Air Pollution and Control
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Lecture 24
Emission Inventory for Residential and Commercial Sectors

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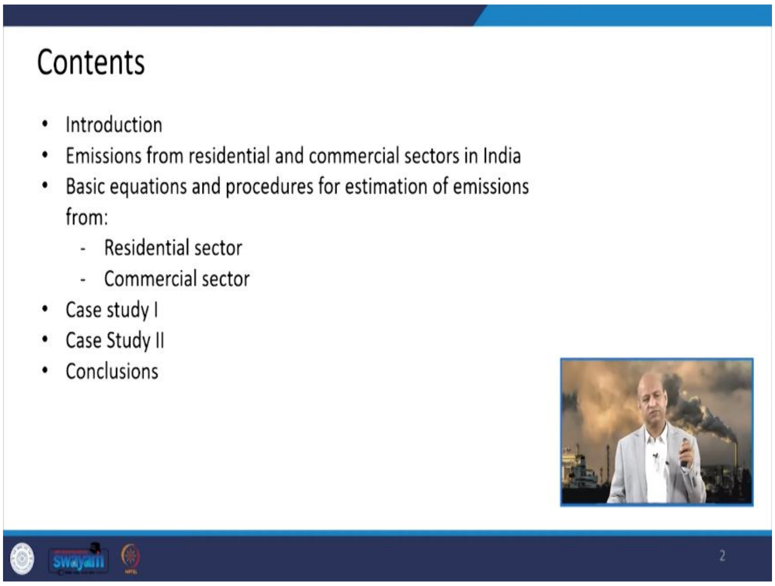

Hello friends. So, you may recall that emission inventories are very important in case of when we want to use dispersion modelling. For dispersion modelling, emission inventories basically play like input value parameters. So, when we develop emission inventories, we develop emission inventory for each sector. When I say sector, so that means, there are several sectors which are responsible for emissions of air pollutants emissions like power sector, agriculture sector or domestic or transport, those kinds of things.

So, we have already seen how to develop emission inventory for industrial sector for transportation sector and for agriculture sector. Today we will discuss how to develop emission inventory for residential and commercial sectors and basically, you should remember one thing whatever sector it is fundamentally what we do, we try to assimilate the activity data, whatever activity is using certain fuels and that fuel consumption, burning of the fuel is resulting in emissions, whether greenhouse gas emissions or air pollutant emissions.

So, we need to calculate activity based this fuel consumption and then we have to multiply it with the emission factors, activity-related emission factors. So, that fundamental thing we have to apply in every sector. So, let us see today what we will do to this residential and commercial sector. So, first of all we will look into the introduction basic things like, what are the residential sectors, what are the commercial sectors and what kind of emissions are important from perspective of residential sector and commercial sector in India.

Then the basic equations, because when we are talking about calculation of emissions, we are talking about certain equations, certain mathematical relationships and the procedures or methodology for estimating the emissions for residential sector or commercial sector. Then to understand the thing, we will go for case study for India based case study and then mega city Delhi based case study and then we will conclude.

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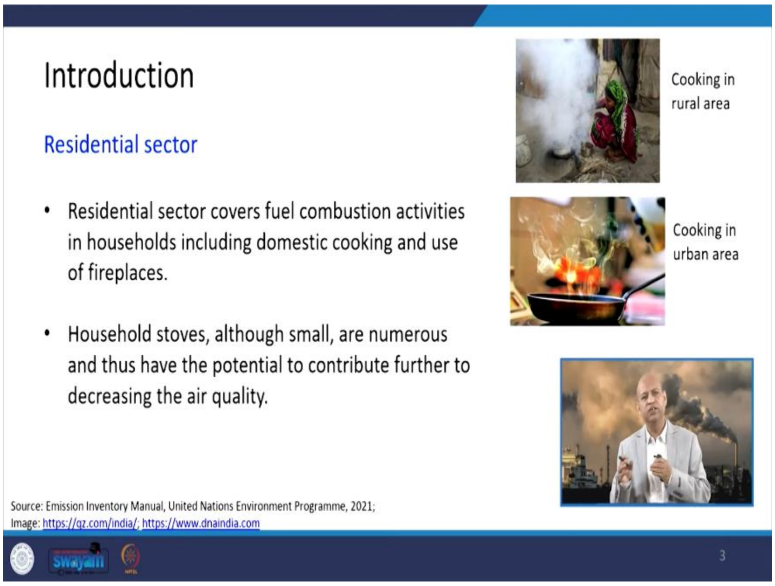

So, when we talk about like residential sector basically, this covers like fuel combustion in different activities of domestic nature, household nature like cooking or using fireplaces, whatever we burn for our domestic activities, we call it in residential sector and like household stoves, whether it is using LPG or cow dung different kinds of stoves are there depending upon the economic background of the household or the family.

So, whether it is a small, or a large household stoves, where it is multiplied in millions of numbers when we talk about a country, so the emission becomes very significant. Otherwise, first impression we feel that what is that is very small emission from a household activity, but when we combine it at the city level or state level or country level, then this becomes very large amount of emissions of air pollutants and greenhouse gases.

So, their contribution is very important, when we talk about ambient air quality, because these emissions ultimately deteriorate the ambient air quality, also the indoor air quality, because the kitchen or those kind of household activities, first of all, they deteriorate the indoor air quality.

Then if there is a chimney or exhaust fan etc, then it goes to the outside means in ambient environment and they again affect the ambient air quality.

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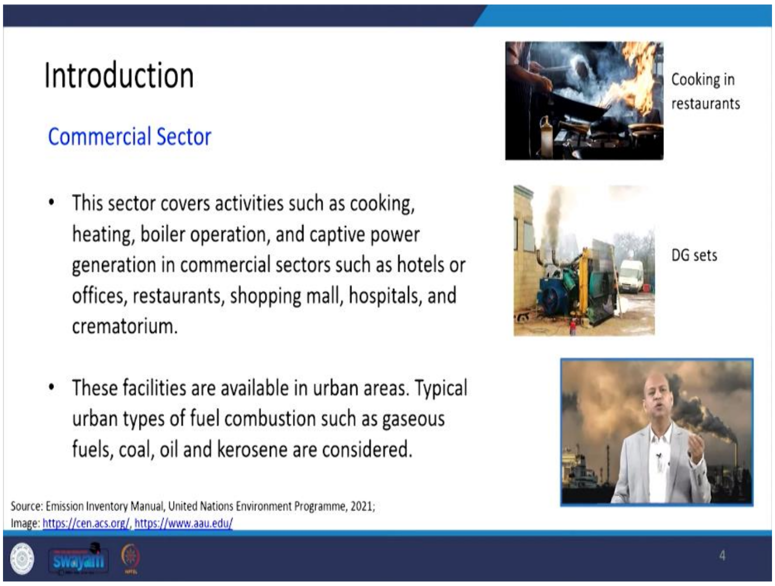

When we talk about commercial sector, then basically it covers like cooking, heating, boiler operations, captive power generation in commercial sectors, like hotels, restaurants, offices, shopping malls, hospitals, crematorium, all those kinds of activities are into this commercial sector.

Then these facilities are basically available in urban areas and typical urban types of fuel combustion such as gaseous fuels or coal, oil or kerosene are considered when we consider or when we compute the emissions from the commercial sector and in rural areas basically, household related activities are more important otherwise, in between rural and urban areas there are other activities of commercial nature like marriage gardens and resorts etc. They are also responsible for emissions of pollutants and greenhouse gases.

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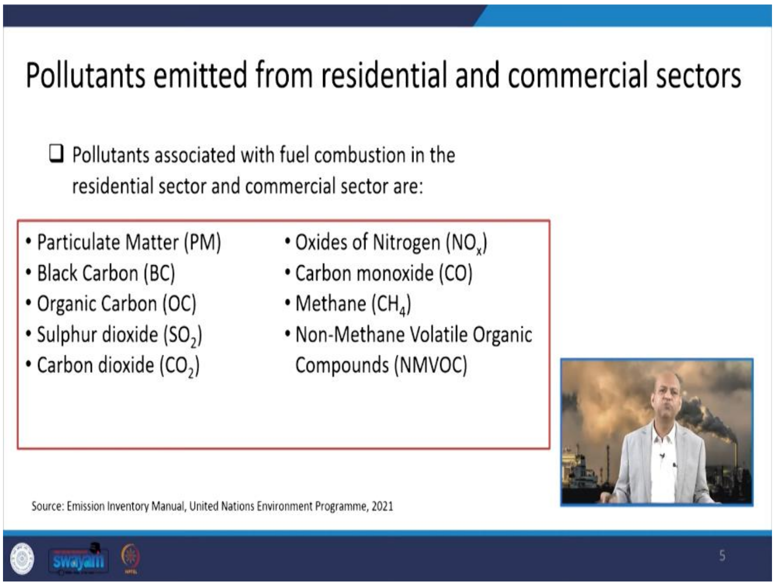

When we talk about pollutants, which are emitted from especially residential sector and commercial sector, then the major pollutants are like particulate matter, then black carbon organic carbon, sulphur dioxide or carbon dioxide, carbon monoxide or oxides of nitrogen, then methane or known methane volatile organic compounds or hydrocarbons, all these are the pollutants, which are emitted from both the sectors of residential and commercial.

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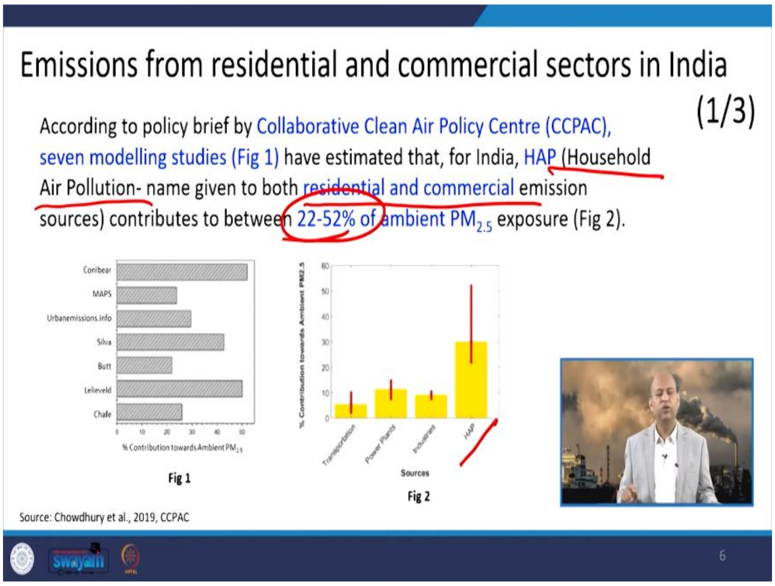

Well, if we try to have a visual kind of scenario at India level, so there are one steady report policy report brief policy report and this was developed by Collaborative Clean Air Policy Centre (CCPAC) in Delhi. So, the seven modelling studies were compiled and their data and their range of emissions were assessed and it was known that these residential and commercial sector in total both these sectors are responsible for 22 to 52 percent of ambient $PM_{2.5}$ exposure to the public.

So, this is a very significant range or the proportion, if you look into $PM_{2.5}$, because $PM_{2.5}$ exposure is responsible for several respiratory problems to the people. So, health impacts are very important in that respect. So, you can see here these HAP means household air pollution. So, these are basically combining residential and commercial activities according to the definition. So, they are responsible for 22 to 52 percent of ambient $PM_{2.5}$ emissions or exposure. So, that is very high range.

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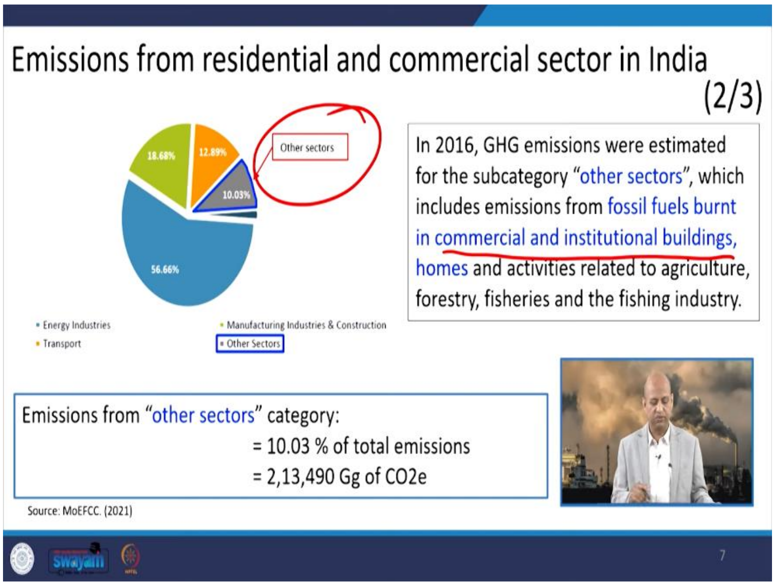

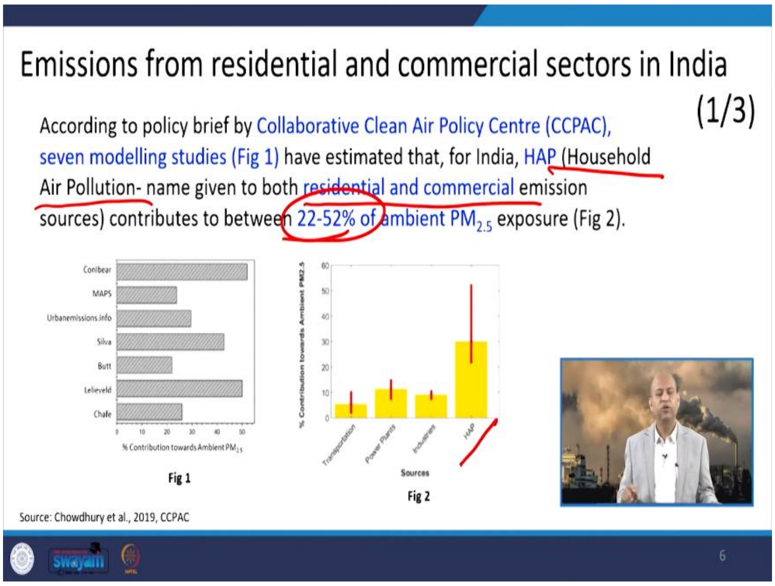

Then when we talk about this emissions for these residential and commercial sector or household activities, these household air pollution, so when we divide it into like other sectors or energy industries and then manufacturing industries, so the other sector which is basically this commercial and institutional buildings related, which we are talking today about, so that contributes around 10 percent.

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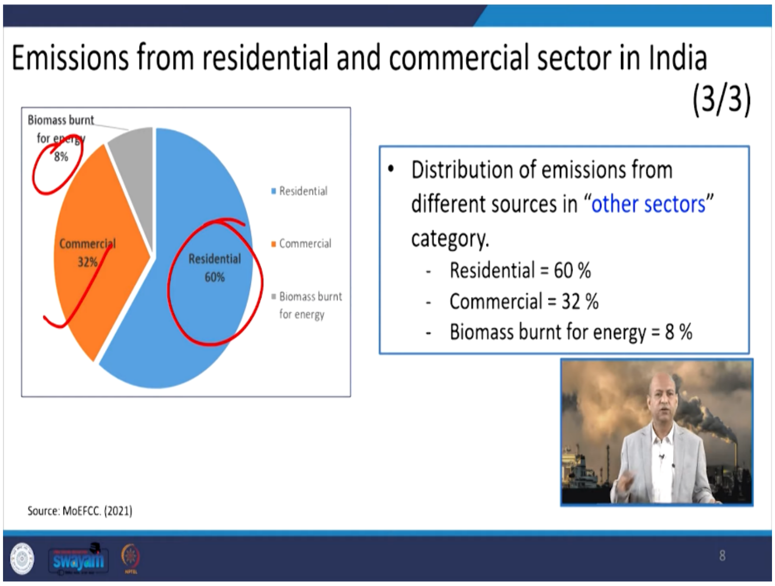

And within that 10 percent basically, if you further divide into sub sectors, so the commercial is responsible around 32 percent and the residential is around 60 percent. So, the residential is dominating in this particular other sub sector you can say and then biomass burnt is around 8 percent. So, that way the three major components are of that basically household related emissions.

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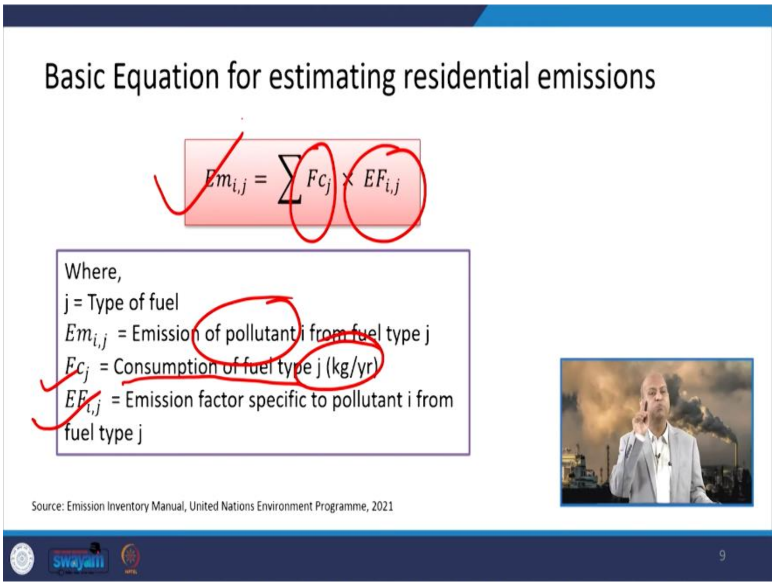

Well, then, we come to the basic equations, which are used for estimating residential emissions. So, as I said, the fuel consumption we have to estimate first, so we need to know, what is the activity, which is causing the fuel consumption? So, according to that activity, we need to first compute the fuel consumption. So, FC is nothing but fuel consumption for the type j, fuel type j like LPG, then biomass or kerosene or whatever you take one particular fuel and see different activities which are using that particular fuel and how much of that fuel is consumed.

$$Em_{i,j} = \sum Fc_j \times EF_{i,j}$$

So, that will be the FCj, then from that particular type of fuel j, then we have to see how much pollutant type of i is emitted. So, different pollutants emissions we need to calculate. So, that emission factor has to be there for that particular emission of pollutants, that particular pollutant. So, that will give this total multiplication will give the emission of that particular pollutant i from the particular fuel j, that is the point and then if you go for, for different fuels, then combine you can get the total emissions. So, this is the basic thing which we will see in all kinds of activities.

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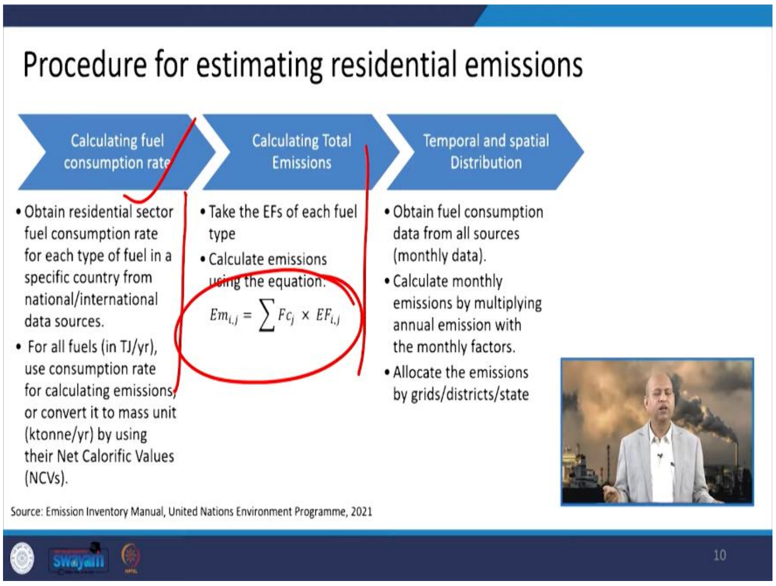

So, you can see the procedure of estimating residential emissions. Basically, first of all you have to calculate the fuel consumption rate. So, you have to see different activities, how much that fuel is consumed per day or per month or per year you can take the unit whatever you want to have the time span.

Then the total emissions are calculated by that particular equation, which we have seen and the temporal and spatial distribution can also be seen like weekly or monthly or daily, that depends means you can really play with that, that is not a very complex thing, once you calculate, annual emissions or hourly or daily whatever, you can further scale it up in different kind of time span.

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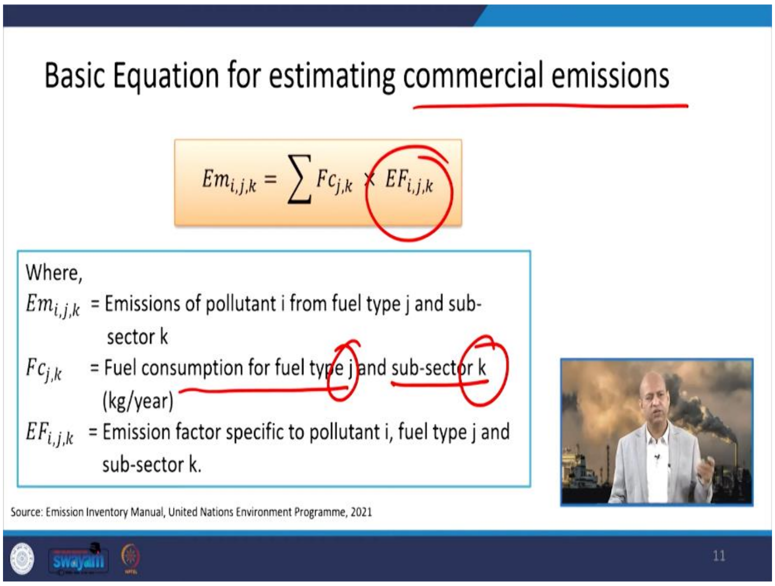

Well, when we talk about the commercial emissions, again similar equation is there. So, here you can see the fuel consumption from sub sector k. So, in commercial, when we have sub sectors in that particular sub sector what kind of fuel is there? The fuel type j in sub sector k, so different sub sectors are there different fuel types out there.

$$Em_{i,j,k} = \sum Fc_{j,k} \times EF_{i,j,k}$$

So, for each fuel type or each fuel sub sector you have to compute and for that you have to know this emission factor. Multiply it have the submission for the particular sub sector for that particular fuel for that particular pollutant and replicate it for each kind of sub sector for each kind of fuel for each kind of pollutant.

So, that will be very exhaustive exercise, but nowadays in the age of computer it is very easy even you can use a spreadsheet or there are certain models also readymade models, you can write simple, code or logarithmic equations and then you can compute these emissions.

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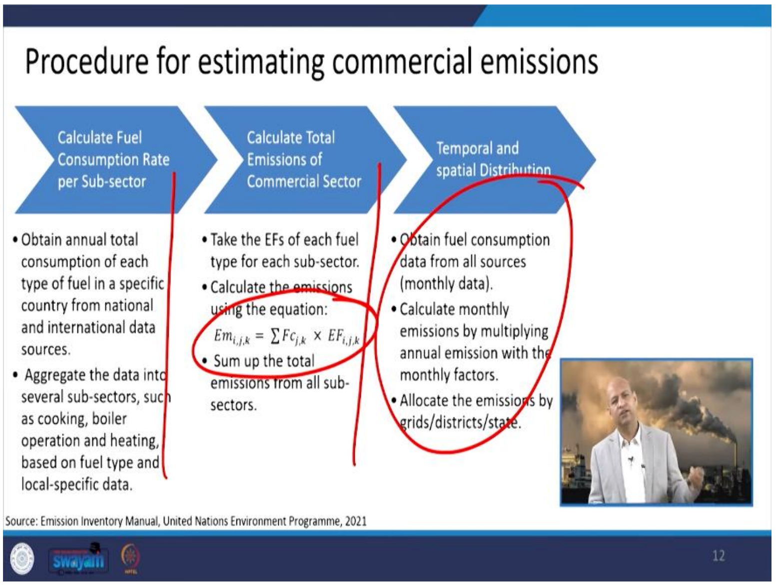

Well again the same procedure first of all, for sub sector based fuel consumption of the particular fuel type and then calculate the total fuel consumption of that particular subcategory and fuel type and emissions of the pollutant and then you can distribute it into according to the desired time span, whether weekly or monthly.

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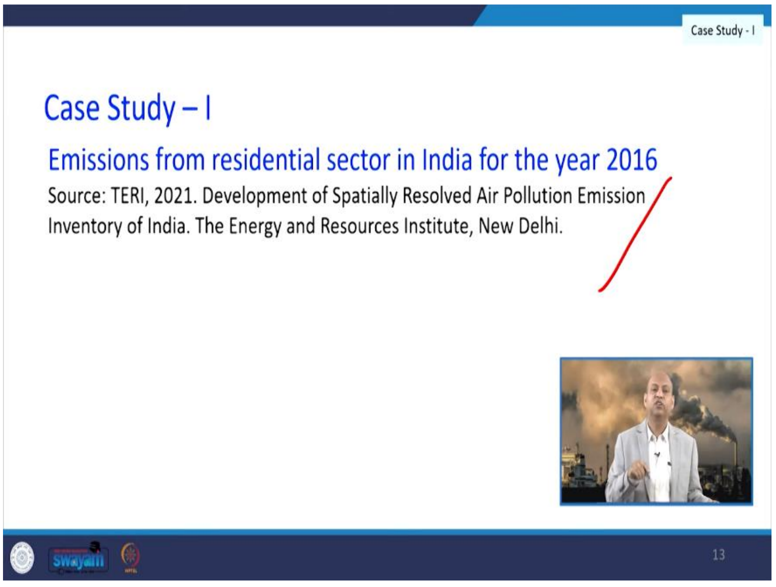

So, to understand it in a better way, let us go for the case studies. First case study, we will focus upon India level case study. So, this we have taken from one TERI's report, which is the development of a spatially resolved air pollution emission inventory of India, that was developed by TERI. So, this is the report of 2021 it was published. So, we are using our only domestic or residential sector we are focusing, otherwise this report contains all kinds of sectors, but in this case study we will focus only on residential sector.

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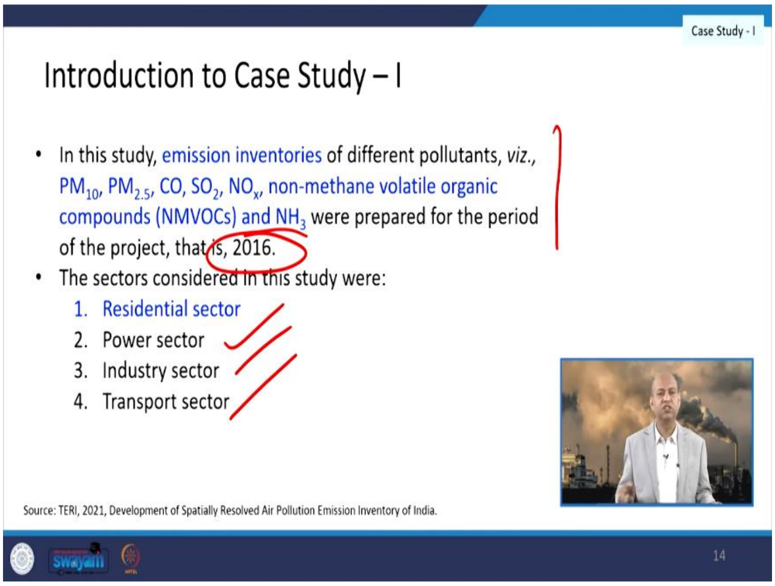

So, you as it is shown residential sector, power sector, industry sector, transport sector, all these sectors are there and these are the different pollutants, which have been considered in this study, like PM_{10}, $PM_{2.5}$ carbon monoxide, sulphur dioxide, nitrogen dioxide or oxides of nitrogen, non-methane volatile organic compounds that is NMVOC, ammonia, all these are there. And this is for 2016, this was the year for that this computation was done in this study.

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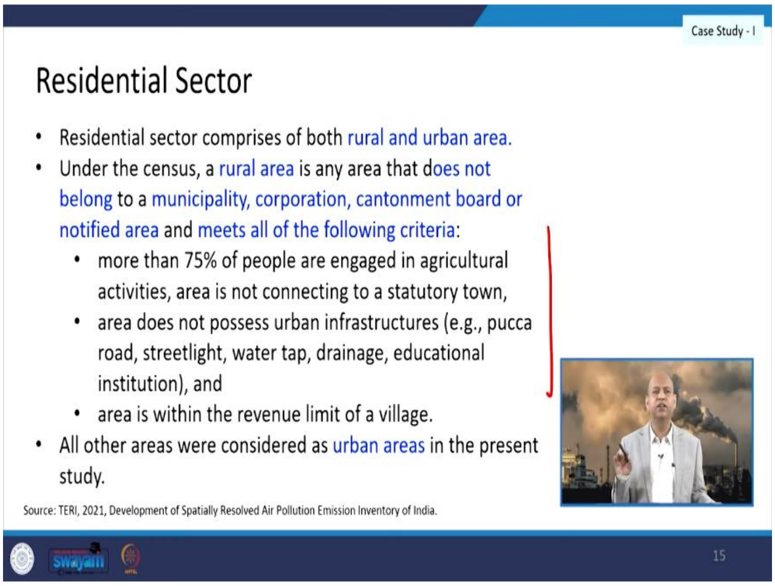

So, in the residential sector basically they have taken both rural and urban area. It is not only the rural but urban also. So, because residential sector is both ways, but only the fuel type differs in rural area and urban area. In urban area you will find that LPG those kind of cleaner fuels are used in much more quantity, whereas in rural areas you will find that agriculture waste, cow dung or fuel wood, all those kinds of fuels are still being used, although nowadays there are several schemes from the government side they are pushing towards the clean energy ladder, household activity they are providing through Ujwala scheme these LPG connections.

So, better situation is coming, but for 2016, we have different data, where we are we have this agriculture activities related waste etc, which people are burning and when we talk about the rural and urban what is the difference. So, these are the basic fundamental yardsticks, which are used for judging, whether it is rural area or urban area.

So, in the rural area, they assume that more than 75 percent people are engaged in agricultural activities. And this area is not connecting to a very this municipality or township related kind of things and those amenities urban amenities are not available. So, that kind of rural related definition is there.

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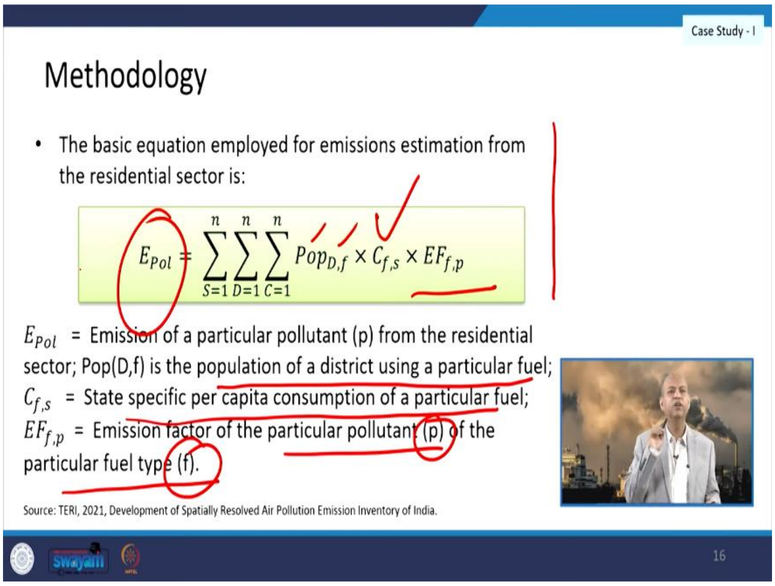

Then we go for again basic equation. So, this is like population, which is in a district using particular fuel F, so the population which is using in that district, how much population is there, then this CFS state is specific per capita consumption of that particular fuel, that data we should have then emission factor related to that particular fuel type must be there, particular fuel type F and particular pollutant p. For each pollutant different emission factor is there.

$$E_{Pol} = \sum_{S=1}^{n}\sum_{D=1}^{n}\sum_{C=1}^{n} Pop_{D,f} \times C_{f,s} \times EF_{f,p}$$

So, for each pollutant for each type of fuel, we reuse this equation and then we sum it up for all the districts for all the fuels or for all the pollutants different pollutants means, you will have the metrics for different pollutants PM_{10} is emitted so much, SO_2 is emitted so much, those kinds of things. So, this is the emission of that particular pollutant. So, this is the equation which we use.

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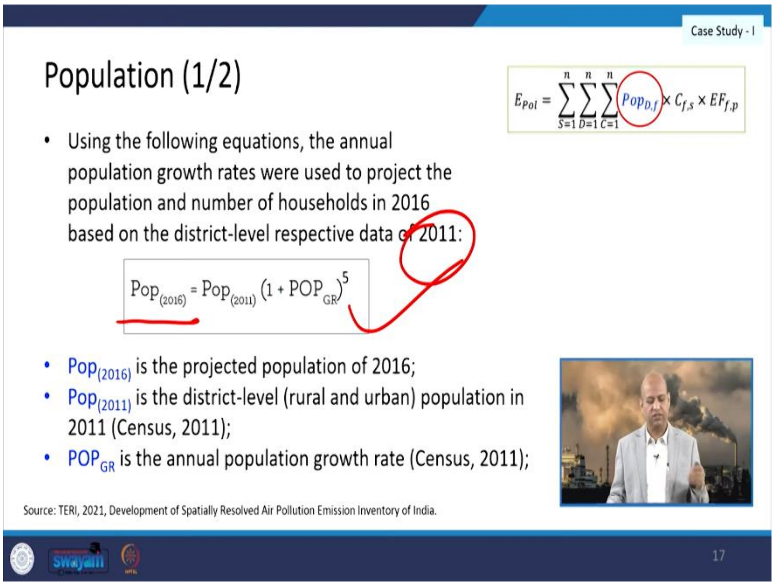

And the population data here is very important in the sense, because there are certain data which are indirectly calculated for example household, how many household activities are there. So, that is again calculated based on certain relationships like here population of 2016 was estimated based on the population census data of the population of 2011, that was the data available. So, for 2016 it was estimated. So, this is the relationship, which was used for you can say projection of the population for 2016.So, this relationship was used.

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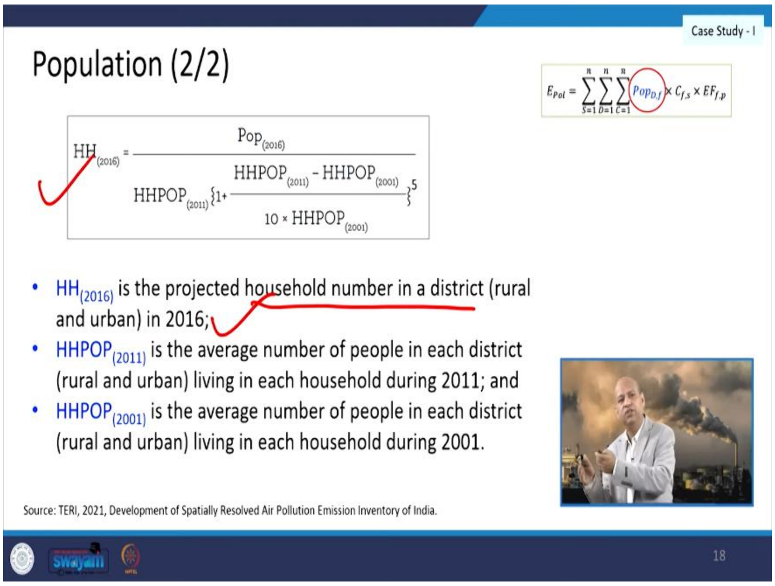

So, that way you can see this household activities also how many these household in 2016 projected household number in district level, rural and urban in 2016. So, this relationship was used. So, again for 2011 data is there we are projecting to 2016.

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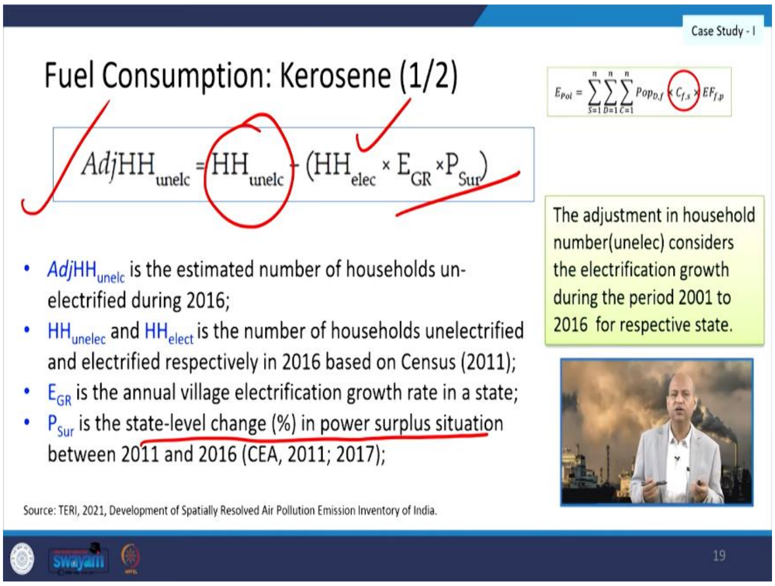

And in this we have to be careful like for example, we want to know how much households are there, which are un-electrified, which are using fuel wood etc. So, for that again the direct computation is like you are estimating based on that 2011 data, un-electrified and then electrified also, but there is the growth rate according to population this is state level change in power surplus those kind of things. So, that data is subtracted to have the adjusted household un-electrified number, that correction factor is there you can say otherwise that projection will be a little bit erroneous.

So, this relationship is used for computing the net household numbers, which are un-electrified, because they will be used for estimating pollution from fuel wood etc, because kerosene etc. If there is no like electricity for having energy, meeting the energy needs, then people will have the energy from fuel wood or those kinds of sources.

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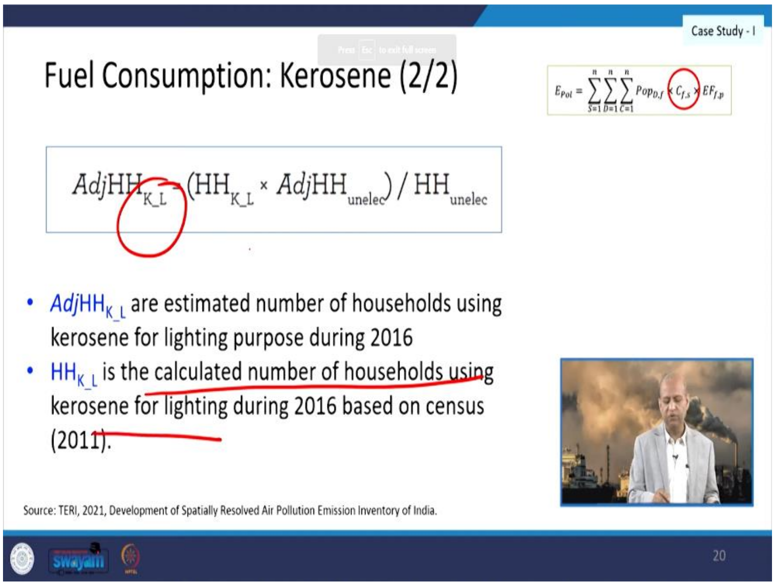

Similarly, this kerosene related consumption, calculated number of households using kerosene. So, the same way you have to calculate the adjusted household numbers.

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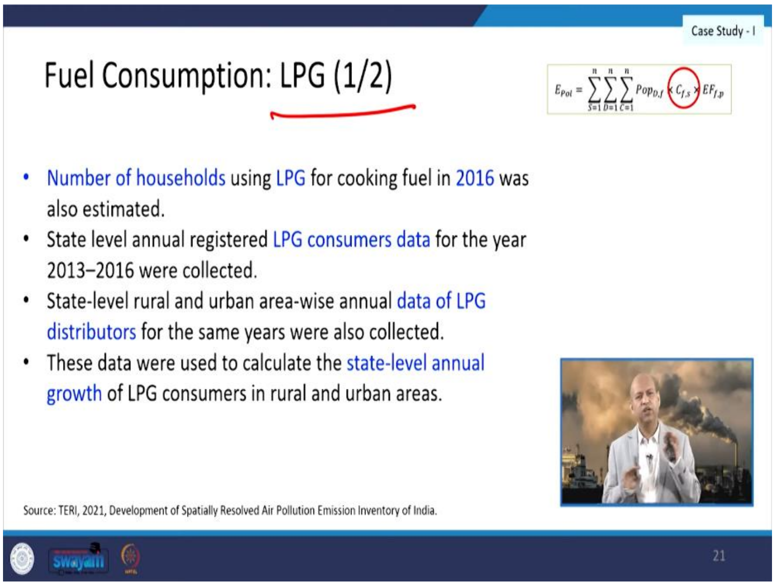

So, the fuel consumption for LPG again, so numbers are there for different years and you have to compute or project for 2016. So, based on the data available from the secondary literature, you have to compute you have to estimate, it is very, very difficult to get the absolute data. So, it is only the exercise, which is estimating, so there is always some uncertainty, but nevertheless, we are going for baseline data or that data which are available based on certain surveys and those are only the things, which we can use for estimation purposes.

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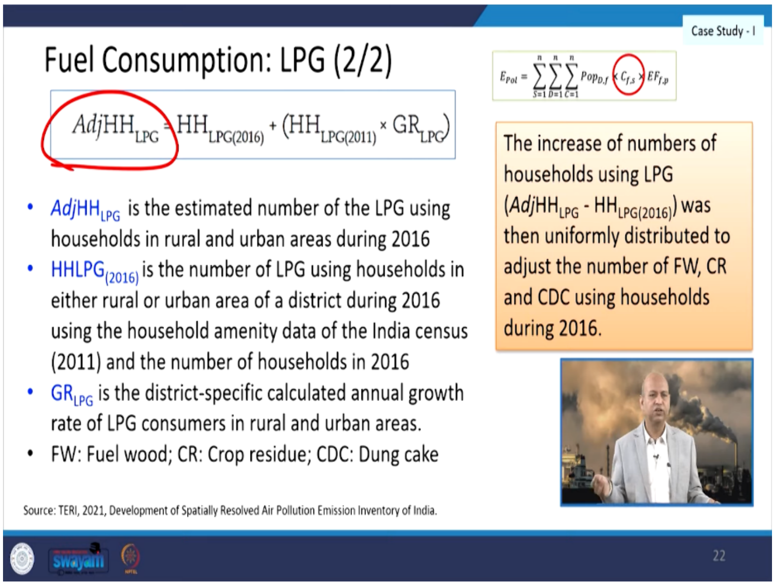

So, the fuel consumption again LPG adjusted. So, the similar equation relationship are used for correction factor based on 2011 data, then projection of 2016 and those growth rates etc.

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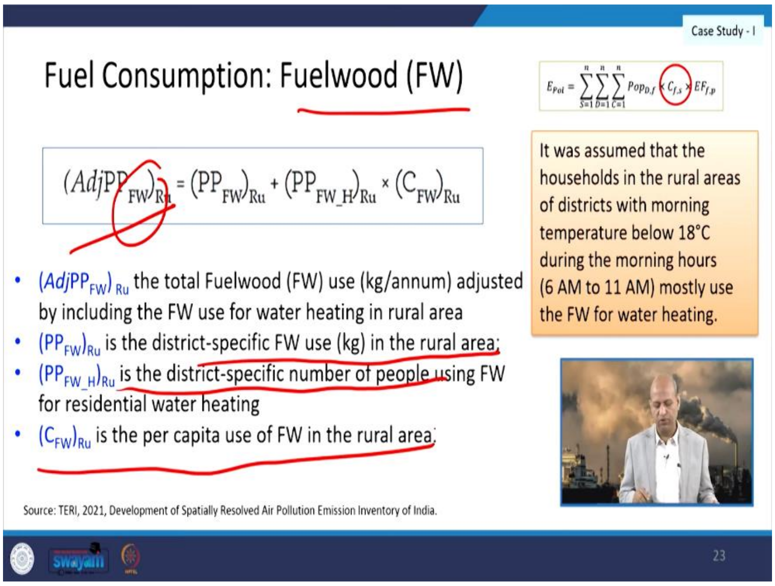

Well, similarly, fuel wood also you can have this adjusted population of the house fuel wood related consumption. So, you can see this district specific fuel wood in rural areas, and PP_{FW}, H, rural areas district a specific number of the people using fuel wood, so those kinds of there, then C_{FW} is the per capita use of fuel wood in rural area. So, all these parameters must be there which are available from different survey different reports which we use.

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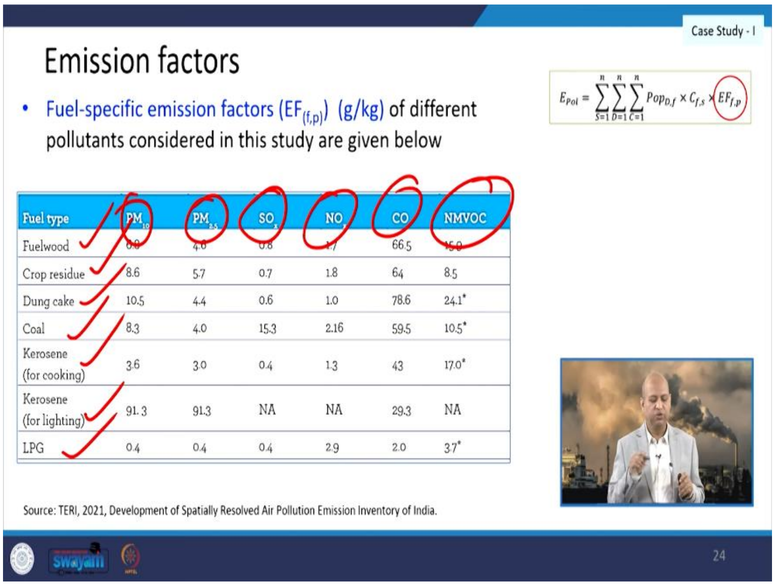

Then emission factors, what kind of emission factors? So, again they are available from different studies, which people publish the have certain lab based experiments as well as field based experiments and they bring out the numbers, that how much a gram of that particular pollutant is emitted, when we burn one kg of the fuel. Fuel can be different like fuel would crop residue, dung cake, coal, kerosene, for cooking kerosene for this lighting, LPG. So, all these fuel and activities are there.

So, for per kg of fuel burned, how much pollutant of PM_{10} or $PM_{2.5}$, SO_x, NO_x, CO, NMVOC, how much it is emitted per kg. So, that is known as the emission factor. You can see all these values are given in this table, that is are those are the emission factors for each fuel type for each pollutant type. So, these are the grams per kg, that is the unit which we will use in those equations for calculation of emissions.

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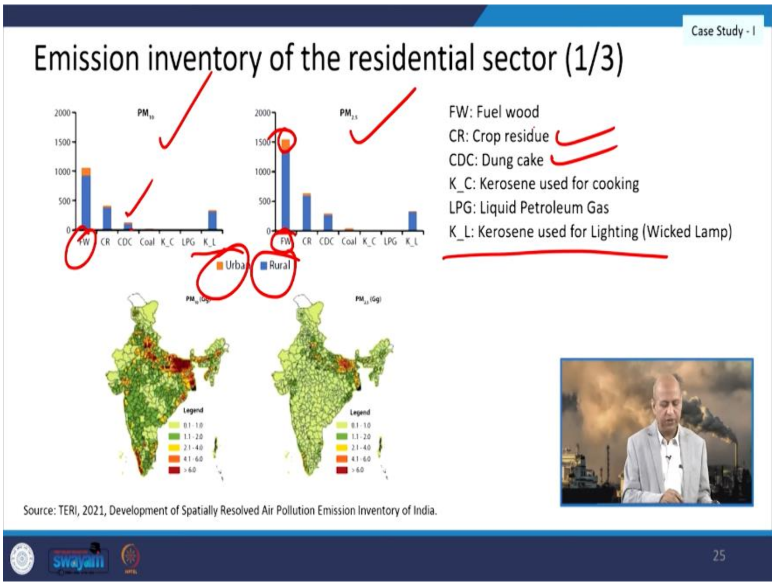

When we see this emission inventory for residential sector and compare, like for PM_{10}, $PM_{2.5}$, then you can see these are the fuel wood, FW, fuel wood related emissions are more in comparison to other fuel types like CR is crop residue, the second number is crop residue. CDC is dung cake. So, the dung cake is the third one, then kerosene for lighting can say third one and this is the fourth one CDC, but there is also you can see different colour blue and this orange or yellow. So, that is the for urban, urban-related and this blue is for rural.

So, always these emissions from fuel wood emissions of PM_{10} and $PM_{2.5}$ are more in case of rural areas in comparison to the urban areas, when we are talking about residential sector, please focus upon we are not talking about industrial sector or other otherwise things will change.

So, the fuelwood consumption in residential sector in rural areas is emitting more PM_{10} $PM_{2.5}$. Then this crop residue and kerosene for lighting purpose they are also responsible. When we talk about SO_x and NO_x, then again situation is same fuel wood is more responsible. For NO_x is emitted very high. Again, you can see like here SO_x is not so much you can see these values.

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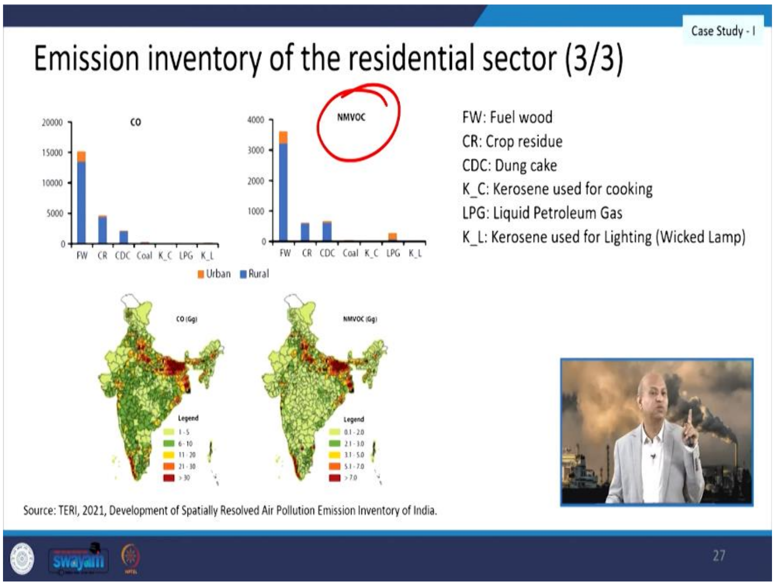

Then when we talk about CO, the CO from fuel wood and NMVOCs are also from fuel wood are very high. So, that means if we can shift the population from fuel hood to better clean fuels like LPG etc, then these emissions can be reduced, although NO_x emissions may not be reduced, because whenever we go for efficient burning, NO_x emissions also increase, that is very tricky thing, but at least a CO emissions can be significantly reduced and other emissions can also be reduced.

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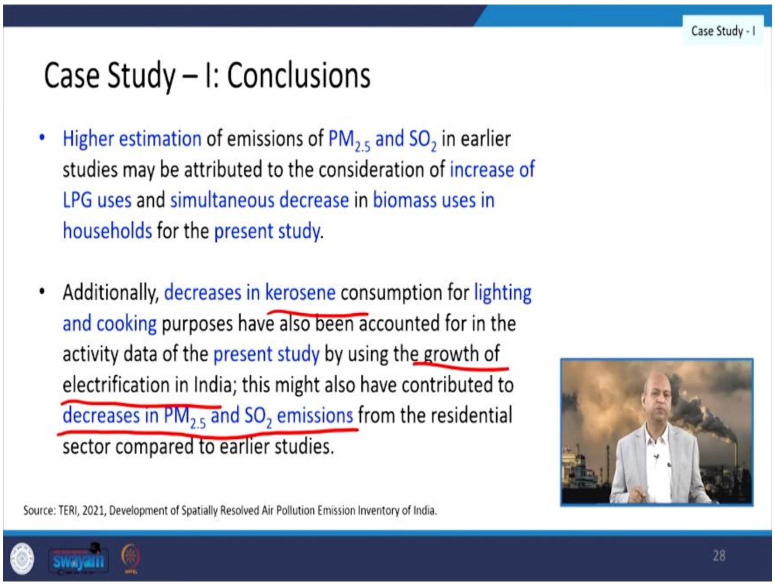

So, the conclusion in the case study first we can say that the higher estimations of emissions of $PM_{2.5}$ and sulphur dioxide in earlier studies may be attributed to the consideration of increase of LPG uses and simultaneous decrease in biomass uses. So, means increase of $PM_{2.5}$ and SO_2

may be there, but decrease may be there in CO, if we compare. So, you can see here decrease in kerosene consumption in lighting and cooking.

And then this is responsible for increasing growth in electrification, they are responsible for decrease in $PM_{2.5}$ And SO_2 emissions. So, those kind of inferences, we can make from these kind of studies.

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Now, we come to the second study, case study that is focused on mega city Delhi. So, this has been taken from one paper, which is emissions from domestic sector means this paper is basically for all kinds of emission estimations from 1990 to 2004 mega city Delhi, but we have taken only domestic sector municipal solid waste and wastewater treatment related emissions for the mega city Delhi. So, that we will present here.

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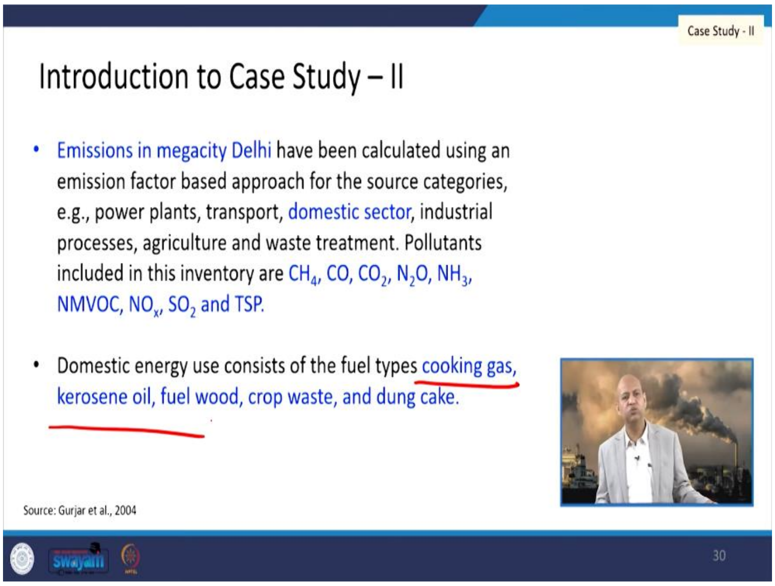

So, you can see this mega city Delhi is responsible for any urban area is responsible for several kind of emissions from several sectors, whether it is power or transport, domestic, industrial all those, but we are considering only domestic and those sectors like municipal solid waste burning and this wastewater treatment those kind of emissions we are focusing in this is study. And you can see in domestic also we have considered only the cooking gas, kerosene oil, fuel wood, crop waste and dung cake.

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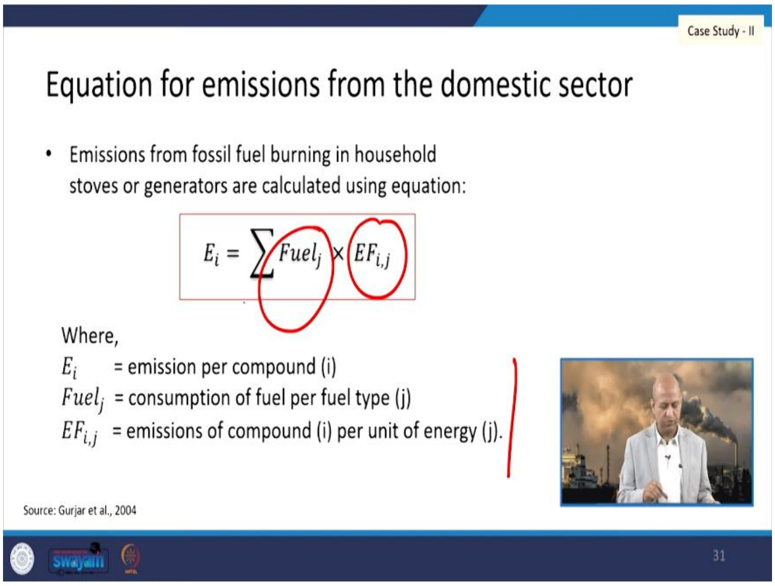

And this basic equation is the same as I said earlier like fuel how much fuel is consumed of j type and from that j type fuel how much emission of i type pollutant is there, that is the emission factor. We multiply them we get the emission of that i pollutant and then we go on doing this exercise repeating this exercise for all other pollutants. So, you can see this is the equation, which we are using very simple equation.

$$E_i = \sum Fuel_j \times EF_{i,j}$$

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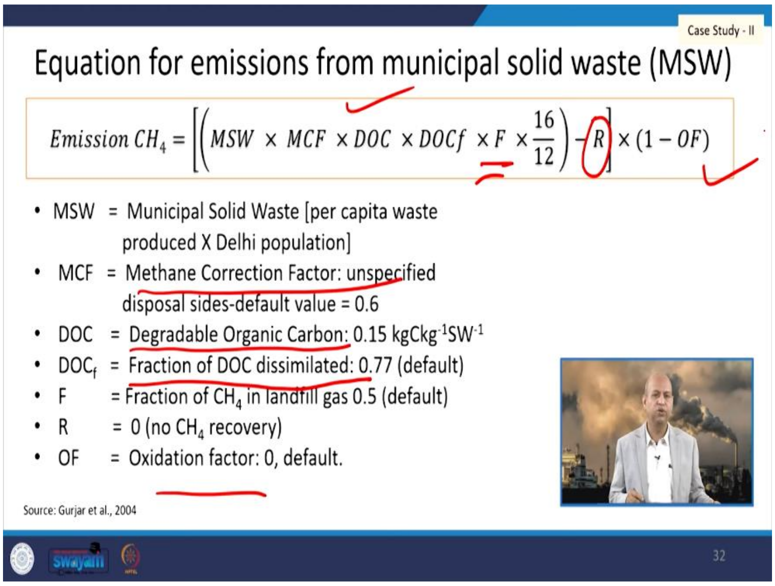

For municipal solid waste burning this is the particular equation, where we are applying certain factors like methane correction factor MCF is there. Then degradable organic carbon DOC, DOCF fraction of DOC, dissimilated like 0.77 default we have taken. Fraction of methane in landfill gas F is there. R here in particular case, we have taken only 0, because we are not recovering any methane. Then oxidation factor default is 0. So, this is the general equation which we use for emission of methane from municipal solid waste, municipal solid waste.

$$Emission\ CH_4 = \left[\left(MSW\ \times\ MCF\ \times DOC\ \times DOCf\ \times F\ \times \frac{16}{12}\right) - R\right] \times (1 - OF)$$

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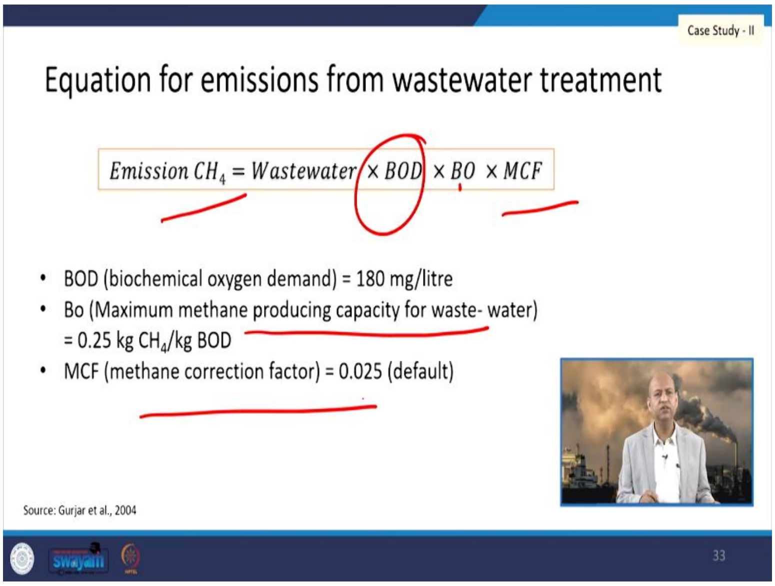

Similarly, from wastewater treatment, if we are going for anaerobic treatment, this methane generation is there. So, we have to consider what is the BOD, and what is the maximum this methane producing capacity of the wastewater that is BO, and MCF of methane correction factor again there are correction factors depending upon different parameters or variables, but the default value we are using is at 0.025.

$$Emission\ CH_4 = Wastewater\ \times BOD\ \times BO\ \times MCF$$

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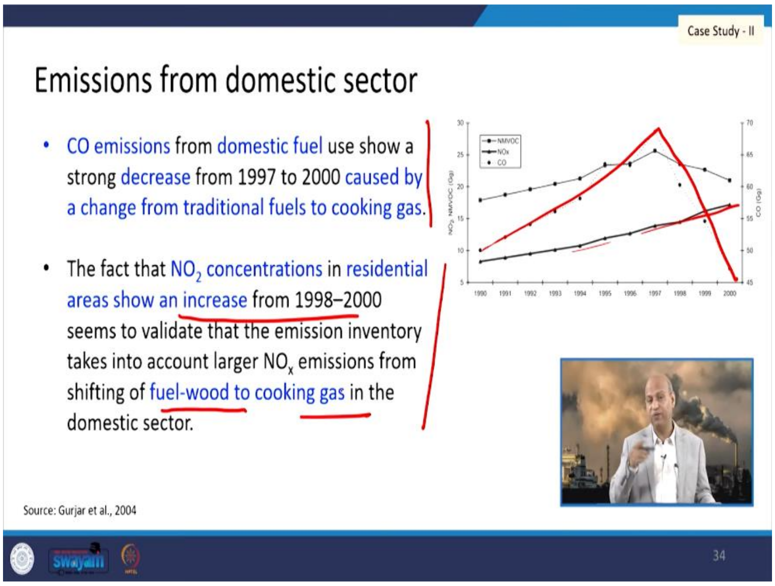

Well, so, the emissions from domestic sector, when we see these emissions are there and the CO emissions this is increasing and then decreasing from 1997 up to 2000, otherwise you can see this NOx emission is increasing continuously. NMVOC is also decreasing from 1997 to 2000, but drastic change is there in CO and that basically is related to the decrease in CO emissions is basically change in the traditional fuels to cooking gas. So, as I said because when efficient burning occurs in good stoves of the LPG, CO is very less, because directly CO_2 is emitted more instead of CO.

Whereas in fuel wood etc. the combustion is not a complete and this incomplete combustion is responsible for higher emissions of CO, but in when we go for LPG etc, or cooking gas, then CO becomes less comparatively.

Similarly, this NO_2 concentration in residential area is showing an increase you can see here and that is because as I said these when we go for from fuel wood to cooking gas, so efficient burning, so nitrogen is present in air. So, whenever this oxidation happens in an efficient way, then NO_x emissions automatically increases and we have to control it, otherwise these NOx emissions may be responsible for ozone production, because of photosynthesis reactions if sunlight is more. So, those things we have to keep in mind when we are considering different kinds of emissions.

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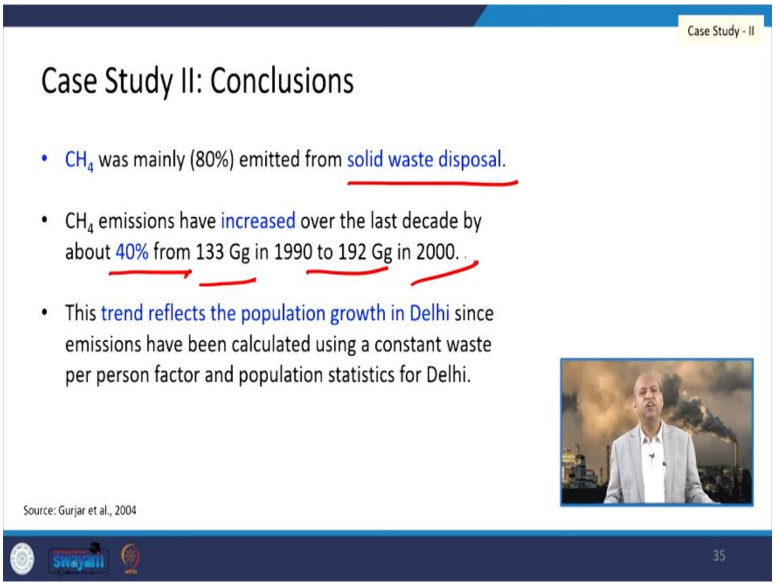

In this case study, we can see that the methane was mainly in 80 percent of the methane emitted in Delhi was from the solid waste disposal kind of activity and this has increased over the last decade by about 40 percent from 133 Giga gram in 1990 to 192 in 2000 and the trend reflect the population growth in Delhi, because many people come here and different activities are increased and the waste generation is also increased accordingly. So, that is why these kinds of emissions are also increasing.

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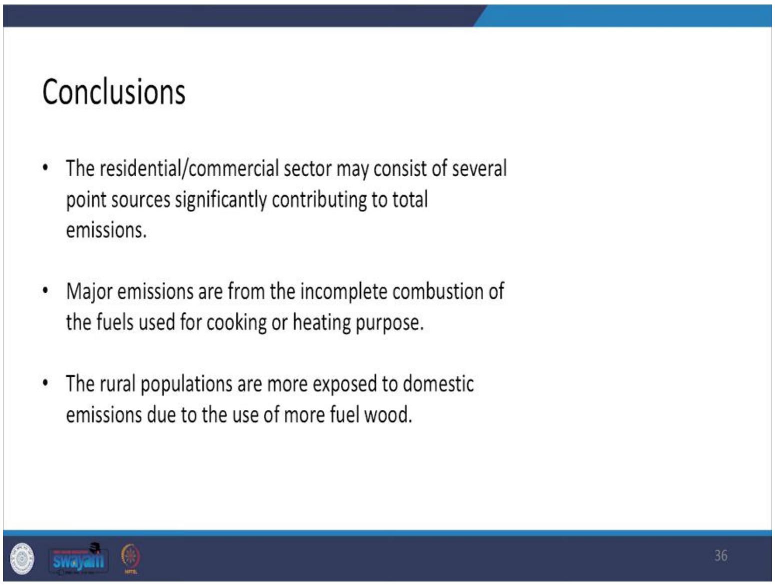

So, in overall we can say that, the residential and commercial sectors may consist of several point sources significantly contributing to total emissions of different kinds of pollutants. And the major emissions from incomplete combustion of the fuels used for cooking or heating purposes like CO etc, maybe there and the rural population are more exposed to different kinds of emissions, because they are using fuel wood and agriculture waste etc, cow dung, and highly emitting fuels you can say, so indoor air quality is poor and they are exposed to high concentrations of pollutants.

And it is a good thing that like Indian government is now pushing through different policies and programs, the cleaner fuels to poor people, so that they are not exposed to these high concentration of pollutants.

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Well, these are the references for additional information. So, thank you for your kind attention and see you in the next lecture. Thanks again.