



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.

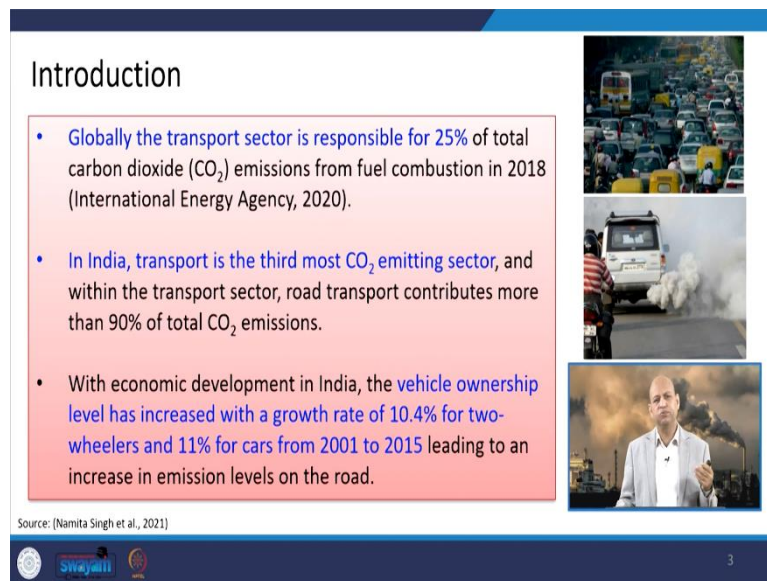
So, when we talk about transport emission inventory, basically, we need to know what kind of different models are there which can be used for development of emission inventory for the transportation sector and what are their basic requirements, what are the input values the need for estimating the emissions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

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Introduction

- Globally the transport sector is responsible for 25% of total carbon dioxide (CO₂) emissions from fuel combustion in 2018 (International Energy Agency, 2020).
- In India, transport is the third most CO₂ emitting sector, and within the transport sector, road transport contributes more than 90% of total CO₂ emissions.
- With economic development in India, the vehicle ownership level has increased with a growth rate of 10.4% for two-wheelers and 11% for cars from 2001 to 2015 leading to an increase in emission levels on the road.

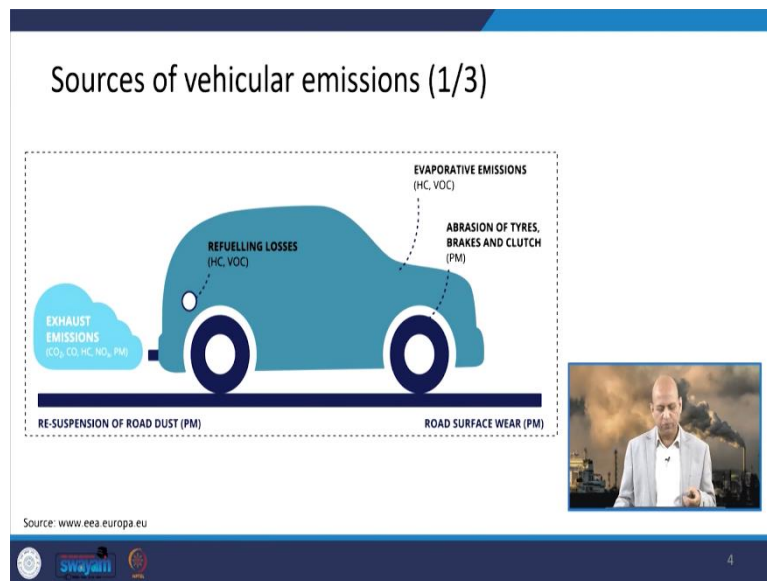
Source: [Namita Singh et al., 2021]



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 CO₂ emitting sector.

And within the transport sector road transport contributes more than 90 percent of the total CO₂ 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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Sources of Vehicular Emissions (2/3)

- Exhaust emissions
 - The exhaust emissions is emitted from the tailpipe as a result of incomplete combustion of fuel inside the engine chamber.

Major pollutants emitted from exhaust emissions include:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Nitrogen oxides (NO_x)
- Carbon dioxide (CO₂)
- Particulate matter (PM)



Source: (Vikas Singh et al., 2020, Image <https://www.chemistryworld.com>)



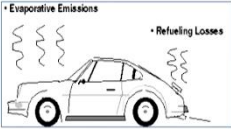
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Well, so when we talk about exhaust emissions, then the predominant those pollutants are like carbon monoxide, or oxides of nitrogen, then CO₂ is of course any kind of burning activity, fuel burning activity, ultimately CO₂ is there, because we are 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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Sources of Vehicular Emissions (3/3)

- Evaporative emissions
 - These are the emissions due to the evaporation of gasoline in the vehicles
 - For e.g., Volatile Organic Compounds (VOCs)
- Non Exhaust emissions
 - Non-exhaust emissions is either generated from the abrasion of tyres, road, and brake wear as well as from resuspension of the dust from the road surface due to vehicle-induced turbulence.
 - Major pollutants: PM₁₀ PM_{2.5} and heavy metals



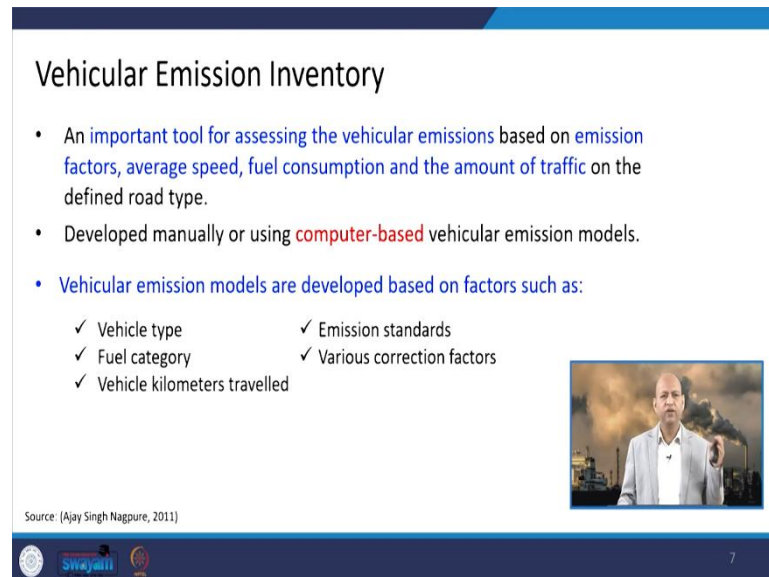
Source: (Vikas Singh et al., 2020, Image <https://ww2.arb.ca.gov>, <https://mste.illinois.edu/>)

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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 PM₁₀, 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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Vehicular Emission Inventory

- An important tool for assessing the vehicular emissions based on emission factors, average speed, fuel consumption and the amount of traffic on the defined road type.
- Developed manually or using computer-based vehicular emission models.
- Vehicular emission models are developed based on factors such as:
 - ✓ Vehicle type
 - ✓ Fuel category
 - ✓ Vehicle kilometers travelled
 - ✓ Emission standards
 - ✓ Various correction factors

Source: [Ajay Singh Nagpure, 2011]

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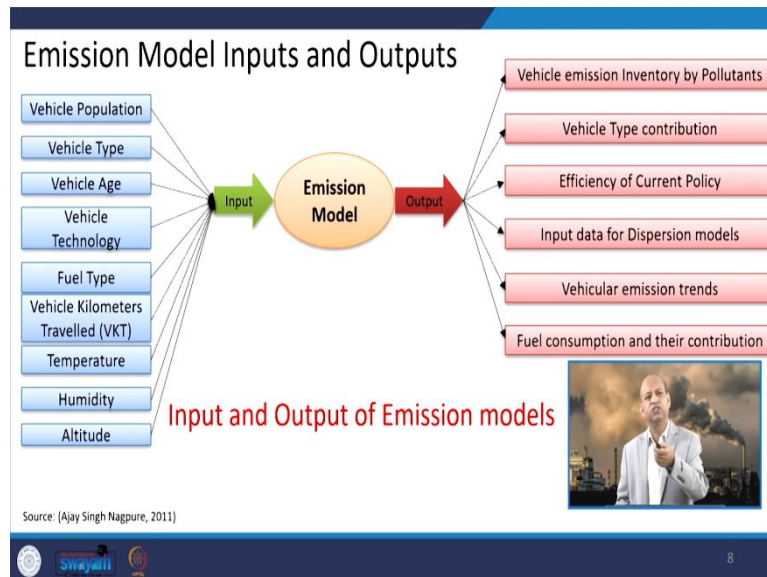
Well, so when we focus on vehicular emission inventory. So, basically we need to have different kind of input data, like what kind of vehicle it is? Whether it is light duty vehicle, heavy duty vehicle, two wheeler, three wheeler, four wheeler? Then technology two stroke and four stroke engine? So, much 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 CO₂ is emitted, how much PM₁₀ is emitted, how much CO is emitted, those kinds of things.

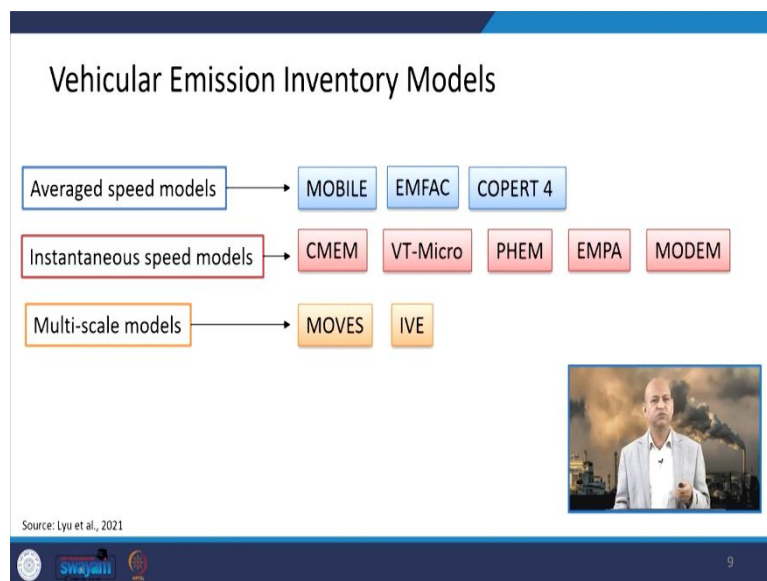
Vehicle type contribution means we know the values, which kind of vehicle is emitting how much amount of a particular pollutant, like how much PM₁₀ is coming from two wheeler, three wheeler, four wheeler, those kinds of things. Then efficiency of the current policy, because when you are implementing 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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MOBILE, USEPA (1/3) Averaged speed models

- MOBILE model series, was developed by the USEPA, for calculating emissions from highway vehicles in the U.S, **except California.**
- MOBILE 6.2 was the last version of the series, in 2004. (Later updated to MOVES series)
- Calculates emissions of HC, NO_x and CO from cars, motor vehicles, light and heavy duty vehicles.
- Superseded by the MOrtor Vehicle Emission Simulator (MOVES).

Source: [Ajay Singh Nagpure, 2011]



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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, NO_x 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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MOBILE, USEPA (2/3) Averaged speed models

- MOBILE estimates emission based on external geographical and climatic factors such as:
 - Ambient temperature
 - Humidity
 - Altitude
- Calculates basic emission rates for an average speed of 31.5 km/h for light duty gasoline vehicles, classified in terms of model year and vehicle technology.



Source: (Ajay Singh Nagpure, 2011)

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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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MOBILE, USEPA (3/3) Averaged speed models

- MOBILE computes the hot running emissions of per unit distance (e_x) in freeway and arterials as a function of travel speed for 5 mile/hr speed increments.

$$e_x = SCF (BER + EO)$$

Where,

- e_x = Emission in per unit distance
- SCF = Speed Correction factor
- BER = Basic emission rate
- EO = Emission offset, a correction factor to account for BER "off-cycle" emissions, i.e. additional emissions due to high power operation, not included in the BER.



Source: (Ajay Singh Nagpure, 2011)

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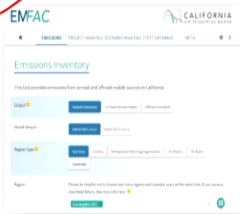

This is the basic equation, where you can see like emission in per unit distance is estimated and the speed correction factor is there, then basic emission rate is of course used and emission offsets are there which are calculated or they give the value of emission in per unit distance.

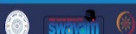
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Emission FACTor (EMFAC) model (1/3) Averaged speed models

- Emission FACTor (EMFAC) model was developed by the California Air Resources Board (CARB).
- Estimates the emission inventories of onroad mobile sources in California.
- The input to the model is provided by CALIMFAC (California Motor Vehicle Emissions Factor Model), which provides emission rates and WEIGHT to estimate vehicle activity by model year.

Source: EMFAC2021 Volume III Technical Document, 2021; <https://ww2.arb.ca.gov>


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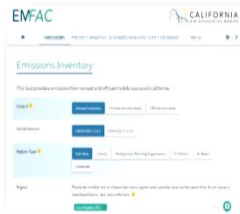

Well, you can convert that know how much distance is travelled by so many vehicles. So, you can calculate total vehicles. Now, we come to another model which is emission factor EMFAC model, EMFAC model. So, this EMFAC model was developed by California Air Resources Board. And this is provided for like 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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Emission FACTor (EMFAC) model (2/3) Averaged speed models

- The emission factors calculated from CALIMFAC are corrected in EMFAC, for several correction factors.
- The Vehicle characteristics such as VKT, number of starts, number of vehicles are provided to the EMFAC by the BURDEN model to produce the emission inventory.
- EMFAC2021 was released on January 2021.
EMFAC2021 is now available online - [EMFAC \(ca.gov\)](https://www.emfac.ca.gov)

Source: EMFAC2021 Volume III Technical Document, 2021; <https://ww2.arb.ca.gov>


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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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Emission FACTor (EMFAC) model (3/3)


Averaged speed models

- The hot running emissions in per unit distance (e_x) is calculated by the EMFAC, using the equation


$$e_x = \text{BER} \times \text{SCF} = \text{BER} \times \text{EXP}(b_1(v - 27.4) + b_2(v - 27.4)^2)$$

Where,

- e_x = Emission in per unit distance
- BER = Mean emission factor value of individual vehicle
(calculated as the total emissions (g) generated during laboratory test procedure using unified cycle length (mile))
- SCF = Speed Correction Factors, developed from 12 driving cycles,
- b_1 and b_2 = model parameters, v = speed expressed as mile/hour



Source: EMFAC2021 Volume III Technical Document, 2021; <https://ww2.arb.ca.gov>


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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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Averaged speed models

Computer Program to Calculate Emission from Road Traffic (COPERT) (1/2)

- The Computer Program to Calculate Emission from Road Traffic (COPERT) is developed by the European Environment Agency (EEA).
- The Core Inventory of Air Emissions (CORINAIR) working group, the first European initiative to tackle road traffic emissions was later transformed to COPERT in 1989.
- COPERT version 5.5.1 is the latest update of the model released on September 2021.

Source: (EEA, <https://www.eea.europa.eu>)



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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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Averaged speed models

Computer Program to Calculate Emission from Road Traffic (COPERT) (2/2)

- COPERT computes the hot running emissions, evaporative emissions and non exhaust emissions from brakes and tyres.
- Includes 105 Vehicle categories belonging to 5 vehicle classes such as cars, light and heavy duty vehicles, urban buses and coaches and two wheelers.
- Estimates pollutants such as CO, NO_x, VOC, CH₄, CO₂, N₂O, NH₃, SO_x, diesel exhaust particulate matter (PM), PAHs, and POPs, Dioxins, Furans and heavy metals contained in the fuel such as Lead, Cadmium, Copper, Chromium, Nickel, Selenium and Zinc.

Source: (EEA, <https://www.eea.europa.eu>)



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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, NO_x, VOCs, methane, CO₂ and N₂O, NH₃, ammonia SO_x. 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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Instantaneous speed models

Comprehensive Modal Emissions Model (CMEM) (1/3)

- The Comprehensive Modal Emissions Model (CMEM) was developed by **National Cooperative Highway Research Program (NCHRP)**.
- The model evaluate the emission pollutants of **CO, CO₂, HC, NO_x**, and **PM**, as well as fuel consumption.
- The main purpose of the CMEM is to **predict vehicle tailpipe emissions** associated with **different modes of vehicle operation**, such as idle, cruise, acceleration, and deceleration.


Source: NCHRP, 2000; Image: <https://www.cert.ucr.edu/cmemy/cmemy-model>

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Averaged speed models

Computer Program to Calculate Emission from Road Traffic (COPERT) (2/2)

- COPERT **computes the hot running emissions, evaporative emissions and non exhaust emissions** from brakes and tyres.
- Includes **105 Vehicle categories** belonging to **5 vehicle classes** such as cars, light and heavy duty vehicles, urban buses and coaches and two wheelers.
- Estimates pollutants such as **CO, NO_x, VOC, CH₄, CO₂, N₂O, NH₃, SO_x, diesel exhaust particulate matter (PM), PAHs, and POPs, Dioxins, Furans and heavy metals** contained in the fuel such as **Lead, Cadmium, Copper, Chromium, Nickel, Selenium and Zinc**.



Source: (EEA) <https://www.eea.europa.eu>

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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, CO₂, hydrocarbons, NO_x, 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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Instantaneous speed models

Comprehensive Modal Emissions Model (CMEM) (2/3)

- Second-by-second vehicle tailpipe emissions are modeled as the product of three components:


$$\text{tailpipe emissions} = FR \times \left(\frac{g_{\text{emission}}}{g_{\text{fuel}}} \right) \times CPF$$

FR = fuel rate (FR) in grams/seconds

$\frac{g_{\text{emission}}}{g_{\text{fuel}}} = \text{engine-out emission index}$ is grams of engine-out emissions per gram of fuel consumed.

CPF = time-dependent catalyst pass fraction, the ratio of tailpipe to engine out emissions.

Source: NCHRP, 2000



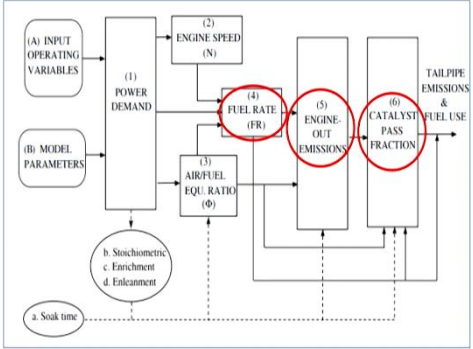
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Well, then, you come to this particular other part of the CMEM model. So, this is the basic equation which is used for emissions estimations and different input parameters are their CPF like time dependent catalyst, past fraction is there, the rate 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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Instantaneous speed models

Comprehensive Modal Emissions Model (CMEM) (3/3)



The flowchart illustrates the process of estimating emissions. It starts with (A) INPUT OPERATING VARIABLES and (B) MODEL PARAMETERS, which lead to (1) POWER DEMAND. (1) POWER DEMAND is influenced by (2) ENGINE SPEED (N) and (3) AIR/FUEL EQU. RATIO (ϕ). (1) POWER DEMAND leads to (4) FUEL RATE (FR). (4) FUEL RATE (FR) leads to (5) ENGINE-OUT EMISSIONS. (5) ENGINE-OUT EMISSIONS leads to (6) CATALYST PASS FRACTION. (6) CATALYST PASS FRACTION leads to TAILPIPE EMISSIONS & FUEL USE. The flowchart also includes a sub-process for (3) AIR/FUEL EQU. RATIO (ϕ) involving (b) Stoichiometric, (c) Enrichment, and (d) Enleanment, which is influenced by (a) Soak time.

Source: NCHRP, 2000



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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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Instantaneous speed models

Virginia Tech microscopic vehicle fuel consumption and emission model (VT-Micro)

- The model is used to calculate emissions of HC, CO, NO_x, and CO₂, and the fuel consumption with second-by-second vehicle characteristics.
- This model typically utilizes the instantaneous speed and acceleration to represent the characteristics of vehicle operation modes.
- Based on the tests of the emission rates, and fuel consumption for eight light-duty passenger cars and trucks.



Source: Lyu et al., 2021

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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, NO_x, CO₂ 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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Instantaneous speed models

EMPA

- EMPA is based on a mathematical model.
- Developed by “Handbook Emission Factors for Road Transport” (HBEFA) and the former European ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) and PARTICULATES projects.
- It uses advanced measurement and modeling techniques, and the solving of a series of differential equations, it is possible to estimate emissions from individual vehicles over short time scales.



Source: Lyu et al., 2021

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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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Instantaneous speed models

EMPA

Limitations

- EMPA models **do not include the dynamic behaviour** of the engine.
- Inclusion of a catalyst model should lead to improvements in the existing model.
- The main disadvantage of the model is that it has been developed only for LDV (Light Duty Vehicle)



Source: Lyu et al., 2021

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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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Instantaneous speed models

Passenger car and Heavy-duty Emission Model (PHEM)

- The "Passenger car and Heavy duty Emission Model" PHEM was developed at the [Graz University of Technology, Austria \(TU Graz\)](#)
- Following versions are available:
 - **PHEM Basic**: simulation of single vehicles
 - **PHEM Advance**: interface with micro traffic models and automated allocation of the vehicles to user defined shares in mileage
 - **PHEM Batch**: automated simulation of lists of vehicles with a list of driving cycles, as used for the HBEFA (Handbook Emission Factors for Road Transport)



Source: Graz University of Technology (TU Graz), 2009

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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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Instantaneous speed models

Passenger car and Heavy-duty Emission Model (PHEM)

Data inputs

- Passenger Cars (diesel, gasoline, EURO 0 to EURO 6d)
- Light Duty Vehicles (diesel, gasoline, EURO 0 to EURO 6d)
- Heavy Duty Vehicles (diesel, EURO 0 to EURO VI, split into weight categories)
- Buses
- Coaches



Source: Graz University of Technology (TU Graz), 2009

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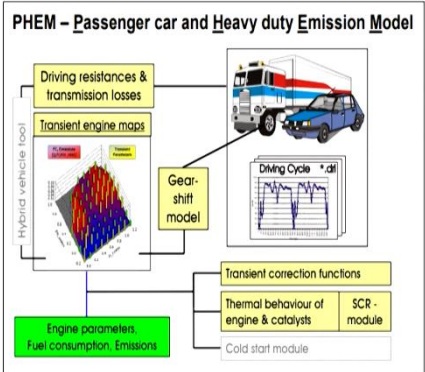
Some input values like passenger cars, diesel or gasoline-based, which is the norms EURO-0 to EURO-6d, those kind of versions of emission norms can be incorporated. Light-duty vehicles, heavy-duty vehicle, buses, coaches all those kinds of things can be incorporated into it.

(Refer Slide Time: 20:04)

Instantaneous speed models


Passenger car and Heavy-duty Emission Model (PHEM)

PHEM – Passenger car and Heavy duty Emission Model



Scheme of the emission model PHEM for the simulation of HBEFA (Handbook Emission Factors for Road Transport) emission factors

SCR - Selective Catalytic Reduction



Source: Graz University of Technology (TU Graz), 2009

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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.

(Refer Slide Time: 20:18)

Modeling of emissions and consumption in urban areas (MODEM)

- **MODEM** (Modeling of emissions and consumption in urban areas) is an **instantaneous emission model** that produced during **DRIVE (Dedicated Road Infrastructure for Vehicle safety in Europe)** programme of the European Commission.
- The model is capable of estimating fuel consumption and emissions of **CO, HC, NOx and CO₂**.
- **Limitation:** MODEM is not capable of estimating cold start emissions, evaporative emissions, emissions from HDV and motorcycles, or emissions of particulate matter (PM₁₀), benzene and 1,3-butadiene.



Source: Saharidis et al., 2018



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 CO₂. 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.


(Refer Slide Time: 21:08)

Multi-scale models

MOTOR Vehicle Emission Simulator (MOVES) (1/2)

- MOTOR Vehicle Emission Simulator (MOVES) is currently the state-of-the-science emission system of the USEPA.
- Estimates emissions for mobile sources across the U.S **except California**, for air pollutants, GHGs and air toxics.
- MOVES3 is the latest version of the MOVES.
 - Follows MOVES2010 and MOVES2014 versions.

Source: (USEPA, <https://www.epa.gov/moves>)



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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.


(Refer Slide Time: 21:31)

Multi-scale models

MOTOR Vehicle Emission Simulator (MOVES) (2/2)

- Estimates different types of emissions such as:
 - Engine running, startling, hoteling (extended idling), evaporative, brake and tyre emissions.
- The input to MOVES model includes:
 - Default National averages such as Vehicle counts, Vehicle Miles Travelled (VMT), temperature, fuel, location and country specific inputs etc.

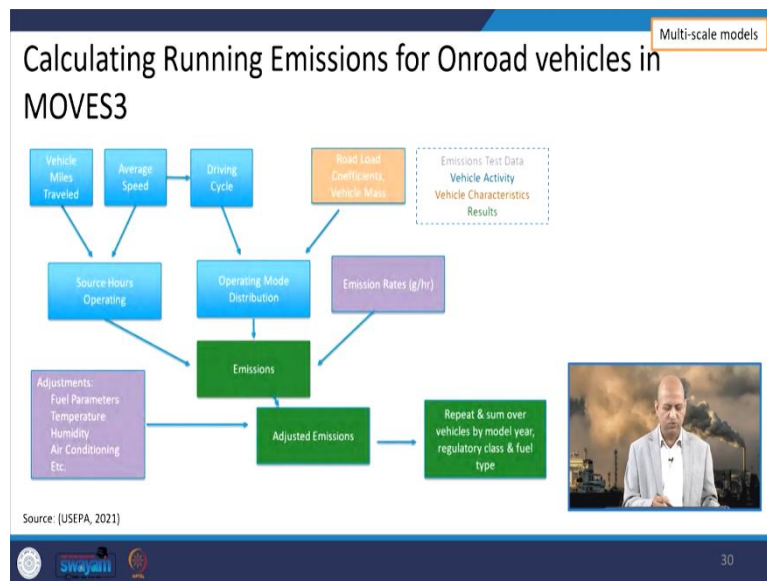
Source: (USEPA, <https://www.epa.gov/moves>)



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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.

(Refer Slide Time: 21:59)



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.

(Refer Slide Time: 22:16)

Multi-scale models

International Vehicle Emissions (IVE) model (1/2)

- Developed jointly by the University of California at Riverside, College of Engineering- Center for Environmental Research and Technology (CE-CERT), Global Sustainable Systems Research (GSSR) and the International Sustainable Systems Research Center (ISSRC).
- Funded by the USEPA.
- Takes into account various technologies and conditions that exist in the developing countries such as vehicle driving patterns, vehicle specific power (VSP), Engine stress distributions etc.

Source: (Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org))

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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.

(Refer Slide Time: 22:43)

Multi-scale models

International Vehicle Emissions (IVE) model (2/2)

- **Inputs to the model includes:**
 - Type and age of vehicle fleet
 - Local conditions such as ambient temperature and pressure
 - Fuel specifications
- **Estimates Criteria pollutants, GHGs and toxic pollutants.**
- **Pollutants includes** CO, VOC, NO_x, PM_{2.5}, PM₁₀, CO₂, N₂O, CH₄, NH₃, Benzene, Lead, 1-3 Butadiene and Aldehydes.



Source: (Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org))

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And it can estimate emissions for a range of different pollutants like PM_{2.5}, NO_x 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.

(Refer Slide Time: 23:09)

Multi-scale models

Basic Equations in IVE model (1/3)

Where,

$B_{[t]}$ = Base emission rate in for each technology (start (g) or running (g/km))

$Q_{[t]}$ = Adjusted emission rate for LDCVs running (g)

Q = Average emission rate for entire fleet (running (g))

$f_{[t]}$ = Fraction of travel by specific technology

$f_{[dt]}$ = Fraction of each type of driving or soak by specific technology

$U_{[FTP]}$ = Average velocity from the specific driving cycle as input by user in location (kph)

$K_{[base][t]}$ = Adjustment to the base emission rate

$K_{[Temp][t]}$ = Temperature Correction Factor

$K_{[Humd][t]}$ = Humidity Correction Factor

$K_{[Alt][t]}$ = Altitude Correction Factor

$K_{[Fuel][t]}$ = Fuel quality Correction Factors

$K_{[IM][t]}$ = Inspection/Maintenance Correction Factors


$K_{[Cntry][t]}$ = Country Correction Factors

$B_{[t]}$ = Base emission rate in for LDCVs running (g/km)

D = Distance travelled by LDCV in one day (km)

E_i = Emission of compound i (CO, NO_x, VOC)

$K_{[dt]}$ = Driving Correction Factor



Source: (Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org))

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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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Multi-scale models


Basic Equations in IVE model (2/3)

- Can estimate emissions from a single roadway or an entire area for specific time periods.
- Based on 2 basic equations:

$$Q_T = B_{(t)} \times K_{(base)(t)} \times K_{(temp)(t)} \times K_{(Hmd)(t)} \times K_{(IM)(t)} \times K_{(Alt)(t)} \times K_{(Cntry)(t)}$$

Equation 1

- **Equation 1** estimates the adjusted emission rate by multiplying the base emission rates by various Correction factors.



Source: (Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org))

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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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Multi-scale models


Basic Equations in IVE model (3/3)

$$Q_{Running} = U_{[FTP]} \times D/Uc \times \sum_t \{f_{[t]} \times Q_{[t]} \times \sum_d \{f_{[dt]} \times K_{[dt]}\}$$

Equation 2

- **Equation 2** weights the adjusted emission rate by the travel fraction for each technology and amount of each driving type of each technology.
- **Final step in Equation 2** is to multiply these results by the ratio of the average velocity of **LA-4 driving cycle** and average velocity of the modeled cycle and multiply by the distance travelled (for running emissions only).
- Result is the overall fleet running emissions for allocated time or distance (in grams).

The U.S. FTP-72 (Federal Test Procedure) cycle is also called Urban Dynamometer Driving Schedule (UDDS) or **LA-4 cycle**



Source: (Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org))

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Multi-scale models


Basic Equations in IVE model (2/3)

- Can estimate emissions from a single roadway or an entire area for specific time periods.
- Based on 2 basic equations:

$$Q_T = B_{(t)} \times K_{(base)}(t) \times K_{(temp)}(t) \times K_{(Hmd)}(t) \times K_{(IM)}(t) \times K_{(Alt)}(t) \times K_{(Cntry)}(t)$$

Equation 1

- **Equation 1** estimates the adjusted emission rate by multiplying the base emission rates by various Correction factors.



Source: [Nicole Davis et al., 2004, International Vehicle Emissions Model (issrc.org)]


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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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Limitations of these emission models for Indian scenario (1/2)

- All major models like MOBILE, MOVES, COPERT etc. are developed in developed countries such as US, Japan, Australia etc.
 - Extensive data set are available in those countries.
 - Difference in technology, infrastructure, driving cycle in comparison with Indian scenario.
- Emission factor or basic emission rate of emissions for all models are US and Europe based.
 - Enhance the error in model emission outputs for use in Indian scenario.



Source: [Ajay Singh Nagpure, 2011]

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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.

(Refer Slide Time: 24:27)

Limitations of these emission models for Indian scenario (2/2)

- IVE model was designed for developing countries similar to India.
 - However, the complexity of the model is similar to the US and European models, which needs extensive data requirements.
 - Difficult to compile such complex datasets in Indian scenario.
- Most models are not able to give output for more than a year.
- Most models require experimental data, which are not available for Indian conditions.
- Most models are region specific.



Source: (Ajay Singh Nagpure, 2011)


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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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The Vehicular Air Pollution Inventory (VAPI) Model

- The VAPI model is designed specifically for developing countries like India.
- VAPI model have incorporated Climatic correction factors, making the estimations more realistic and region specific.
- The VAPI model estimations show fair agreement with the air quality observations in India.
- The model is simple to use and is available in public domain.



Source: (Ajay Singh Nagpure, 2011)

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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.

(Refer Slide Time: 25:06)

Assumptions in the VAPI model

- The growth in vehicles per 1000 persons over time is assumed to follow a Sigmoidal (S-shaped) relationship.
- One car plus two wheelers per family are assumed to be the Saturation level.
 - Ex. In Delhi, a typical family size is of 5 members. Hence, each family is assumed to have a car and a two-wheeler.
- The seating capacities of auto-rickshaws and taxis are 3 and 5 respectively, implying that the saturation levels per 1000 persons are assumed to be 330 and 200 respectively.

Source: [Ajay Singh Nagpure, 2011]



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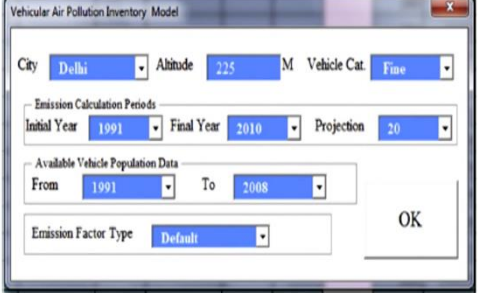
So, this was developed in IIT Roorkee as a PhD thesis and now it is popular and many people are using and for small cities to mega cities, you can it has a lot of flexibility in that sense. And you can go for like estimation of different future scenarios also, like how many vehicle population will be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

(Refer Slide Time: 25:33)


Basic Inputs to the VAPI model

Requires basic data such as:

- City
- Vehicle category types
- Emission inventory period
- Projection year
- Available data and emission factor type



Source: [Ajay Singh Nagpure, 2011]



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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.

(Refer Slide Time: 26:08)

Other Inputs to the model

Other inputs to the model required data such as:

- **Vehicle types** (Vehicle population information such as vehicle model, technology, emission control, fuel used etc.)
 - Broad categories
 - Fine categories
- **GDP/PCI** (Used to estimate future vehicle population)
- **Phasing out age** of vehicles
- **Population** (For estimating future vehicle population)
- **Vehicle ownership saturation level**
- **Vehicle Kilometer Travel (VKT)**
- **Temperature/Humidity/Altitude** (Correction factors)

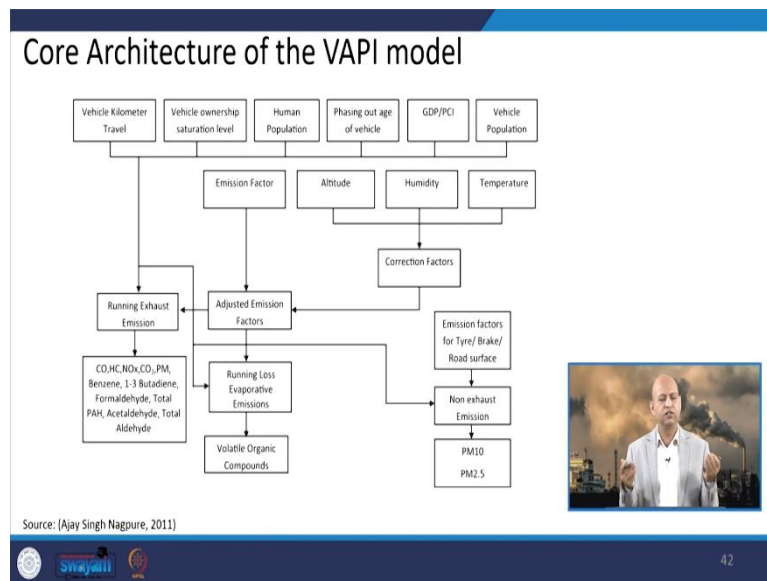


Source: [Ajay Singh Nagpure, 2011]

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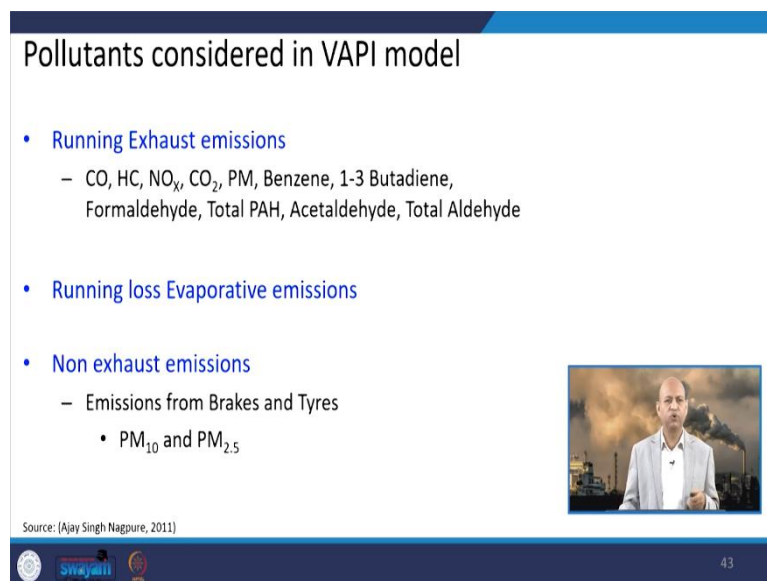
So, other input values for this particular model are needed like vehicle type broad categories, fine categories depending upon their categories. Then phasing out age of the vehicles after which age this is taken out of the road, then these GDP or purchasing power or income of the people. Then population 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.

(Refer Slide Time: 26:48)



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.

(Refer Slide Time: 27:00)



Well, when we talk about like running exhaust emissions. So, carbon monoxide, hydrocarbons, NO_x, 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, PM₁₀, PM_{2.5}, these emissions can easily be estimated depending upon which emission factors you have.

(Refer Slide Time: 27:32)

Running Exhaust emissions

$$EF_{p,i} = EF_{p,i} \times CT_{p,i} \times C_{H,p,i} \times C_{A,p,i}$$

$$E_{t,p,i} = P_i \times EF_{p,i} \times V_i \times D_{t,i}$$


The **main concept** in calculating the running exhaust emissions in the VAPI model is to apply an emission factor with climatic and geographical correction factors.

Where,

- $D_{t,i}$ = Annual travelling days of i vehicle category
- $E_{a,p,i}$ = Adjusted emission rate of pollutant p from i vehicle category
- $EF_{p,i}$ = Emission factor of pollutant p from i category (g or mg km⁻¹)
- $E_{p,i}$ = Total emissions of pollutant p from i vehicle category (unit depends on EF unit)
- $C_{t,p,i}$ = Temperature correction factor of pollutant p of vehicle i category
- $C_{h,p,i}$ = Humidity correction factor of pollutant p of vehicle i category
- $C_{a,p,i}$ = Altitude correction factor of pollutant p of vehicle i category
- P_i = On-road Population (model wise) of i vehicle category (numbers)
- V_i = Per day distance travel (km day⁻¹) by i vehicle category

Equation 1

Equation 2



Source: [Ajay Singh Nagpure, 2011]

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.

(Refer Slide Time: 27:54)

Climatic Correction factors

Temperature Correction factor

$$C_{T,p,i} = \left[\left(\frac{C_{p,i,High}}{C_{p,i,Low}} \right)^{\frac{1}{(High-Low)}} - 1 \right] \times 100$$

$$C_{T,p,i} = C_{Low} \times (1 + C_{TC})^{(t-Low)}$$

Humidity Correction factor

$$C_{H,p,i} = \left[\left(\frac{C_{p,i,80\%}}{C_{p,i,20\%}} \right)^{\frac{1}{(80-20)}} - 1 \right] \times 100$$

$$C_{H,p,i} = C_{20\%} \times (1 + C_{HC})^{(h-20)}$$

$C_{T,p,i}$ = Growth rate of correction factor according to low and high temperature of pollutant p of i vehicle category

$C_{p,i,High}$ = Correction factor in high temperature (t) (40 °C) of pollutant p of i vehicle category

$C_{p,i,Low}$ = Correction factor at low temperature (t) (4 °C) of pollutant p of i vehicle category

tHigh = High temperature (t) (40 °C)

tLow = Low temperature (t) (4 °C)


t = Ambient temperature (t in °C)

$C_{H,p,i}$ = Growth rate of correction factor according to 20% and 80% humidity of pollutant p of i vehicle category

$C_{p,i,80\%}$ = Correction factor at 80% humidity (8%) of pollutant p of i vehicle category

$C_{p,i,20\%}$ = Correction factor at 20% humidity (8%) of pollutant p of i vehicle category

h = Ambient humidity (%)



Source: [Ajay Singh Nagpure, 2011]

So, you can see different correction factors, empirical 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.

(Refer Slide Time: 28:13)

Geographical Correction factors

Altitude Correction factor


$$C_{A_{p,i,C}} = \left[\left(\frac{C_{p,i@1700\text{ m}}}{C_{p,i@950\text{ m}}} \right)^{\frac{1}{(1700-950)}} - 1 \right] \times 100$$

Equation 7

$$C_{A_{p,i}} = C_{a@950\text{ m}} \times (1 + C_{A_{p,i,C}})^{(a-950)}$$

Equation 8

$C_{A_{p,i,C}}$ = Growth rate of correction factor according to 950 m and 1700 m of pollutant p of i vehicle category
 $C_{p,i@1700\text{ m}}$ = Correction factor at 1700 m altitude (m) of pollutant p of i vehicle category
 $C_{p,i@950\text{ m}}$ = Correction factor at 950 m altitude (m) of pollutant p of i vehicle category
 a = altitude (m)



Source: (Ajay Singh Nagpure, 2011)

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 Characteristics (1/2)

On-road Vehicle population, vehicle projections and phasing out of vehicles included in VAPI model.

Vehicle population

- Present and past registered vehicles are considered in the VAPI model

The onroad vehicle population for a year is found out by projecting the vehicle population for the past year (Eq. 9 & 10) and then subtracting from the cumulative registered vehicle population upto that year (Eq. 11)

$$X_{Pop,i} = \left[\left(\frac{RPop_{i,Final}}{RPop_{i,Initial}} \right)^{\frac{1}{y}} - 1 \right] \times 100$$

$X_{Pop,i}$: Average geometric rate of annual growth of population (Pop) of i vehicle category
 $RPop_{i,Initial}$: Registered population of i vehicle category at the initial year of the period
 $RPop_{i,Final}$: Registered population of i vehicle category at the final year of the period
 y : length of time (years) between the initial year and final


$$RPop_{i,Final} = RPop_{i,Initial} \times (1 + X_{Pop,i})^y$$

Equation 10

$$Pop_i = RPop_{i,C} - RPop_{i,C-Z}$$

Pop_i = Total on-road population of i vehicle category.
 $RPop_{i,C}$ = Registered population of i vehicle category at current year C.
 $RPop_{i,C-Z}$ = Registered population of i vehicle category, in current year minus phasing out age of vehicle where Z is the phasing out age of vehicle.

Equation 11



Source: (Ajay Singh Nagpure, 2011)

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

(Refer Slide Time: 28:31)

Vehicle Characteristics (2/2)

Vehicle population projection


- Vehicle population is based on the GDP and per capita income.
- The Gompertz model is used, in the VAPI model.

Gompertz model

$$V_{pt} = \lambda e^{\alpha e^{\beta G}} \quad \text{Equation 12}$$

Where, λ is the saturation level (measured in vehicles per 1000 people), G is GDP or per capita income and α (slope) and β (Intercept) are parameters, which define the shape or curvature of the function. The parameter values α and β are calculated by

$$\alpha = \frac{n(\sum GP_{it}) - (\sum G)(\sum P_{it})}{n(\sum (G^2) - (\sum G)^2)} \quad \text{Equation 13}$$

$$\beta = \frac{(\sum P_{it})(\sum (G^2)) - (\sum G)(\sum GP_{it})}{n(\sum (G^2) - (\sum G)^2)} \quad \text{Equation 14}$$


Source: [Ajay Singh Nagpure, 2011]

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

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Vehicle model wise Calculation

Base emission factors are based on vehicle age and model year

Registered vehicle population in a year

$$RPop_{m,j} = RPop_{m,c} - RPop_{m,c-1} \quad \text{Equation 15}$$


Where

$RPop_{m,j}$ = Each year newly registered (model wise) population of i category vehicle.
 $RPop_{m,c}$ = Population of i category vehicle in current year c
 $RPop_{m,c-1}$ = Population of i category vehicle in previous (current year-1) years

Percentage of vehicle model present in a year

$$\%RPop_{m,j} = \frac{RPop_{m,j}}{RP_{c,i}} \times 100 \quad \text{Equation 16}$$

$\%RPop_{m,j}$ = Vintage/Model year wise percentage of population of i category vehicle in each year.
 After getting percentage of model wise vehicle population for registered vehicle population in each year this percentage is applied for on-road vehicles

$$Pop_{m,j} = \frac{Pop_{m,c} \times \%RPop_{m,j}}{100} \quad \text{Equation 17}$$


Source: [Ajay Singh Nagpure, 2011]

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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.

(Refer Slide Time: 28:56)

Running Evaporative emissions


- Running losses from petrol vehicles are largest compared to other sources.
 - Ex. Diurnal emissions, hot soak emissions and resting losses.
- VAPI model calculates the Evaporative adjusted emission factor from the equation:

$$E_{a,p,i} = EF_{p,i} \times CT_{p,i} \times C_{A,p,i}$$

Equation 18

Vehicular evaporative emissions are the largest contributors to the total evaporative emissions of VOCs.

Running losses are the result of vapor generated in gasoline tanks during vehicle operations.



Source: (Ajay Singh Nagpure, 2011)

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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.

(Refer Slide Time: 29:06)

Non-Exhaust emissions


- Non-exhaust PM from road traffic is generated mechanically by abrasion (wear) of tyre, brake, and road pavement and by the resuspension process of road dust
- VAPI model calculates the Non exhaust emissions using the equation:

$$E_{tpi} = P_i \times E_{p_i} \times V_i \times D_i$$

Equation 19

Where,

- D_i = Annual travelling days of I vehicle category in year
- EF_{p_i} = Emissions factor of pollutant p from I vehicle category (g or mg km⁻¹)
- E_{p_i} = Total emissions of pollutant p from I vehicle category (unit depends on EF unit)
- P_i = Pollution of I vehicle category
- V_i = Per day distance travel (km day⁻¹) by I vehicle category



Source: (Ajay Singh Nagpure, 2011)


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

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Model	Type	Origin	Advantages	Disadvantages/Limitations
MODEM	Modal/ instantaneous	DRIVE project	<ul style="list-style-type: none"> • Easy to use - only user requirements is driving pattern. • Capable of estimating fuel consumption and CO, HC, NOx and CO2 emissions on a second-by-second basis 	<ul style="list-style-type: none"> • Includes only legislative class of vehicles EURO I • Not capable of estimating: <ul style="list-style-type: none"> ✓ cold start emissions, ✓ evaporative emissions, ✓ emissions from HDV and motorcycles, ✓ emissions of PM10, benzene and 1,3-butadiene
PHEM	Modal/ instantaneous	RTEMIS & COST Action 346	<ul style="list-style-type: none"> • Easy to use - only user requirements is driving pattern and vehicle characteristics • New types of engines are included (e.g., EURO V for HDV, EURO IV for passenger cars and LCV), as well as perspective for up to EURO VI for any type of vehicle 	<ul style="list-style-type: none"> • Assessment of the emission behaviour of engines meeting EURO IV, V and VI standards is highly uncertain. • The effects of the new technologies used to meet the type approval limits are difficult to predict, and extrapolating emission factors from older engine technologies to future standards according to the future emission limits is not a suitable approach


Source: Saharidis et al., 2018



Summary of models main characteristics (1/5)

Model	Type	Origin	Advantages	Disadvantages/Limitations
VeTESS	Modal/ instantaneous	DECADE project	<ul style="list-style-type: none"> • Innovative mathematical technique, that "looks up" each emissions value from the corresponding engine map • Model is suited to the analysis of individual cases 	<ul style="list-style-type: none"> • Modeling technique considers only one vehicle at a time and one journey at a time. Precise journey details need to be known. Although this method tries to take into account the transient generation of emissions, the prediction quality is not satisfactory
CMEM	Modal/ instantaneous	NCHRP	<ul style="list-style-type: none"> • It inherently handles all the factors which affect emissions. • It can be used with both micro-scale and macro scale vehicle activity characteristics. • It can handle average vehicle activity characteristics such as average speed, peak average speed and idle time. • It is transparent, and its results can be easily dissected for evaluation. 	<ul style="list-style-type: none"> • The model is highly complex due to the large amount of data required. • Too high degree of parameterisation may complicate the modeling process and can substantially accumulate errors. • Developed in the United States, it is not wholly appropriate to apply it to the European vehicle fleet.

Source: Saharidis et al., 2018



Summary of models main characteristics (2/5)


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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Model	Type	Origin	Advantages	Disadvantages/Limitations
ADVISOR	Model/instantaneous	US Department of Energy and the US National Renewable Energy Laboratory	<ul style="list-style-type: none"> • Tool with a wide range of capabilities, e.g.: <ul style="list-style-type: none"> ✓ estimate the fuel economy of concept vehicles ✓ compare tailpipe emissions produced on a number of cycles and different conditions ✓ optimize the gear ratios in transmission to minimize fuel use or maximize performance, etc. It inherently handles plenty of the factors which affect emissions 	<ul style="list-style-type: none"> • It is empirically based. Relies on drive train component input/output relationships measured under laboratory conditions, and data collected in steady state (e.g. constant torque and speed) tests. Usually used to simulate single-vehicle responses. Does not include HDV
MOVES	Multi-scale emission model	US EPA	<ul style="list-style-type: none"> • easy to use • complete and accurate model to use. • Includes evaporative emissions calculations. • HDV are also examined. 	<ul style="list-style-type: none"> • Compared to volumes of data available for LDV, the amount of data available for HDV is small • The main disadvantage of the model is that it has been developed in the United States, it is not wholly appropriate to apply it to the European vehicle fleet red to volumes of data available for LDV, the amount of data available for HDV is small • The main disadvantage of the model is that it has been developed in the United States, it is not wholly appropriate to apply it to the European vehicle fleet.

Source: Saharidis et al., 2018




Summary of models main characteristics (3/5)

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

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Model	Type	Origin	Advantages	Disadvantages/Limitations
COPERT (4)	Average Speed Model	PARTICULATES, COST 319 Action, MEEI, ARTEMIS, CORINAR	<ul style="list-style-type: none"> • Its method balances the need for detailed emission calculations on one hand and use of vehicles that we don't have detailed information as for example the exact driving patterns (only main characteristics are known such as number of stops, idle time, mean speed) and exact type of the vehicle (only the exact category/ies is known) few input data on the other • The method can also be used with a sufficient degree of certainty at a higher resolution • It is continually updated • Include all major pollutants from exhaust emissions, as well as non-exhaust PM emissions • Tier 3 method can be used when it is necessary to calculate the emission produced by a fleet. 	<ul style="list-style-type: none"> • Does not to include other parameters in the estimation of an emission factor (such as mean positive acceleration, or speed variation) • There is still an issue regarding emissions from light duty trucks, as the ARTEMIS failed to develop reliable emission factors for these vehicles. • There is not good information for upcoming vehicle emission standards, such as the new vehicle technologies at Euro VI for HDV.
VERSIT +	Suite of models (Multiple Linear Regression Model & Average Speed Model)	1987 VERSIT	<ul style="list-style-type: none"> • This suite of models is capable of predicting emission factors and energy use factors that are representative for vehicle fleets in different countries. Emission factors are differentiated for various vehicle types and traffic situations, and take into account real-world driving conditions. 	<ul style="list-style-type: none"> • Requires a relatively detailed driving pattern, and it could be very complex

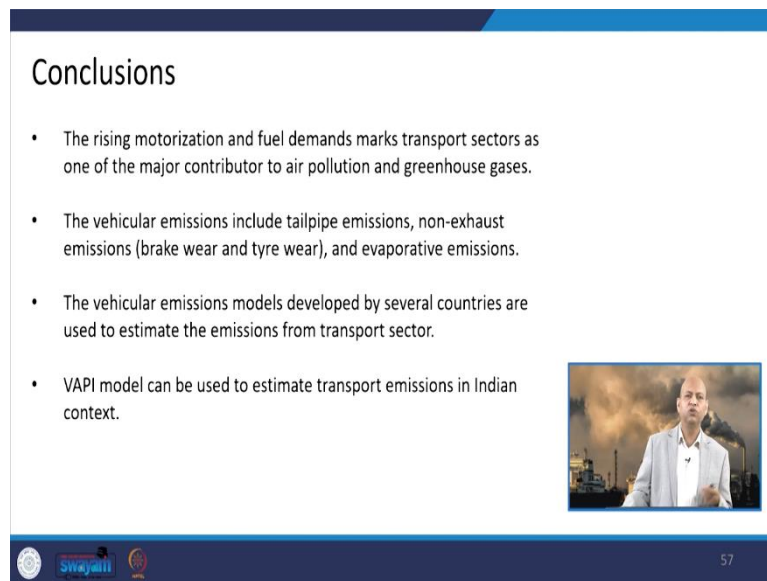
Source: Saharidis et al., 2018



Summary of models main characteristics (5/5)


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


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Conclusions

- The rising motorization and fuel demands marks transport sectors as one of the major contributor to air pollution and greenhouse gases.
- The vehicular emissions include tailpipe emissions, non-exhaust emissions (brake wear and tyre wear), and evaporative emissions.
- The vehicular emissions models developed by several countries are used to estimate the emissions from transport sector.
- VAPI model can be used to estimate transport emissions in Indian context.



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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.