Air Pollution and Control
Lecture 21
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Transport Emission Inventory

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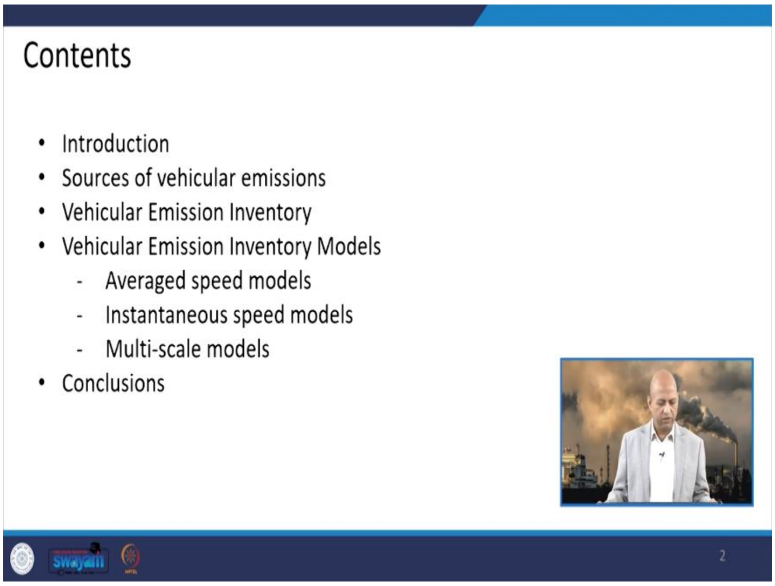

Hello friends. So, you may recall last time we discussed about introduction to emission inventory. So, how to develop emission inventory, what is the significance of emission inventory, as we know, we need the emission inventory for the air pollution modelling, air quality modelling or to discuss or to review various policy measures, which have been implemented, whether their impact has been positive or negative, all those kinds of things can be studied based on emission inventory.

So, now emission inventory can be developed for any kind of sector. When we want to have emission inventory for an urban area, then we have to get emissions or we have to estimate emissions for every kind of sector, whether it is domestic sector, transport sector, or industrial sector, or waste burning, or whatever activity you can imagine all those activities which are emitting one or other kind of air pollutant, we have to estimate it. So, that is the part of emission inventory development.

So, when we talk about transport emission inventory, basically, we need to know what kind of different models are there which can be used for development of emission inventory for the transportation sector and what are their basic requirements, what are the input values the need for estimating the emissions all those kinds of things we will see.

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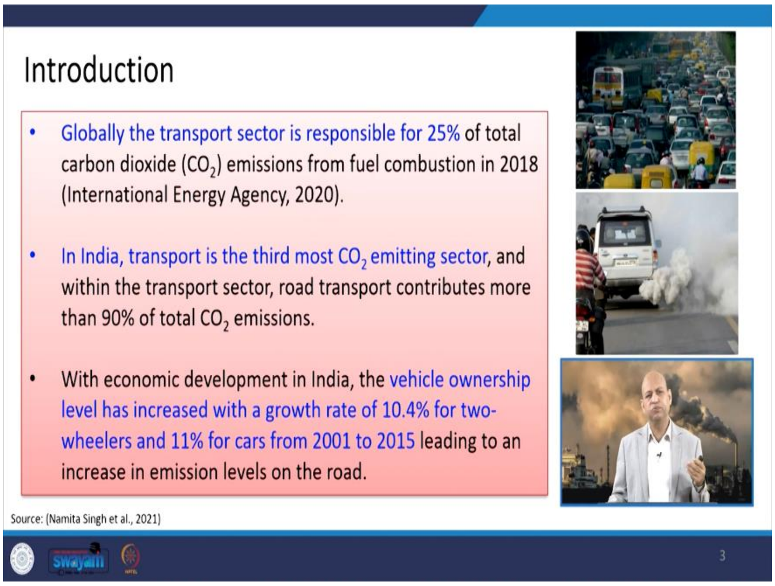

So, when we go for introduction of this transport sector-based emission inventory, then we need to know why it is so important. As the globally, at the global level the transport sector is responsible for around 25 percent of total carbon dioxide emissions, which is very predominant greenhouse gas as we know. From the fuel combustion in 2018 International Energy Agency (IEA) estimated and they publish this particular figure. In Indian context if you want to see the significance of transportation sector, then basically this transport activity is the third most CO_2 emitting sector.

And within the transport sector road transport contributes more than 90 percent of the total CO_2 emissions, that is the greenhouse gas emissions and when we compare with the economic development in India, the vehicle ownership is growing, the level has increased of the vehicle ownership with a growth rate of around 10 percent for two wheelers and more than 11 percent for cars within the 2001 to 2015. So, this has led to increased levels of emissions, congestion, energy consumption, all those kinds of those activities, which are responsible for more emissions.

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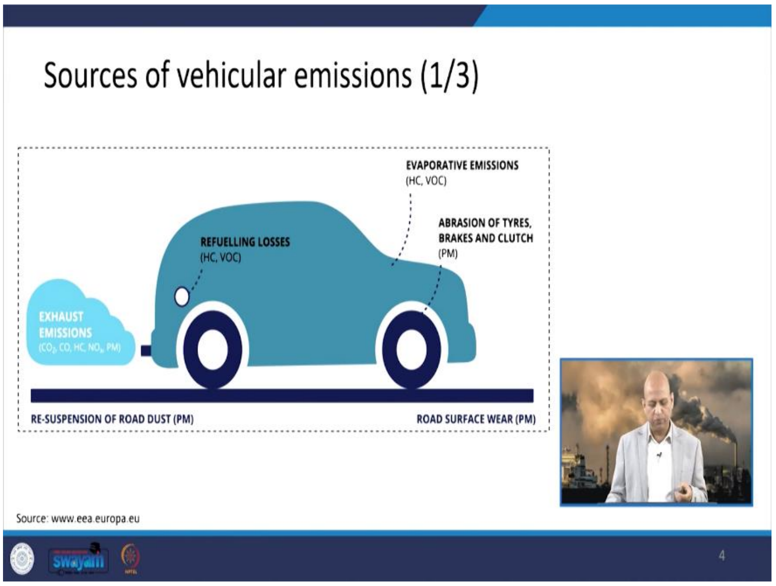

So, if we talk about the emissions from vehicle categories, different kinds of vehicle categories or road transportation basically, otherwise transport sector can be like even air ships or ships or these waterways related container moving those boats or other kind of transportation modes, all our transportation sector related emissions.

But for an example, for a sample if you talk about road transportation vehicles, then if we categorize those emissions from vehicular emission sources, then basically like exhaust emissions are there from tail pipe you know that. You go for the, that air pollution control certificate when you go for that agency which measures from the tailpipe emissions. Then there may be some emissions from like friction with the tire with the road.

So, those kinds of non-exhaust emissions can also be there, resuspension of dust when vehicle is moving or when we are applying brakes, then some sort of emissions can be there. Other kinds of emissions could be evaporative emissions, like from engine some oil is leaking. When you are filling the tank with the fuel at the petrol pump, then again some these emissions are also there or VOC's etc. Those kinds of operative emissions can be there. So, basically three, four, type of emissions are there, exhaust tailpipe emissions, non-exhaust emissions from tires, brakes, etc, and evaporative emissions.

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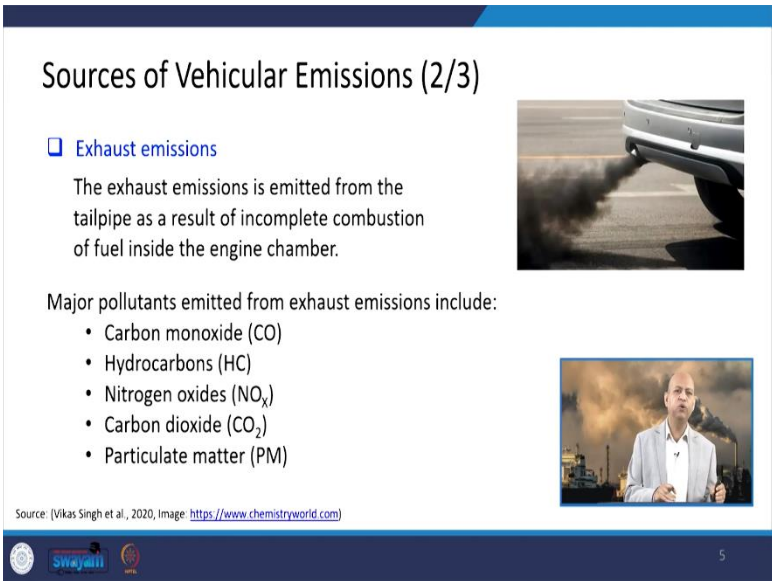

Well, so when we talk about exhaust emissions, then the predominant those pollutants are like carbon monoxide, or oxides of nitrogen, then CO_2 is of course any kind of burning activity, fuel burning activity, ultimately CO_2 is there, because we are burning some sort of hydrocarbons. Then particulate matter is also there, then particulate matter can be like carbonaceous elemental there are many variety of particulate materials and size also, but overall we can say that particulate matter emission can be from exhaust emissions.

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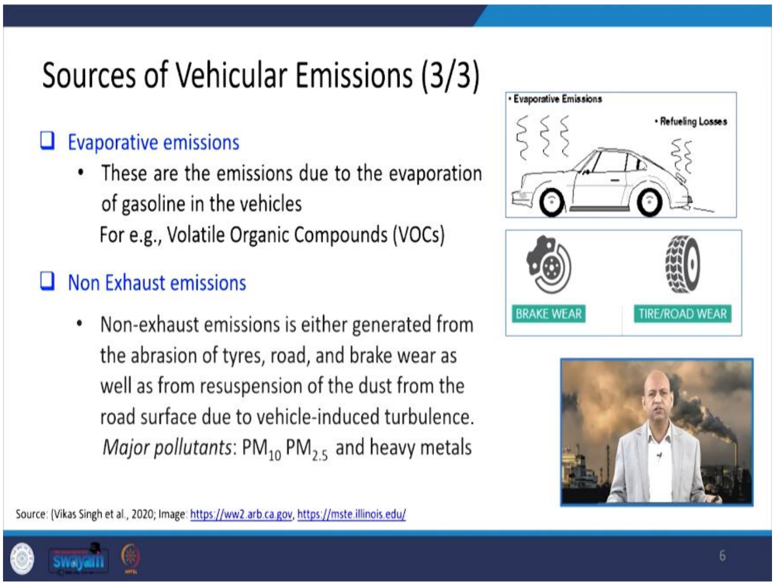

Well, when we talk about operative emissions, then basically mostly volatile organic compounds those hydrocarbons, they get emitted from fuel leakage etc. Non-exhaust emissions as I said like these PM_{10}, $PM_{2.5}$, heavy metals from break wear or tires, roads etc. They are the predominant air pollutants, which are emitted from non-exhaust emission sources of the vehicle or category.

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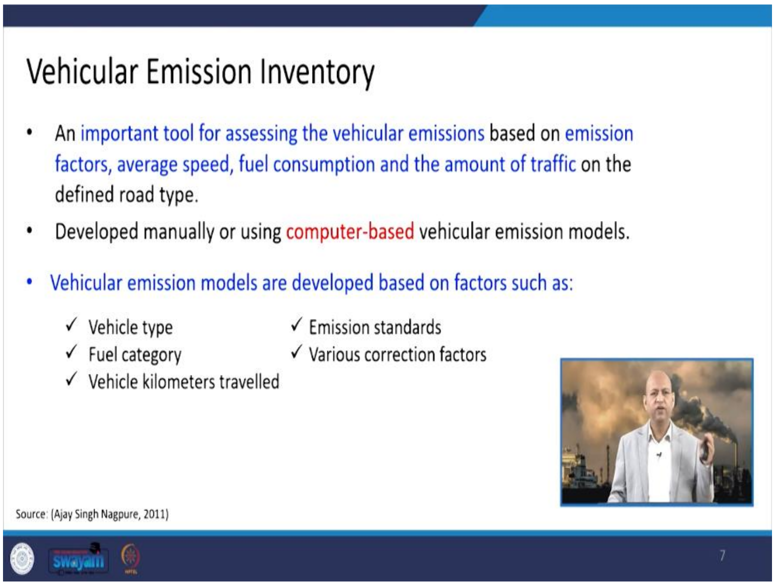

Well, so when we focus on vehicular emission inventory. So, basically we need to have different kind of input data, like what kind of vehicle it is? Whether it is light duty vehicle, heavy duty vehicle, two wheeler, three wheeler, four wheeler? Then technology two stroke and four stroke engine? So, much data is required for estimating the realistic emissions.

Then emission standards, whether they are following or not. Fuel category, whether it is diesel-based, petrol-based, CNG, LPG, ethanol, so many fuel are there. then various correction factors, because the same vehicle if you are running at the like flat road or at the lower levels like in Delhi and you take it to Dehradun, or Mussoorie, or any hilly area the same vehicle will emit differently, because the pressure change, humidity, temperature every kind of meteorological or atmospheric these parameters they also influence the burning activity, fuel combustion activity.

Then vehicle kilometer travelled, some vehicle are running for hundreds of kilometres, then their emissions will be more automatically and then how do you drive that is also important, although in only sophisticated models that driving cycle is incorporated otherwise, it is difficult, because we do not have much data especially in developing countries otherwise, in developed countries, they also take the driving cycle into account, like somebody is applying more brakes, some uses high speed, every person has different kind of driving pattern.

So, that also influence the emissions even if vehicle is same, same brand, same year, but emissions will be different according to the driving behaviour.

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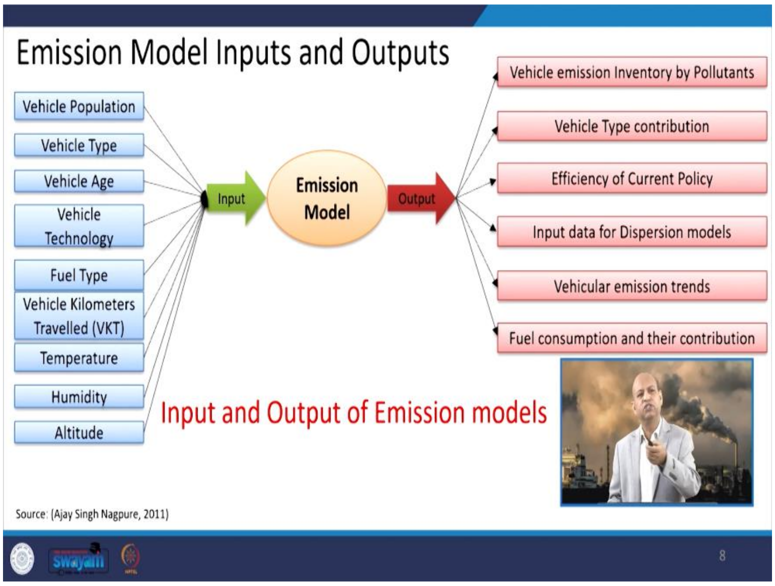

Well, so when we go for modelling of the emission inventory, so input data and output data this can be seen from this particular flowchart, like vehicle population, how many vehicles are there in a city or in a country whatever, scope of the emission inventory is there that depends on. Then types of the vehicle, what is the age of the vehicle, because as vehicles goes aging, then emissions are more. Vehicle technology as I said two stroke, four stroke, or those kind of thing.

Then fuel type, vehicle kilometer travelled, VKT, temperature, humidity, altitude, because that influence the time this pressure etc. All these are the input values. Then they go into the emission model and emission model what they give us, like vehicle emission inventory by pollutants, like how much CO_2 is emitted, how much PM_{10} is emitted, how much CO is emitted, those kinds of things.

Vehicle type contribution means we know the values, which kind of vehicle is emitting how much amount of a particular pollutant, like how much PM_{10} is coming from two wheeler, three wheeler, four wheeler, those kinds of things. Then efficiency of the current policy, because when you are implementing certain vehicular emission related policy or fuel related policy, that will be impacting the emissions also. So, that can easily be visible, that can be seen in that the patterns of the emissions, if you have temporal emissions like for every year like 10 years or so.

So, for example, when CNG was implemented in Delhi. So, when you have those temporal emissions for yearly like annual emissions for decades or so, you can easily see when this CNG was implemented, how much these those particulate matter got reduced those kinds of things, how much other gaseous pollutant got reduced, those kinds of things we can easily see.

Then input data for dispersion models it is useful, because for dispersion models emissions are the basic input values. Then vehicular emission trends, so which vehicle is emitting more which vehicle is emitting less. So, accordingly we can intervene technologically or according to the policy, fuel consumption and their contributions.

So, which fuel category like diesel is emitting more particular pollutant or petrol, depending upon how much it is consumed. So, that all those kinds of charts and tables, or metrics, we can have. So, this gives a lot of information for us to decide about policies, decide about transport-related activities or what kind of intervention we need to reduce certain pollutants, those kinds of things.

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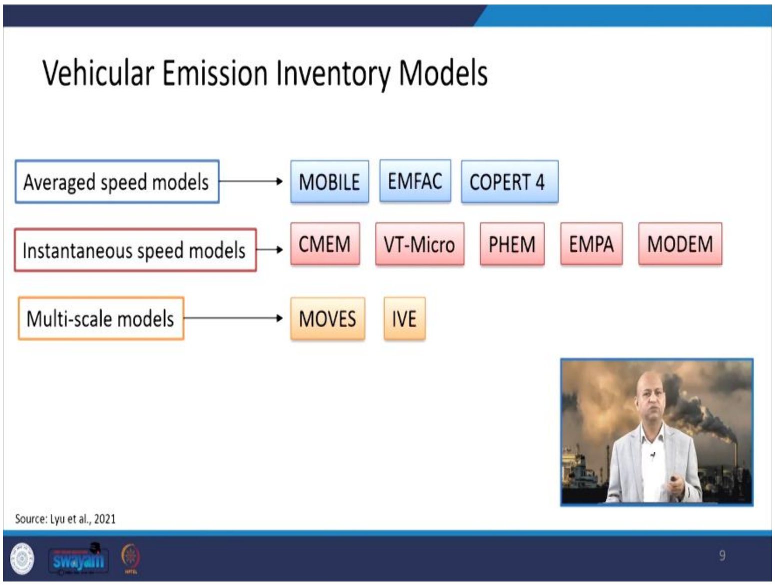

Now, when we talk about like inventory models, because these are mathematical models and they have different kind of characteristics like, we can broadly categorize them into like average speed models, which uses basically the average speed which a vehicle runs with, because we do not have driving cycle related data which is very complex.

Then we can have instantaneous speed models, which has the driving cycle related patterns. So, for each second, minute, they can have they can estimate the emissions. Multiscale models may be there which can go for different kinds of like exhaust, non-exhaust, evaporative, every kind of very versatile models, they can have. Even in instantaneous speed models there are models, which can you can use for that kind of activity well or average also.

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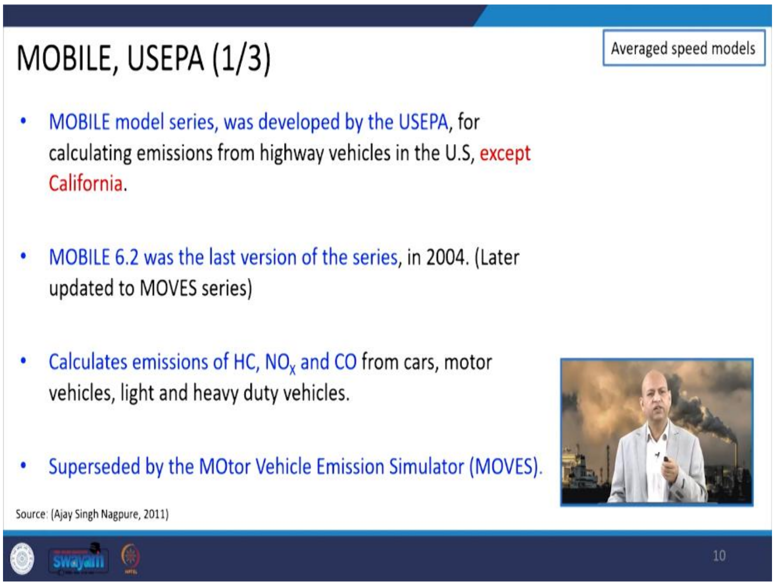

So, when we talk about like MOBILE, this model's name is MOBILE and this is developed by United States Environmental Protection Agency. So, this is one of the average speed related models. And the latest version is like MOBILE 6.2. This was last version in that series in 2004 and later updated to MOVES series. So, MOBILE got converted into MOVES series basically.

And this is applied in entire USA accepted by California. California has its own emission inventory model. It can calculate like hydrocarbon emissions, NOx emissions, CO from cars, motor vehicles, light and heavy-duty vehicles. So, good range is there for different categories of vehicle. When we talk about like this MOVES, which is Motor Vehicle Emission Simulator, MOVES. So, this has taken care now after the MOBILE. So, MOVES is more sophisticated or improved version of the MOBILE you can say in that way.

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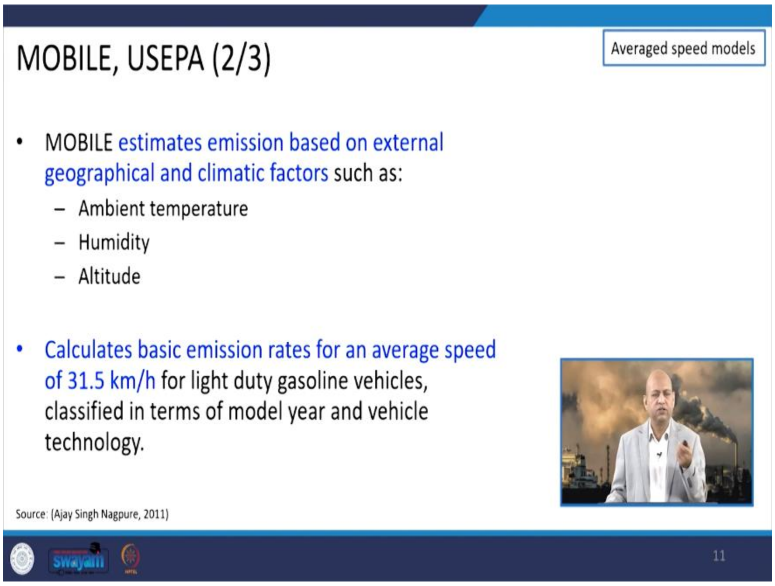

Well, when we talk about like which are the correction factors which are to be used in this emission inventory. So, ambient temperature, humidity or altitude related, correction factors they use basically and then it can calculate basic emissions as per average speed which is around 31.5 kilometer per hour for light duty gasoline vehicles.

Similarly, for other vehicles some average speed can be taken. This depends upon the city-to-city and region-to-region and based on some ground level surveys we bring these kinds of values which we use.

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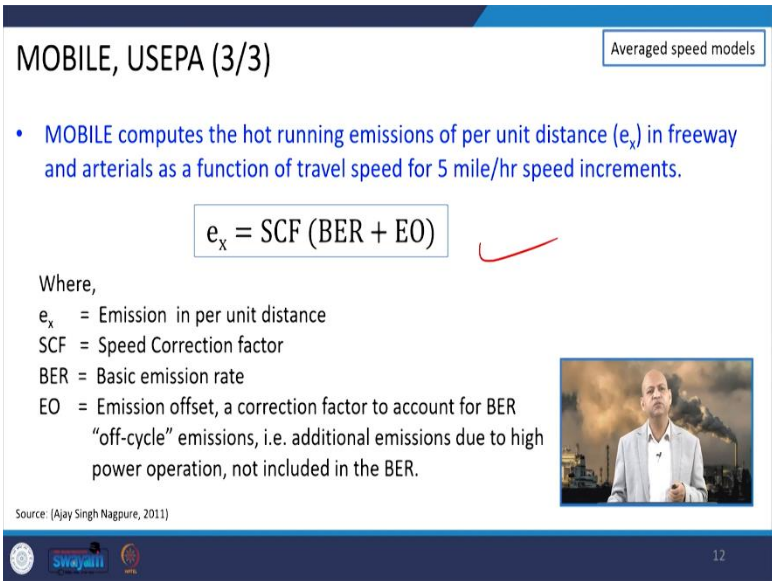

This is the basic equation, where you can see like emission in per unit distance is estimated and the speed correction factor is there, then basic emission rate is of course used and emission offsets are there which are calculated or they give the value of emission in per unit distance.

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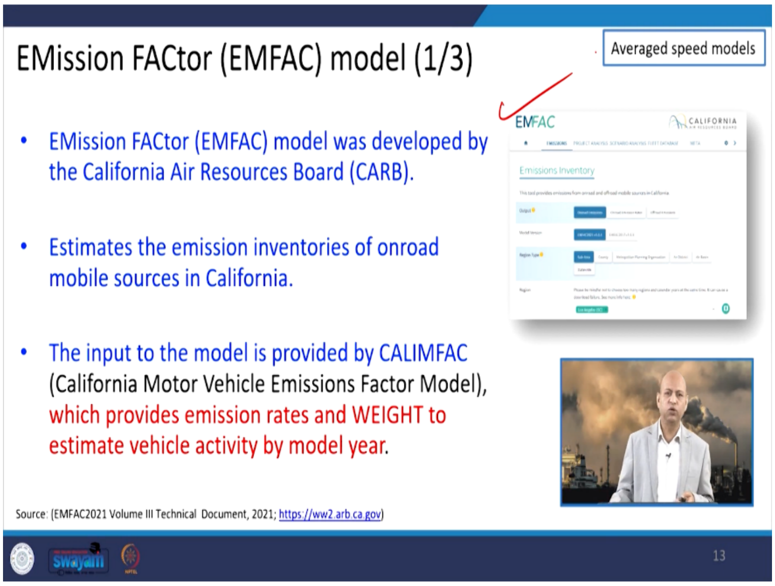

Well, you can convert that know how much distance is travelled by so many vehicles. So, you can calculate total vehicles. Now, we come to another model which is emission factor EMFAC model, EMFAC model. So, this EMFAC model was developed by California Air Resources Board. And this is provided for like emission rates or weight to estimated vehicle activity by model year, those kind of parameters are there and this is the website of this EMFAC model and one can go through it and they can use online also.

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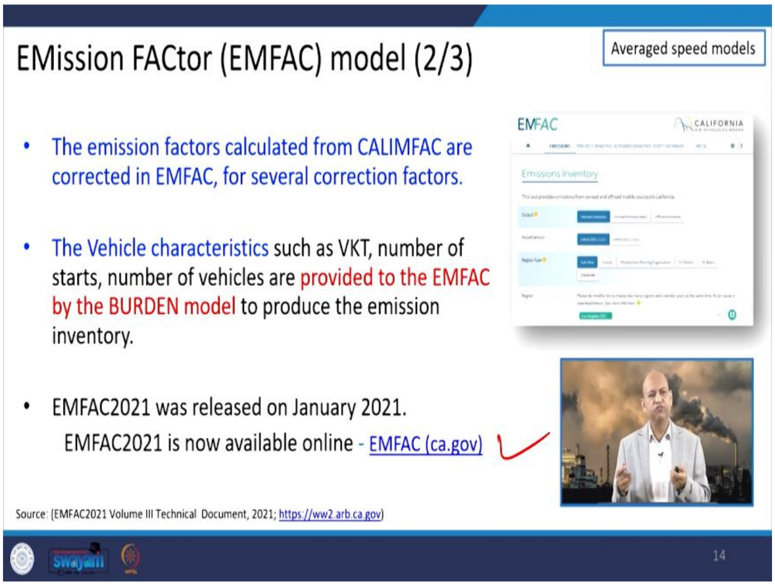

Well, when we see around like the vehicle characteristics, such as the vehicular kilometer travelled, number of starts and number of vehicles are provided to the EMFAC by the BURDEN model. So, another model is there, which gives some input values for the EMFAC. So, then may be different modules, which can feed that required values input values to this model. And this EMFAC 2021 was released on January 21 and now it is available on this particular website, where you can look at it, you can go through in detail, how it is used, what are important features. We are just giving an overview of these kinds of models.

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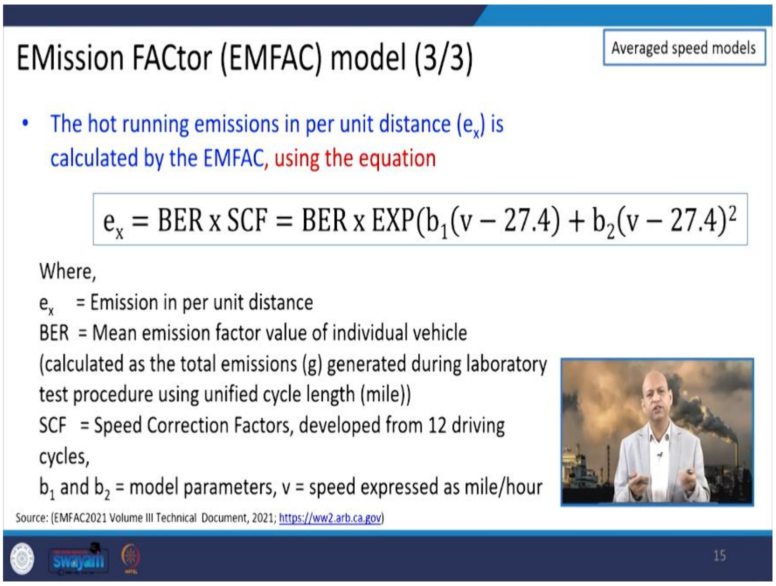

These are the equations which are used for the estimations of emissions, where again this e_x is admission in per unit distance, then you integrate it for all the vehicles. So, for each category of vehicle you can calculate that way and then you can club them or some summation you can have.

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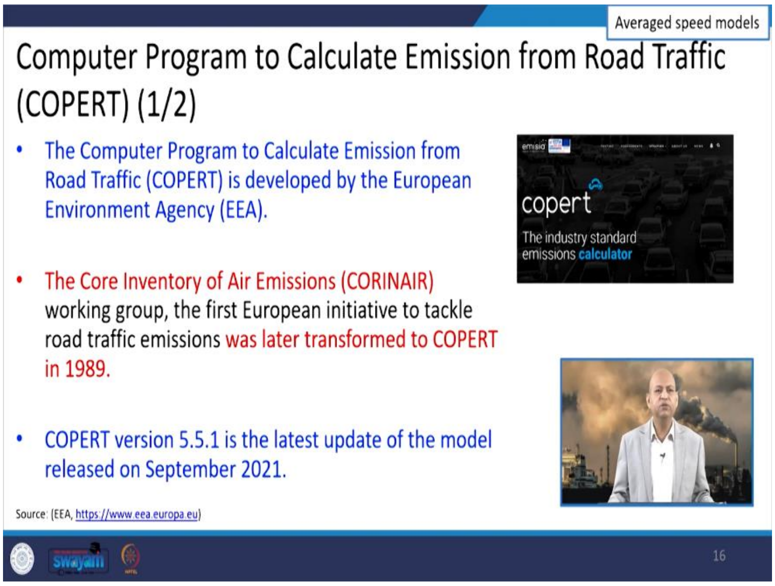

Then one very important and popular model is COPERT, which is computer program to calculate emissions from road traffic. So, in short it is called COPERT and it is very popular in European countries. Basically, it was developed by European Environment Agency, EEA. And the latest version is this COPERT version 5.5.1. This is the latest one and it was released in recently in September 21 basically.

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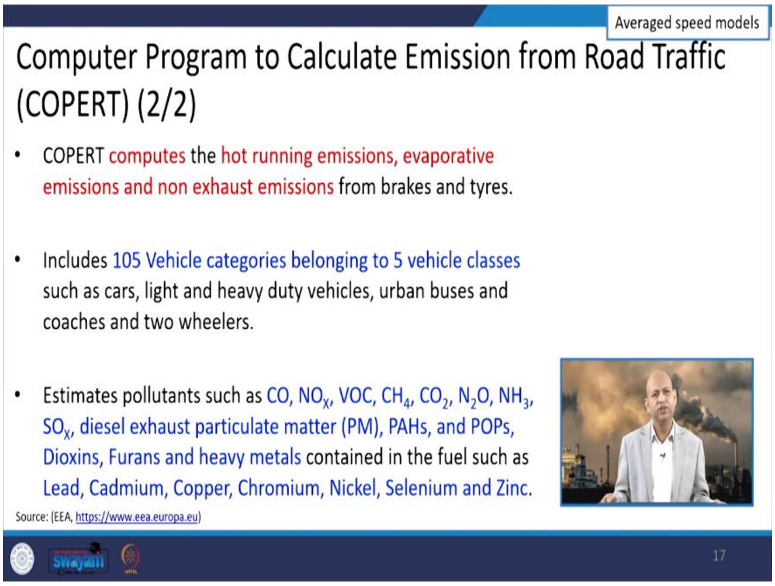

And it has huge scope for computational purposes of hot running missions, or evaporative emission, or non-exhaust emissions, all those kinds of things. 105 vehicle categories, and different 5 classes of the vehicles, cars, light and heavy-duty vehicles, urban buses, coaches, two wheelers, everything is inbuilt in this particular model. So, you can play with it, you can have emissions for different kinds of pollutants like CO, NOx,, VOCs, methane, CO_2 and N_2O, NH_3, ammonia SOx. You see, all kinds of air pollutants are there heavy metals, everything is included in this model. That is why this is very popular and very versatile model you can see.

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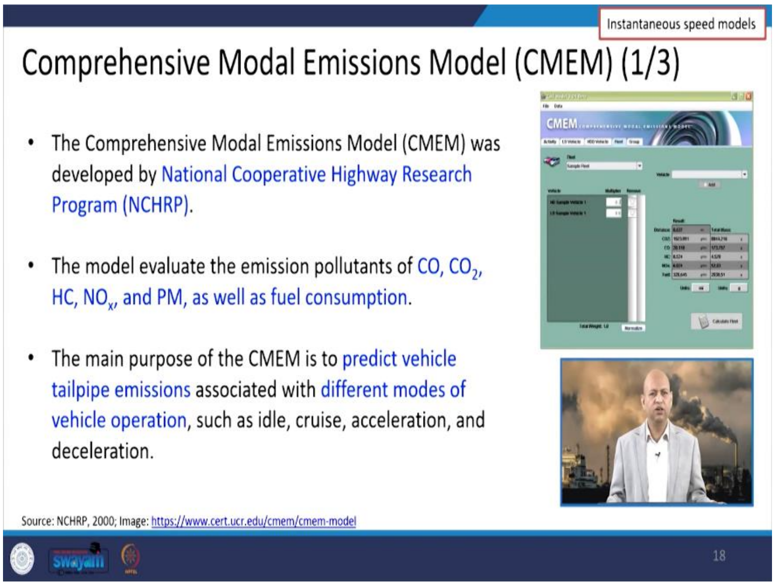

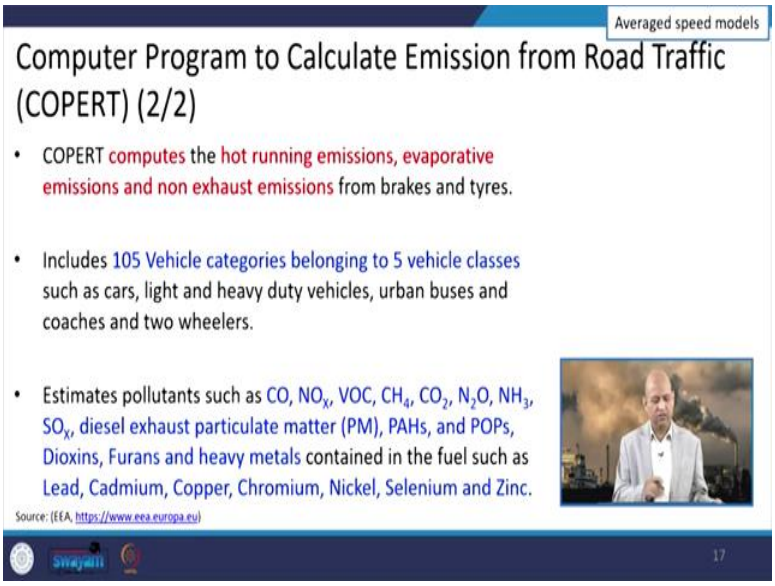

Well, then there is this Comprehensive Model Emissions Model, CMEM. And this is National Cooperative Highway Research program related model basically and it gives the emissions for CO, CO_2, hydrocarbons, NOx, particulate matter and as well as the fuel consumption. The main purpose of this model is to predict vehicle tailpipe emissions associated with different modes of the vehicle operations like idle, cruise, acceleration and deceleration. So, I mean to say driving cycle is incorporated in this particular model and this is the instantaneous speed model. COPERT was the average speed model.

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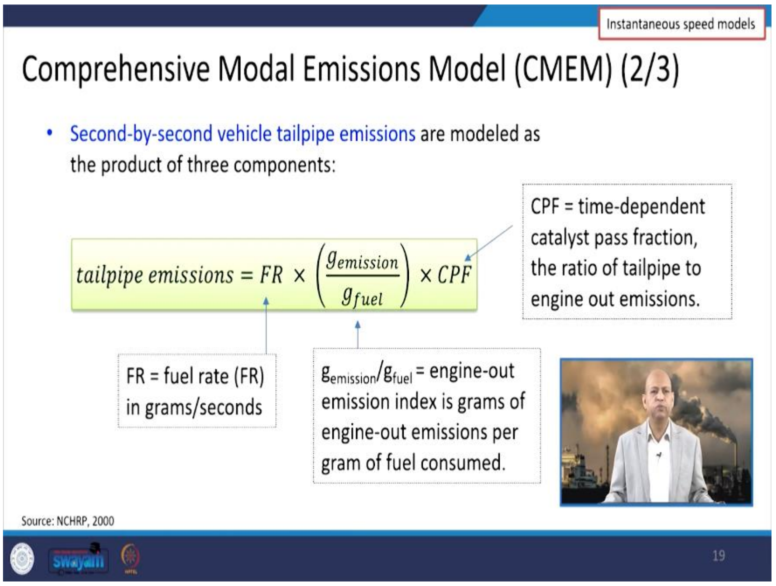

Well, then, you come to this particular other part of the CMEM model. So, this is the basic equation which is used for emissions estimations and different input parameters are their CPF like time dependent catalyst, past fraction is there, the rate of tailpipe to engine out emissions, all those kinds of things are available based on survey and those agencies can provide these kind of values.

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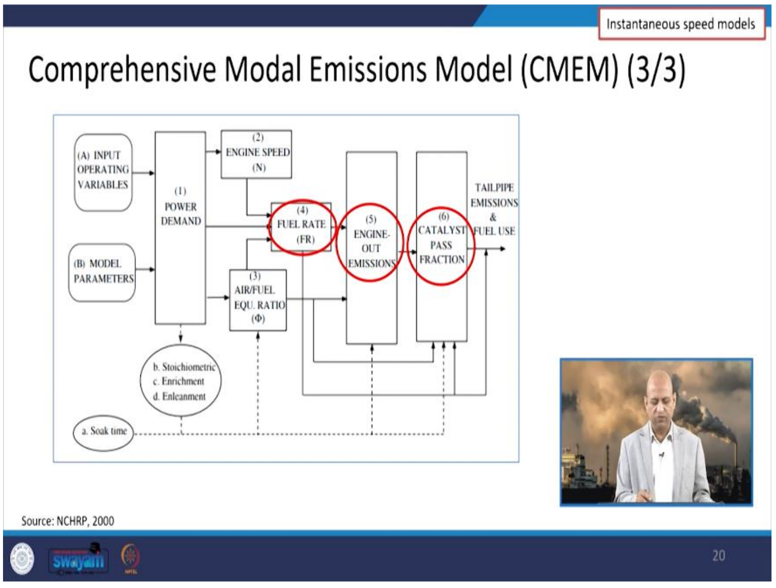

Well in flowchart it is also given how these different kind of steps are there stages are there for estimating emissions.

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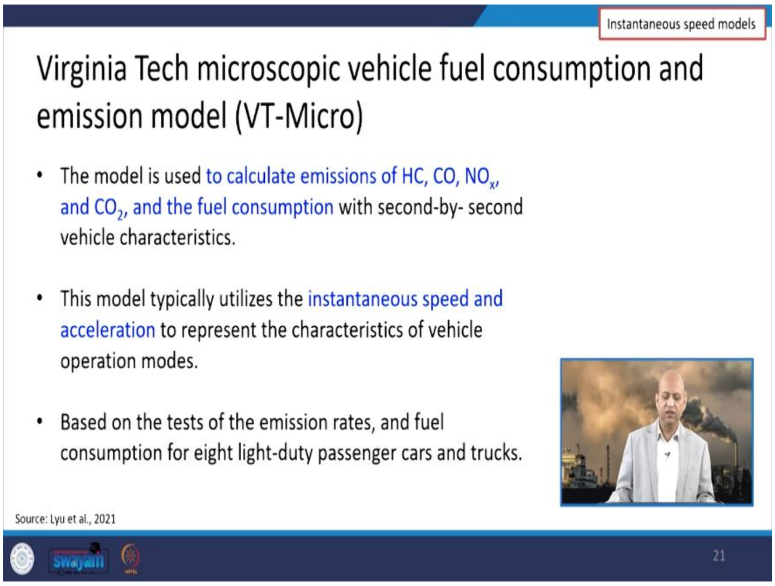

Well, then another model is VT-Micro, which is Virginia Tech Microscopic Vehicle and fuel consumption and emission model, this is VT-Micro model and this is used to calculate emissions of hydrocarbons or carbon monoxide, NOx, CO_2 fuel consumption. So, similar to other models and this is again instantaneous speed model. So, it can have the driving cycle related values inside it.

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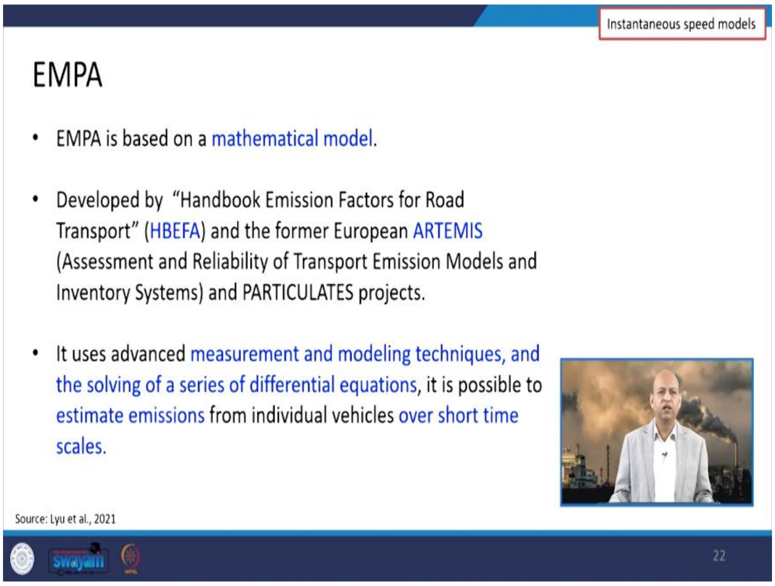

Then, EMPA model is their mathematical model, which is Handbook Of Emission Factors For Road Transport (HBEFA) is developed by the former European this assessment and reliability transport emission models and inventory system. And this particular project is there which has supported this particular modelling activity and the advanced measurements and modelling techniques have been used in this to solve series of differential equations. So, it is a sophisticated created one it gives good range of estimated emissions from individual vehicles, over short time scales also. So, at micro scale you can calculate.

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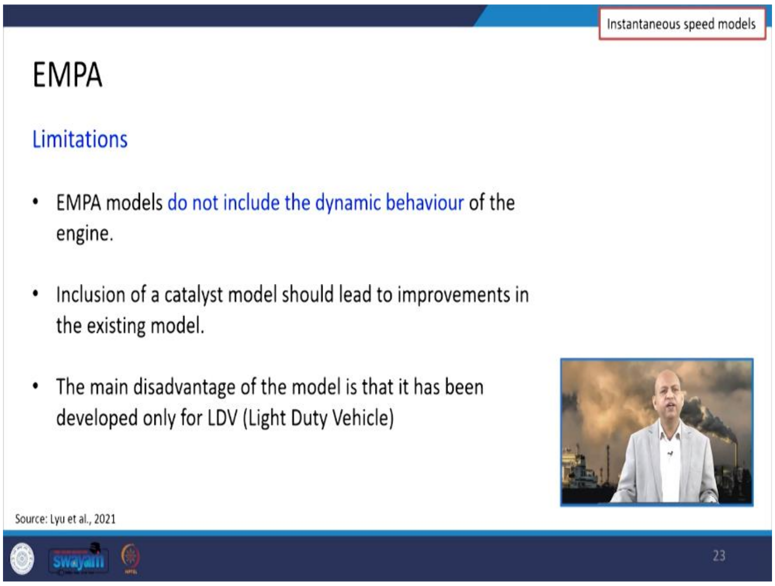

But certain limitations are also there, like it does not include the dynamic behaviour of the engine. And the inclusion of a catalyst model should lead to improvements in the existing model that is also one scope and the main disadvantage of this model is that it has been developed only for the light duty vehicle. So, for heavy-duty vehicle, this model cannot be applied.

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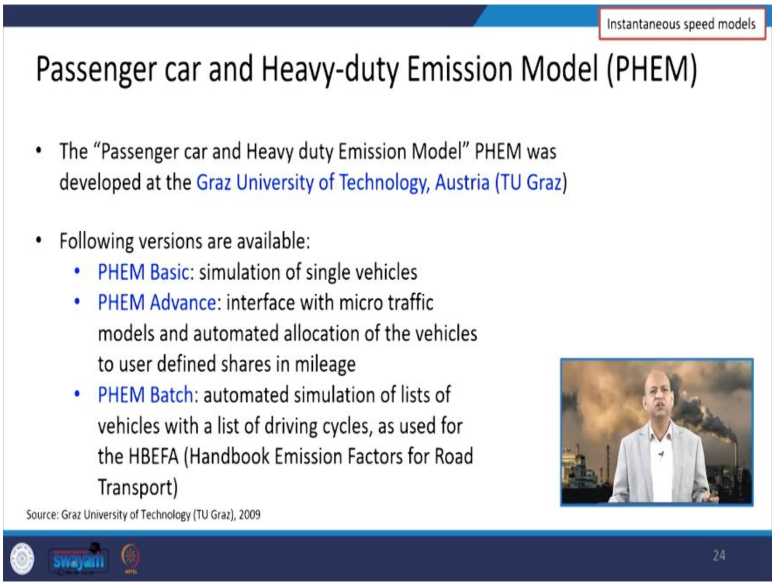

Then, when we talk about Passenger car Heavy-duty Emission model (PHEM). So, this is another one which is developed by Technology University, the Graz University of Technology in Austria. So, this have different versions available and according to the need it can be used for particular purpose of emission inventory development.

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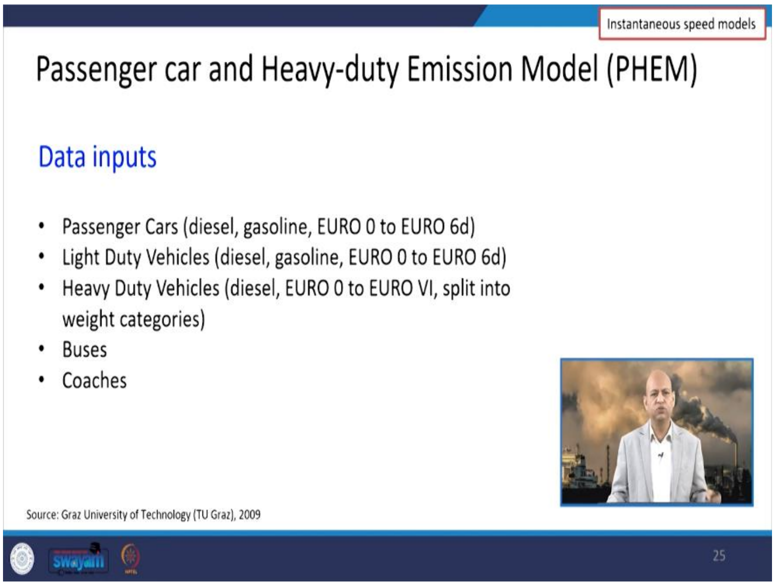

Some input values like passenger cars, diesel or gasoline-based, which is the norms EURO-0 to EURO-6d, those kind of versions of emission norms can be incorporated. Light-duty vehicles, heavy-duty vehicle, buses, coaches all those kinds of things can be incorporated into it.

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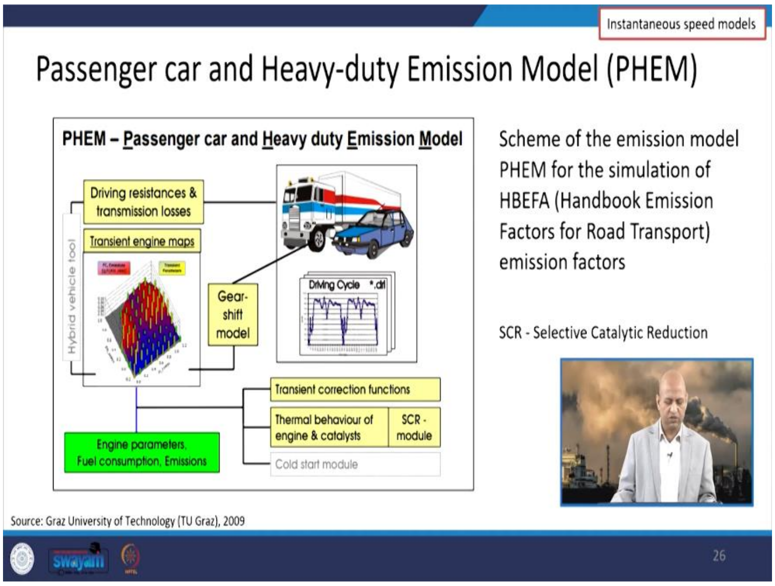

And all these values are given according to. So, this chart is given how it is used basically what is the scope and for utilization of this model is represented in this particular figure.

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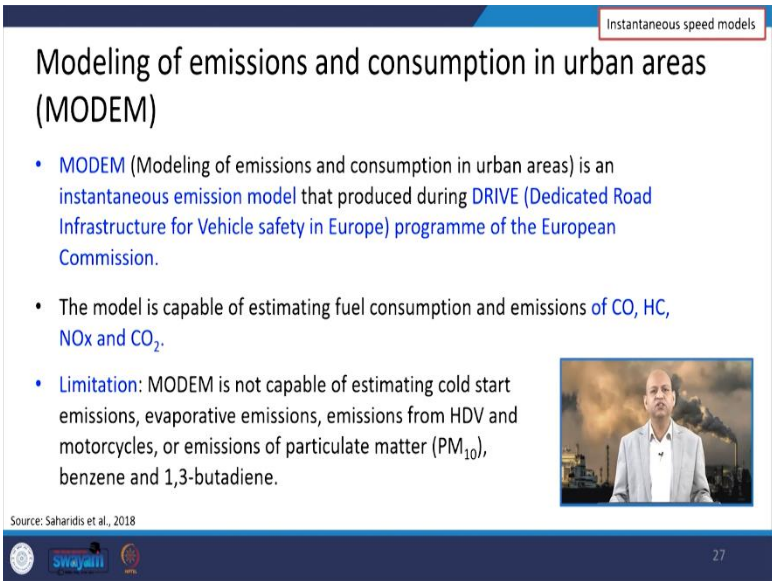

Then, we go for another this instantaneous speed models, like Modelling of Emissions and Consumptions in Urban Areas, MODEM. And this MODEM is an instantaneous emission model as I said which is like produced during this DRIVE, dedicated road infrastructure for vehicle safety in Europe. So, DRIVE is related that very good acronym very interesting acronym. This was the program of the European Commission.

And this model is capable of estimating fuel consumption and emissions of carbon monoxide, hydrocarbons, NOx and CO_2. Certain limitations are there like it is not capable of estimating cold start emissions, evaporative emissions, emissions from heavy duty vehicles and motorcycles, or emissions of particulate matters benzene. So, a lot of limitations are there with this model.

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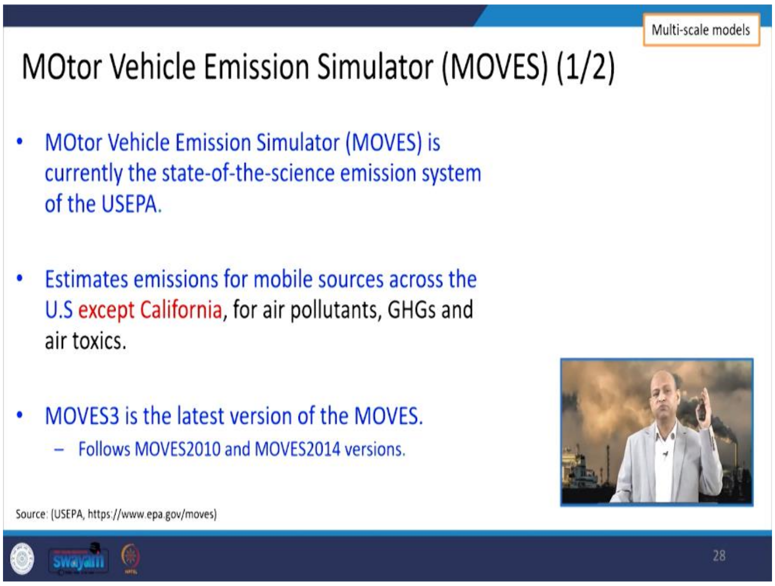

Another model as we discussed when we were discussing about MOBILE modal, MOVES, Motor Vehicle Emission Simulator. So, this is the new version and again except California, it is used in entire USA and this gives again quite range of air pollutant and the latest version is there MOVES 2014 version is there.

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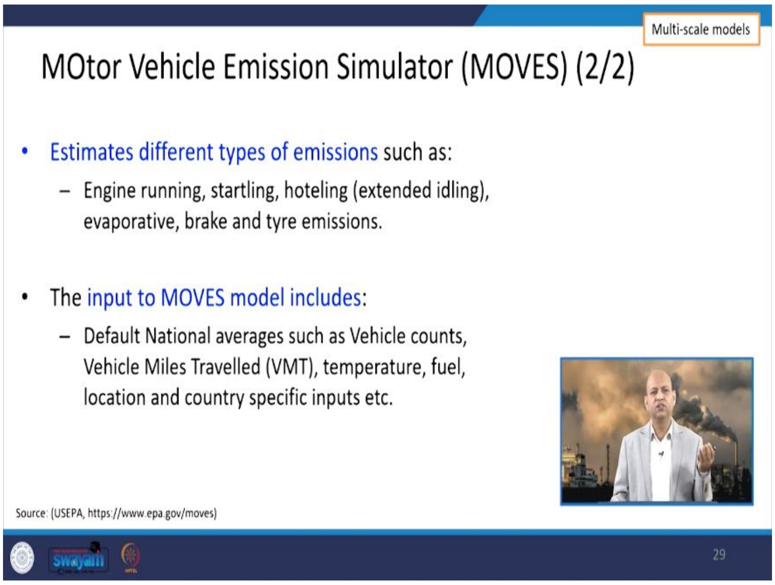

And this can estimate different types of emissions, such as engine running, starting and then extending extended idling, evaporative emissions, brake-related, tire-related emissions, So, that is why it is known as multi-scale models basically and then the input to MOVES model when you want to estimate emissions. So, like vehicle mile travel, temperature, fuel location, and the country specific inputs are needed for calculation purpose.

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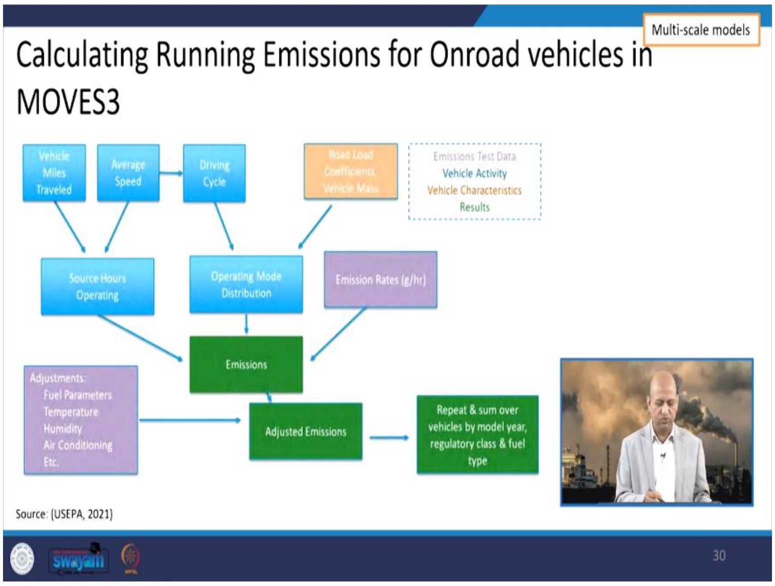

This is the flowchart for these moves. So, you can see different kinds of input values, where they come from which kind of modules help them to have these input values and ultimately, what kind of these output values are there.

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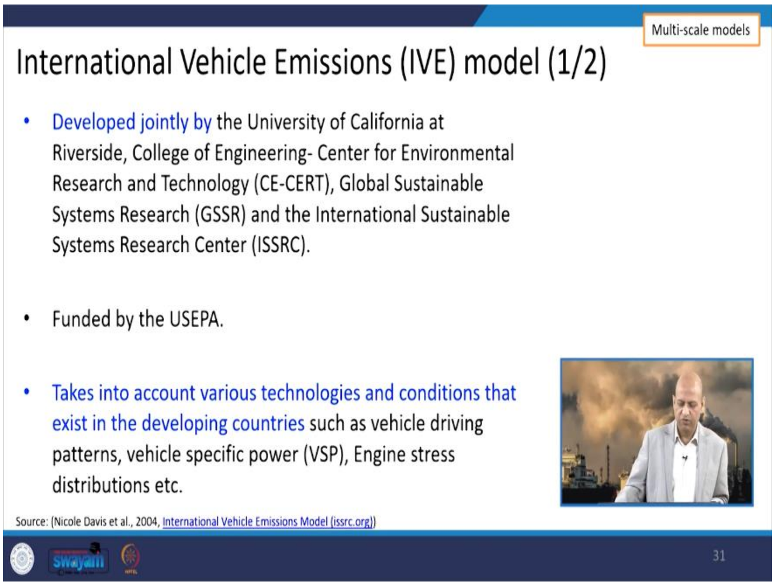

When we talk about another this multiscale model, which is International Vehicle Emissions, IVE model, this is very versatile model and very popular. It can it was developed basically keeping in view about the limitations of data available in developing countries. So, this was developed for developing countries basically and it was used in different countries including in India also like in Pune, one study was conducted based on this IVE model.

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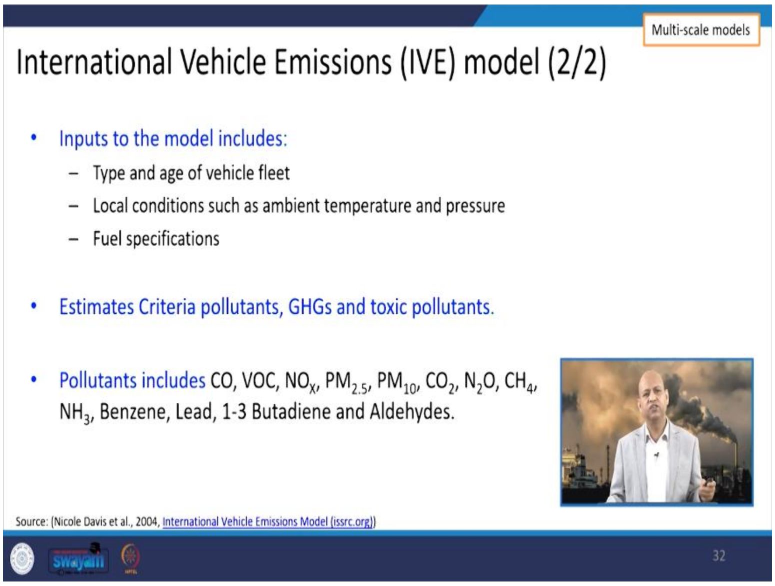

And it can estimate emissions for a range of different pollutants like $PM_{2.5}$, NOx etc, but it needs different input values like types of age of the vehicle fleet, local conditions, ambient temperature, all those whatever we have discussed so far fuel specifications etc. because they will influence the emission factor and the emissions.

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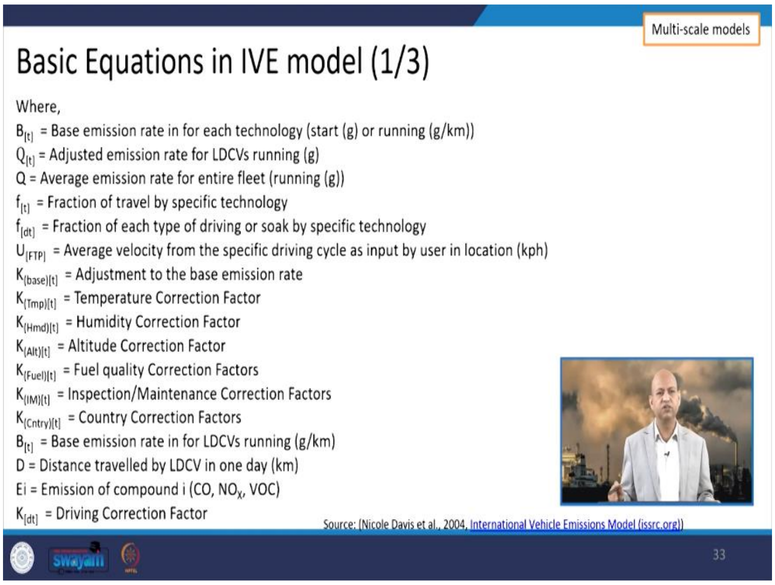

The basic equations are using different kinds of parameters, which are the nomenclatures, given in this particular page, you can go through like Q is adjusted emission factor which is ultimately estimated.

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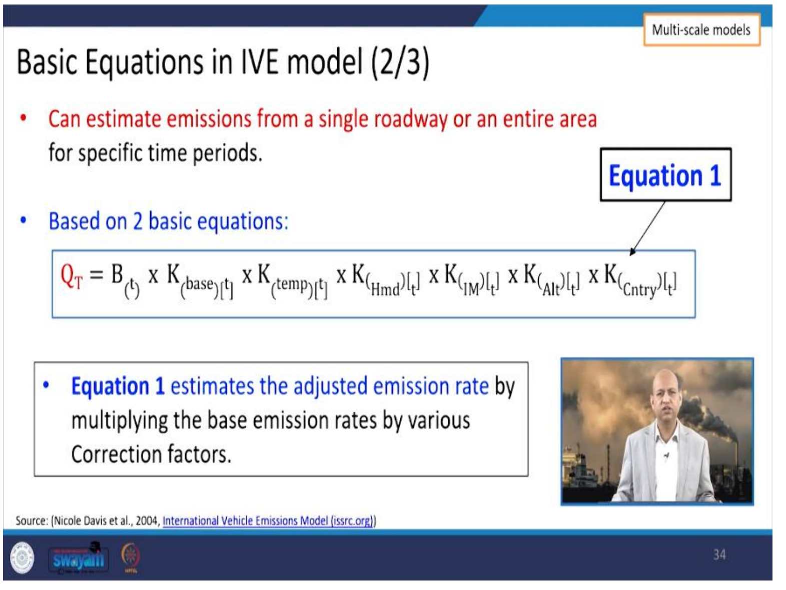

Otherwise, there are many other factors for input values for this estimation of emissions from this IVE model.

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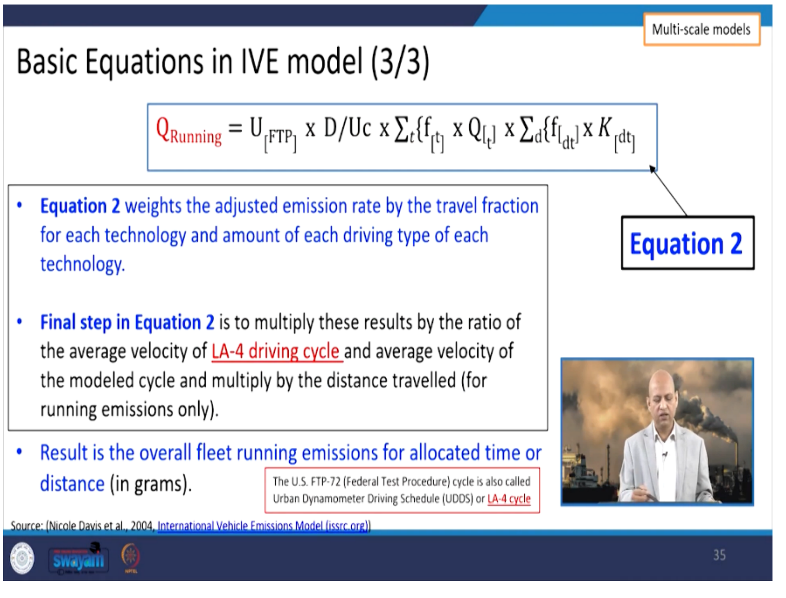

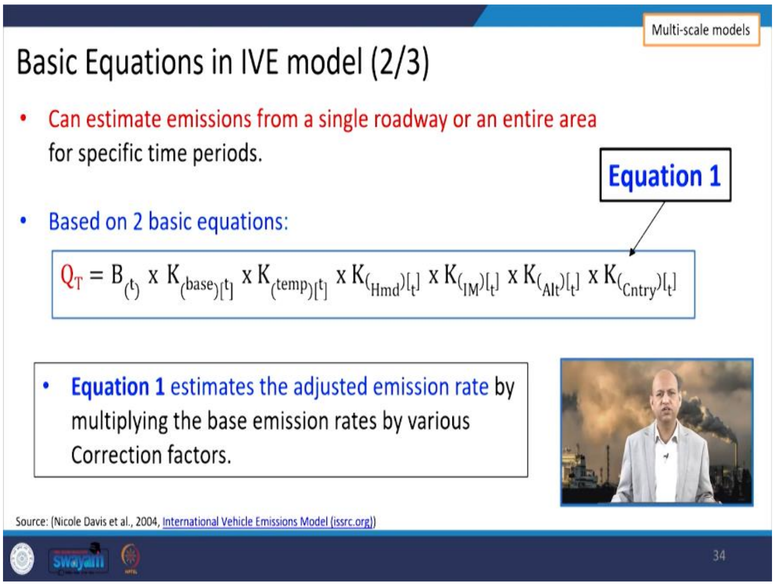

You can see these are different kinds of like $Q_{running}$ And this is driving cycle related emission estimations.

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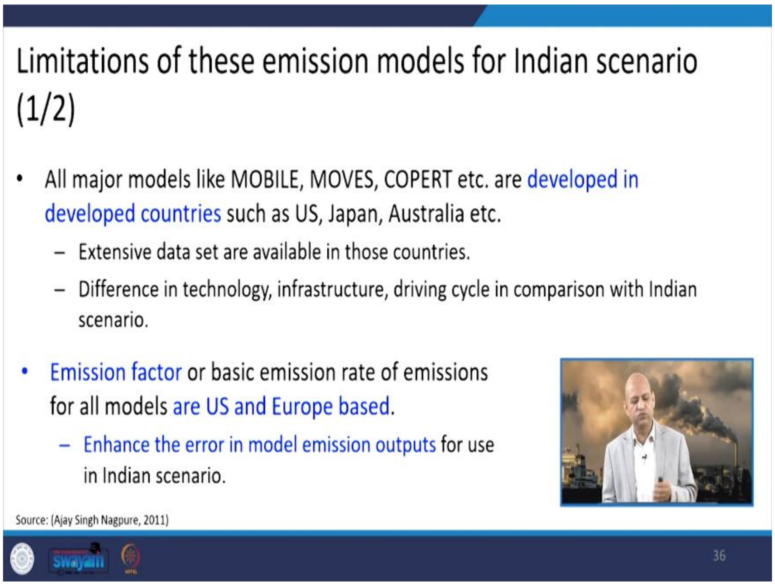

And then all models like these MOBILE, MOVES, COPERT etc. if we talk about limitations of these models, which are available in developed countries, they have certain limitations for developing countries, we cannot just use them for developing countries as it is. We have to do a lot of like adjustments or because these are data intensive, a lot of data is needed, extensive data set which is not available easily in developing countries like India.

And then there are technology differences also. Their vehicles have advanced technologies which our vehicles do not have. So, the estimated figures maybe not realistic in this case, if we are using those models, which are very sophisticated, very data intensive, and that is why we need to have our own model.

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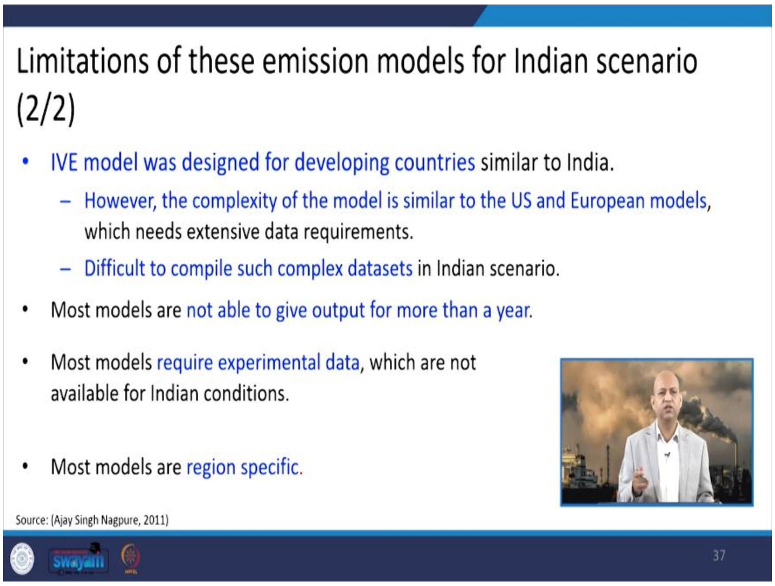

And then IVE model was designed but again, similar we found similar limitations with this model also, it was not free from those kinds of limitations, which have discussed for other sophisticated or advanced models.

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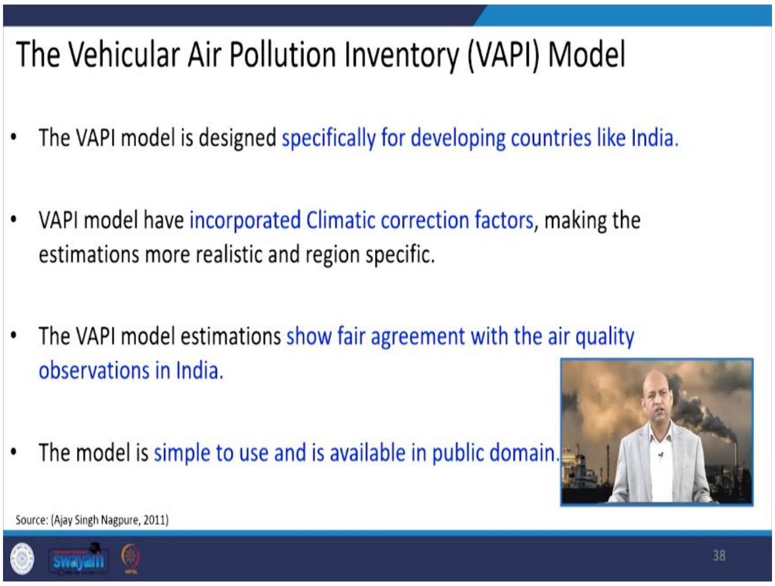

So, that is why we thought that we should have our own model and this Vehicular Air Pollution Inventory Model, VAPI model was developed in IIT Roorkee to address this particular gap, so that we can estimate emissions from road related vehicles, different kinds of vehicle categories particularly in Indian context.

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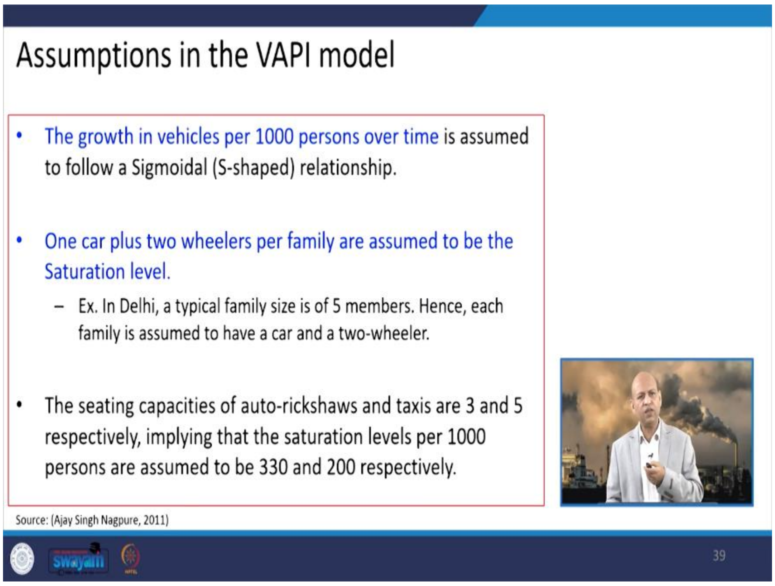

So, this was developed in IIT Roorkee as a PhD thesis and now it is popular and many people are using and for small cities to mega cities, you can it has a lot of flexibility in that sense. And you can go for like estimation of different future scenarios also, like how many vehicle population will be there in a city? So, those kinds of estimations are possible with this model.

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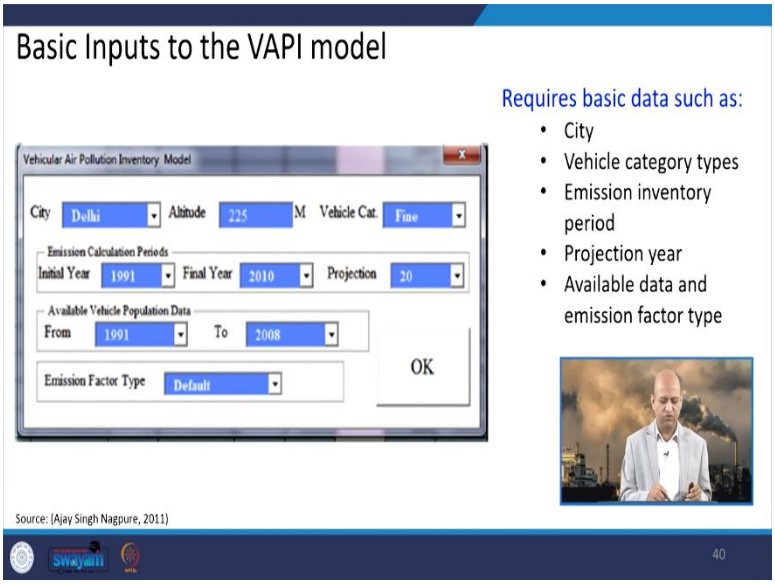

This is basic input for VAPI model like what is the city? What is its altitude? It has inbuilt values for several cities, but you can manually also give our input values initial year or final year, projections for future, how many years projections you want to have, scenario creation depending upon different technologies or policy implementation, which is the base year, emission factors you want to have the default one which are part of this model or you can have your own emission factor. So, that way this model is very, very flexible and very simple procedure it has.

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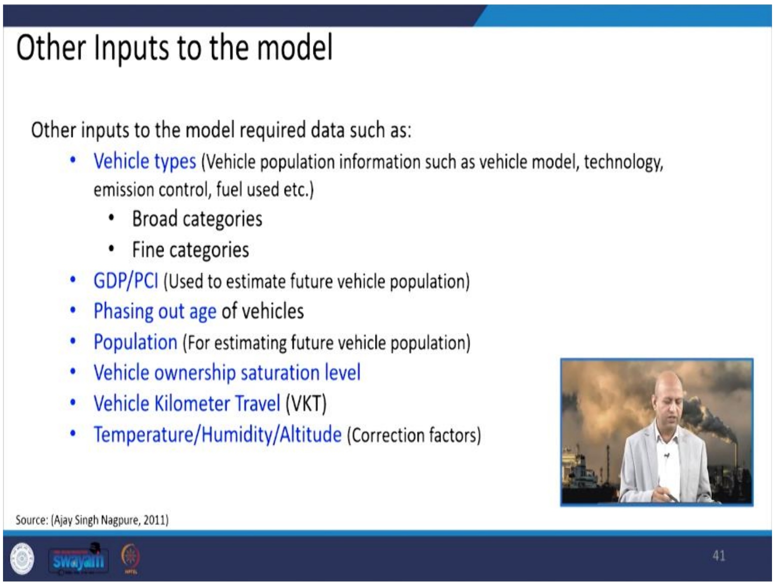

So, other input values for this particular model are needed like vehicle type broad categories, fine categories depending upon their categories. Then phasing out age of the vehicles after which age this is taken out of the road, then these GDP or purchasing power or income of the people. Then population growth, vehicle ownership, saturation level, vehicle kilometer travel, VKT, temperature, humidity, altitude, these are the correction factors, all these have been incorporated, which are easy to get in Indian context. So, only those input parameters have been given more importance.

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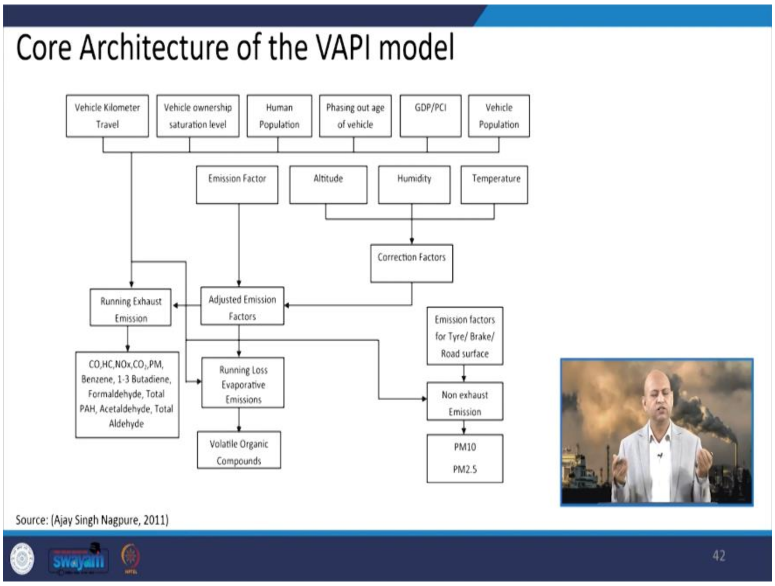

Well, this is the core architecture of this VAPI model. So, you can see all those input values are there and how these correction factors at what stage they are used to estimate the emissions from different kinds of vehicular emissions.

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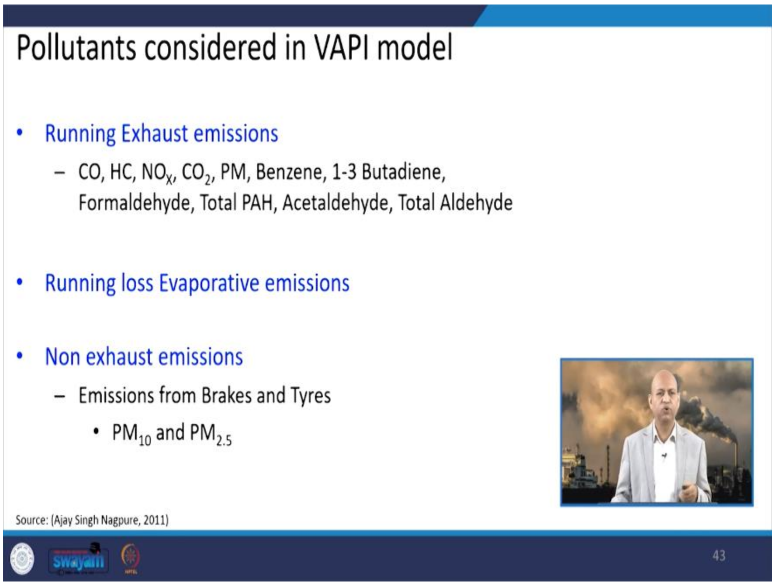

Well, when we talk about like running exhaust emissions. So, carbon monoxide, hydrocarbons, NOx, CO2, PM benzene, all these VOCs etc, can be estimated by using this particular model. Then running loss of evaporative emissions are also possible to estimate. Non-exhaust emissions are also possible to estimate from brake, like wears or tires, PM_{10}, $PM_{2.5}$, these emissions can easily be estimated depending upon which emission factors you have.

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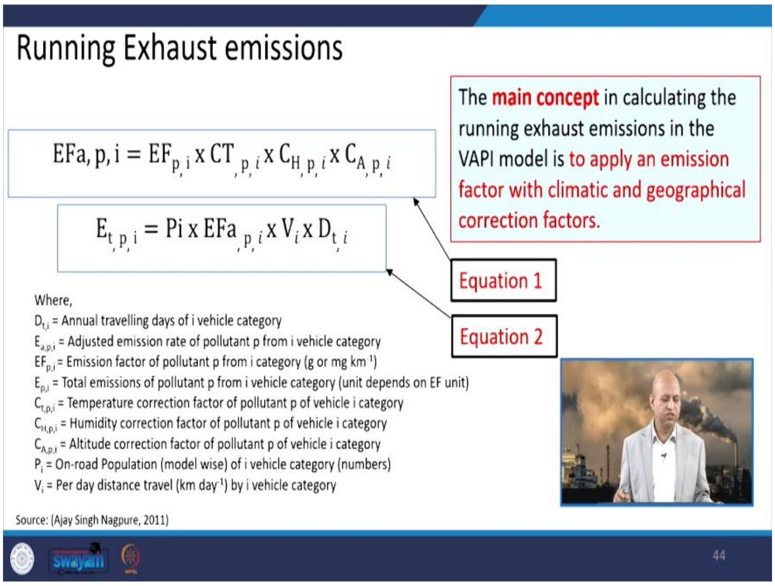

And this is the basic equation, which has been used for this particular VAPI model. So, the main concept behind this is calculating running exhaust emissions. And it can apply emission factor with climatic and geographical correction factors like temperature, humidity, altitude etc.

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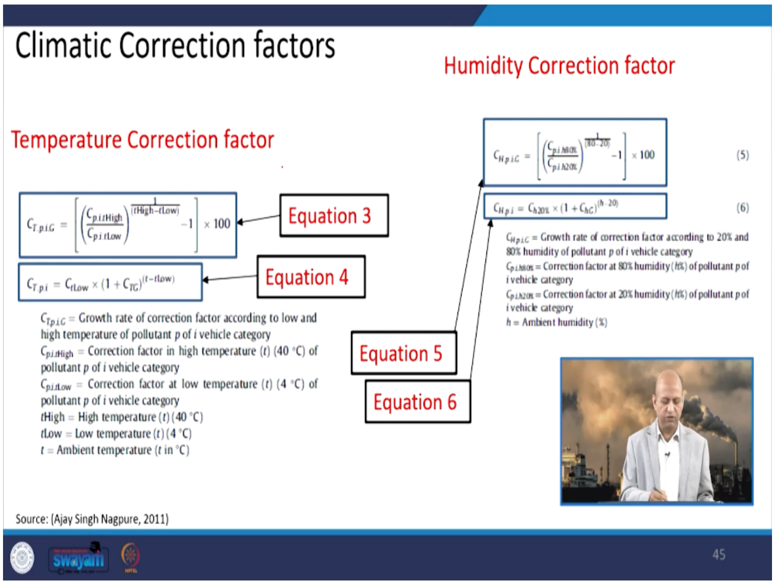

So, you can see different correction factors, emperical relationships are there which have been borrowed by from different literature. So, we have taken best features of all good models and we have tried to make it as convenient and comfortably usable in the Indian scenario.

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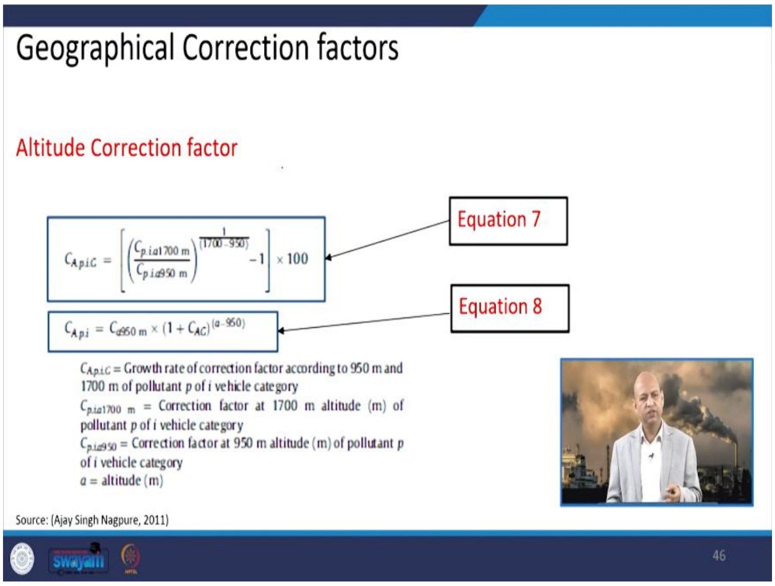

Well geographical correction factors are there which can be calculated by this equation. So, this is the part of this calculation part of the model.

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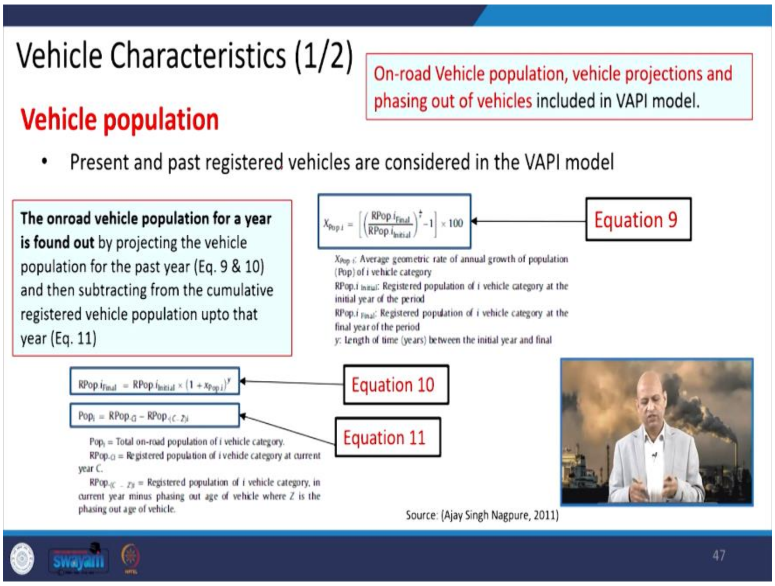

Vehicle population at what stage it will be saturated those are that kind of equation is also there for calculating the vehicle population.

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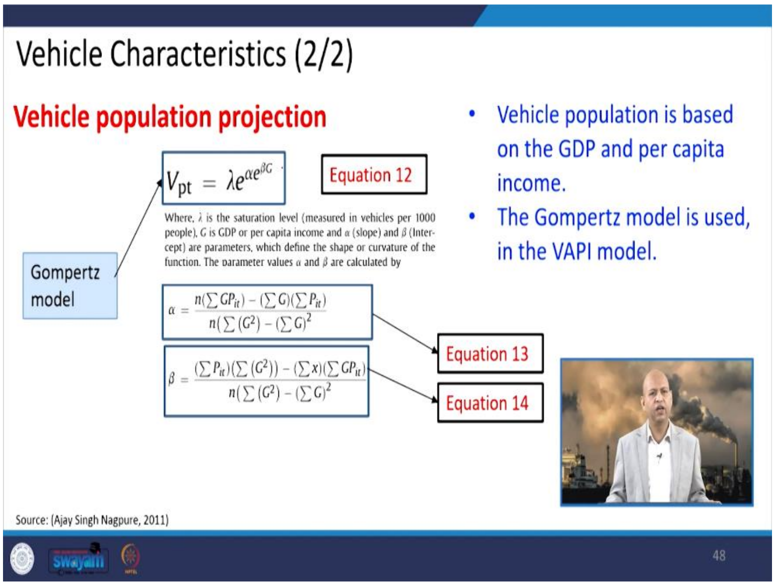

So, projects and can be made and you can have a good reliable fair figure.

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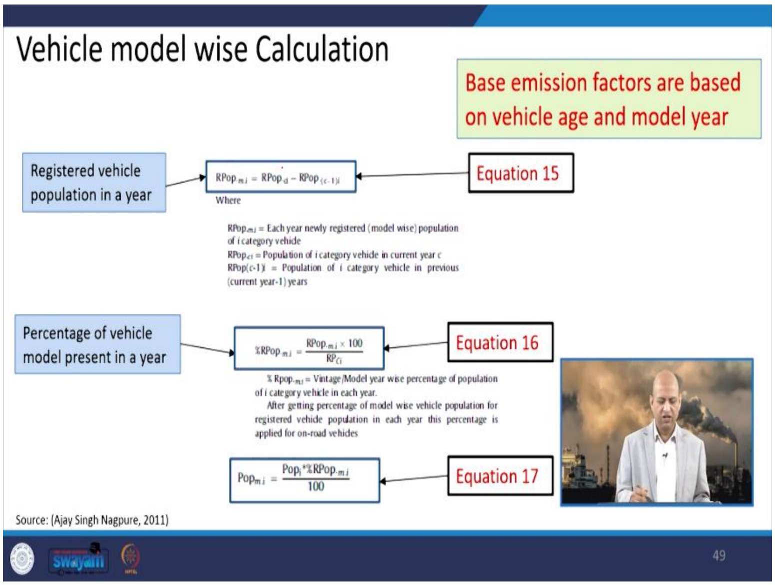

And then you can have these registered vehicles, different kinds of models and after a certain age, how many vehicles will go out. So, at a certain point of time, how many vehicles are there on the roads, how many vehicles go out of the city, how many enter, all these are incorporated in this based on the survey based figures.

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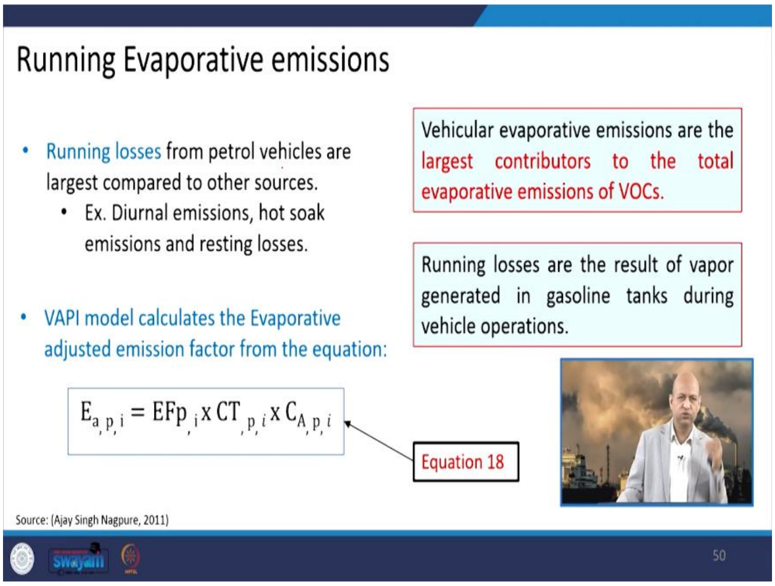

When we run these operative admission model, so this is the basic equation which is emission factor-based which can give you those values.

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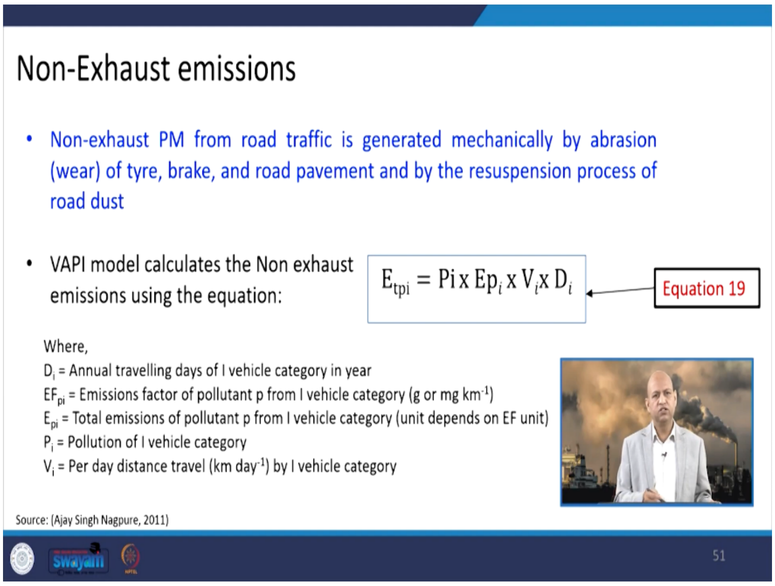

Similarly, for non-exhaust emissions, this is the equation which can give you non-exhaust emissions.

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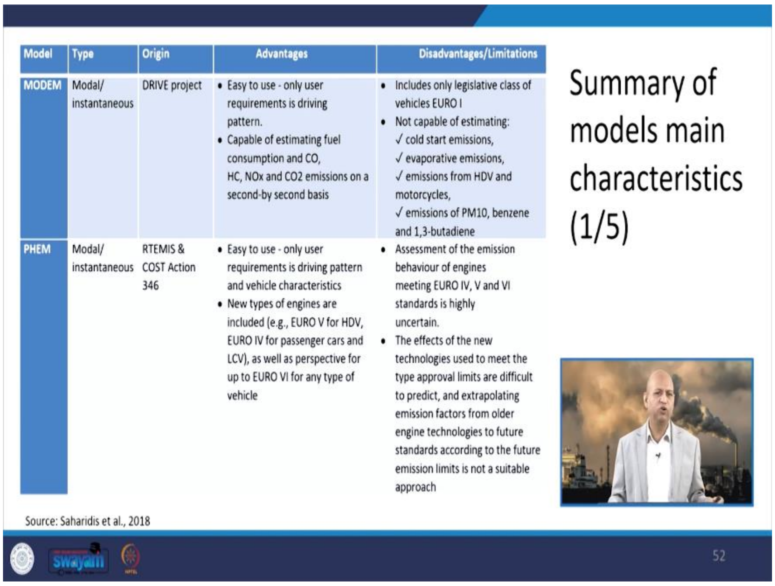

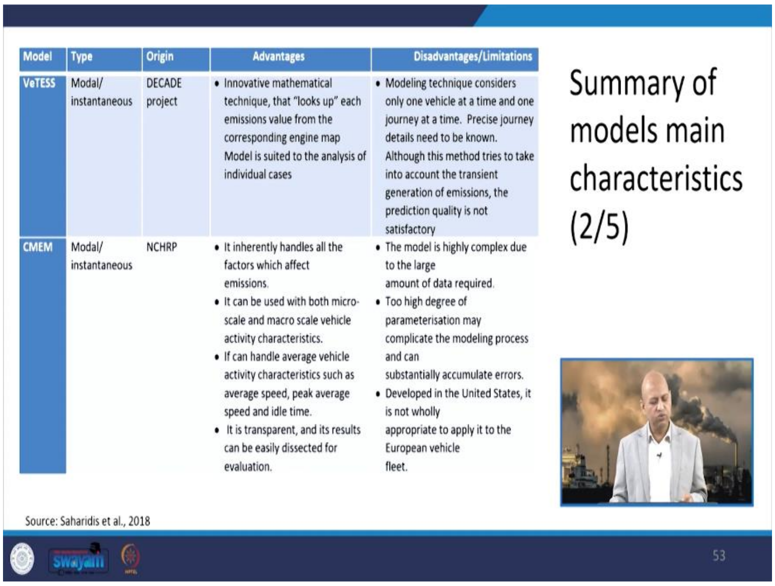

Then, if we try to compare different kinds of models and we want to see what are their special features? What are their advantages, what are their limitations? So, we have compiled these data in this particular table which you can go at leisure.

So, they have comparison depending upon range of these pollutants, which kind of pollutants they can measure or type of the vehicle category like some models are only for light-duty vehicles. Some are for heavy-duty, some are incorporating all types of vehicles.

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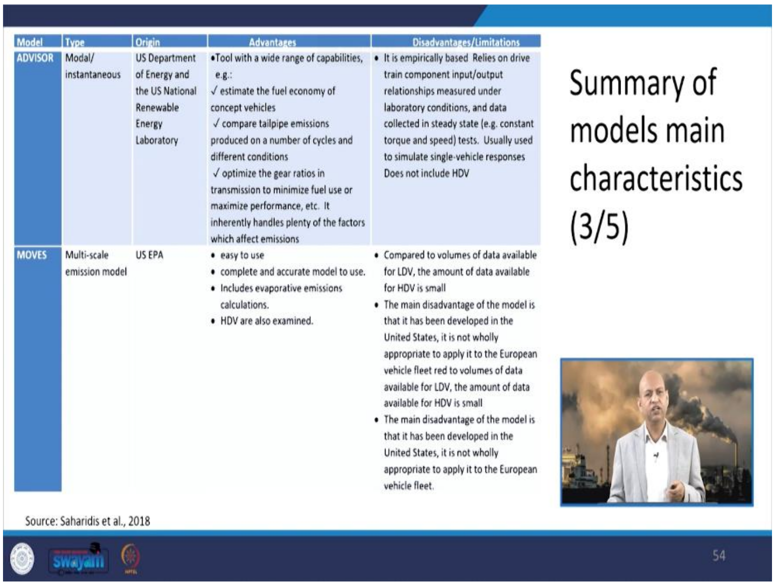

So, depending on those characteristics, different models have different advantages and disadvantages.

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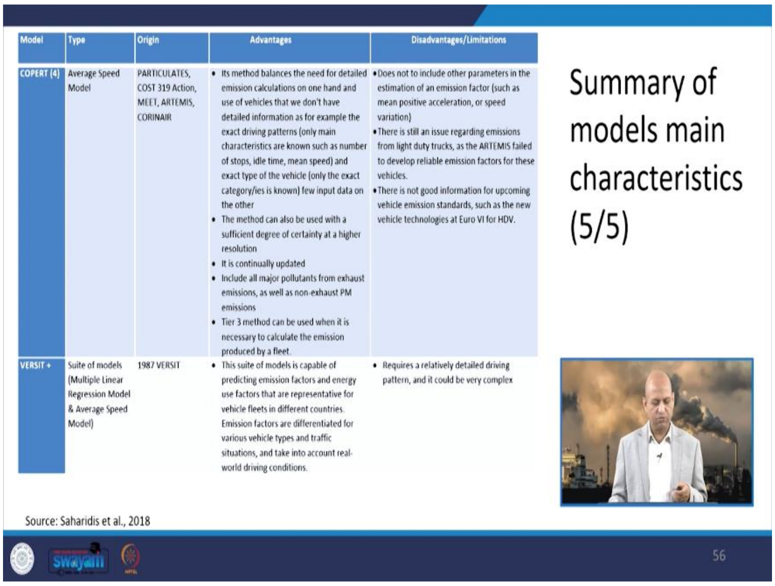

So, this is, the summary in this table for all kinds of models which we have discussed.

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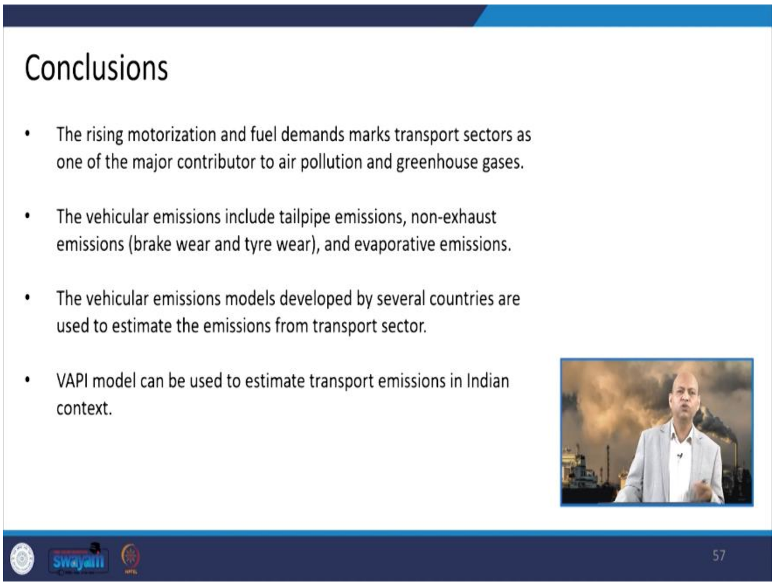

So, this is all for today in conclusion, we can say that the rising of urbanization, increasing of urbanization and industrialization, they have given the need of this motorization and the fuel demand and that is why the increasing of the emissions of air pollutants and greenhouse gases from transport sector and especially, road vehicles and the vehicular emissions that can include tailpipe emissions, non-exhaust emissions, all those kinds of emissions, they can be estimated by using different kinds of models.

And the vehicular emissions models, which are developed for several countries are used to estimate emissions from transport sector in those, specific country's context. So, it is not good that we just use those models for estimating our transport sector related emissions. We should rather have our own emission inventory model.

So, in that way VAPI model is good for India or like developing countries, which can give quick and it is less resource intensive and quick model, which can give you the like baseline related scenario for policy making activities or for checking whether some policy or technology has given positive impact or not, how much improvement is there all those kinds of things are possible with the result of the VAPI model.

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So, this is all for today. Thank you for your kind attention. These are the references you can go through for having additional information. See you in the next lecture. Thank you.