Energy Resources, Economics, and Sustainability

Prof. Pratham Arora

Hydro and Renewable Energy Department

Indian Institute of Technology Roorkee, Roorkee, India

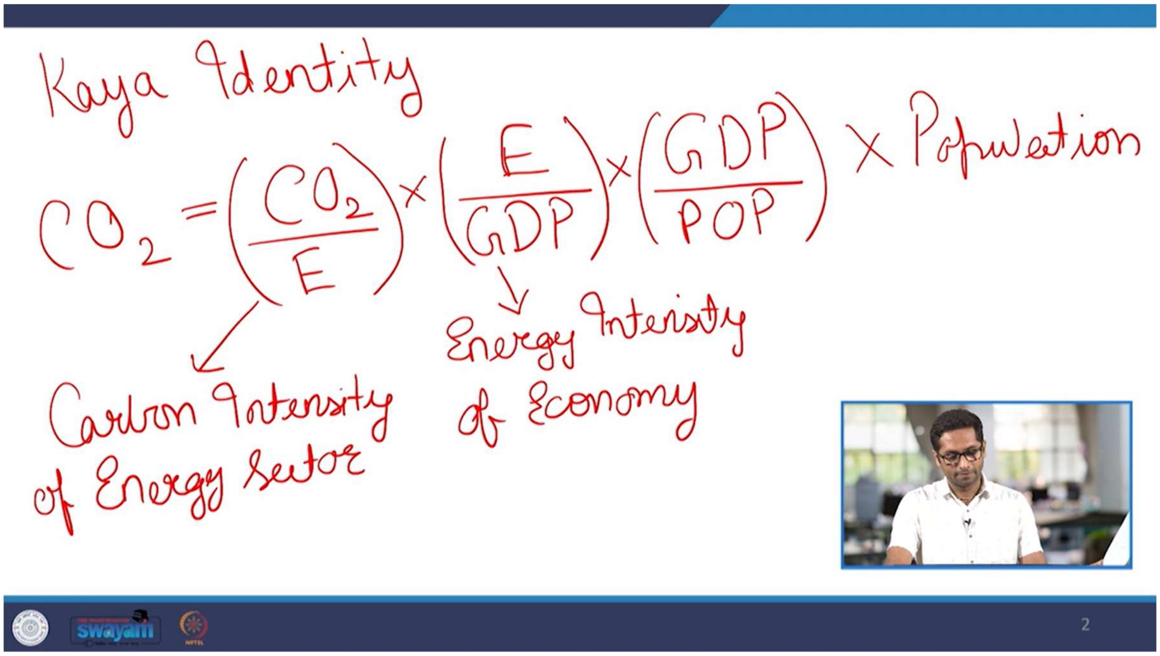
Week – 02

Lecture – 01

Lecture 06 - Energy Consumption

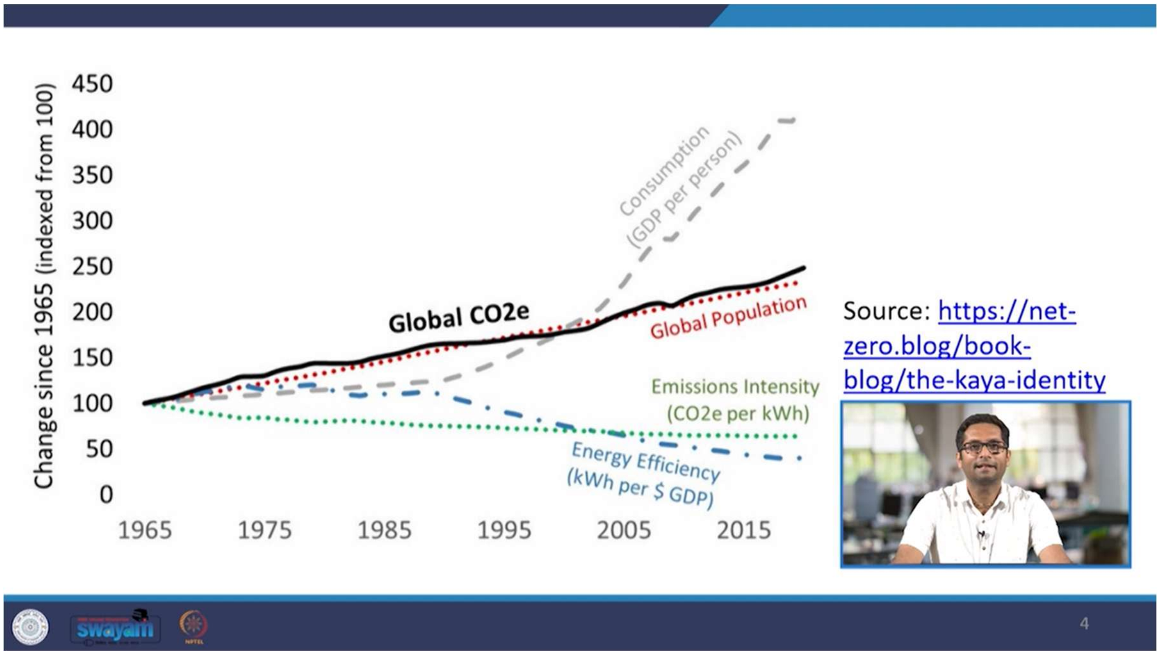
Hello everyone, welcome back to the course Energy Resources, Economics, and Sustainability. In the past few lectures we have been discussing how the consumption of energy varies among the population of different countries and even among the different countries how the variation of energy among different sectors is widely diverse. Different people, different countries have been consuming energy in very different ways in the past, in the present and also expected to change in the future. In today's class we are going to discuss how this energy consumption and the CO2 emissions are interrelated and we also try to get an understanding of the net zero targets of the different countries. You would have been coming across in the popular literature about different countries announcing their net zero targets, why only countries and different corporates, the major corporates have been announcing the net zero targets. This is the year by which they want to achieve net zero emissions of CO2 as they say. We will try to understand what is India's net zero target, how difficult that target is, is anything special about that target and also try to understand the different pathways of achieving that net zero. So as we proceed let us start something or with something known as the Kaya identity. This identity was proposed by a Japanese scientist named Kaya and it has been named after him.

The identity goes as the CO2 emissions of any system which could be a small energy system, a corporate or even a country, would be a function of these four items. The first one is the CO2 emissions per energy use. This is also known as the carbon intensity of the energy sector. We multiply that with the energy consumed per GDP growth. This is also known as the energy intensity of the economy.



We multiply this with the GDP per population and finally multiply that with the population of a particular entity or country. Let me repeat it again. The CO2 that is released by any country would be a function of the CO2 emissions per use of energy, the energy use per GDP, the GDP per population and finally the population. So as you see the consecutive terms will cancel out each other and what will be left finally is the CO2. Now it might seem intuitive and quite trivial but it has implications.

Many major reports in terms of like future energy pathways that you will come across will have a mention of terms like this because this helps us break down how the energy consumption is increasing, how that energy consumption is linked to GDP and how that GDP growth is linked to the population and not to mention the energy consumption would have the CO2 emissions. Now it also, one also might think like if we are living in an economy which has a very low energy intensity will that be not very efficient economy or will that be a very efficient economy? Well we cannot think in that lines because depending upon whether the economy is based on the service sector or the manufacturing sector this number would be very different. If we talk about a very developed country, it might have an energy intensity that is very low because those kinds of economies are primarily service sectors. In the service sectors the energy that goes in the production of or money or the growth of GDP is quite small. Compare that to a very industrialized nation it would have a very high energy intensity per GDP.



So let us try to understand more as we move further. So if we look at the past trends maybe for the last 80 years or so starting 1965 and the different categories or the different entities that we have discussed are maybe said to be around 100 in the year 1965 and let us try to understand how their growth has been so far. So what I will do is for the year 1965 we will consider that as the base year and we will make the CO2 emissions, the population, the emission intensity, the energy efficiency, the consumption all to be 100 and let us try to understand how they have been increasing for the past maybe 70 or 80 years or so. If we see the global CO2 emissions, they have been rising linearly. We have given that in black and that matches very well with the global population.

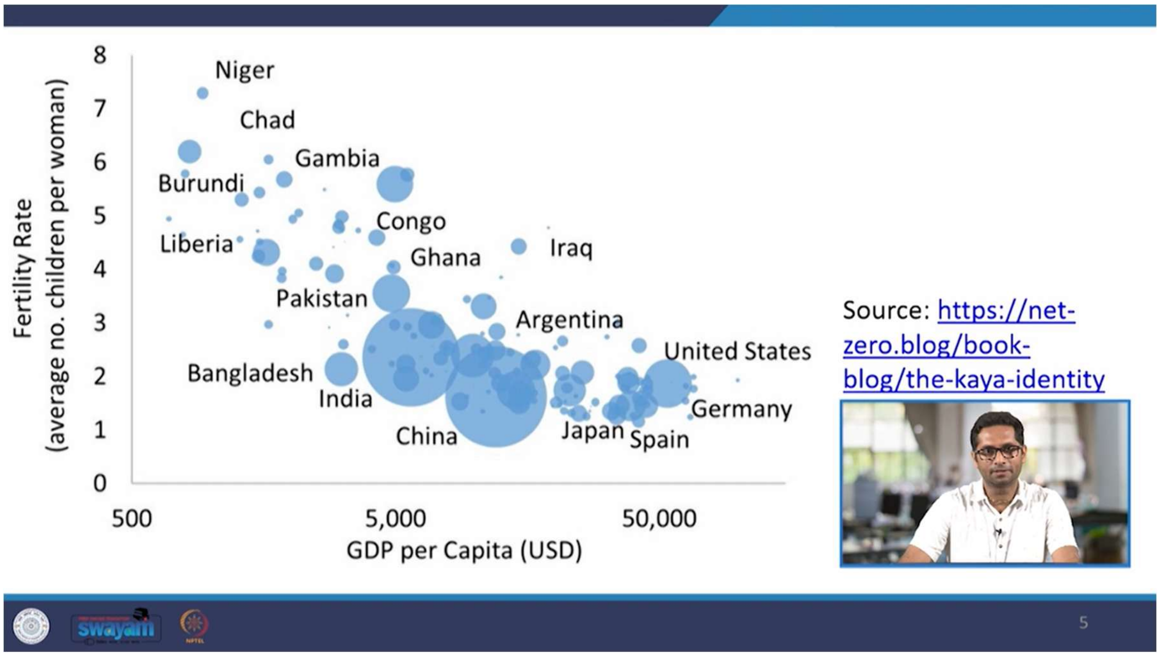
So the population has been rising ever since and so has been the global CO2 emissions. So this becomes a very nice one to one correlation one would say as the population has been rising the CO2 has been rising quite in tune with that seems to be like a linear relationship. But if you remember the kaya identity which we have just written down the CO2 emissions are a product of four different entities and if we look at those individual terms we see a very different output. Although the population has been increasing steadily the consumption which is the GDP growth per person has seen an exponential rise in the past 70 years or so which could be seen in these grey lines. So consumption has been increasing at a very fast pace which also brings us that if the consumption has been increasing at such an exponential rate why did not the CO_2 emissions rose at a similar level.

The answer is that because of the two other levelling factors which were the emissions intensity and the energy efficiency. Both have seen a significant improvement over the time. Let us see if we see about the emissions intensity that has seen a significant decay since the 1960s there was an initial growth but after that there has been a decay. One of the primary reasons for that decay has been movement of the major economies from coal based economies to natural gas or oil based economies. So as we move towards more cleaner or more efficient fuels the CO_2 emissions per kilowatt hour of energy that is generated tends to become lower and lower.

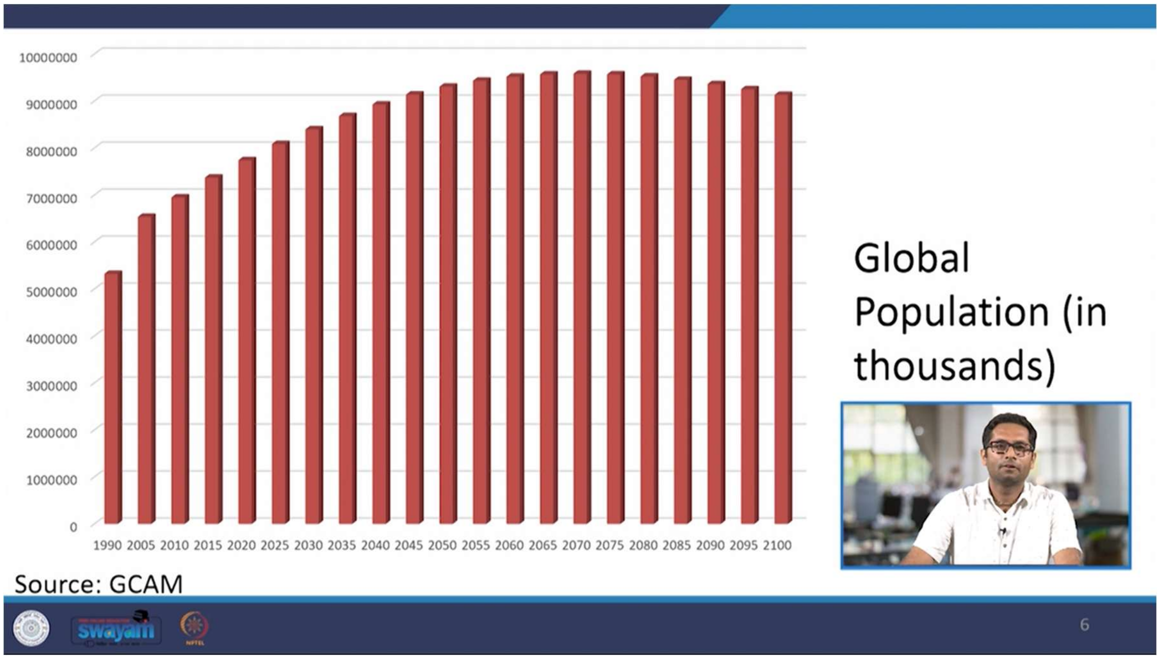
Although we are still majorly in the ambit of fossil fuels we have been moving towards cleaner sources of coal or maybe from coal to natural gas. Another factor that affected this rise in CO_2 was energy efficiency. With the increase in technology processes are becoming more and more efficient. The power plants that were running earlier maybe at the efficiency of 25% could now run at almost 40% efficiency. So we have seen that with the increase of technologies we are trying new and new technologies the processes have become more and more efficient and the energy that we need for a per unit growth of GDP has been coming down.

So one lesson that we learn is although the CO_2 emissions seem to be very well in line with the global population rise there have been other factors. One factor has been consumption which has been rising exponentially. The other ones which have been leveling this exponential rise in consumption have been the emission intensity which is the CO_2 emissions per kilowatt of energy produced that has been reducing so has been a reduction in the energy efficiency. Now you would have come across the targets by the Paris agreement which says let's limit the global temperature rise to around 2 degree Celsius or countries coming around with the net zero targets. Now there could be different strategies for achieving that. One could be why don't we limit population. The population has been seen as a driving factor. Increase in population is linked with increase in CO2. Let's limit population. The other factor would be let's limit consumption.

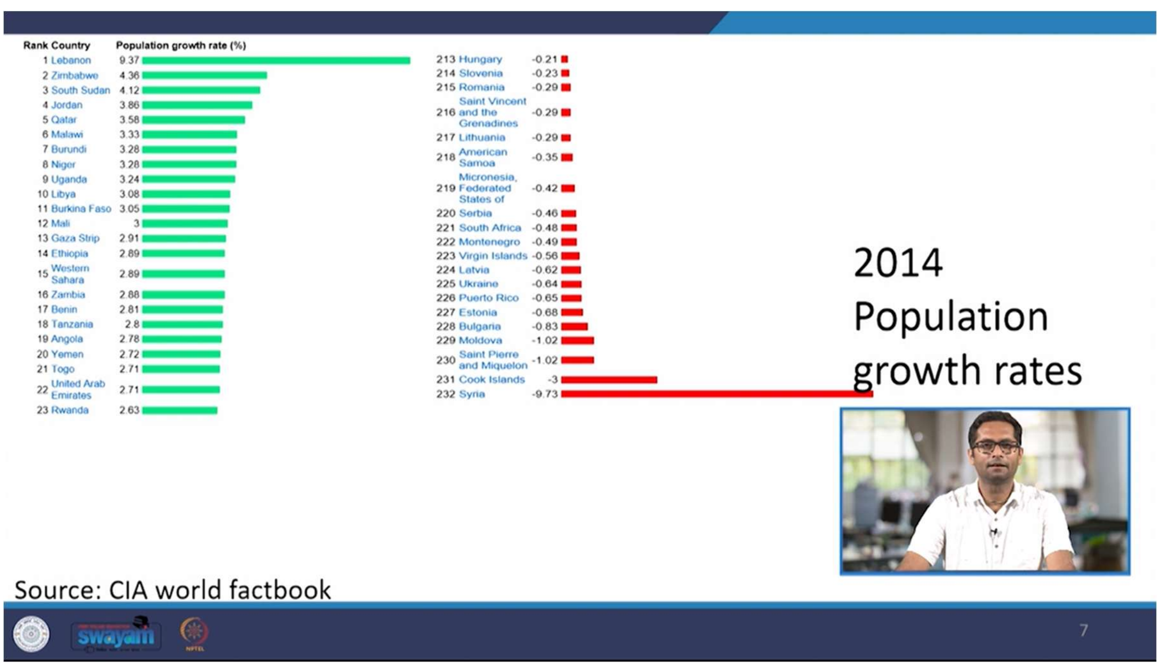
Let's not allow the people to spend at an exponential rate. Others could be let us also improve the energy efficiency to the best possible manner. Another strategy would be let's bring down the emission intensity to as low as possible. Let us try to analyze these four strategies which is again coming from this well-known Kaya identity. Now the first thing could be let's limit population.



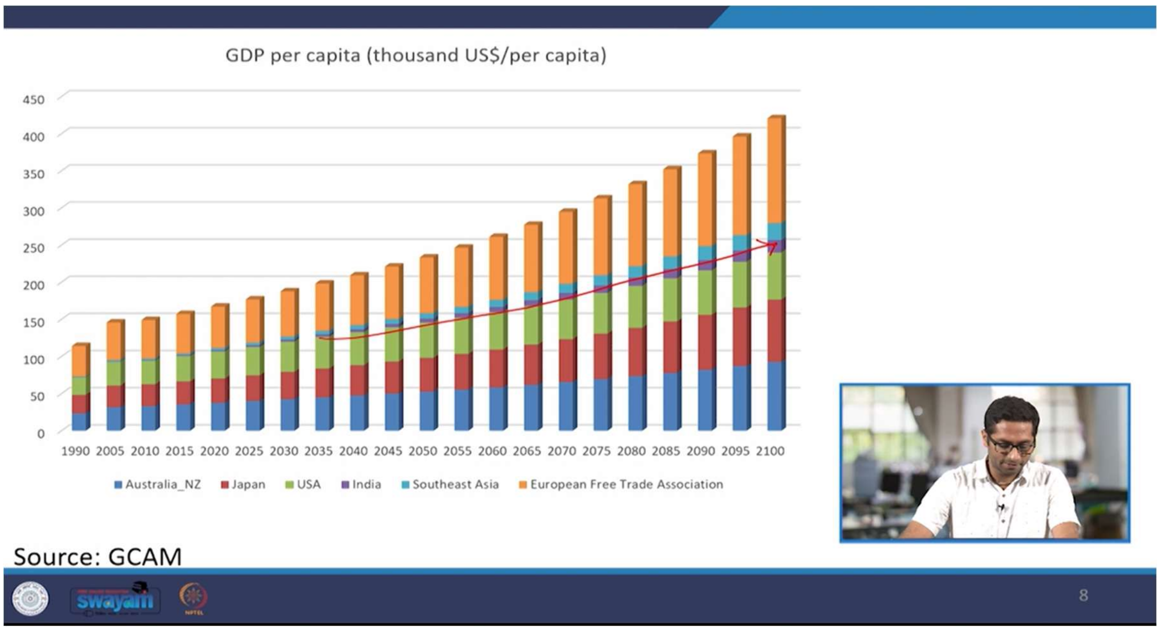
So we see that the population or the fertility rate is normally very well correlated to the GDP per capita. As the GDP of a particular society rises, the population tends to stabilize and also in some aspects reduce with time. So one aspect could be let us create increase the GDP which means people will become more and more educated, the family size might become smaller and population will stabilize as slowly which achieve a maxima and there would be a decay in population which means there would be decay in the energy use and there would be a decay in the CO2 emissions. So this is one particular strategy that could be adopted. If we go with the normal statistics that are available, we did try to model that how the global population is going to change in the near future without any intervention or any major policy that is brought down by the different governments.



So the world population is expected to stabilize or peak at around 2070s and then reduce. What we are planning in the strategy is let us limit the population from now onwards and let us try to see the effect that it would have on the CO2 emissions. Then of course we also understand that different countries would have very different population growth rates.

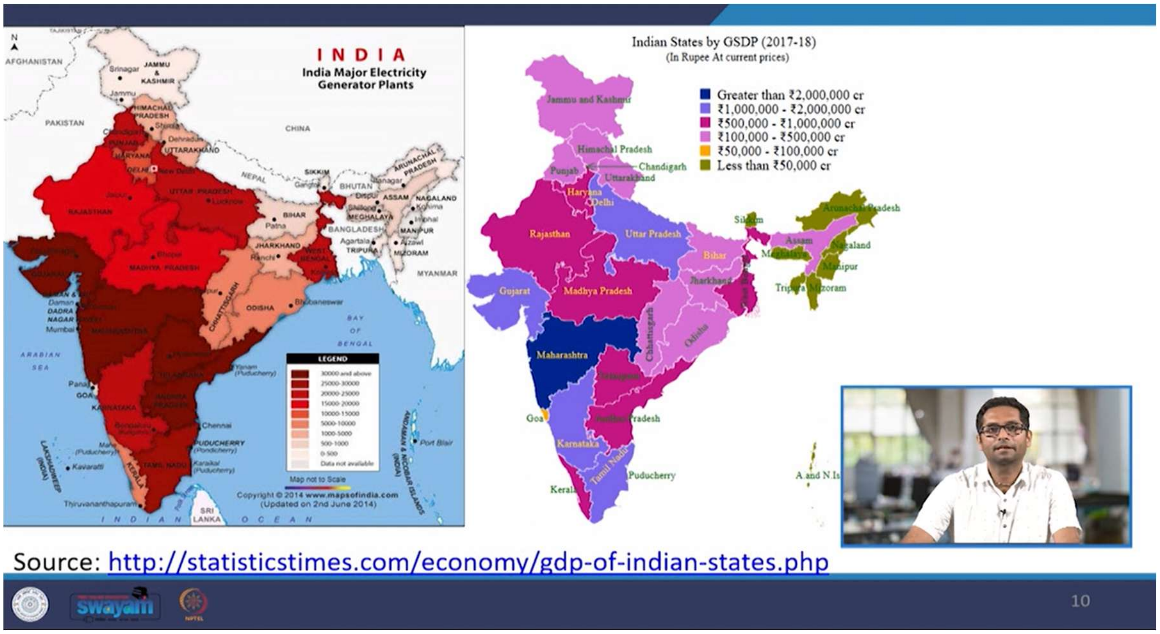


So normally a population growth rate of 2.1 is projected to be a fair growth rate for the population to be stable but we see that there are countries on the left hand side that have very high growth rates and there are also countries on the right hand side which have almost negative growth rates. There could be different factors around it but we see there is a very vast variation among the different countries of the world in terms of the growth rates that they have been exhibiting.



Then another strategy that could be adopted for like achieving the targets of maybe 2 degree Celsius would be let us also try to limit the GDP per capita. So we have seen in the earlier classes like how the GDP per capita is very different from the different countries of the world. Although India might have a very huge GDP in absolute terms but when it comes to per capita terms we are like way behind the other major countries. And in this graph what you see is that like the GDP growth rate of major economies of the world have been projected and we can also see in purple India's growth rate has been projected and we are expected to grow at a fairly high rate almost doubling or tripling the economy in the next 50-60 years.

So far so good. If we limit the GDP consumption per capita for the whole globe at around 14000 dollars per capita or so this would also mean that energy consumption is also stabilized. If the energy consumption is stabilized so would be the CO2 emission. So this could be another strategy in which we limit the energy consumption for whole the world we have projecting like a world average. So for a country like India there might be an increase in the consumption for a country like the US there would be a decrease in consumption for the citizens and that could be another strategy. Then there could be another strategy which is the energy consumption per GDP.



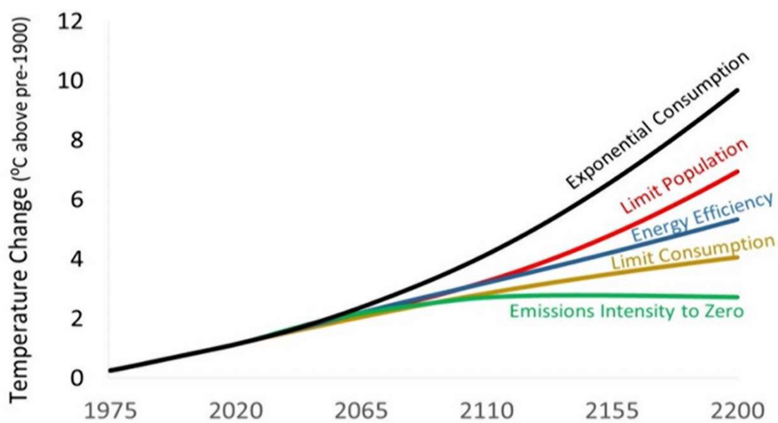
We can also try to limit that. So here in what we see is and they are the different states of our country and what you see on the left hand side are the countries which are the major electricity producers and of course consumers as well and what you see on the right hand side is the state specific GDPs of those particular states. So we see that there is a very strong correlation between the states which are having a very high GDP and the states which are one of the major producers and consumers of electricity. So that relationship is something that we have seen for different countries as well. We have seen an infographic in the previous classes which tries to map this very relationship that if the GDP of a particular country is rising it is very closely linked with energy consumption.

So another strategy that could have been adopted or that we could adopt is can we limit the energy consumption per GDP rise. So that could have its own implications. And finally what we can do is we can reduce the CO2 intensity of the energy. We have different sources of energy. They could be quantified as renewable sources of energy and fossil fuels.

CO2/Energy

- The amount of carbon by weight emitted per unit of energy consumed
- Can be decomposed into fossil and non-fossil shares, and emissions can be expressed as carbon emissions per unit of fossil energy

Fossil fuels tend to have a very high carbon footprint. The amount of CO2 that would go into the atmosphere per unit of energy use. If we go towards renewable sources of energy they tend to be operating at a lower end. Not many of the renewable sources of energy are based on carbon and that means they would not emit much carbon as compared to the fossil fuels. So what we have tried to do in this lecture is try to compare four different strategies for achieving a temperature target or a global temperature rise target of 2 degree Celsius.



Source: https://net-zero.blog/book-blog/the-kaya-identity

One we could limit the population. We could limit the GDP growth per population. We could limit the energy used per GDP or we can reduce the CO2 emissions per energy. So here we have the results in front of you that I have taken from another source. So what you see on the y axis is a temperature rise degree Celsius above the pre 1990 levels.

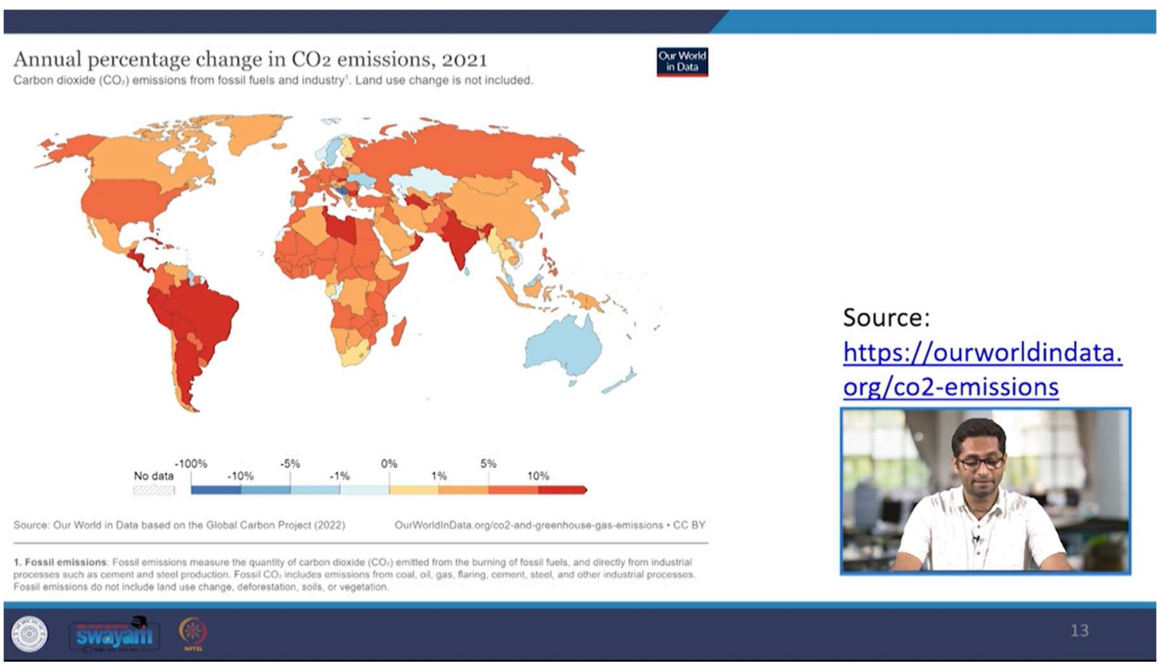
We want to achieve a level of around 2 degree Celsius. What we have on the x axis is the years as we progress. What you see in the black line is the exponential consumption. So this is how we would proceed if we go ahead with the business as usual case. We do not make any amendments in the way things have been happening.

The population keeps on rising. The GDP growth per population also keeps on happening. The efficiency might increase as it has been happening and there might be an increase in the energy sorry in emissions intensity of the different renewable energy sorry sources of energy. So if we go with the exponential consumption by the year maybe 2065 will be around 2 degree Celsius and in the future will be way exceeding this target. Now comes the first strategy. If we limit the population we increase the education, we increase the GDP of the population which means the families will become much more educated.

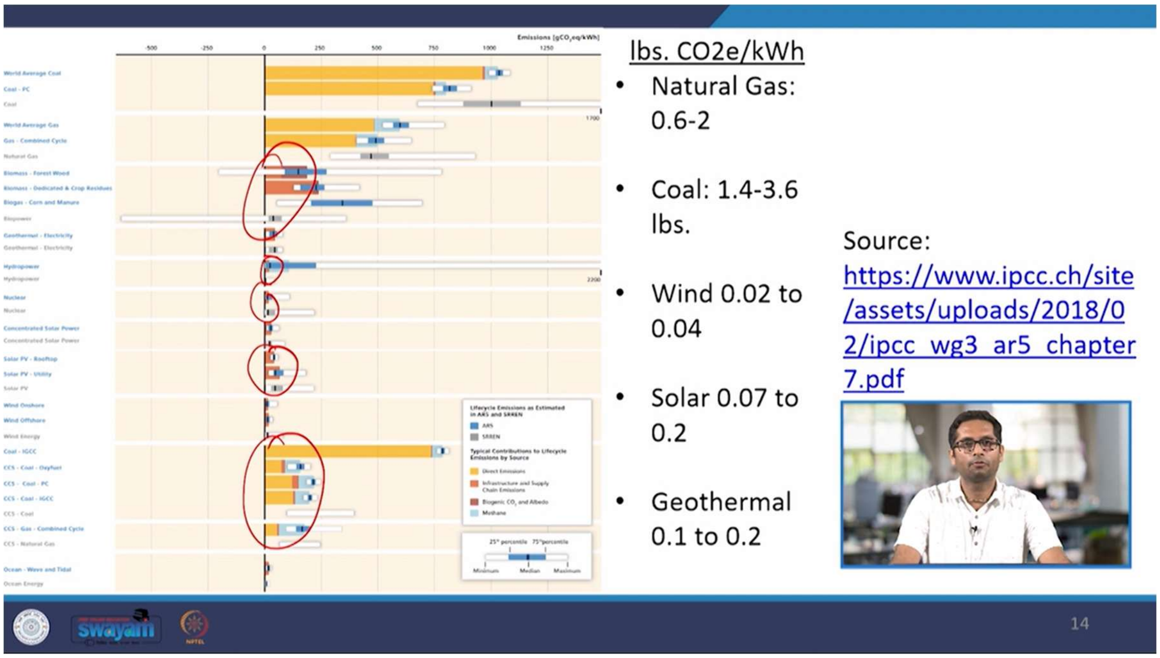
The family size would decrease; the population would also decrease. But even if that was the case and that was the only strategy that was applied there would be a rise in the temperature level which is linked to the energy use. So the energy use is going to rise even if we limit population and it is going to go around 8 degree Celsius in the coming 200 years or so. The second strategy could be we limit the consumption. We limit the consumption at the world average of around 14000 dollars per annum and that is expected to limit the temperature rise in terms of the energy consumption.

But still the temperature is going to rise. It might be slowed down but we would expect it to rise to run 4 degree Celsius in the coming 150 years or so which means we would lose many of the island nations. Then there could be another strategy where we increasing the energy efficiency which is basically the energy use per GDP growth rate. Now that again is not going to help us much. There are thermodynamic limits to the way the efficiency could be improved.

The energy efficiency has been improving steadily at around 1 to 2 percent every year and the same can be expected but there could not be very drastic changes because many of these processes would have thermodynamic limits or there is a limit to what could be achieved physically and the energy efficiency in itself could achieve only so much. Then comes reducing the emission intensity to zero. Let us use the sources of energy which do not emit any CO2 emissions into the atmosphere and that is the only strategy in which the temperature rise could peak and could also slowdown in the future and it has the ability to slow down or decrease in the future and this is one of the reasons why different countries are going towards cleaner fuels and at net zero targets. We believe there are other strategies like limiting population, increasing the efficiency, limiting consumption but all those if applied in isolation are not going to help much. Whereas if this is the only strategy that we apply that is the emission intensity reduction of the fuels or the sources of energy that we use that could have meaningful outputs in the future. So, this is this would help us understand why different countries or different scientific communities have been calling for reducing the emission intensity of the different fuels and bringing that to zero and this is where the net zero targets come in.



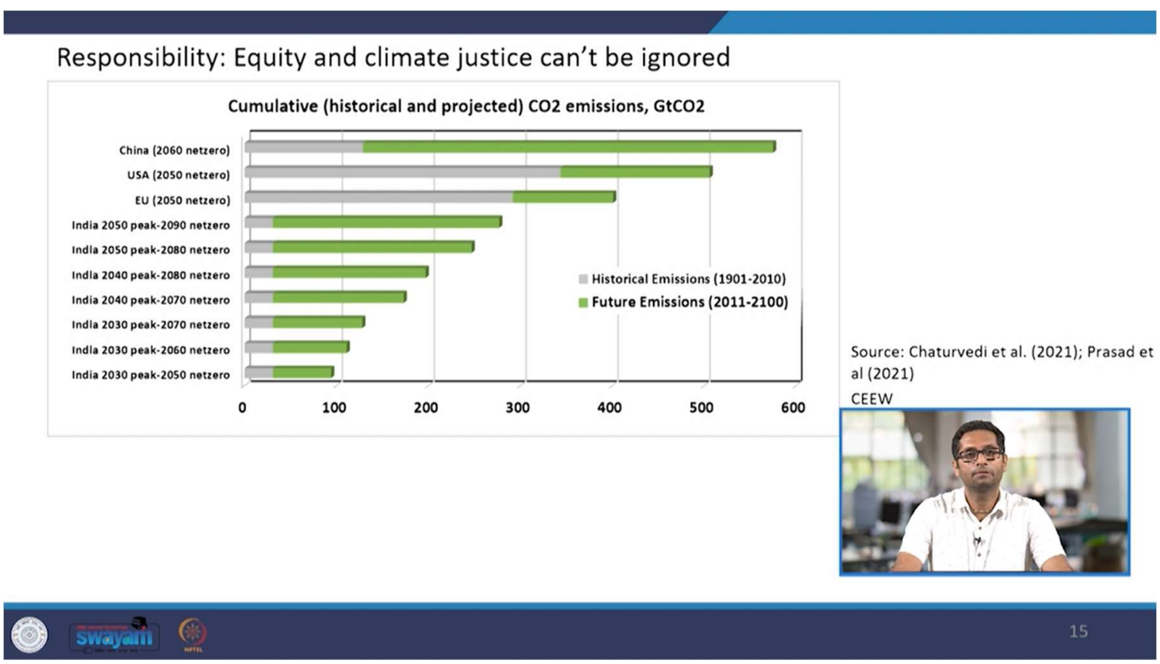
Then we also understand that different countries have been progressing differently in terms of the CO2 footprint growth rate. So, this particular infographic basically gives you the percentage of the CO2 emissions for the different countries and we can see that India as a country is poised to increase at a very fast rate it is almost around 10% or so. So, in the future as our GDP rises we would have to increase our energy consumption and very closely linked to this energy consumption would be the rise in CO2. Because we have although we have been moving towards renewable sources of energy that movement is not very high we are still majorly dependent on coal or crude for major supply of energy in our country.



Then we also understand that different sources of energy would have a very different carbon footprint. This could vary like what you see is coming from the IPCC documents on the left hand side you have the name of the source and on the x axis what you have is the emission which is the gram of CO2 equivalent emissions per kilowatt hour of energy that is produced. So, if we take about the CO2 intensity of coal so that almost varies around 1000 grams or 1 kg of CO2 per kilowatt hour of electricity produced or energy produced. And that is very similar to the electricity footprint that we have in our country India so this normally varies around 1.8 to 1.24 is the normal range and that is one of the highest carbon intensity for energy production. Then if we go towards gas it is almost half of it almost around 0.5 kgs per kilowatt hour of energy produced. And this is one of the reasons why like the developed countries tend to have a lower carbon footprint or a greener grid as compared to India because they are primarily dependent upon natural gas as a fuel. Even if we consider the so called renewable sources of energy like solar and wind their emission intensity does not happen to be 0.

They could be very low around 50 or 100 as you see in the case of solar PV utility or rooftop it varies around somewhere around 50 to 100. The same could be said for a source like a nuclear or hydro power. So we need to understand although like we would aim for a source of energy which have a zero emission intensity in practicality that is very difficult. The only source of energy that can make that happen is biomass. Biomass has that inherent ability to capture CO2 during its growth.

So biomass is any biogenic organic matter that grows and that encompasses many of the plant species. So plants when they are growing and because of the photosynthesis process they take in CO2 they have the natural ability to take in CO2. So that is one of the pathways which have the ability of going net carbon negative whereas and this ability is almost absent in any other source of energy that you might consider. Then there is also a huge momentum towards carbon capture and storage which could be linked to coal or natural gas based plant which could bring the carbon intensity of the energy produced from fossil fuels almost at par with that of renewable sources of energy. But this carbon capture and storage would also involve good amount of energy use.

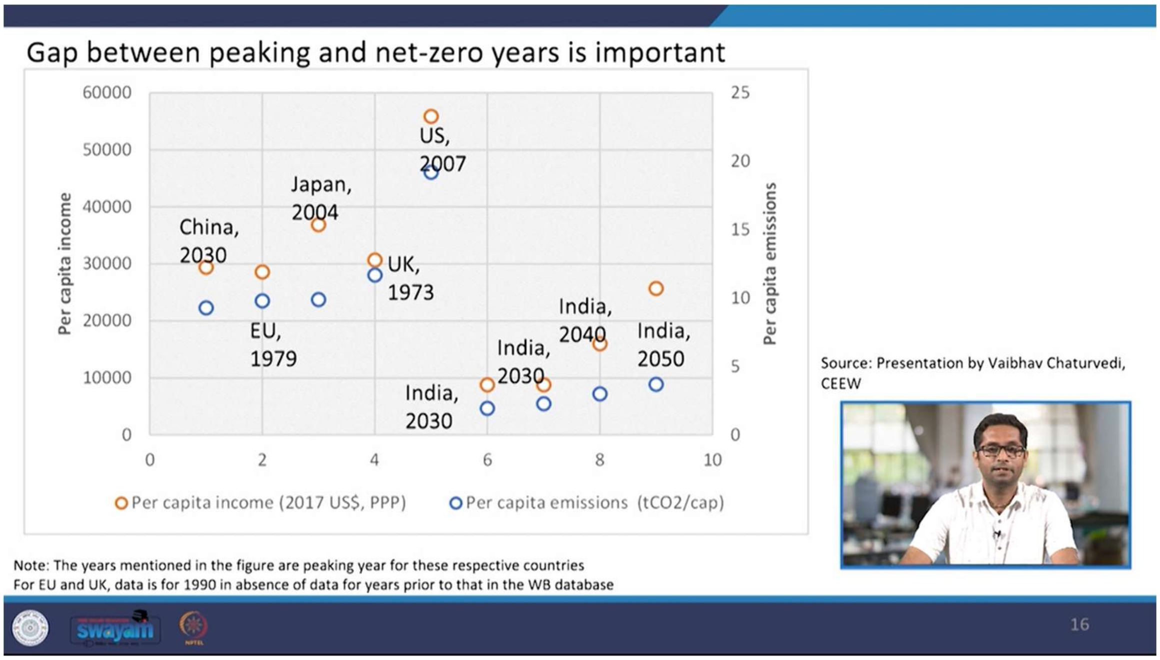


Now let us try to understand all this in terms of India's net zero target. So what you see in front of you in the figure is the CO_2 emissions in terms of gigatons of CO_2 that have been emitted by the different countries and that India might emit like based upon its net zero target. So the different scenarios have been created. So on the top you see the three major economies or clusters like China, USA and EU. They have had historical emissions and they are also expected to emit in the future till the time they emit they reach their net zero targets.

So we see that USA by far has been the largest emitter of CO_2 in the past followed by European Union and China. So what you see in the grey color are the emissions that has already been emitted. What you see in the green is the emissions that are expected to be emitted based upon the net zero targets by the respected countries. So we see that if we go by the China's target of 2060 net zero China's cumulative emissions are going to be the largest followed by the US and the Europe.

What you see in the bottom figures are India's target. India has given a net zero of 2070 but an important fact to consider here is whereas the three major economies that have been told earlier above have almost achieved a peaking or near peaking India is yet to achieve a peaking of the CO_2 emissions. So what do I mean by peaking? As the GDP is rising and the population is rising the CO_2 would keep on rising it would reach an optimum or a maxima and then keep on reducing. The US and the EU has already achieved that it has already achieved the maximum emissions that were there in a particular year and now year on year their emissions are tending to reduce. China is expected to achieve a peaking in around 2030s and that makes the trajectory quite smooth for them to achieve a net zero by 2060.

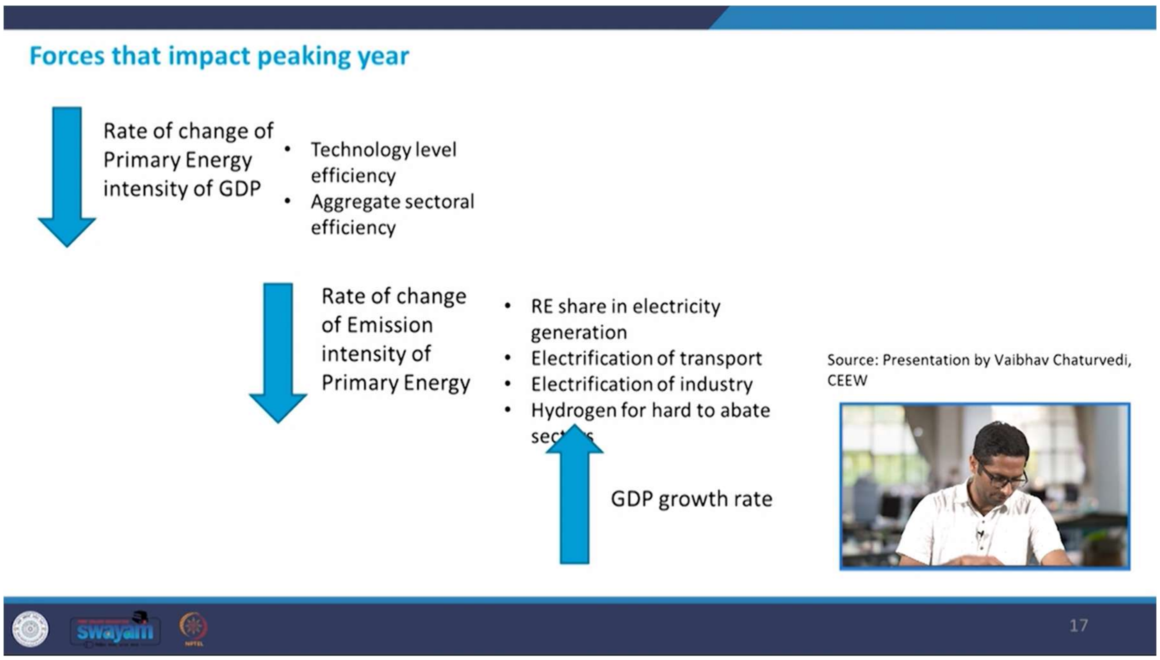
Whereas in India we are still not sure when we will peak. If we go by the current trend the peaking might happen at around 2070s or so and this is very close to the emission or to the net zero target that has been given by our country. And the later the targets the more emissions India would be producing if we go with the later peaking and the net zero we will be having more emissions. But even if we have the worst possible targets for peaking and net zero we would still be way lesser than major economies of the world in terms of the cumulative CO_2 emissions. Given the condition like we being the largest population in the world now the emissions that we have been emitting or we would be emitting in the future for the worst case net zero and the peaking years would be way less than the major economies of the world. Then we can also try to understand that when these countries achieve like have been peaking they have been much more richer than what India is or what India will be in the future.



What you see on the y axis on the left hand side is the per capita income and what you see on the right hand side is the per capita emissions. What we have given in the black is the peaking years so China is expected to peak at around 2030s, US is around like has been peaking around 2007, Japan 2004. The important thing to note here is that all these economies had a much greater per capita income when they peaked. Most of the range of around 30,000 dollars per capita. Whereas given the India's peaking in the future it might be 2030, 40 or 50.

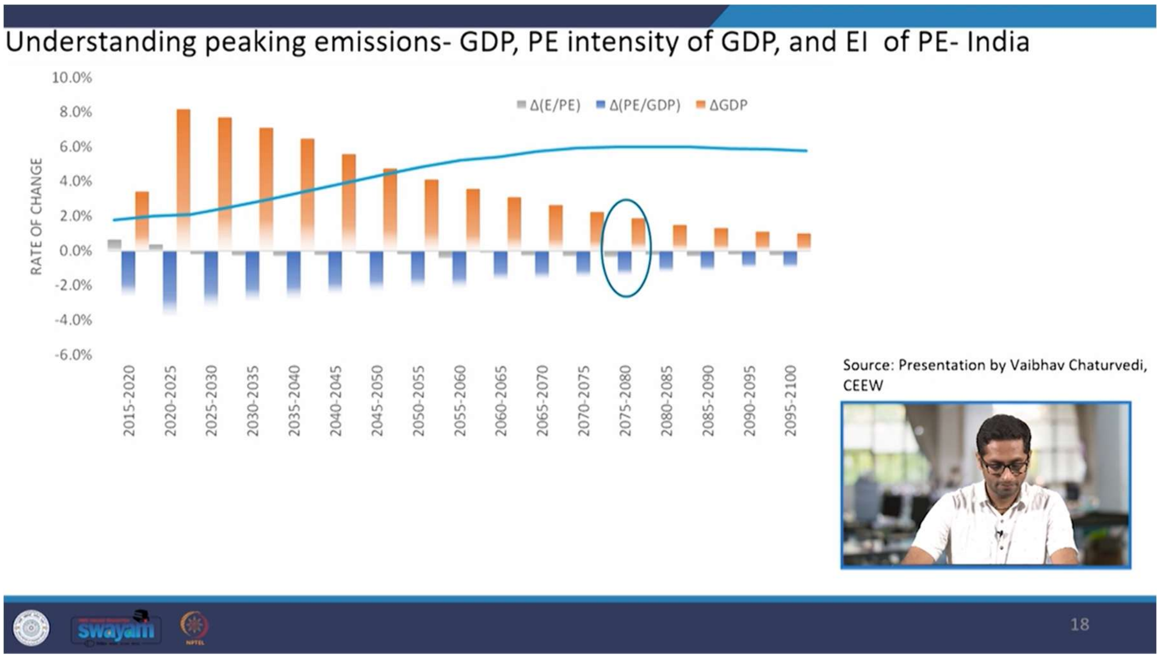
The per capita income is expected to be much lesser. Only if we peak in 2050 it is going to be near to what the major economies have been. If we peak before that the income is not expected to be very high. And the same goes with the per capita emissions. All these economies also had a very high per capita emissions in the year in which they peaked or expected to peak like in the case of China.

Whereas for the India's case it would be much lower. So as compared to the major economies of the world we have been trending a very nice way. Our contribution to the global climate change problem has been way less lesser as compared to the other economies. Now we will also try to understand what impacts the net peaking year. So there would be three terms that will be coming into play which we have understood in the kaya identity. First thing is the rate of change in the primary energy intensity of the GDP which means the energy efficiency would be increasing.



That has thermodynamic limits but it is expected to increase in the future. Second thing is we would be reducing the emission intensity of a primary energy and that is the reason why we see a lot of push towards EVs. We now have a very great push towards hydrogen economy. All that is basically dictated by the one thing which is we need to reduce the emission intensity of a primary energy.

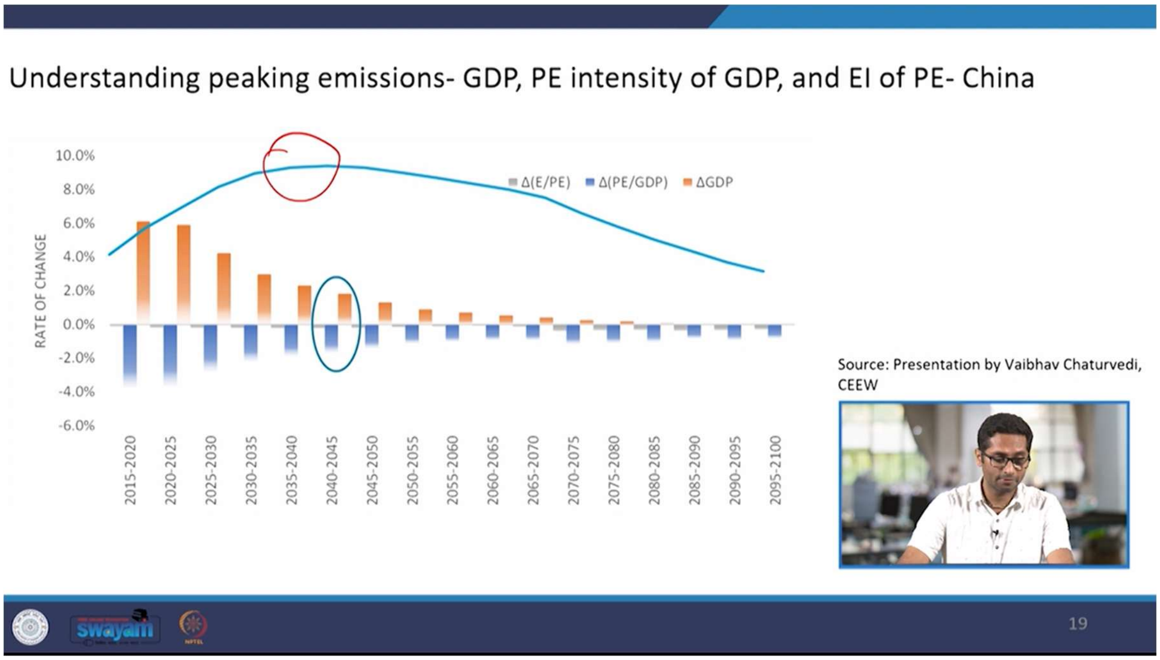
Plus, we expect the GDP growth rate to be increasing in the future. So when the decrease in the energy efficiency, sorry increase in the efficiency and decrease in the emission intensity is balanced by the GDP growth rate for our country that will be the year will be peaking. So if we try to understand with the help of a graph and this is how things are expected to happen. Our GDP is expected to grow at a fast rate almost at around 8% for the present decade or so and then it would be slowly reducing in the intensity. So what you see in orange is the GDP growth rate per year.



That is expected to be positive for the coming 100 years or so. Then we would also have the energy intensity per GDP which is positive as of now but would reduce in the future as we move towards more and more renewable. And then we also have the emission intensity which is also expected to be reducing. So when the three balance out each other themselves that is the year we are expected to peak and the line on the blue basically gives you the CO2 emission so they are expected to rise. And given on the business as usual case will peak at around 2070s or 2080s when the rise in GDP would be balanced out with the increase in efficiency as well as the reduction in the emissions intensity for a country.

And this is what makes our targets really important. So given the business as usual case 2070s or 80s is the year when we are expected to peak and the leaders of the country have given a target of around 2070s to be a net zero target. So this makes it even more difficult to achieve as compared to other countries. You might hear in the popular debate that while US or major countries in the Europe have given a fairly recent target of 2030s, 2050s as net zero why is India has gone so far to 2070s to be net zero. The reason is that we still have a mammoth task in front of us even though it is like the target is like maybe

20 years or 30 years delayed by the major economies what India has to do is much more difficult than any other economy for the world.



Compare that and this result for that of China these are the trajectories of the change in the different values for China and given their GDP rise, their emission intensity they are expected to peak around in the next decade 2030s or so and after that it becomes easier for them to achieve the net zero target of 2060.

Whereas for India let me reiterate it again both of these targets stay in line. So this basically provides emphasis on like the net zero targets of India. So in today s lecture we have been tried to understand the Kaya identity, how the different factors like the population rise, the GDP per population, the emissions per the energy per GDP and the emissions per energy are finally contributing to the total CO2 emissions, how these trajectories have been there in the past, how they are expected in the future and what is the impact that they are going to have on the India s net zero target. So with this we end today’s lecture. Thank you.