energy required globally by the earth.

From this if we look at the different sites that reduces to a potential of 140 to 145 and with a particular use factor. This comes out about 50 to 60 EJ, then looking at economic factors. This can come to about 30 EJ. So, that is the estimated potential in 2010. Now which is a reasonable amount of the total which can be provided by large hydro.

The problem with large hydro is that in this involves submergence of large areas of land, and because of this, there is resistance to this from the people who were displaced. There are also problems in terms of sometimes they are on site where there is a, which are earthquake prone. There is a problem in terms of when you have a large water quantity they it might affect the disease vectors.

And so, in many countries of the world there is opposition to large hydro with the result that large hydro has not been growing at the rate that it used to grow earlier. And because of that, we are not quite sure that the total hydro potential will be realised. But there is a reasonable amount of potential.

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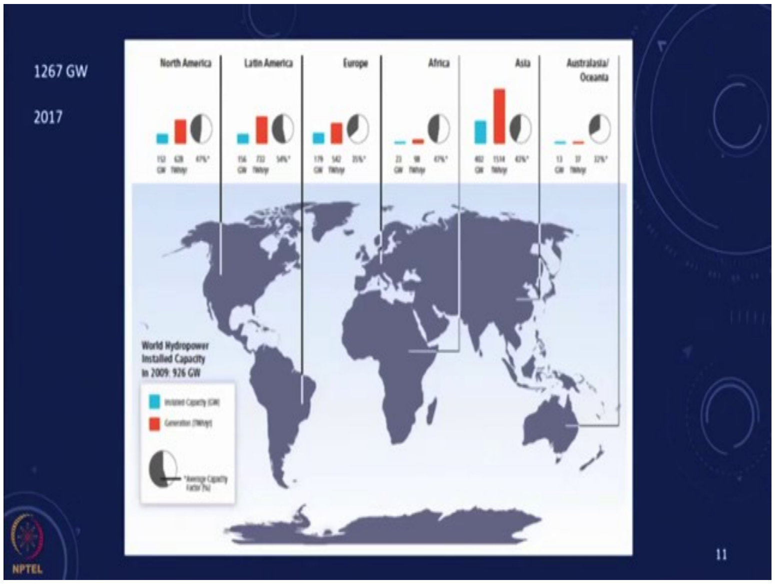

You can see, of course, in terms of generation. There is an overall growth in the hydro power generation, and you can see that if we look at the distribution of hydro in different countries and this is in terms of the generation which we are looking at, about 14000 TW/year is the hydropower technical potential which is a significant proportion of the electricity use.

In the installed capacity, if you see this is the kind of distribution of the installed capacity in the different continents, and in 2009 we are talking of 920 GW which was installed. The updated values in 2017, about 1267 GW, so hydro large hydro has been growing, but we do not expect it to grow at very much faster rate because of the kind of opposition which is there.

So, we can have in the case of hydro, we can have dams, we can also have run of the river schemes. So, question of large hydro and small hydro in many countries of the world, large hydro was excluded from the calculation of renewables. This was done primarily because large hydro already had a large number and the renewables were relatively small.

So, in order to make it distinguished we looked at small hydro and different countries had different characteristics in terms of what was considered as small hydro. But typically, you know which started from 10 kW going up to 5 MW in some cases going up to even 25 MW.

Now, in the case of hydro it could be run of the river's schemes or even with low heads and low heads as low as 3 meters have been considered to be viable in the smallest areas, we look at schemes which are not necessarily grid connected. They could be isolated and if you go if the megawatt range, then they could be connected to the grid.

In all of this, the question is whether the water flow is annual or it seasonal. So, there is a capacity factor which is there. But in most of the cases there is a reasonable amount of potential of cost-effective power generation because the water itself the operating cost is negligible. It is only the initial capital cost.

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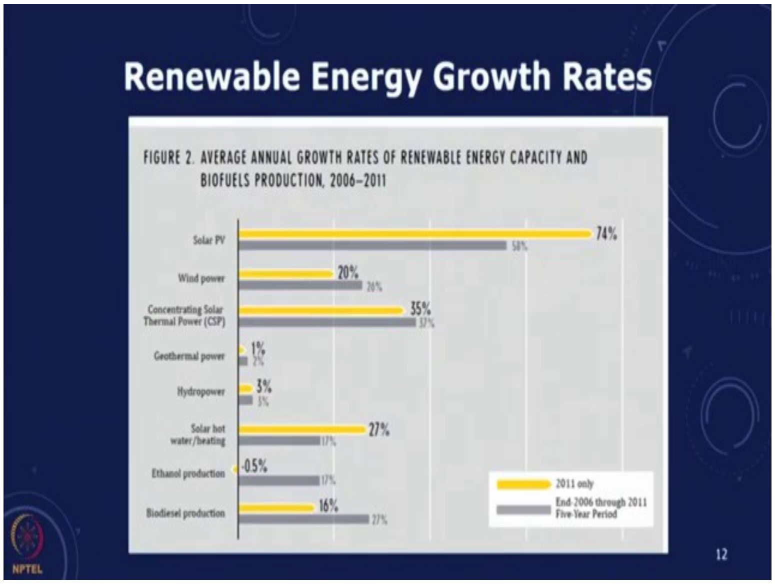

When we talked about renewables, I also told you that we have starting from a small base, but we have been growing at very fast rates and you can see that with the kind of 74% and 30%, 74% for the solar PV and 35%, 20% starting from a small base, but very high growth rates. Of course, these will sort of. they will taper off and they will come to some reasonable numbers in the future. But as of now, they account for a reasonable high.

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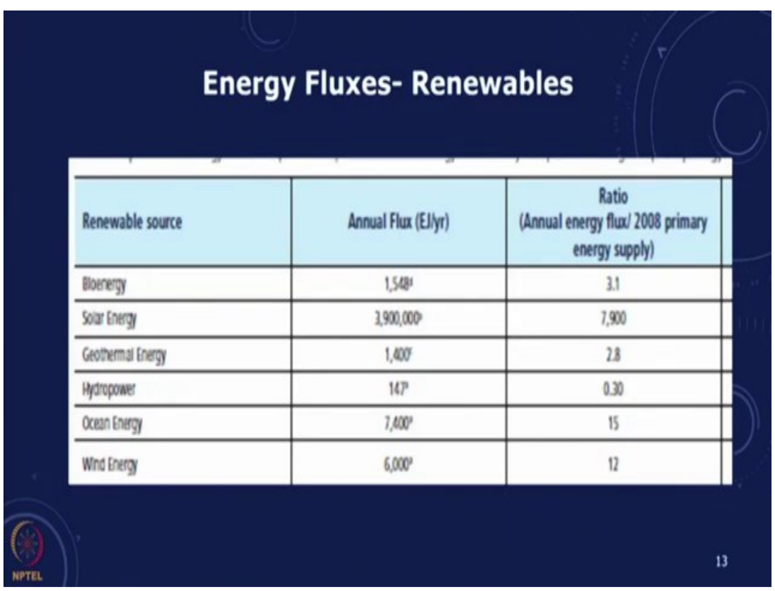

Renewable source	Annual Flux (EJ/yr)	Ratio (Annual energy flux/ 2008 primary energy supply)
Bioenergy	1,548	3.1
Solar Energy	3,900,000	7,900
Geothermal Energy	1,400	2.8
Hydropower	147	0.30
Ocean Energy	7,400	15
Wind Energy	6,000	12

If we look at the overall annual fluxes. When we look at bio energy, solar energy, geothermal, hydro power, ocean energy, wind energy and we take the fluxes, you can see that these fluxes are actually significantly higher than what is the energy use in the primary energy use in the world in a particular year.

So, if we look at the ratio of the annual energy flux by the 2008 primary energy supply we can see that solar is almost 8000 times that amount. So, it means we are not constrained by the amount of solar energy we have sufficient amount of solar energy. Geothermal is also about 2 times, bioenergy about 3 times, wind energy 12 times, ocean energy 15 times. So, in many of these cases on a global basis. If we look at the total energy fluxes they are orders of magnitude higher than our requirement.

However, these fluxes are not concentrated, they are dilute and they are distributed around the world and we will look at. So, when there are issues in terms of costs, there are also quite variable and hence there is a need for storage and that also adds to the costs.

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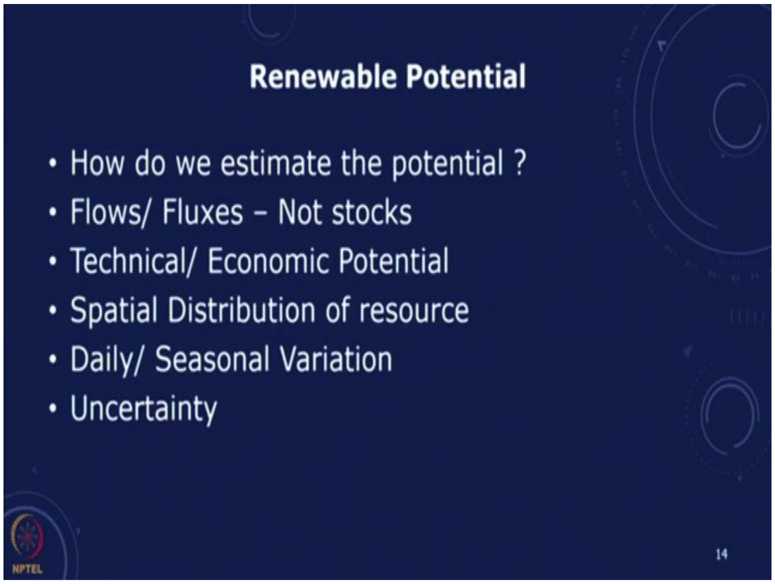

So, we will look at, this in terms of we will try to answer the following questions first is how do we estimate the potential for a particular renewable energy? We already said that we are talking of flows and fluxes not stocks. Unlike in the case of coal or oil or natural gas, in each of these cases there could be a technical potential and an economic potential.

There be a spatial distribution of the resource. There will be a daily and a seasonal variation and there will be uncertainty. So, unlike in the earlier case where we had a certain amount once you mine it you know how much coal is there and then you can use it whenever you want. In the case of solar at a particular time of day depending on whether there is cloud depending on the kind of insulation, you will have a particular generation, it is more or less predictable, but there are uncertainties and we will need to be able to tackle those variabilities.

These energy sources and these energy resources will have a different way of operation and we need to understand that and we need to design a system a little differently from the way in which we design fossil fuel-based systems.

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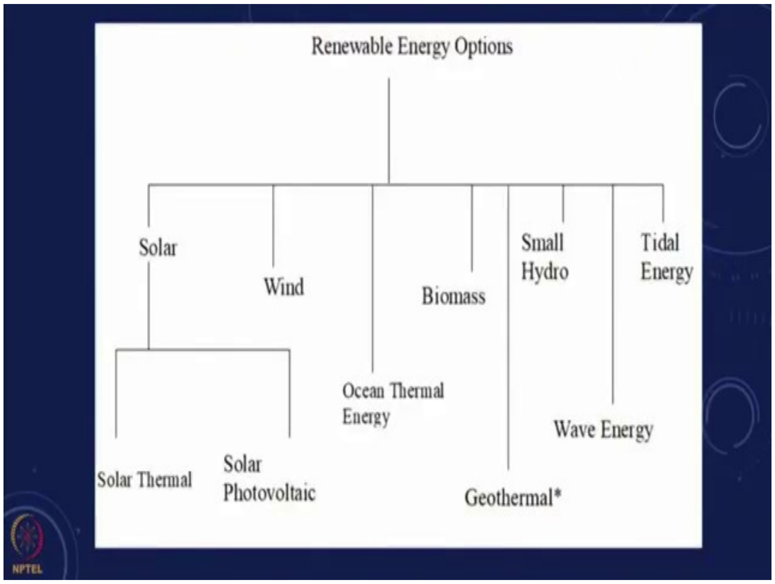

So, if we look at this what are the options that are there? The renewable can be direct solar that means solar which you use to heat up water or working fluid or heat transfer oil this is called solar thermal. Or we can look at solar conversion of solar into electricity through a photovoltaic cell and this is solar photovoltaics.

When most of the electricity that we generate is from solar photovoltaics. and solar thermal is used can be used for electricity generation, but that is currently a little costly. It is being used mainly for solar thermal applications, which is for heating and cooling.

Wind one of the earliest electricity sources and now also the largest chunk currently of electricity generation. Wind, again, is caused from indirect solar because of the differential heating of the earth surface. You have high pressure and low-pressure regions and then you have wind going from the high pressure to the low pressure and depending on the kind of wind there is a local factor. We can see what are the wind rates. And there is a power which is available in the wind.

We can put a turbine within that power and extract that power connected to a generator and then use that electricity. Ocean thermal, we will talk about ocean thermal wave energy and tidal are all associated with the course. They are localised and we will see what other kind of possibilities in this.

We talked about large hydro already. Small hydro does not have the disadvantages of large hydro. They and there is quite a significant amount of potential. The problem is that many of these are in remote areas and not so accessible. There may be a capacity factor, and so even though there may seem cost effective they have not been growing at a very at the same rate as the wind and solar PV.

Biomass is can happen in terms of, there are many different sources of biomass including waste and crop residues, agricultural residues, and we will look at their different modes in which we can use for conversion. Geothermal is happening is an energy source, which is happening because of the Earth's crust being, Earth's core being much hotter than the Earth's surface and then there are hot spots and when the water comes in contact with these hot spots we get steam which comes out and that can be used for power generation for energy. So, we will look at each of these in detail in terms of seeing what are the resources. What is the potential? What is the current status? So, we start with wind which is one of the earliest commercial renewable energy use.

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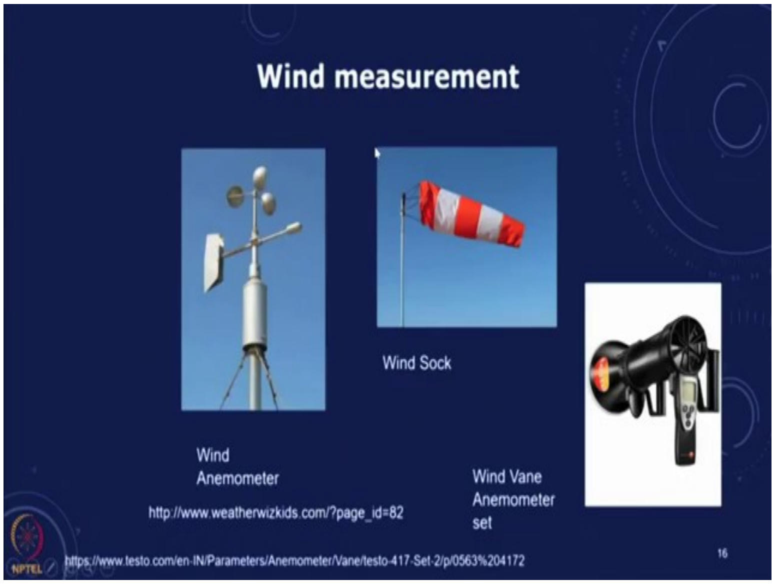

$$P_w = \frac{1}{2}\rho V^3$$

¿ $\frac{1}{2}\times 1.2\times(7)^3$

¿ $205.8\, W/m^2$

$$\frac{1}{2}\rho C_p A V^3$$

When we talk about wind in the wind, if you see the depending on the velocity of the wind. The power in the wind is half rho v cube. So, if you just take let us say rho is 1.2 kg per meter cube and if we look at the, let us say, a wind velocity of 7 m/s. If you calculate this, you will find that this comes out to be 205.8. This is an SI units watts per meter square.

So, this is at a wind speed of 7 m/s. If the wind speed is half this amount, what would happen? The power in the wind will become 1/8th is proportional to cube of the velocity will become 1/8th of this amount. So, it is going to be of the order of 22 watts per meters square. So, this is the power which is there in the wind. Now, depending on the turbine, it will have its own coefficient of performance.

So, the actual power which you get will be half rho Cp into the area into V cube. This Cp is typically you will get something of the order of 0.3 to 0.4 and depending on the machine that we have. So, in general, what will happen is we can measure if you see here. This is a wind anemometer, which will give you the direction and the speed and then there is a wind vane anemometer this is of this type and the windsock is giving you the direction.

So, we have usually wind measurement stations located all across in the areas where we expect to have high wind and these this data is then monitored. It is then mapped and you have maps which show you the distribution of wind speeds.

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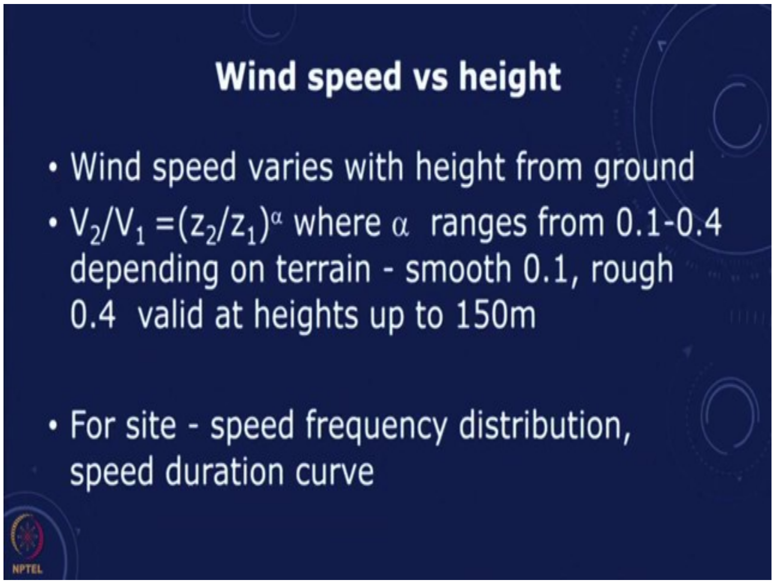

$$\left(\frac{V_2}{V_1}\right) = \left(\frac{Z_2}{Z_1}\right)^\alpha$$

$$\alpha\, 0.1 - 0.4$$

Wind speed varies with the height from the ground, and typically what we have is we have a formula which is. If we measure. So, if we have a wind monitoring station at a particular height and we want to estimate what will be the wind speed at a different height. Because we may put we may have wind speed monitoring at let say 50 meters, but we will put a turbine at 80 meters or 100 meters. We can use this correction factor, this correction factor.

The values of alpha are for different. It goes between point one to point four, and if it is a relatively smooth terrain, we can use point one and then we can use this and get extrapolate what will be the wind speed at a different height and we can use this to get maps of the wind speeds.

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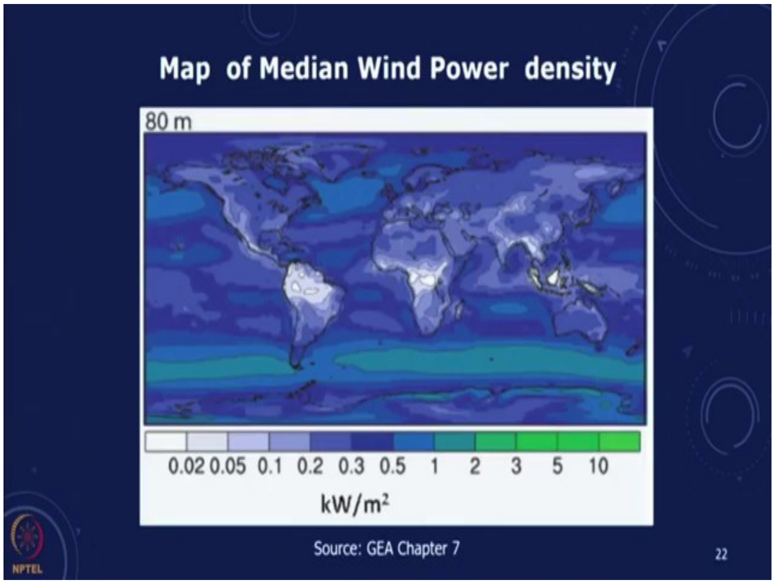

When we look at this, you will see that this is the kind of map which is available and we talked about the, you know for 7 m/s. We said it is about 200, that means point 2. You can see that in this case we are looking at you look at these colours you can see some of the largest, highest winds are of course offshore. But we have the different kinds of wind regimes which are there.

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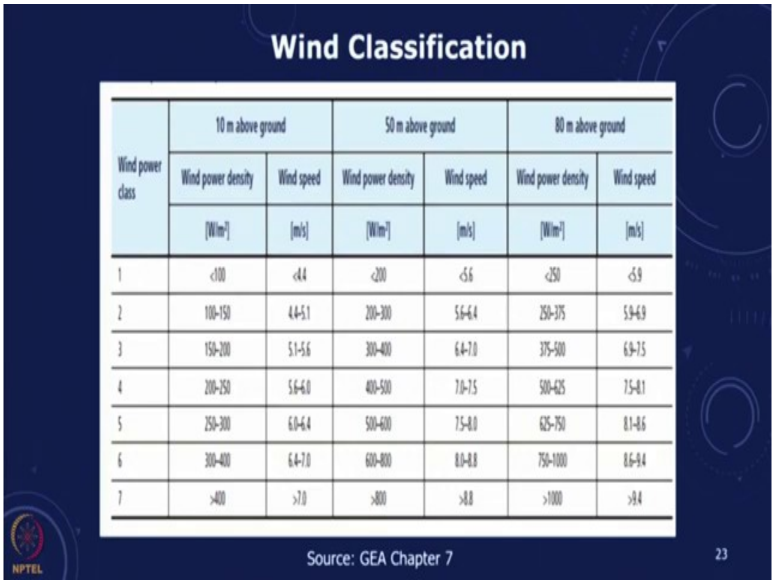

Wind power class	10 m above ground		50 m above ground		80 m above ground	
	Wind power density	Wind speed	Wind power density	Wind speed	Wind power density	Wind speed
	[W/m²]	[m/s]	[W/m²]	[m/s]	[W/m²]	[m/s]
1	<100	<4.4	<200	<5.6	<250	<5.9
2	100-150	4.4-5.1	200-300	5.6-6.4	250-375	5.9-6.9
3	150-200	5.1-5.6	300-400	6.4-7.0	375-500	6.9-7.5
4	200-250	5.6-6.0	400-500	7.0-7.5	500-625	7.5-8.1
5	250-300	6.0-6.4	500-600	7.5-8.0	625-750	8.1-8.6
6	300-400	6.4-7.0	600-800	8.0-8.8	750-1000	8.6-9.4
7	>400	>7.0	>800	>8.8	>1000	>9.4

Look at the wind classification again in the GEA Chapter 7 you can see that these are the types of wind classification the wind tower class going from less than 100 and going to the largest one, the highest wind power class wind class 7 greater than 400 and this is the kind of wind speeds at 10 meters above the ground and in the case of 80 meters above the ground, that same class is greater than a 1000 watts per meters square and you can see this is the kind of wind speed which we are talking of.

In every wind machine, when you put a turbine, there will be a curtain speed, which is the minimum speed at which the turbine must rotate in order to overcome all the inertia and then start generating and from the minimum to the rated speed to the cut-out's speeds. There is a maximum speed beyond which the turbine will get damaged so that within that range when you have a wind speed within that range, it will generate.

And remember, the wind fluctuates over the day, fluctuate over the season. And because of that when you talk about the power supply, we need to be able to adjust that and match this supply with the demand and I will show you some data about the Indian context before we do that.

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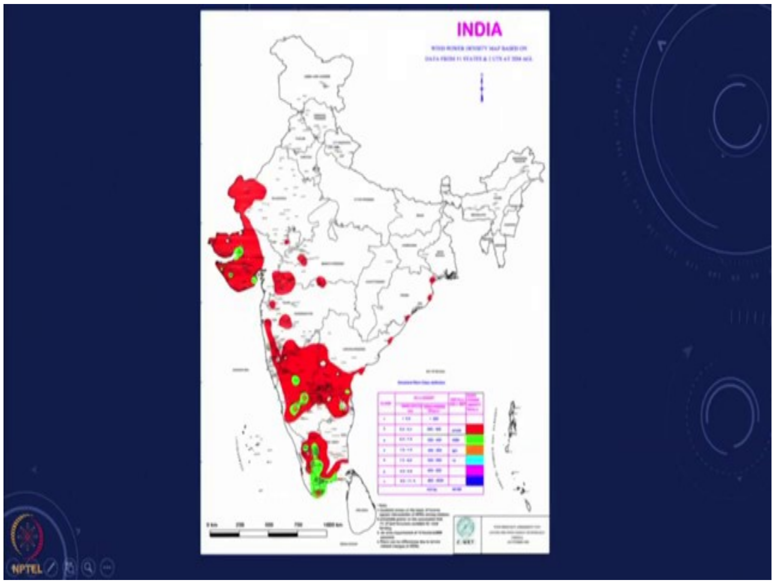

Let us look at. So, this is giving you some of the fractions in different countries. What are the kind of wind speeds in the and the number of sites extra. In the Indian context. If you see this is a, this is the MNRE’s map, the ministry of a new renewable energy and you can see that we have some sites in Tamil Nadu and some in Gujarat and the most of the wind is related is typically along the coast.

You will also see that we do not have most of the wind speeds that we have are much lower than the high wind speeds which are there in the US and Europe. The other point that we have is that our wind is very, very seasonal. We get the highest wind during the monsoon months, four months of the year where you get the maximum amount of generation.

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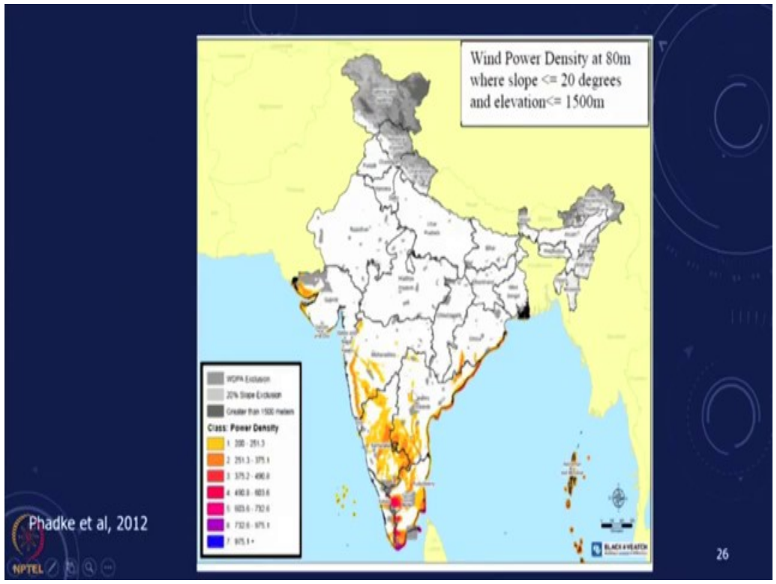

A similar kind of map has been drawn. This is at 80 meters and you can see here that we do have some of the generation of the order of you know most of them are still in the lowest Category 1 and 2. The high winds regimes are in the wind class 2. We really do not have anything at a very high wind regime. However still in many of these cases even with a seasonality and with this wind regime we can have wind which is cost effective and that is why we have quite a number of wind machines which have been installed.

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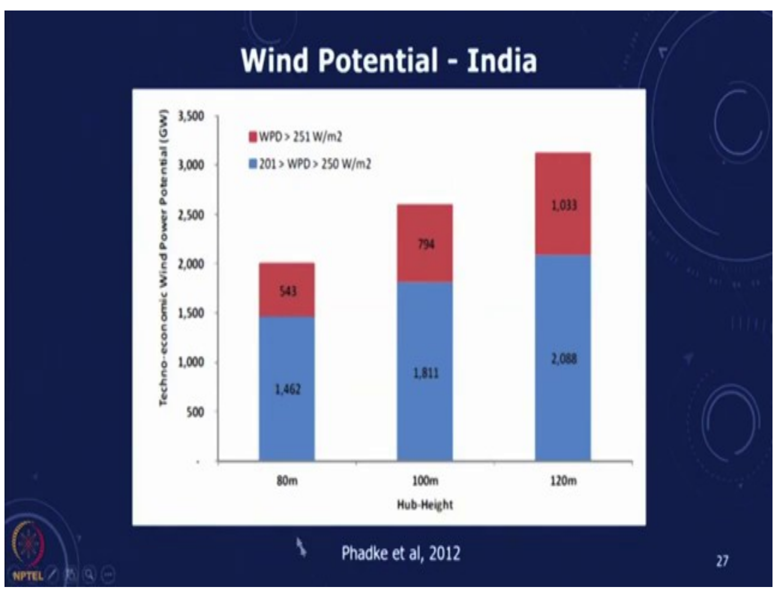

If you look at the wind potential 80 meters you can see that wind power density going greater than 250 watts per meter square at a height of this, we are looking at a 1400 GW of wind. That is a fairly large potential. And then if we if we look at something which is higher, this is this is we are talking of 800 gigawatts of this.

So, total we are looking at something of the order of 2000 gigawatts of total wind potential at 80 meters. If we go to higher heights of course the potential can increase. This is based on a study done by LBNL.

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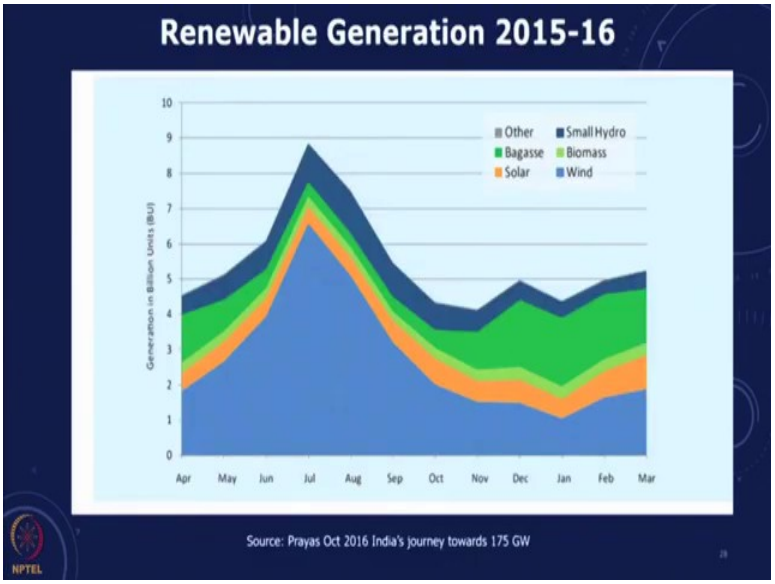

We like to take a look at what is the actual renewable generation in our country. And if you see this, this is in 2015-16. This is the picture of the renewable generation for different months. A couple of things emerge from this picture. The first thing is that it is actually wind which is the largest chunk of course there is a reasonable amount of bagasse base and biomass based as well as some small hydro and solar also coming up, solar increasing in coming up.

We find that there is a significant amount of seasonality in the renewable generation and that is predominantly driven by wind where wind is mainly during the monsoon months and then tapers other cases.

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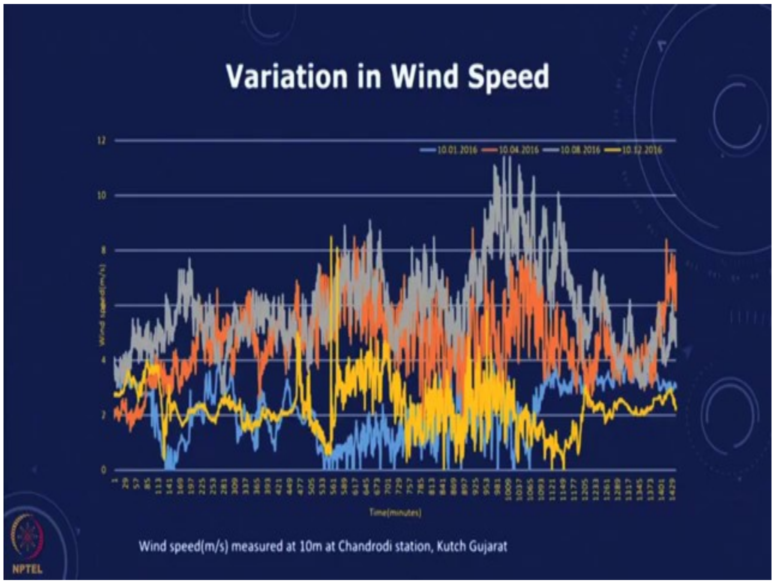

So, let us look at some of these in terms of the actual generation you see that this is from a number of sight and talks you about the wind speed you can see that the wind speed fluctuates and significantly and in different months you have different kind of wind regime.

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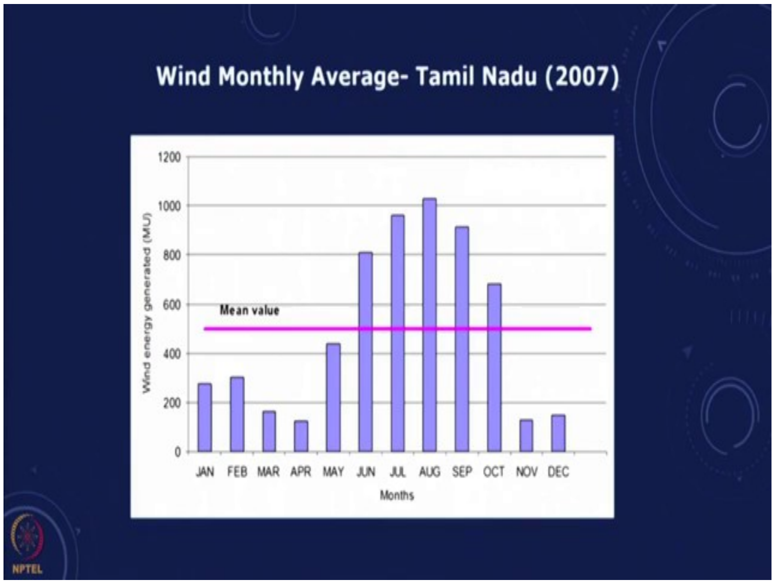

So, if we look at this in a little for Tamil Nadu for a particular year 2007 you can see that the generation in a few months were more than average been generation they wind energy generators with a million units in the monsoon months but in the other months it significantly lower.

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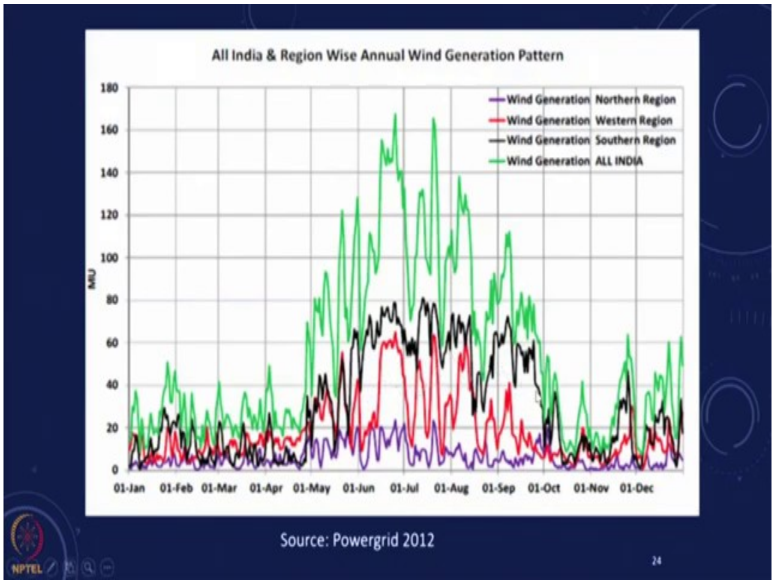

This is show, you can see also this is the annual and all India region wise annual wind generation pattern and you can see even here that most of this is happening during the monsoon months and rest of them time it much, much lower.

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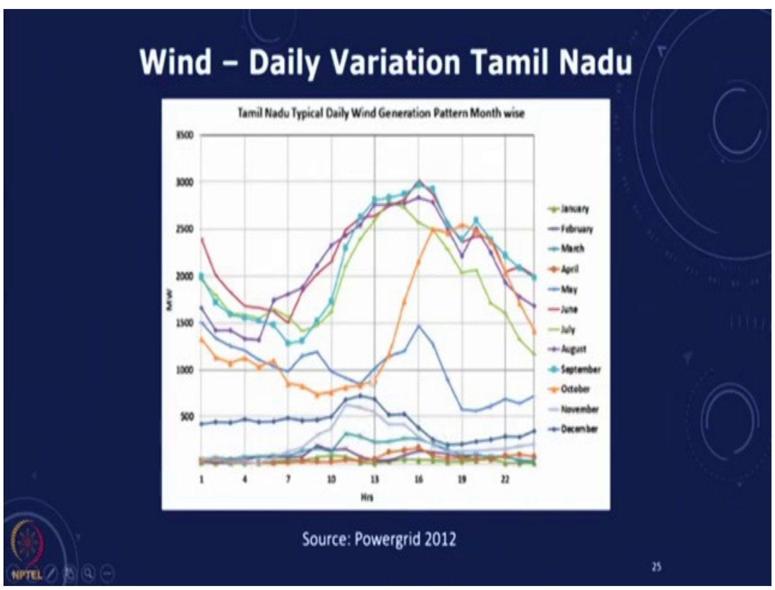

This Tamil Nadu plot shows you the generation over 0 to 24 hours and over different months and you can clearly see that four of the months the generation is very high and, in some months, it is almost negligible. So, what does it mean it means that when we provide the requirement in these months from wind in the months where there is low wind you have to have something else which is meeting that requirement.

And that means if it is a thermal power plant that thermal power plants have to be back down or switched off during the time when there are high wind and this will involve additional costs. So, that cost is being met by the thermal power plant. We need to look at regimes by which we see what is the value of the energy provided? When it is provided and what kind of the wind has to be able to compensate for the non-availability in the other seasons and so this is the situation in terms of wind.