Energy Resources, Economics and Environment
Professor Rangan Banerjee
Department of Energy Science and Engineering
Indian Institute of Technology Bombay
Lecture 26
Future Energy Systems

So, we come to the end of the course, we have looked at various aspects related to energy, the energy resources and the way to do economic calculations and the environmental impact. In all of this we have done a number of tools and techniques, we have also looked at different ways in which one can do the analysis. We have also looked at analysis, the qualitative perspective and try to put everything together.

So, in this last module, I would like to discuss with you what will be the future of energy system So, as we have seen in the past, there have been many changes in the energy systems. And we talk in terms of the transitions that have been made in the energy systems. We are also going to look at, what are the future energy systems going to look like, what are the transitions that we are going through, what are the drivers of those transitions, and whether it is in India or in the world?

What kind of challenges and opportunities do future energy systems throw up? So, just before we look at the future, let us look at some things from the past. Let us look at some what do we mean by a transition now, as we know, an energy system transition often involves not just the transition in the technology, but it also has impacts in the society at large. So just to give you an example of a transition that has already happened in the past, is a transport transition.

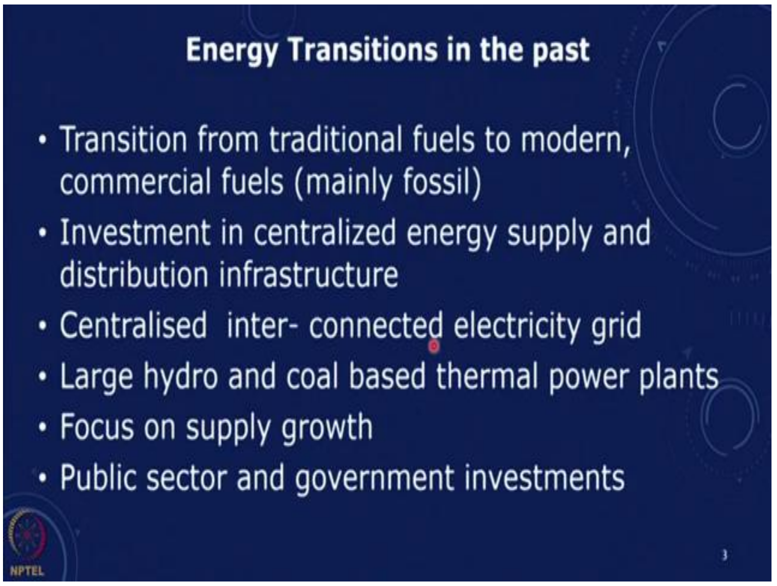
(Refer Slide Time: 02:17)

So this is an image which is quite a famous image. It is an image of us street in New York in Manhattan, it is one of the busiest streets in New York and this is in 1900s. If you look at this image, and you can see that in this image, all of these each of these vehicles are all horse driven carts and this was the predominant form of transport.

In this there is only one, we just show you this. There is only one ICE engine, this is the petrol driven car, there is one car in all of this and the rest of it is all horse driven and this is April 1900. The same street in Manhattan 10 years later a little more than that 1913 March, and you can see over here, all of these are most of them are 40s, these are the ICE engine driven, petrol driven cars. And on one corner you can see there is one horse driven cart in this.

So, you can see a transition where rapid transition has happened over a period of a decade, there has been a shift in the private transport from horse driven carts to ICE engine driven petrol driven, engine driven cars. And we now are looking at similar kinds of transitions where we are going from off from petrol and the diesel based ICE engines, maybe to electric vehicles, maybe to biofuel fired vehicles, maybe to hydrogen fuel fired vehicles.

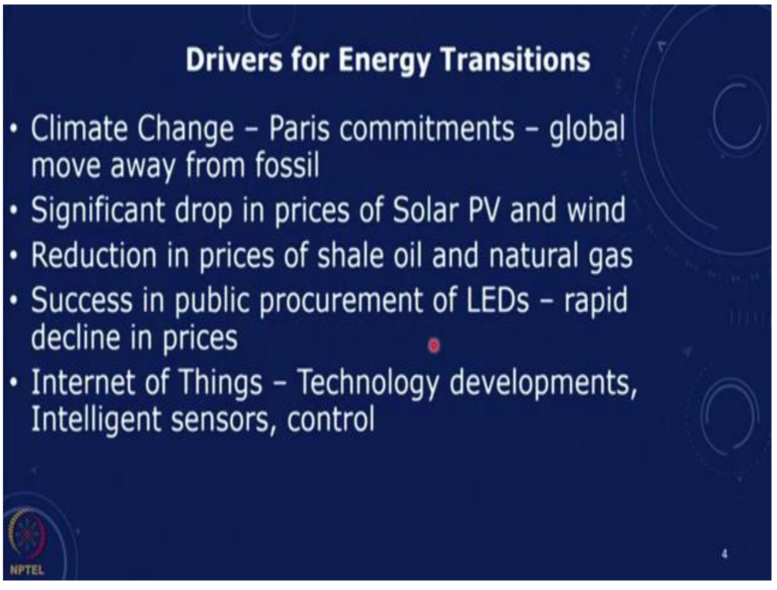
(Refer Slide Time: 04:12)



So let us look at in what were the transitions in the past. So in India and many other countries of the world, we have made a transition from traditional fuels to modern commercial fuels, mainly fossil. We have also had significant investment in large centralized energy supply and distribution infrastructure, and centralize the interconnected electricity grid, which is there now it connects all parts of our country and every single village is now connected to that grid.

We have a large Hydro and coal based thermal power plants and the focus has always been on supply growth. Most of this growth happened through public sector and government investments. What are now the drivers for the energy transitions going into the future?

(Refer Slide Time: 05:00)



The first most important driver is the challenge of climate change, where we are trying to now maintain the global temperature rise, less than 2 degrees, or preferably less than 1.5 degrees. All countries have made commitments in Paris and then there is a global move away from fossil fuels. Today 70-80 % of the energy sources are from fossil and so the transition has to be away from fossil to renewables and maybe some amount of nuclear.

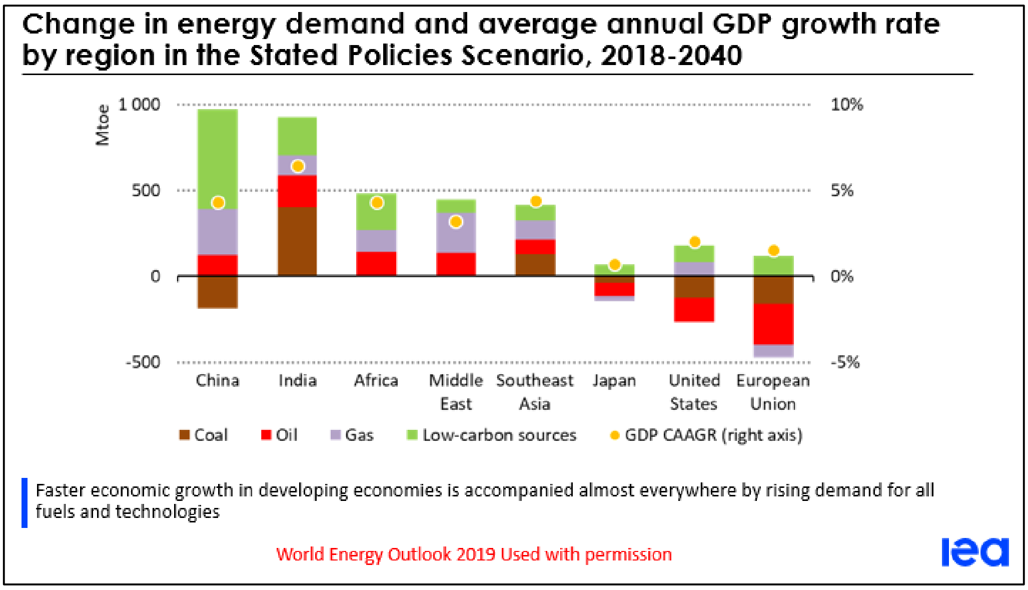
We have also seen one of the biggest drivers has been there has been significant drops in the prices of solar PV and wind. And there has also been reduction in prices of shell oil and natural gas with the result that several countries which were oil importers have become oil exporters. In the Indian context, we have had success in public procurement of LEDs, of fans, and there have been rapid decline in prices.

And this has resulted in us believing that this could be a model by which we can try and spur growth, where we can ensure volumes and reduce prices and make things affordable. And there is also big disruptive change in terms of internet of things, there are technology developments, where we can have intelligent sensors and control at relatively low costs. And this can result in actually having a large number of distributed systems which are controlled, managed, monitored. So these are essentially the drivers for the energy transitions going into the future.

We should remember that the energy sector if you want to make changes in the sector, we will be changing, lifestyles will be changing, businesses, some businesses will, there will be disruptions, some of the existing businesses will disappear. And this will obviously mean some implications of cost and some implications in terms of there will be losers and gainers. And so we need to think in terms of this transition being less painful.

And so to give you an idea of these transitions and possible futures, we will take some of the salient features from the World Energy Outlook. The World Energy Outlook is produced by the International Energy Agency every year and I am going to show you some slides from the IAS World Energy Outlook 2019.

(Refer Slide Time: 8:05)



So the first slide that you can see here shows the change in energy demand. Now, these are based on the IEA's projections, the change in energy demand and average annual GDP growth rate by region. In this there are two scenarios, there is a stated policy scenario which means that we start with whatever are the existing policies that the countries and the regions have stated.

And then there is another scenario which is an aggressive scenario which is a sustainable policy scenario. So, in the stated policy scenario based on the existing policies of the different countries, if we look at the change in energy demand over the time period 2018 to 2040, this is a report in 2019 so 2018 is the base here and we are looking forward to about couple of decades further, which is 2040.

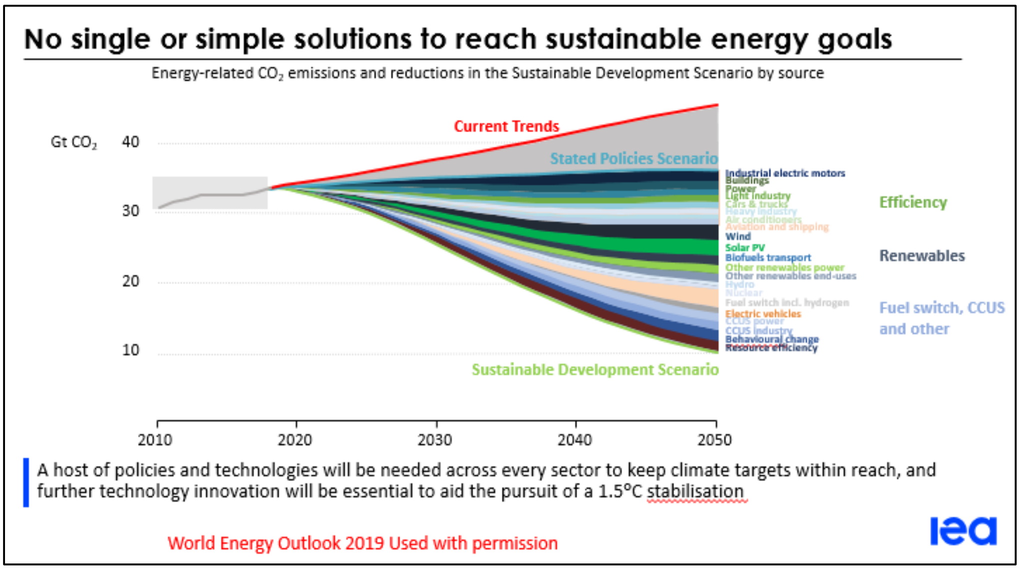
And we can see very clearly in this there is coal, oil gas, low carbon sources. And you can see that there is a reduction in the coal and oil in almost in the European Union and in the United States and in Japan. However, in most of the developing countries, including India, Africa, Middle East, Southeast Asia, these are going to increase the overall Mtoe. You can see that in the world, the growth is propelled by the additional demand required by China, India, Africa and some amount from Southeast Asia and Middle East.

These countries the US and European Union have sort of plateaued and their growth is going to, they will not contribute to increases. However, they are all, the existing base, they start off from a very high base. And we also if you look at the growth rates, in this case, this report uses a slightly a growth rate slightly higher than 5 %, 6 % growth rate for India and slightly lower growth rate for China, Africa and you can see and there are positive growth rates for Japan, US and EU.

But the energy requirement, most of these cases have declined significantly. In the Indian context, there is a significant projected increase and the economic growth in the developing economies if you see the growth rates are much faster, higher than the growth rates of the developed countries and this will result in an increase in the overall energy requirement of the world.

And so clearly the centres of demand have shifted and growth is all in the developing countries. And the focus then is on how the developing countries will make the transition, make the growth and provide the energy services that we need for development, yet try to do this sustainably and that is a big challenge.

(Refer Slide Time: 11:17)

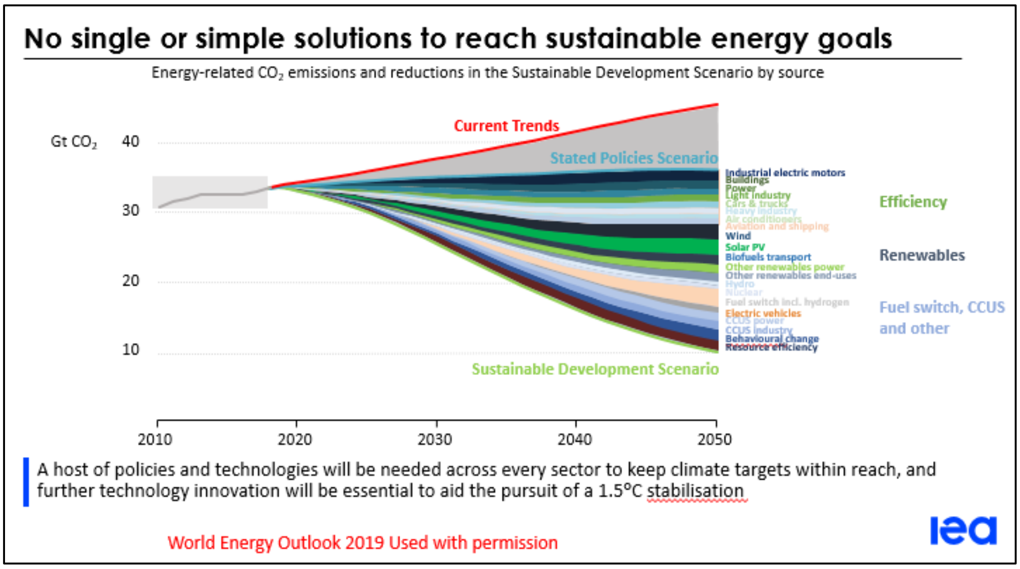


So if we look at it, the IEA basically says there are no single or simple solutions to reach the sustainable energy goals. We start with first that if you look at the current trend in terms of the emissions from 2010 to 2018, and you project that into the future, this is the trajectory that we have if you see, this is the growth trajectory of the CO_2 emissions. Now, if we try to see, you can have a variety of different options, with the stated policy scenario, we can still have a we will go below the current trends because of the policy that we have put in place for the National Development commitments of Paris and the and the local national commitments.

And but in order to go to the Sustainable Development scenario, we have to go much-much below this and this is the biggest challenge. If we look at it, these are some of the possibilities, we can do this through a combination of energy efficiency, renewables and then fuel switches and carbon capture and utilization.

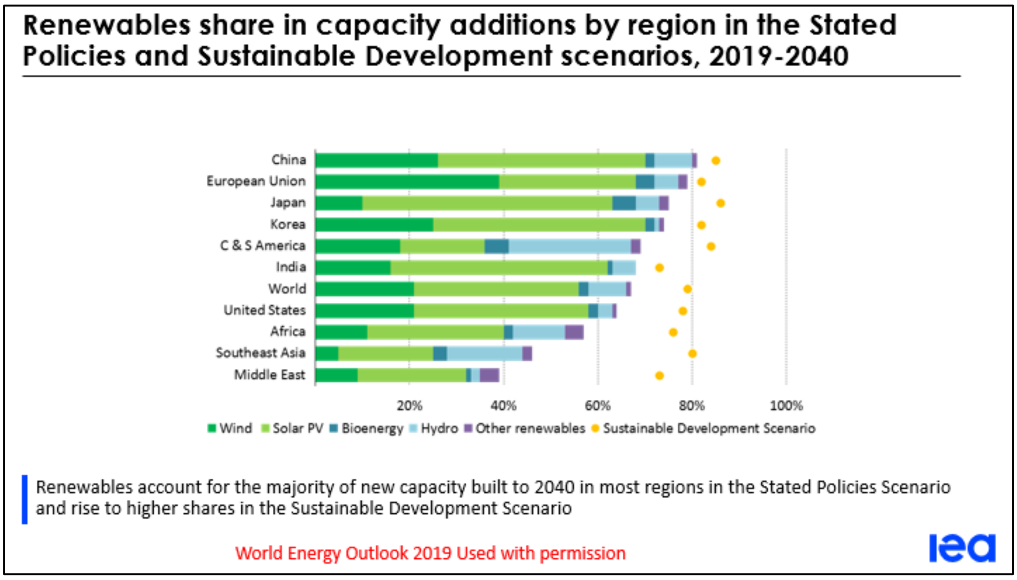
So, this is on an overall macro scale and you can see this is the kind of pathway which is required, this is the projected current trend. If the policies that we have put in place work then we can go down by so much, even then the CO_2 emissions would increase. But if you want to really make it sustainable, we have to go for aggressive efficiency renewables and fuel switch and CCS.

(Refer Slide Time: 13:07)



If you look at this, this is now broken down into different sub-components and the IEA report gives details about how these could be achieved. So there are a host of different policies and technologies that can be adopted in every sector to keep the climate targets within reach, and to look at a 1.5 degree stabilization. And so this is sort of a time frame till 2050 where these options can help us reach sustainable energy goals and this is not going to be just renewables, or just efficiency, it is a whole combination of different things.

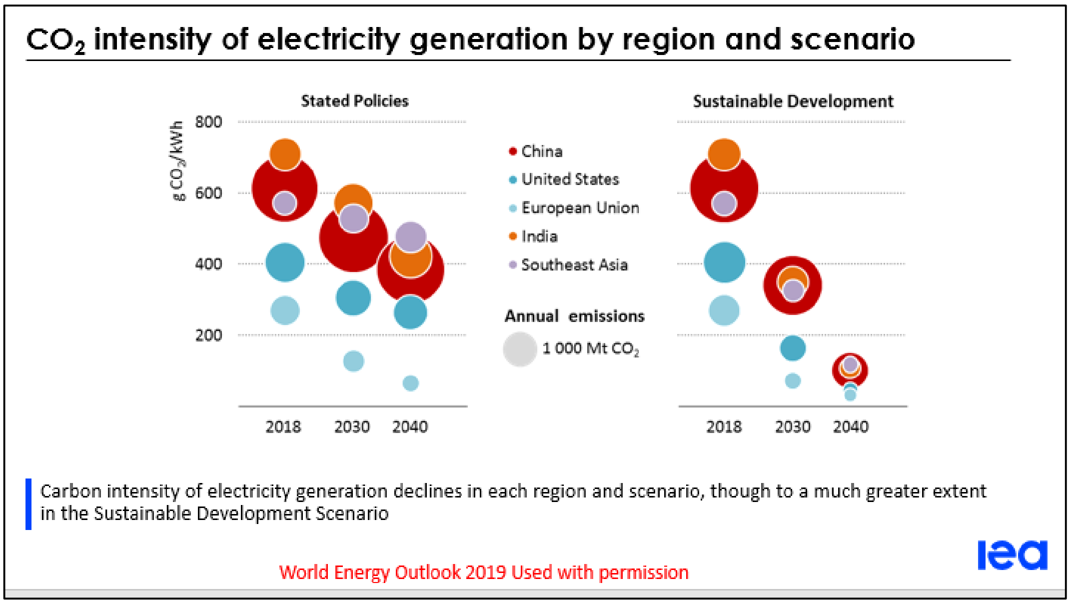
(Refer Slide Time: 13:47)



In the stated policy scenario, you can see that different countries will have different proportions of share in the new capacity additions and you can see in this you can see in the Indian context, a significant amount of share from renewables both wind, PV and Hydro and you can see that the largest chunk, more than 60 to 70 % of the new additions will all be renewables.

And this is based on the projections, this is similar kinds of details are there for most of the other countries of the world. And so that is an interesting kind of trend that we need to keep in mind.

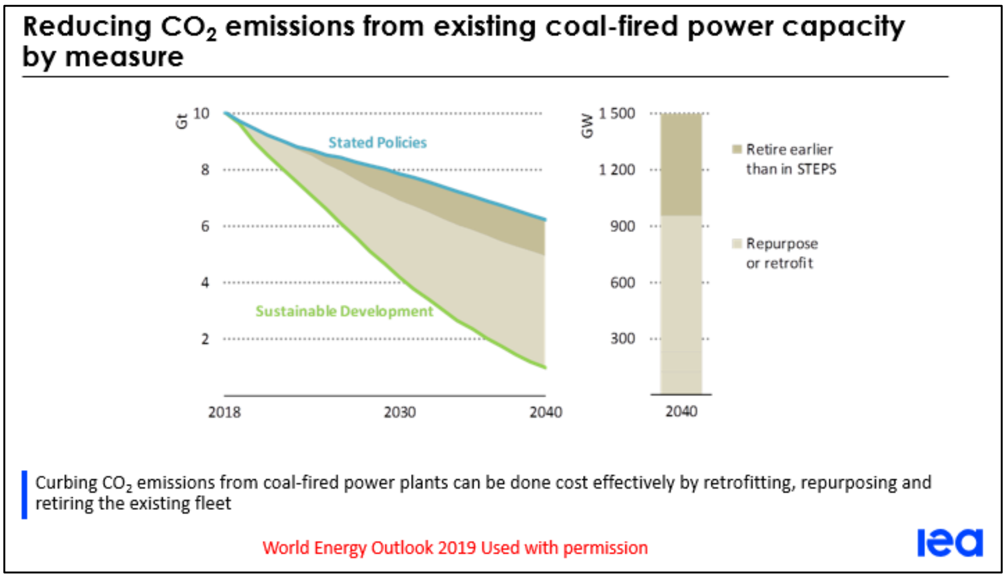
(Refer Slide Time: 14:41)



The other issue which is there is that what is the carbon dioxide intensity of the electricity generation? And if you look at India, we are one of the relatively higher CO_2/kWh. And we can see that over time, we expect that to be going down, in the stated policy scenario it can go down by about a factor of 2, so we can go down to about 400. And in the sustainable development scenario, we can see that we have to go down even more and less than 200.

And so based on this, this also shows us the dimensions and the total amount of emissions which are there in each of these countries. So, the sustainable development scenario of course, results in a far lower carbon intensity of the electricity sector. Now this is that will also affects the transition which we talked off, if we are going to move from ICE engines to electric vehicles. The CO_2 savings will depend on what is the carbon intensity of the electricity sector.

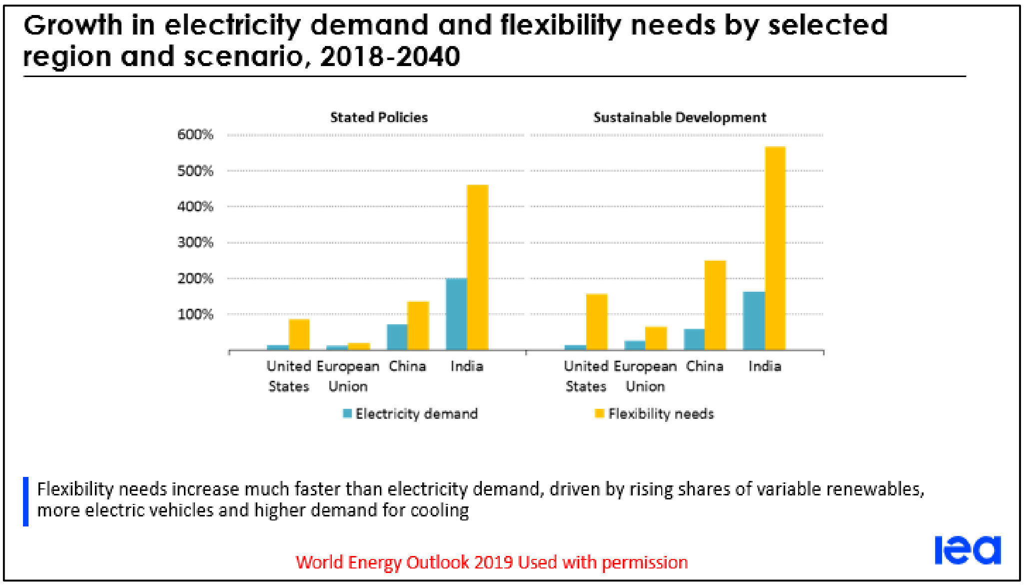
(Refer Slide Time: 16:02)



The other issue which will be there is that today a large part of our energy comes from coal. And in India this is particularly true so what would happen is that we are trying to see the reducing CO_2 emissions from the existing coal fired capacity and you can see that in the stated policy scenario, this is the amount of reduction which will be the, and then in the sustainable development scenario, it would be even higher.

So, some of this would be where you would retire the existing plants, existing plants earlier and then we can also rework the plants or retrofit them to make them feed them with CCS, convert them into combination of hybrid with renewables and these are some of the issues. So, the coal sector will be in deep transition and many of the existing plants would actually have to be phased out or modified.

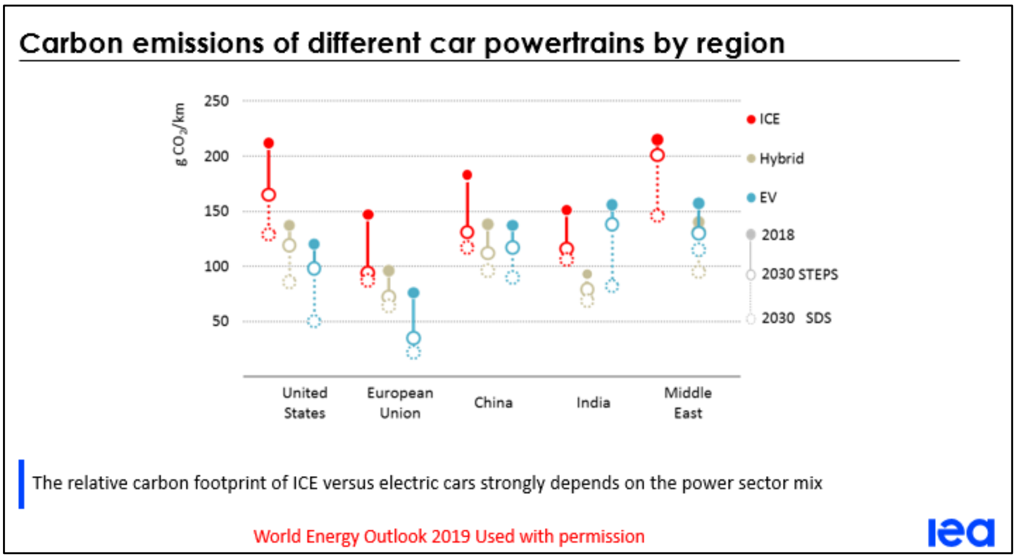
(Refer Slide Time: 17:17)



The growth of, the other issue which will be there is that if you look at the electricity demand, there is a significant growth in the electricity demand. And of course, in the stated policy scenario, it will go up by about 200 % of its existing value in the sustainable development scenario because of efficiency, this is going to be lower, but even then there is a reasonable amount of growth.

There will be because we are having a higher share of renewables there will be a need for flexibility in the system, and flexibility of the system will mean that because we will have variable renewables in our supply, we should be able to quickly ramp up, ramp down, shut down certain plants and be able to adjust and these flexibility would mean that we would need to invest in either demand side management or storage and that might add also to the costs.

(Refer Slide Time: 18:22)



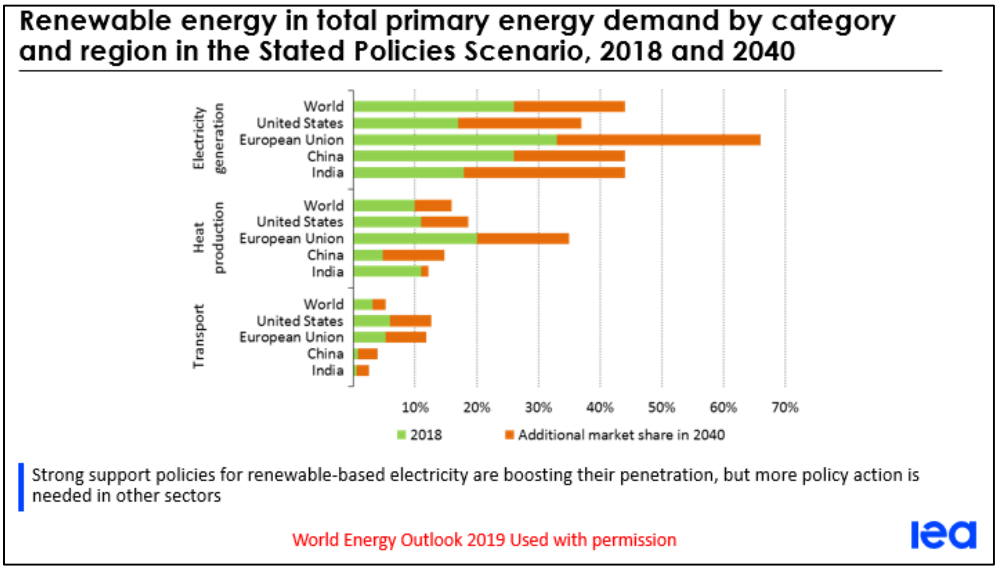
Now let us look at the electric vehicles and let us look at the comparison of electric vehicles with the ICE engine vehicles. So if we look at this, you can see that these red dots are the current emissions of ICE engine vehicles in different countries. And you can see the Indian ICE engine vehicle per kilometre, roughly about 150 grams of CO_2/km. And with the improvements in the ICE engine vehicles, this where that can go.

In the case of electric vehicles, currently depending on the electricity mix of the grid, the CO_2 emissions are actually slightly higher than the ICE engine vehicles. And that is an interesting kind of point to think about. Of course, when we talk of shifting from ICE engines to electric vehicles, this will definitely reduce the local emissions, but on the global emissions, the reduction or non-reduction depends on the intensity electric intensity of the power, the carbon intensity of the electricity mix

And since Indian, the Indian electricity sector is predominantly based on coal, this results in this factor. In the future of course , depending on how the mix changes, it can actually go away, when the sustainable development scenario it would be much lower than this. But this transition comparison between ICE engine and electric vehicle depends very significantly on the electricity mix.

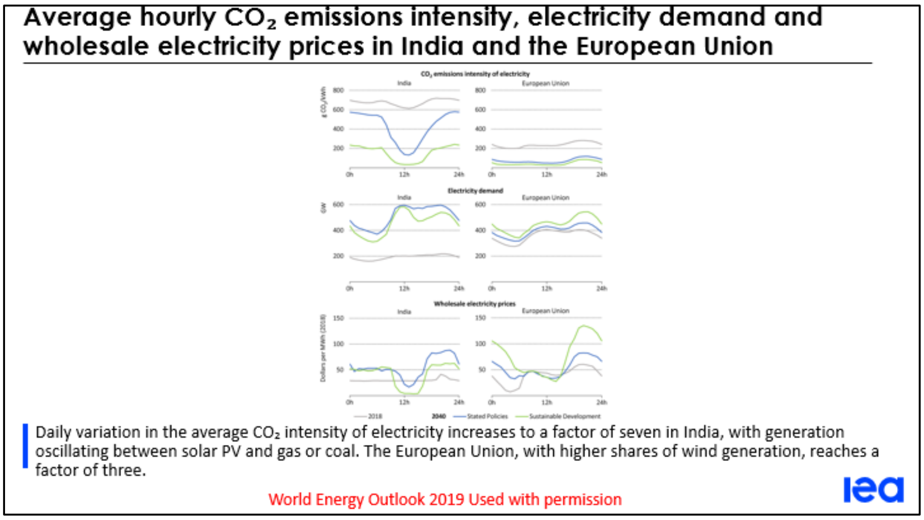
And need not necessarily this transition need not necessarily increase result in a reduction in the CO_2 emissions. So that is a point to be noted that today, if we look at this, it might actually result in a slight increase in the CO_2 emissions. But with the grid becoming more renewable, in future that would not be an issue.

(Refer Slide Time: 20:42)



In the stated policy scenario for different countries, you can see in 2018, this is the overall in the total primary energy demand. We see that in India about a little less than 20 % is from renewables. This includes large hydro, in 2040 that could be more than 40 % of the total. Of course, this is one particular scenario which has been developed by the IEA, there could be other scenarios, you can even think in terms of 100 % renewable scenario.

(Refer Slide Time: 21:14)



Now, one of the issues in this is that in the grid, when we look at the grid over a period of time, what will happen is the CO_2 intensity of the grid would keep changing. And that will depend on essentially the if we have a large amount of renewables as is projected to happen in the future with solar PV during this sunshine hours the CO_2 intensity of the grid would be actually quite low.

And you can see the different kinds of shapes of the grid for India and Europe, the CO_2 intensity versus time. So, depending on at what time you are looking at, the CO_2 intensity would be different. Let me illustrate this issue of what happens when we have a high renewable penetration in the electricity sector?

(Refer Slide Time: 22:13)

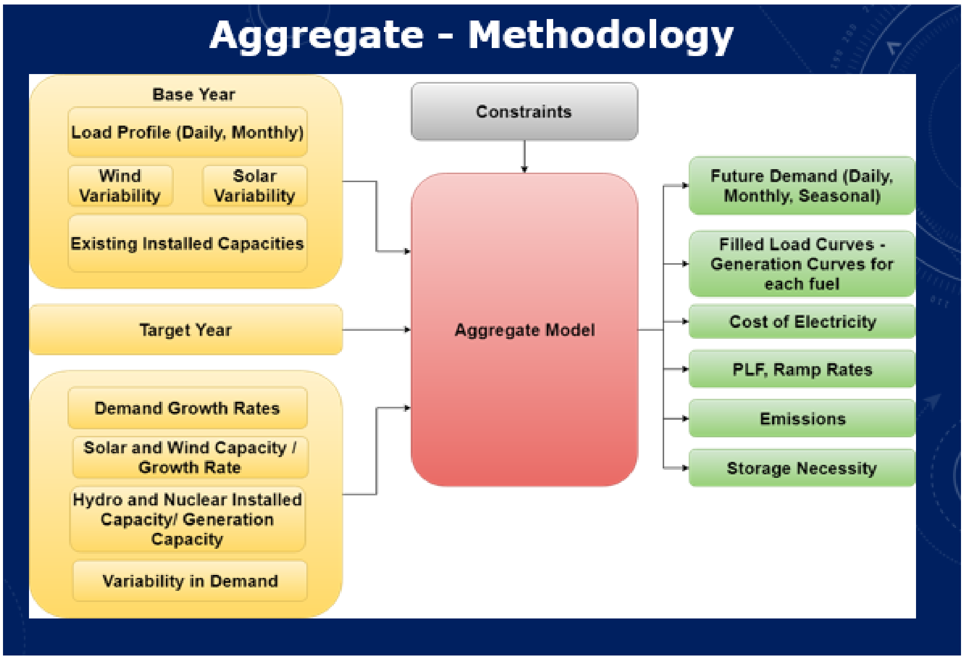
Electricity Generation (Source: Niti Aayog Energy Plan)

TWh	2012	2022		2040	
		BAU	Ambitious	BAU	Ambitious
Gas Power Stations	115	128	154	181	302
Coal power stations	708	1526	1482	2606	1984
Carbon Capture Storage (CCS)	0	5	5	137	137
Fossil Fuel Based Electricity	824	1659	1641	2924	2423
Nuclear power	27	82	87	164	237
Hydro Power Generation	144	214	214	248	324
Hydro and Nuclear	170	296	301	412	561
Solar PV	2	99	99	422	489
Solar CSP	0	11	14	105	185
Onshore Wind	32	129	129	390	423
Offshore Wind	0	6	6	62	92
Distributed Solar PV	0	55	55	164	193
Other Renewable Sources	46	86	101	203	281
Renewable Based Electricity	80	386	404	1346	1663
Electricity imports	5	15	25	71	126
Total	1078	2356	2371	4753	4773

14

So we start with the projections from Niti Aayog. As part of its energy plan, you can see that there is a projection for 2040 business and usual scenario and ambitious scenario with a significant amount of renewables.

(Refer Slide Time: 22:25)



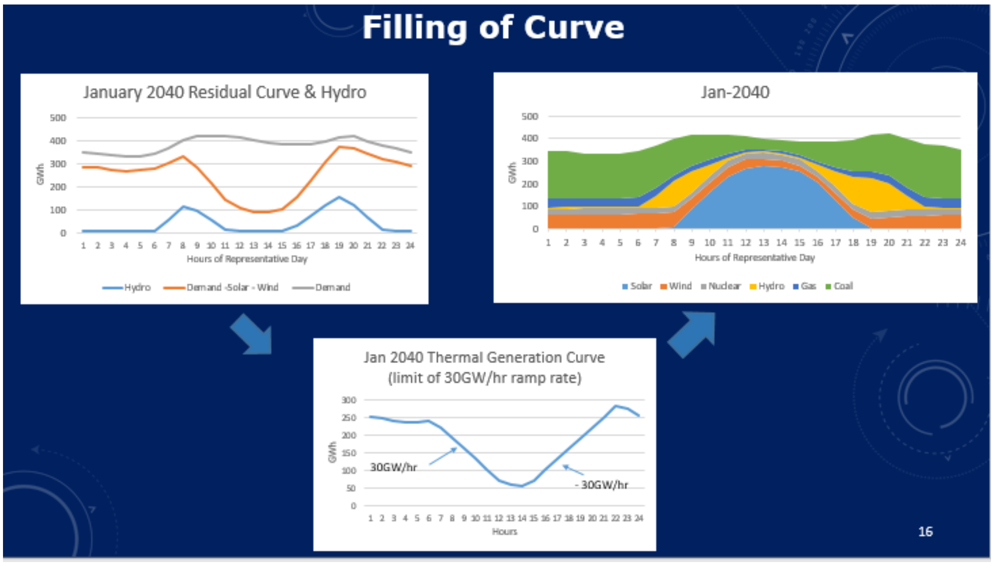
So what we did was, we took a, made a simple aggregate model, where we looked at a base year, the year for which we have all the data, where we had the load profiles. We also had data on the wind variability, the wind at different hours of the day and different seasons and the similarly solar installation.

We also had existing installed capacities by different categories coal, hydro and solar, wind and then using this we then projected for target year with some growth rate, took the load profile and projected it, demand growth rates, solar and wind capacity growth rates, Hydro and nuclear installed capacity growth rates and way variability in the demand. With all of this we then and the kind of constraints which are there we obtained the future demand for different days and by hours, daily monthly and seasonal.

And then we try to allocate based on the capacity, based on thermal, hydro and renewables tried to fill the load curve so that hydro actually met all the sudden requirements, all the ramping as far as possible whenever we need fast ramping up or down, that would be allocated hydro for those parts. Then we based on this we found out after removing hydro and solar and wind, what is the residual load curve which has to be met by the thermal generators.

Then we saw what is the ramp rate and is it possible for the thermal generators to be able to meet those ramp rates. We then calculated the cost of electricity, the PLF, the ramp rates, emissions and then we also found out the necessity of storage.

(Refer Slide Time: 24:39)

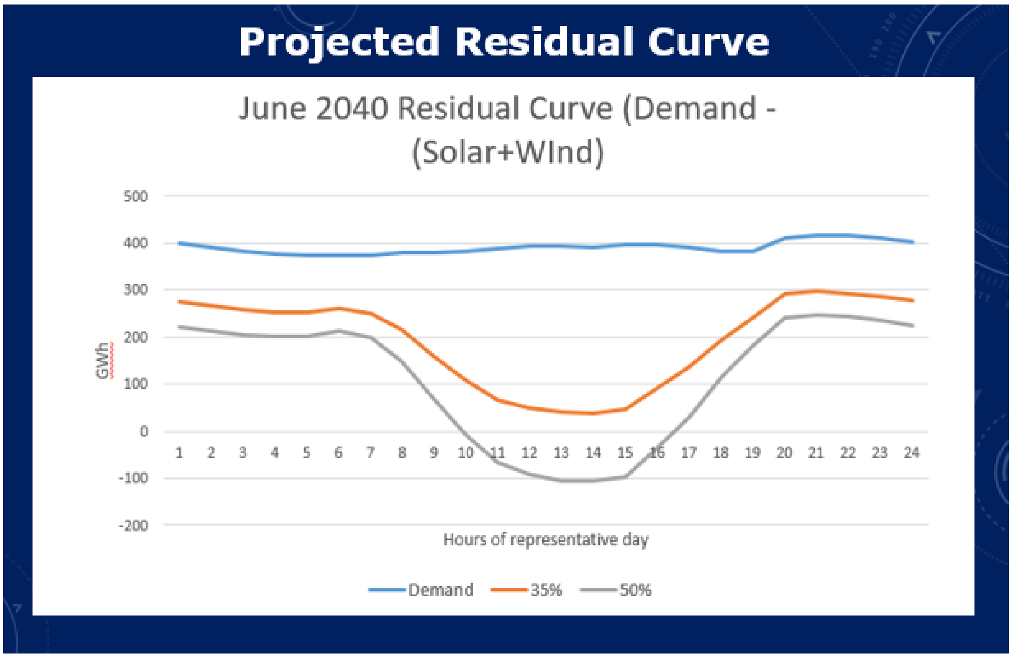


So we just illustrate this in terms of, we projected from the existing curve the demand curve for the country as a whole in January 2040 this is for a typical day, and we have it R by R.

Based on this then we looked at this is what hydro could do. And then there was a we have subtracted the PV and the wind and then we got the residual.

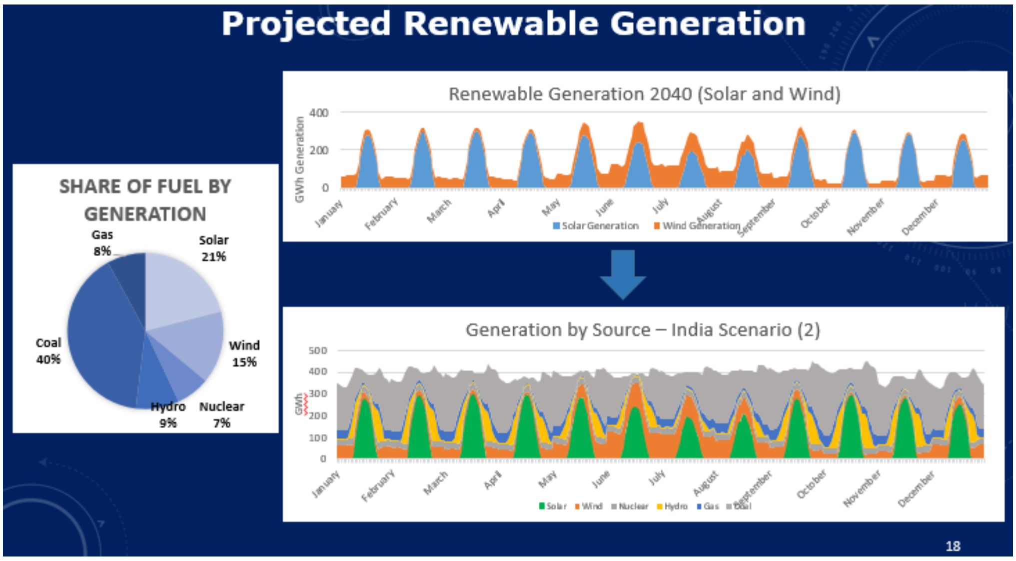
So, this is the different field of load curves as based on this, we then got that this is the amount of, this is the requirement from the rest of the system from the thermal generation and we can see based on this, we can look at the slope of this and that gives us the ramp rate. And so that will give us what is the kind of ramp rates which we are getting and this was above the order of 30 GW/hour and we can see what it means also on a plant by plant bases.

(Refer Slide Time: 25:34)



When we look at this, if we increase the share of solar and wind, we get to a point where the solar, the solar and wind that is generated, the electricity generated from solar and wind is more than the electricity required during that time period. And so then this becomes negative, this area under the curve, if we shade that is the requirement for storage. So, as we go further and further we can see how much every additional unit on solar and wind has to actually go through storage before it is used in some other section.

(Refer Slide Time: 26:19)

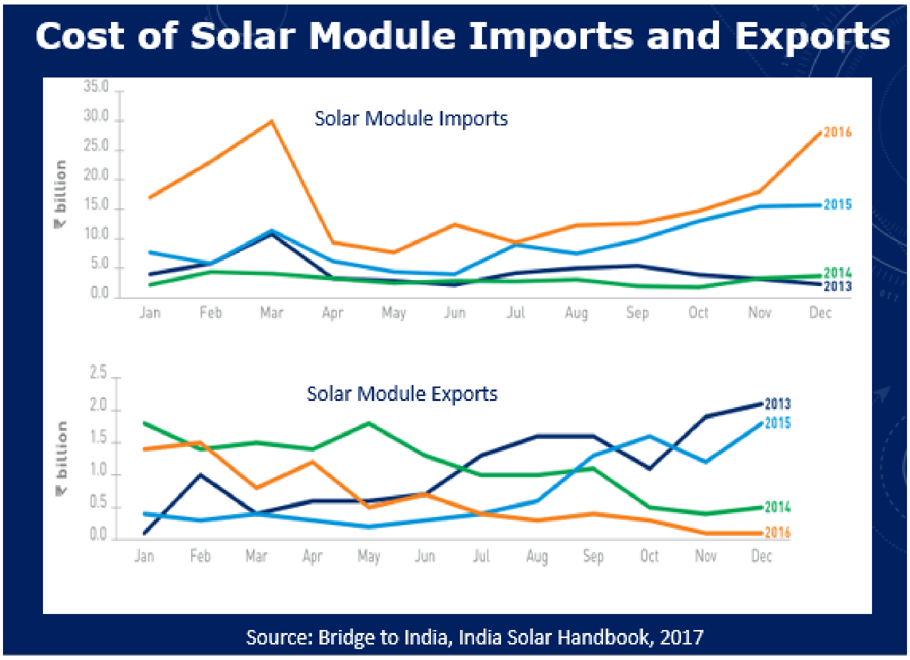


So, this is giving us the final renewable generation, the generation by different sources and this kind of analysis can help us see that as we go for more than this 35 %, 40 % a certain percentage by generation, then every single amount of every megawatt hour of electricity additionally that is generated from PV has to go through storage and then be used at some other time period.

And so, that will depend on what is the cost of storage and even with pumped hydro, it adds to another ₹ 5 or ₹ 6/kWh and so that will you that is one of the challenges when we think in terms of going for large scale 100 % renewable schedule. We will also need to look at variability on a short time frame and that has certain issues. Suddenly if we had cloud cover, say in certain regions, the PV output may drop.

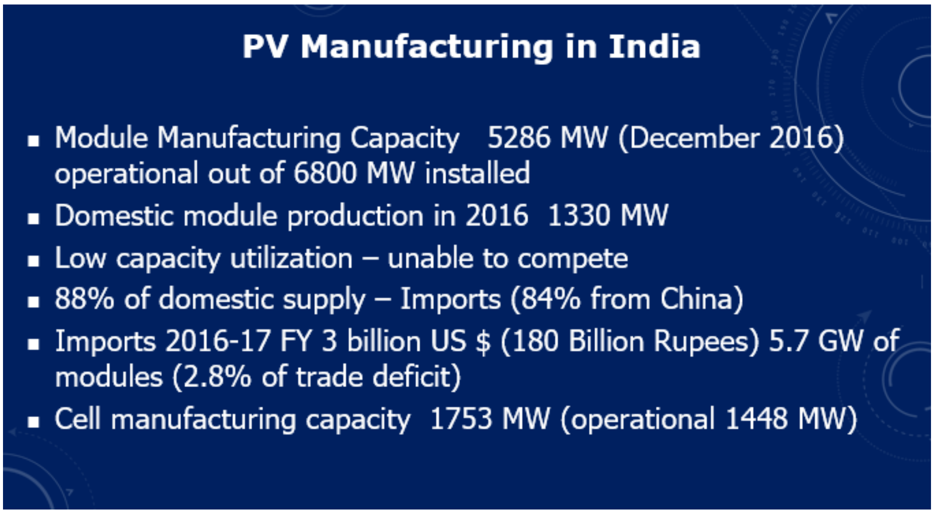
We need to be able to have other sources which can quickly ramp up and meet that requirement and so, the rules of the game for the electricity power sector will completely change. And this is something where there is a lots of there is a lot of scope for doing research and finding optimal solutions.

(Refer Slide Time: 27:53)



Another issue which we should think about when we talk about the transitions. When we started the solar mission, India was a net exporter of PV, but today what has happened is that we are importing a large part more than 80 % of our modules are imported and most of it is imported from China.

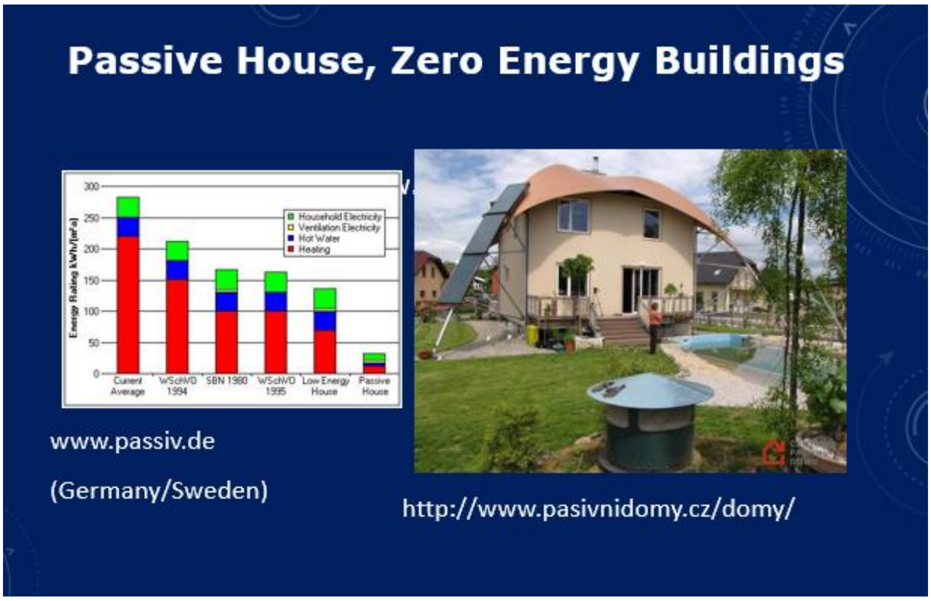
(Refer Slide Time: 28:19)



So this has some, just to give you an idea Module Manufacturing Capacity in 2016 was about 5300 MW, which was operational out of 6800 MW installed. Actual production was only an average of 1330 MW. So it is a very low capacity utilization because we are unable to compete with some of these large Chinese companies. 88 % of our domestic supply is imported and 84 % is from China and this also accounts for a very large amount of import bill.

Similar things are there for this at the cell level. So when we think in terms of future transitions, we need to be able to see what are the things that we can do in terms of technology to try and see that in India we are able to make and we are able to compete and we have the technology and we are providing the supply and it helps our economy and we get also the jobs and the economic benefits out of this.

(Refer Slide Time: 29:34)



Most of our renewable strategy has been with the large centralized mode. It is possible, of course , to think in terms of small decentralized energy. And one of the things which can be done is we can think of each house as a prosumer where it generates its own energy and maybe supplies additional energy back to the grid.

So we have this whole, this whole concept of passive houses and zero energy buildings and energy plus buildings. And if we do this, then we can actually transform the way our energy sector looks because we can have a large number of small houses which are prosumers, which are also producing their own energy also supplying to the grid, and the grid is there as a backup.

(Refer Slide Time: 30:31)

We had an interesting initiative from our students where the students participated in the Solar Decathlon. This is our student team, Team Shunya, it was the first Indian team in the Solar Decathlon finals. The challenge in the Solar Decathlon is to design, fabricate, and implement a completely fully functional solar house, running only on solar energy.

So this house that you see here is a 680 ft^2 house with 5 kW of PV on top, some solar thermal on top, phase change materials. And this was designed and the building was fabricated in the IIT campus, it was dismantled shipped and rebuilt on Versaillies in France in 2014 June and then this was during the competition and it was shipped back and it has been rebuilt on the IIT campus as a demo building.

The focus here is first to design it so that the energy intensity is low, use passive concepts, reduce the total requirement for energy then provide renewables on top. And these can be done in a way where they could be cost effective, and we can reduce the operating energy of the building.

Similar kind of concept, this is a larger one, which was our team in the Solar Decathlon China, this is a 1800 ft^2 house G+1. And in this we also had the requirement of charging an electric vehicle to meet the transport requirements. And these you can see are the images of the student teams which were available. So, one of the possible things is that we may move away from the large centralized energy systems to a hybrid with distributed energy systems, backed up by a grid, which provides reliability and supply.

The current systems and trends seem to be in favour of large, continuing the large centralization with for instance, we have a solar power plant which is almost 700 MW at one place. We have large areas of land under solar PV and because from a business point of view, it is much easier to do this in a centralized fashion.

However, it is possible that if the incentive structure and the technologies work in a way where we can go for a large number of small distributed systems, rooftop systems integrated and along with maybe electric vehicles and public transport, the energy systems that we can see in the future can be quite different. We can look at almost every industry or every product that we make, and it should be possible to make these products with much less energy and also possible to make them with almost zero carbon footprint. And that could be another part of the transition.

So, we are looking at transitions in the electricity sector, we can look at transitions in the transport sector. So mainly going to be electric vehicles, hydrogen vehicles, biofuels vehicles, public transport, biking and walking and trying to redesign the buildings, cities, workspaces and then the transitions in cooking, we are going to go from solid fuels which are being used traditionally to modern renewables.

And we may have LPG and modern renewables as part of it. And then the transitions in the industry where we try to make the industrial products where they are using less energy, redesign them and combine them with zero carbon and carbon capture and storage. There are many different ways in which technologies can evolve and we have seen in literature, a large number of possibilities in terms of different scenarios, energy systems are linked very clearly with development and with the society.

And all these transitions involve some amount of costs, some amount of penalties and problems for individuals. And the winners and losers may also be different. In all of this, it is also likely that there will be a need for some behavioural change, we may need to do things differently in order to ensure that our futures are sustainable and that we can actually continue to provide energy access reliably and provide the energy services that are required to maintain the future of our generation and future generations.

(Refer Slide Time: 36:03)

So, in all of this, as we saw there is there are many dimensions of sustainability. There is the issue of centralized versus decentralized. We know that energy transitions are imminent, we need to assess the impacts of these transitions in terms of equity that means equality, inequality, income, quality of life. And all of this gives opportunities for technology development, R&D jobs, alternate strategies, innovation.

And as we saw, this is a socio-technical problem. The stranded assets which are there for instance, coal based power plants, may cause regional imbalances, may result in jobs lost and we need to work this out and work out solutions that make this transition manageable and also ensure that we are able to go through in terms of looking at not going beyond the climate change tipping point.

And so with this, we come to the close of this course. Please feel free to look at all the references and if you have any queries, please do post them on the forum. And we hope that you have enjoyed and learned about the tools and techniques needed to analyse energy systems. And we hope that you will be using these in your professional career and in terms of looking at different policies and different energy systems and development of energy systems. Thank you.