Sustainable Transportation Systems
Professor Bhola Ram Gurjar
Department of Civil Engineering
Indian Institute of Technology Roorkee
Lecture 34
Life Cycle Assessment (Theory and Practice)

Hello friends. You may recall that last time we discussed about introductory parts or fundamentals of life cycle assessment. So in continuity of that today we will discuss a little bit more theory but practice also. How to implement the LCA theory to make some decisions or to come up with some scenario based analysis and to know better perspective about different situations.

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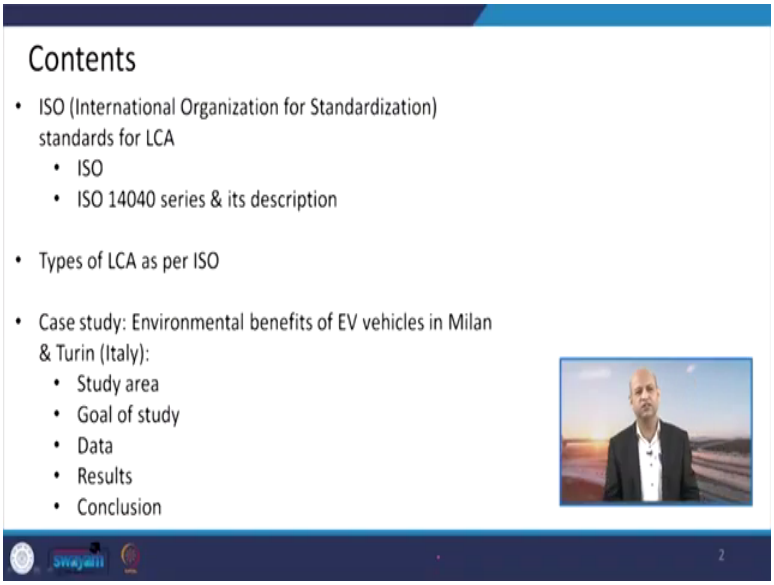

So the contents of today's lecture is basically like this ISO international organization for standardization standards for LCA that is which standards of ISO are related to LCA. So simple ISO plus ISO 14040 series and its little bit brief description we will have and the types of LCA as per ISO, means ISO, how LCA has been defined or different kind of LCA procedures have been described or classified.

After that we will see a case study which will give you better picture or better perspective about how this LCA is implemented to learn about certain situations. So that will be focused on, the case study will be focused on environmental benefits of electric vehicles in Milan and Turin,

these two cities of Italy. And study area, then goal of study, data, results, conclusions, all these things will be part of that case study.

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So let us begin with this ISO related information regarding LCA life cycle assessment and ISO as you know this is one organization which is non-governmental but several countries really are member of that one. This is not purely government, but several governments become members and become part of that. So that its autonomy and independence is protected and also countries have some sort of obligation to follow up those standards or those guidelines which ISO develop from time to time.

So it gives basically some voluntary or consensus based and also the market relevant, because technology changes, market scenario changes, trading and all these things change from time to time. So as per the new realities they develop certain guidelines and consensus based standards, which can support for innovation and that can also provide some sort of solutions for the particular global changes, which are part of the new developments. And it was established in 1947 and after that it is giving standards related guidelines as well as policy frameworks.

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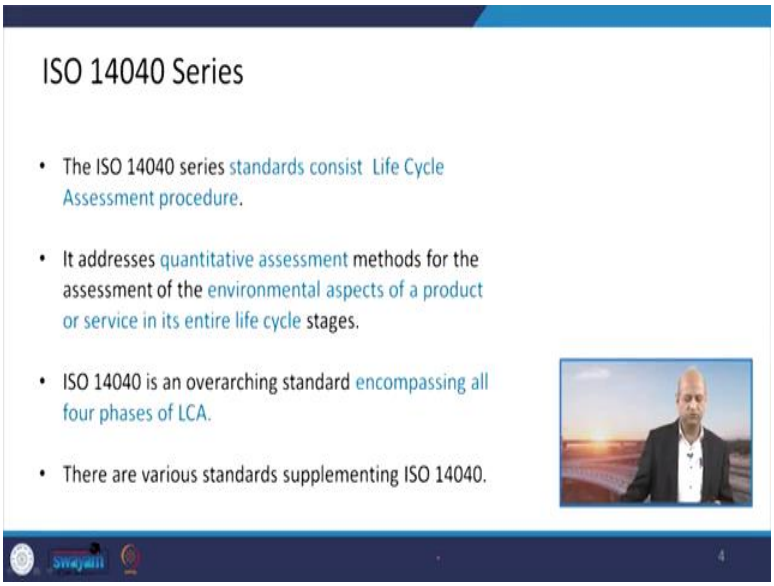

So they have developed several standards basically ISO have given standards for every kind of activity from business to education to any other aspect of our socioeconomic activities. So ISO 14040 series that is basically related to standards which consists of life cycle assessment procedure, and it addresses the quantitative assessment methods, which are used for the assessment of environmental aspects of a particular product or a service during its entire life cycle.

Different stages of that entire life cycle of a product or service, so what is the methodology which is to be used for LCA. So this particular series gives us the step by step information and then this ISO 14040 is a kind of umbrella or overachieving standard encompassing four important phases of the LCA and there are various other standards which supplement to this main standard of ISO related to LCA.

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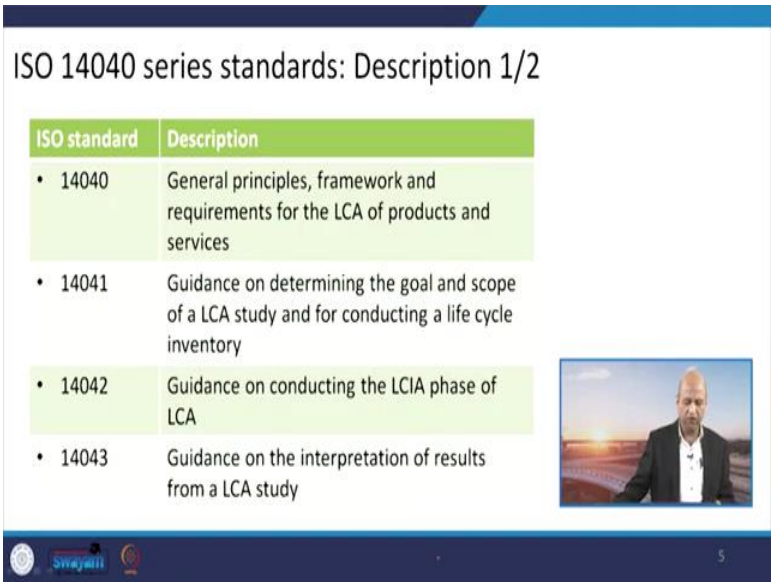

Within this series ISO 14040 series, so there are several standards for example 14040 which is general principal framework, it describes and the requirements of LCA or any product or service so general picture it gives, then special things come and like we go for 14041, so it gives guidance on how to determine goal, how to do scoping of the LCA study and how to conduct the life cycle inventory data related analysis and those.

Then 14042 that gives guidance on conducting the LCA phase of LCIA that is the life cycle inventory analysis, so before that the data collection, what is the inventory, and how this analysis is done that is 14042 that gives the description about that, guidance about that. Next is 14043 that gives guidance about interpretation of the results which have come from the LCIA study or those inventory related LCA study and the overall LCA study.

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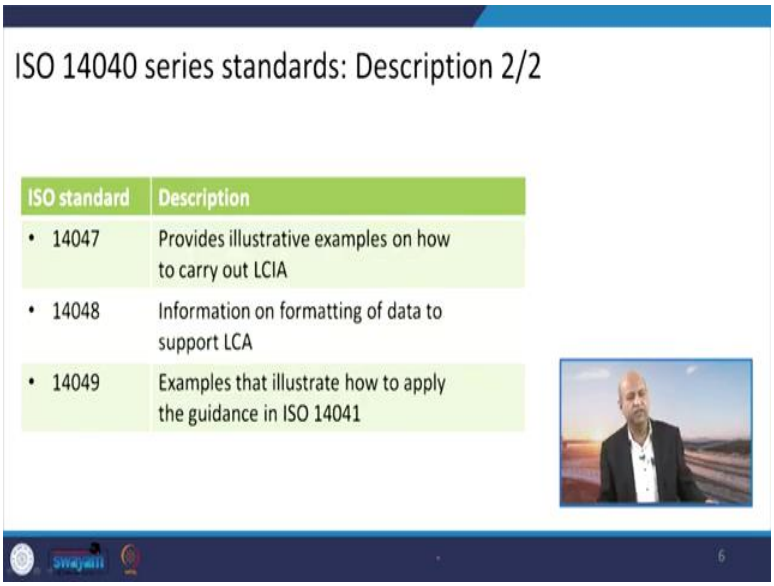

The next one is 14047, which provides kind of example, so that clarity develops in our mind. So they give the illustrative examples on how to carry out basically this life cycle inventory analysis, please focus on, this is the part of entire LCA. LCIA is part of LCA, LCIA is basically life cycle inventory analysis.

So you develop inventory like last time we discussed how inventories developed for different things and data are tabulated and then analysis is done. So next is 14048 and that gives the information about what kind of format we should use for data to support this life cycle assessment. A particular format, a particular matrix gives a kind of easy way to see through the things. Otherwise if you are making a data tabulated in a random form it will not give the real picture or the required picture.

The next is 14049, which gives the examples for further illustration about how to apply the guidance of ISO 14041. So I mean to say these standards prescribed ISO, they give complete picture in different kind of steps. So each standard is there for a particular activity and all, means one series have different kind of standards and the total series gives the complete picture of that particular exercise like 14040 series is giving about the LCA or life cycle assessment.

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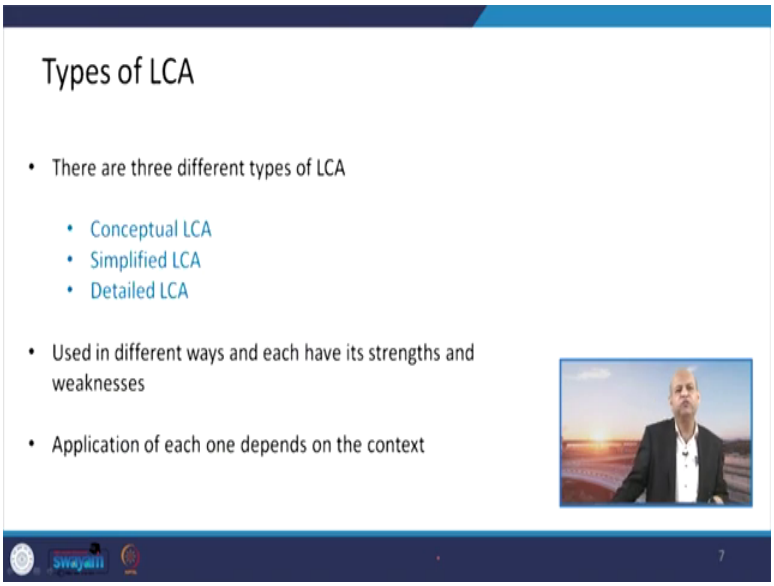

Now if we come to the classification of LCA, what kind of types or categories or different types of LCA are popular and in different contexts what kind of LCA methodology would be good. So if we determine or classify in broader manner then there are basically three types, like conceptual LCA. We will see what is the difference and then the simplified LCA and detailed LCA.

Like environment impact assessment you may recall, we had like the rapid EIA for one season and then the detailed EIA which is having two, three seasons, entire year and so on. So that way this is also based on different kind of scope basically and it is used in different ways and the strengths and weaknesses are there. Of course certain limitations are there, certain strong points are there for each methodology.

But I mean to say if where conceptual LCA can fulfill our requirement then there is no need to go for detailed LCA, because every kind of exercise needs resources. It needs time, it needs efforts so we should do optimization kind of thing. We should not go for detailed LCA where a simple exercise of LCA can give us the information which is required for the decision making or taking things into a particular direction.

Then application of each one depends on context, that means as I said within a particular context A, one particular methodology of LCA will fulfill the requirement and in other context other maybe there where detailed LCA is required, conceptual LCA or simplified LCA may not fulfill

our requirements. So then we have to go for detailed LCA, right? So those are the difference basically.

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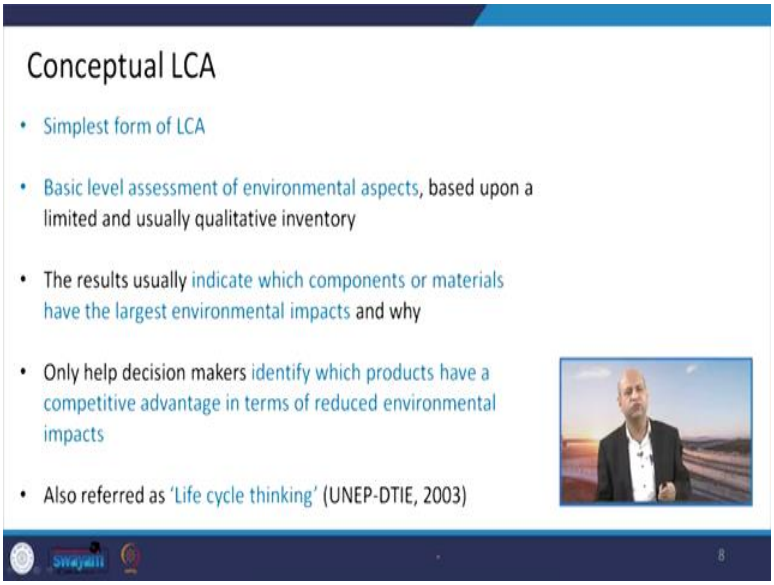

We see what is the conceptual LCA? So this is basically the simplest form and it is more on qualitative basis, you do not go for detailed data collection, inventorization and then analysis. It is based on more on expert opinion and your knowledge based, your experience, so that you can give judgment based on your knowledge and wisdom.

So this is the basic level of assessment of different environmental aspects and some limited information is there and qualitative inventory, not data based, not detailed mathematical kind of information is required. Only qualitative information can give you an idea that what kind of decision would be better in that particular context.

And the results usually indicate which components of which material have the largest environmental impacts. Again in quantitative manner, largest, medium, small, means you do not have values, you do not have mathematical values but you have idea that if this kind of activity we do, we will have larger impact in comparison to activity B.

And it helps in decision making for identifying different products or in competitive advantages, like for a particular purpose, particular service there are two or three products, then simple conceptual LCA can give you an idea that okay this product is better. So let us go for that, rather

than going for the product B or product C, and it is also referred as life cycle thinking, that is why it is known as conceptual form of LCA.

Because you just think and you just get an idea and you just implement your decision that okay let us go for that particular product. You do not need to have a very detailed analysis. This is sometimes in risk assessment we call it back of the annual calculation. So you just list down something and you get an idea, you have that feeling intuition also plays role, because of your experience is there and your expertise is there.

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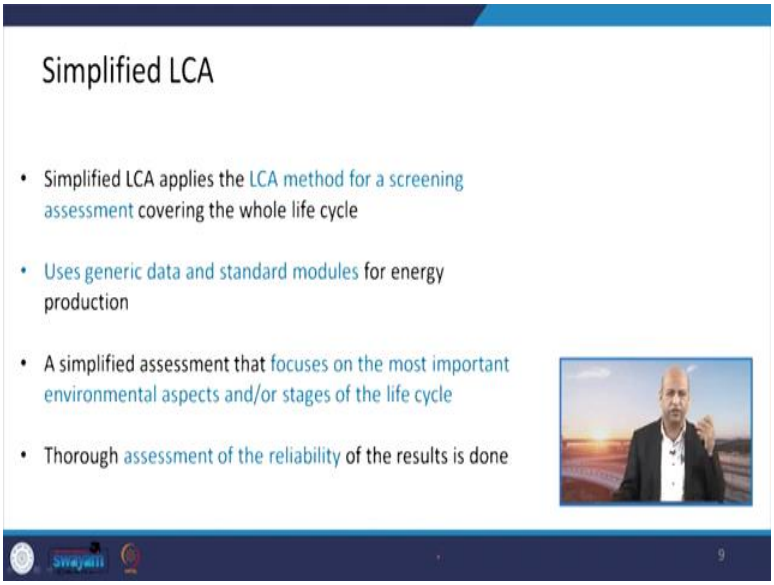

Next is the simplified LCA. So this is a little bit more exercised in comparison to the conceptual LCA. So this demands like screening kind of thing. If you recall in environmental impact assessment also we did screening means tabular form, and then we tick, tick, tick, those kind of things and you know what kind of situation is there, what kind of situation is emerging.

So that way you do screening assessment in that particular simplified LCA, and generic data, means not very specialized, very detailed data is needed for that, only generic data are needed and which are like standard modules for energy production or for environmental impacts. Those kind of things are there, and it focus on most important environmental aspects or those stages which are not very important so that you can ignore them.

So only most important aspects it takes. It does not give much importance to the list or very minimum impact related issues. So this is the assessment which also have some sort of reliability on the results so those kind of things in comparison to the conceptual LCA, this part is there.

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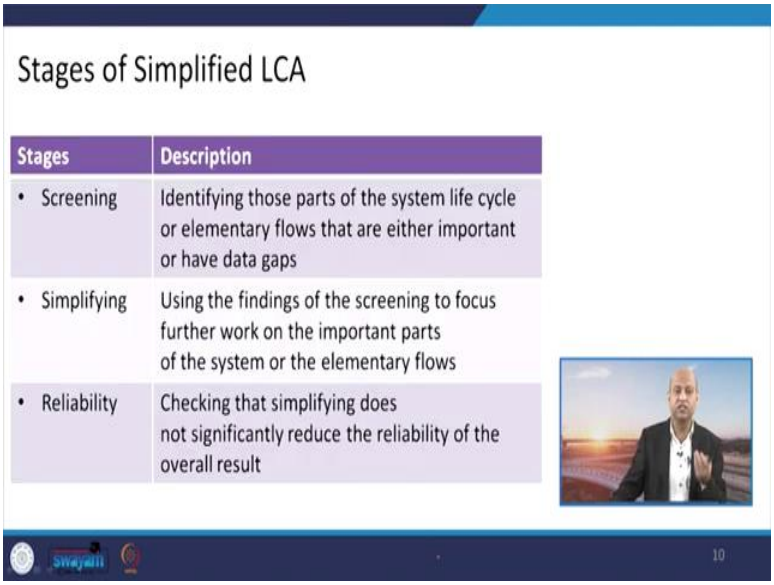

So there are stages of simplified LCA. It is not just a conceptual LCA that you just look at the things and then you have given the decision. No, in this case first you do the screening so you identify those parts of the system of the whole life cycle or some flows or elementary flows where these important aspects are there or where data gaps are there.

So those kind of screening can be done. And then you do some simplifying exercise. So using those findings based on the screening, right? Then you can shift your focus from one important aspect to another important aspect relatively. So that you have information. So elementary flows and important aspects you can give some sort of priority and then reliability related issues. You can see which data is more reliable or which has more significance or which kind of activity is less reliable. So in that comparative analysis way, you can go for simplified LCA.

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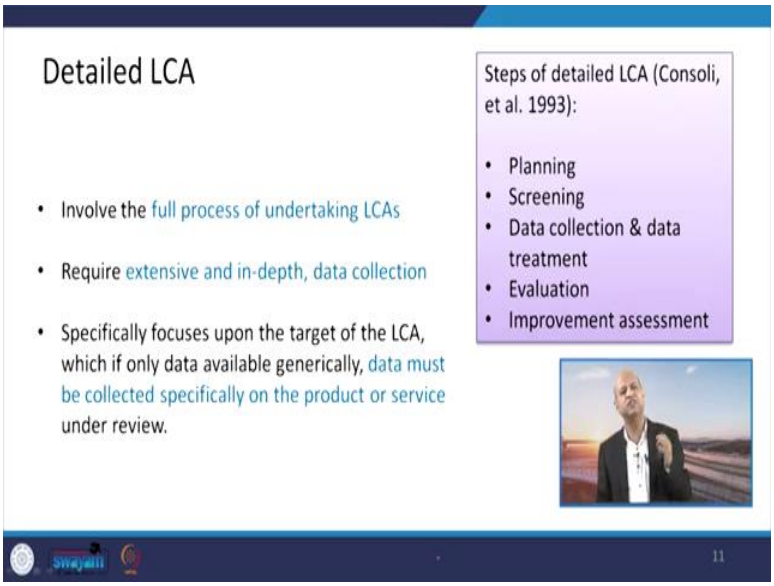

The next is detailed LCA. So like we do detailed environmental impact assessment, similarly life cycle assessment also has this detailed LCA kind of exercise and that is done when you have to do the complete exercise from one end to another end. Nothing is left. So it has several stages. Like first you have to do planning, then screening you have to do, then you do data collection exercise and you also kind of spinning of the data and you process the data.

Some outliers are neglected or left out because some information is based on certain issues, which are not very important. Then you evaluate the things based on those tabulated data and some models maybe used for analysis of the data and then improvement of the assessment based on certain feedback from the experts, etc., those are done.

So it involves full process, complete process underlying different steps of the LCA and it also requires extensive, very extensive in-depth analysis of the data, which are collected and data collection should also be very extensive and in-depth, and then specifically when it is a target of the complete LCA, so you also have those data which are collected specific to the product or service under review.

Means not necessary other data you need to collect but the product related data must be complete. They should not be left out, which are important data, then void of the data will affect your decision.

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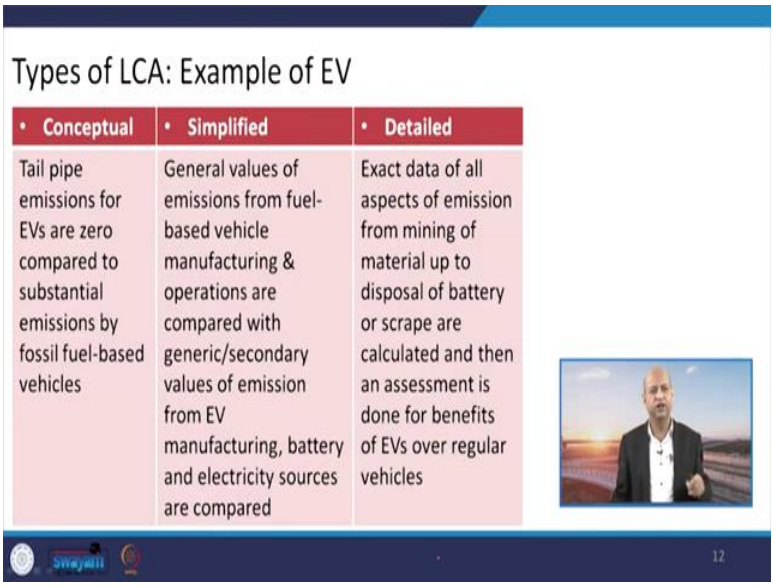

The examples of LCA from the EV perspective of different stages - We can say like conceptual. So if you think about the tail pipe emissions so intuition is there, like when electric vehicle is there is no tail pipe emission so you can simply say that okay, yes, the emissions of the electric vehicle from the tail pipe is zero and from diesel vehicle or other fossil fuel based vehicle there will be some sort of emissions.

So there is no impact from that perspective only, from tailpipe emission. So conceptual, means you know that concept. There is nothing, big exercise to be done for that. Then if you go for simplistic or simplified way of LCA then you have to see like for example the stage of manufacturing and to the production of EV and production of other diesel.

So those emissions are there of course, whether you produce an EV or produce the fossil fuel based car or automobile in factory, there will be emissions there. Because energy consumption is there, material consumption is there, for mining also some material is needed. So, those kind of emissions can be there and those can be compared with manufacturing of the batteries also which are needed for electric vehicle and electricity which is needed for that, those kind of things.

When you go for detailed, so that means how to manufacture EV, how to use it and how to dispose it off from one extreme end of the mining of the raw material to the production of the

EV, to the usage of the EV, when it will serve our purpose and when we will discard it and the batteries will be disposed off and their environmental impact.

So those cradle to grave kind of analysis, if we do for EV, and if we do for similar gasoline based vehicle then that is the detailed analysis, and that can give some other picture. Same picture will not be there, because the context is different. Their scope is different, boundary line is different. So we have to see all these things in that way.

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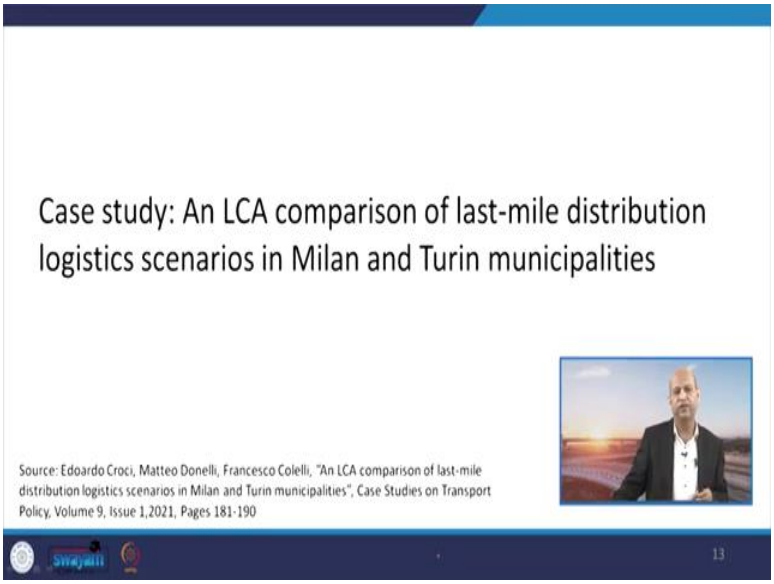

Now to implement the LCA related methodology. We will discuss about a case study that will give you a better picture, and this case study is based on last mile distribution logistics scenarios in two cities of Italy, one is Milan and other one is Turin. So these municipalities have certain locations where issues are there for transportation related. So those kind of studies we will focus now.

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And this study has been carried out for LTZ that is a limited traffic zone of these two cities, Milan and Turin. So what is this limited traffic zone, because of certain regions, certain situations if there are more traffic so you have to do certain policy measure so that less number of vehicles go there. So only limited traffic should be there, because of certain regions maybe hospitals, maybe most people come to that city center kind of a thing.

You may recall this London city center taxation, which gave kind of habit of people to use more public transportation rather privately owned vehicle. So that way, means these are the two cities and within each city there are some zones, limited traffic zones which are the part of this study, and these two cities also have certain characteristics because like Turin is important from business and cultural point of view. It is a center for that and Milan is very important historical city of Italy, and it has second largest population after the Rome of the Italy.

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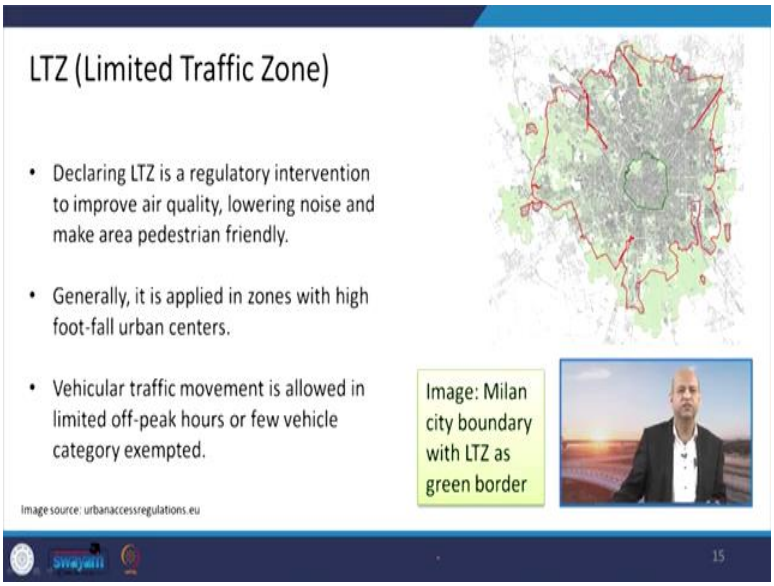

So limited traffic zone as I said, to declare it by regulatory agencies, some interventions are there and target is basically to improve air quality and to lower the noise and to make the area pedestrian friendly. So those are the basic goals or aims and objectives. So to achieve those some zones are classified for limited traffic zone.

So these are the images for Milan city boundary with LTZ. You can see this boundary and green areas, so which is defined as the LTZ and vehicular traffic movement is allowed in limited off-peak hours, not in peak hours and limited off-peak hours, and few vehicle categories are exempted. So that means there are categories which are not exempted, certain categories are exempted and that is why it is known as limited traffic zone.

Complete free flow is not there for every kind of traffic, there are certain rule and regulations which need to be followed.

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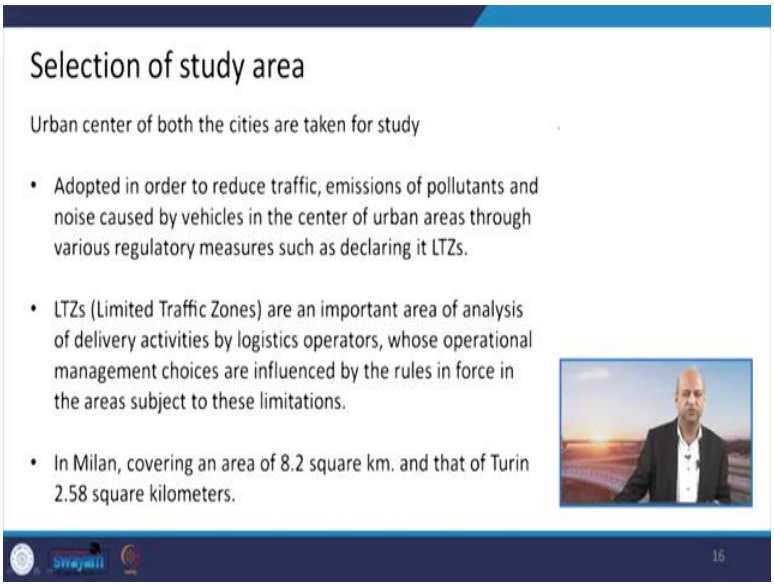

So how to select that? So there are ways, like where, those hot spots, where you need to reduce the traffic flow, where you need to reduce the emissions to improve the air quality or where noise is more so you have to reduce the noise. So that way you classify those areas which are important, maybe some hospitals, maybe some schools are there. Maybe old age houses are more there, institutional areas or even residential areas, nearer to a particular place.

So those kind of areas you can identify, and these are also the pathways for movement. So you have to restrict them for lowering the noise, improving the air quality and that way minimizing the traffic flow. And different areas are there like for example 8 square kilometer for Milan and for Turin it is only around 3 square kilometer, which is defined as LTZ in that perspective.

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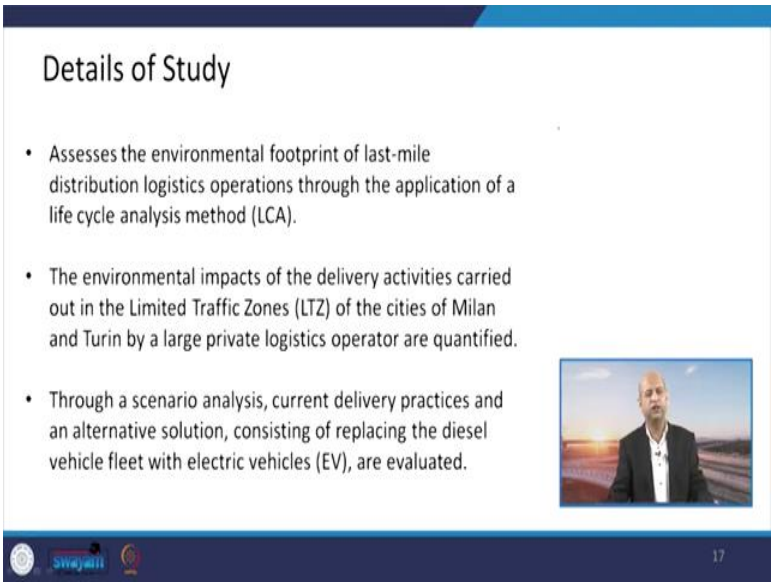

So we go for the detailed study. So the environmental footprints of the last mile distribution logistics operation, means if truck is going, it is coming from another city and at certain location it has to go, so whether the entire truck will go or it will shift the luggage to another smaller ones. Those kind of things are there. So the last mile distribution, only that scenario, that zone has been taken for this detailed analysis for LCA.

And environmental impacts have been taken care in terms of air quality, in terms of the noise and scenario analysis has been done, like what will happen if we shift or we change or we convert the fleet which is coming there like small commercial vehicles which are coming there, if rather than diesel if we convert them in to battery based or electric vehicles. Then what will be the situation?

How much noise will be there in reduction terms? How much improvement of air quality will be there? How much less traffic flow will be there? Those kind of things we can see. So this is the idea basically behind this LCA, that how this will differentiate from each other.

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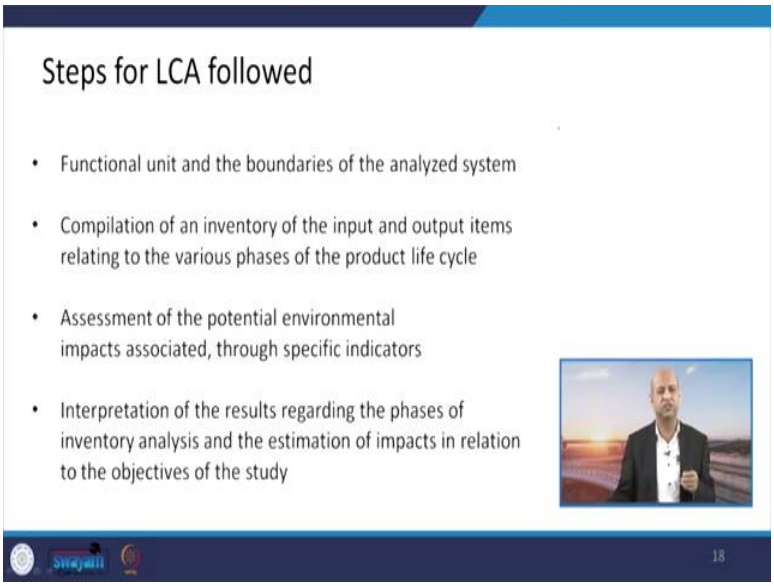

And different steps are there like functional units have to be defined, boundary layers are to be defined, because otherwise city is very large. So only that limited area has to be taken in to account and then potential environmental impacts associated through specific indicators, so those indicators also be determined.

Like in air quality also, which kind of pollutants we want to emphasize, whether acid rain related pollutants or ozone depletion related pollution or ozone production related pollutants or climate change related pollutants, we have to see those indicators. So these kind of tabulations form also have to be there.

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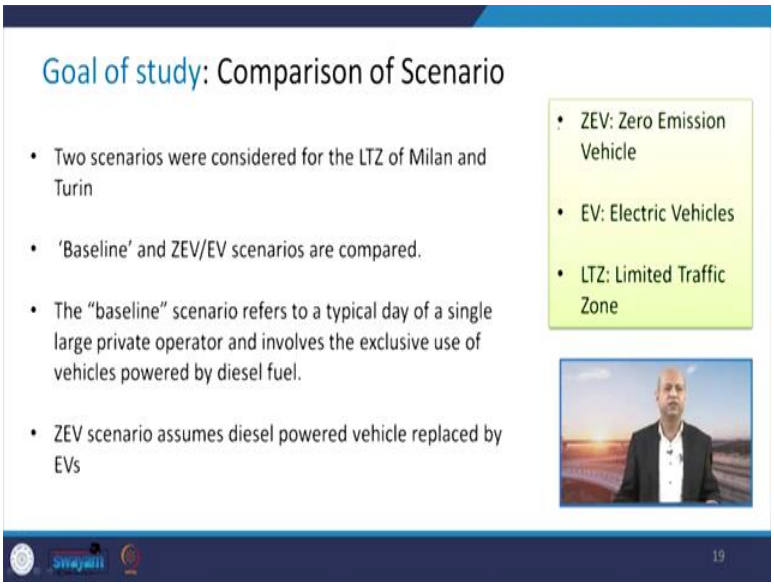

Then we have to define the goal of the study. So two scenarios as I said of the LTZ in Milan and Turin, like baseline data, which is as per going on scenario or what we generally say that status quo kind of thing or business as usual vow related scenario. Second scenario is zero emission vehicle or basically electric vehicle. From tailpipe it is zero emission, that is why they are sometimes known as zero emission vehicle also.

So baseline scenario, based on, in those cities, some single private operator is there which is taking care of these logistic related issues, for goods and luggage transfer and those. So that scenario has been taken and this is like, diesel powered vehicles are basically replaced by EVs. So we have to see the difference, means if we minus these diesel related vehicles and introduce the EVs then what will be the scenario change or what will be the impact.

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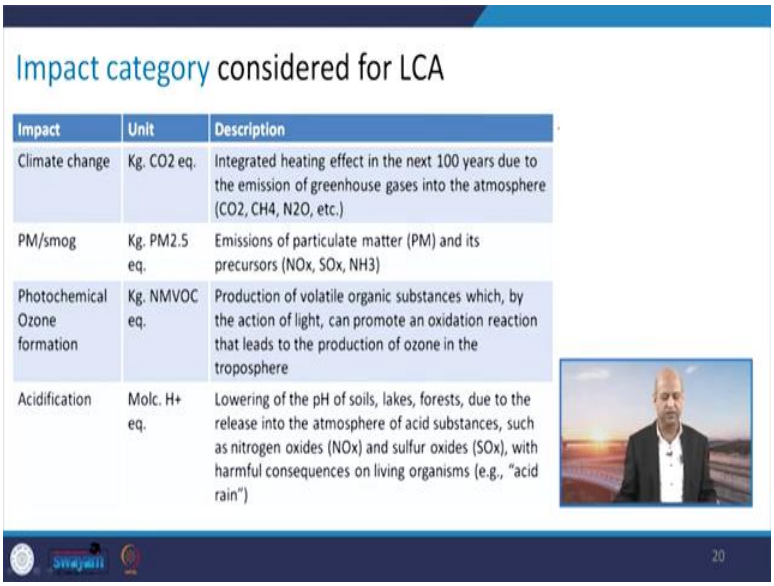

Now you can see here these are the impact related indicators for LCA like climate change related things. So climate change related things are basically greenhouse gas emissions. So we will convert them into CO2 equivalent. How much kilogram CO2 equivalent emissions are there? Those emissions may be of CO2 itself, which is greenhouse gas. It may be methane, it maybe nitrous oxide also.

So, all these are greenhouse gases. So we have to convert them into kilograms CO2 equivalent. So that we can combine and it is easy to compare, right? Then particulate matter or smog creation, so for this we have taken the indicator as PM2.5, which contributes into this air quality deterioration in terms of particulate matter, aerosols and also smog formation, and this can be produced by secondary aerosols.

So we have to see the indicators like emissions of NOx, emissions of sulfur dioxide, emissions or ammonia because ammonium sulfate may be there or ammonium nitrate can be there, calcium sulfate, calcium nitrate all these aerosol formation, secondary aerosol formation may be there. So their emissions also we, to be taken into account.

Then if we talk about ozone production in troposphere, so photo chemical ozone production, then we have to see its precursors, precursors are like carbon monoxide or like NO2, NOx emissions and NMVOC that is non-methane volatile organic compounds. So all different kind of emissions

of precursors we have to convert them into one unit that is kilogram NMVOC equivalent because they participate into production of ozone.

If you try to see the acidification potential then we have to convert the emissions of like SO2 or SOx or NOx and like hydrogen ion equivalent, means moles, how many moles are there so that kind of calculations are to be done. So that we have a better picture, quantitative picture, because engineer, scientists love to discuss in terms of quantitative manner, because then your values are more objective, there is no role of the subjectivity in that case.

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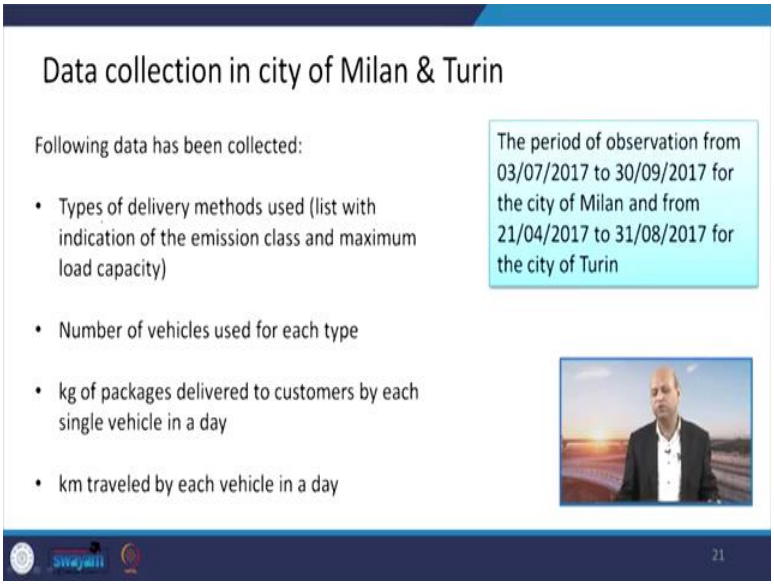

The period of the observation for this study was like for Milan it was from July of 2017 to September of 2017, and in case of Turin it was April 2017 to August of 2017. This was the period for data collection and observations of the study and the data which were collected, you can see these were the emission class, and maximum load capacity of those trucks or commercial vehicles then number of vehicles are there and each type of vehicles so type category kind of vehicle we have to see.

Then kilograms of packages which are delivered by those vehicles from one place to another. So those goods, packages or those kind of things in a single vehicle in a day, how many times, how much packages are to be there, then kilometer traveled by each vehicle in a day, because that will influence the emission part. So those quantities are to be collected and they are tabulated.

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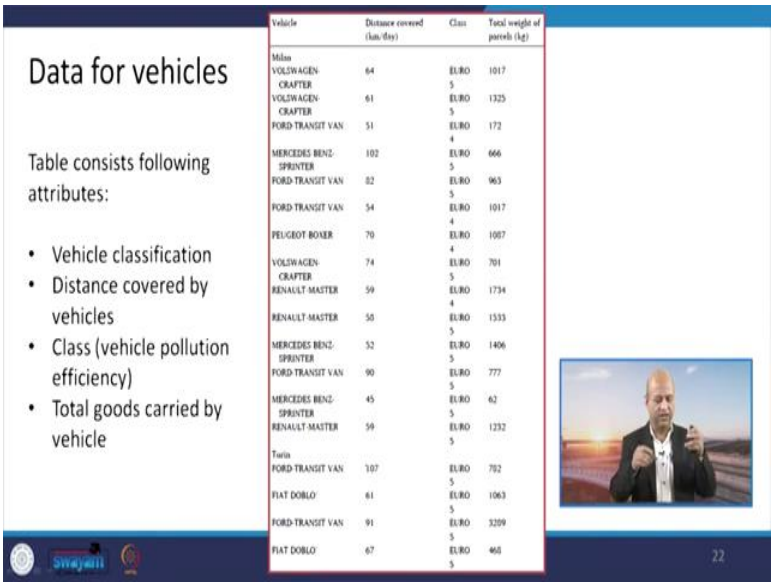

So vehicle classification, distance traveled by each vehicle, class of the vehicle in terms of pollution efficiency, like Euro IV, Euro V, those kind of things can be there, total goods carried by each vehicle. So all these information will be tabulated and analyzed.

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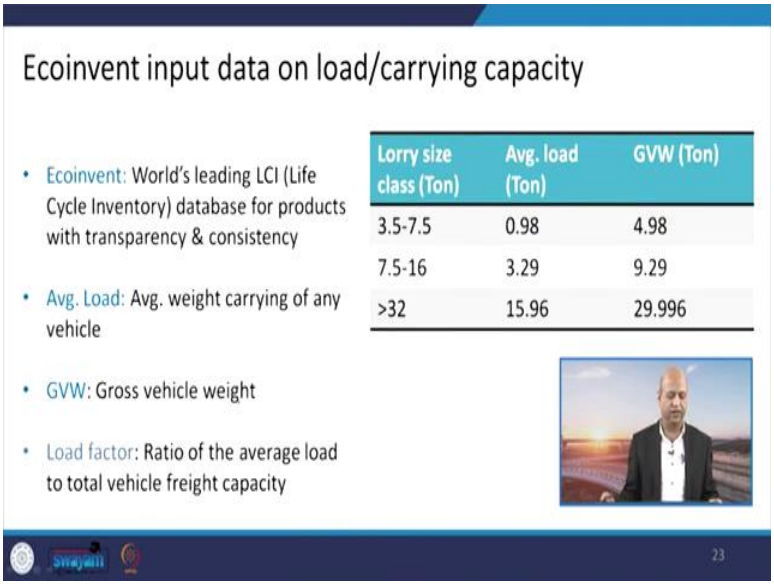

Similarly this data is there, like this economic inventory if you remember that input, output data related thing. So that kind of capacity related data analysis was also there. So average load or gross vehicle weight all these things are tabulated basically to see the impact.

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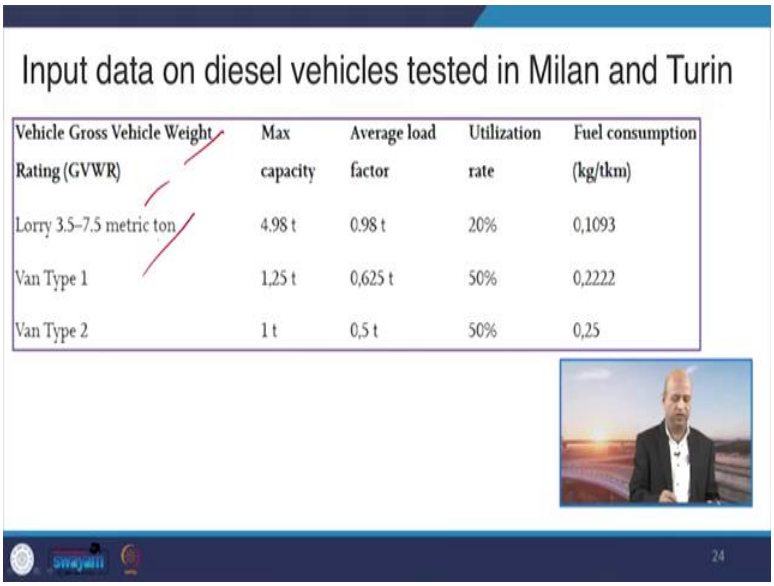

And you can see now this another data set in terms of table. So vehicle gross weight, ratings, lorry, how much tons, type 1, type 2 vans and the capacity, average load, all those, fuel consumption. These all values are there, which will really help us to make calculations for emissions, et cetera.

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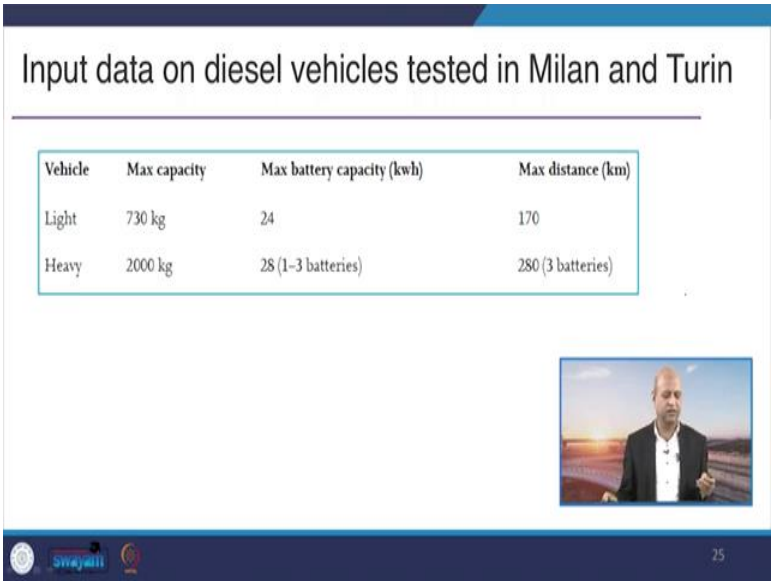

And input data for electric vehicles are very simple like whether it is light commercial vehicle or heavy commercial vehicle and then their capacity like 730 kilogram or 2,000 kilogram, and the

maximum battery capacity in terms of kilowatt hours. So 24 or 28 1 to 3 batteries, maximum distance traveled by those vehicles 170 kilometer, 280 kilometer, these three battery operated vehicles. So those classifications have to be there.

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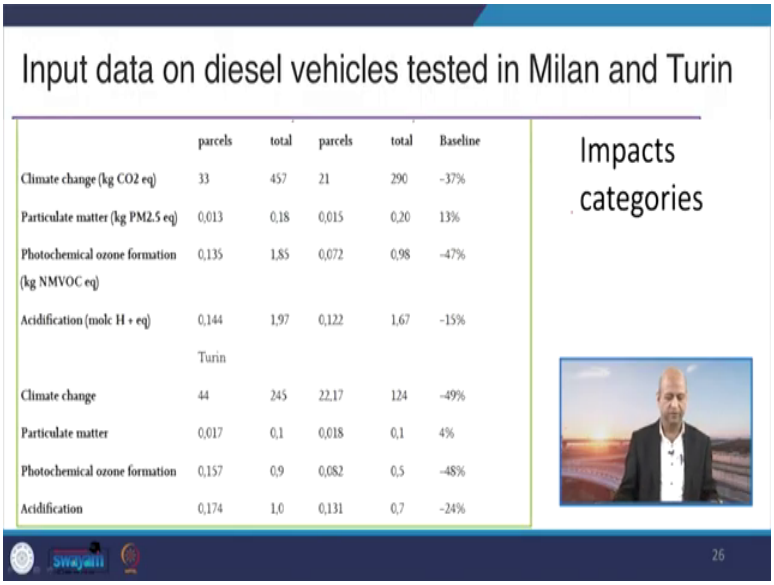

And then climate change related emissions, how much per ton of the parcels in Milan. For Turin similarly this table is there, so for each city all these potential indicators of climate change or acidification or ozone, particulate matter, all these things have been taken into account and seen like how much reduction is there, because of electric vehicle introduction and whether there some significant reduction or not.

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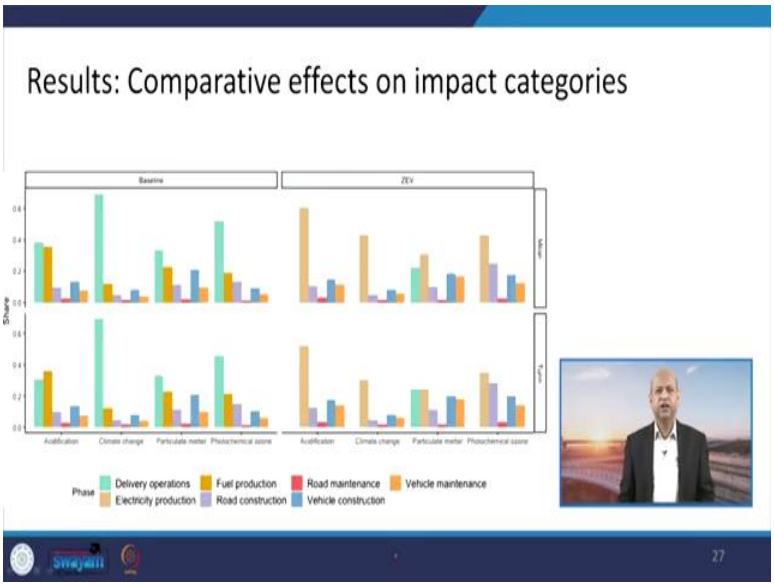

If we see comparative effects on different categories of the impacts then there are some interesting insights which are from this particular case study. So if we compare the baseline related impacts for example acidification or climate change or particulate matter emissions or then photo chemical ozone production then you see this in baseline there is a lot of climate change related issues when delivery operations are considered.

But in case of this electric vehicle kind of scenario, then in climate change basically the reduction is there of course, in totality reduction is there but the more role is from electricity production. That means the emissions from coal based power plants where electricity is being produced for charging the batteries of the electric vehicles.

So similarly acidification, so acidification you can see, in acidification here the contribution is more on from delivery operations or fuel production, but here the contribution is from electricity production again, right? So if we compare other fuel production, so fuel production is basically in baseline. This is contributing in terms of acidification, but in terms of acidification it is not contributing much in case of category of electric vehicles related scenario.

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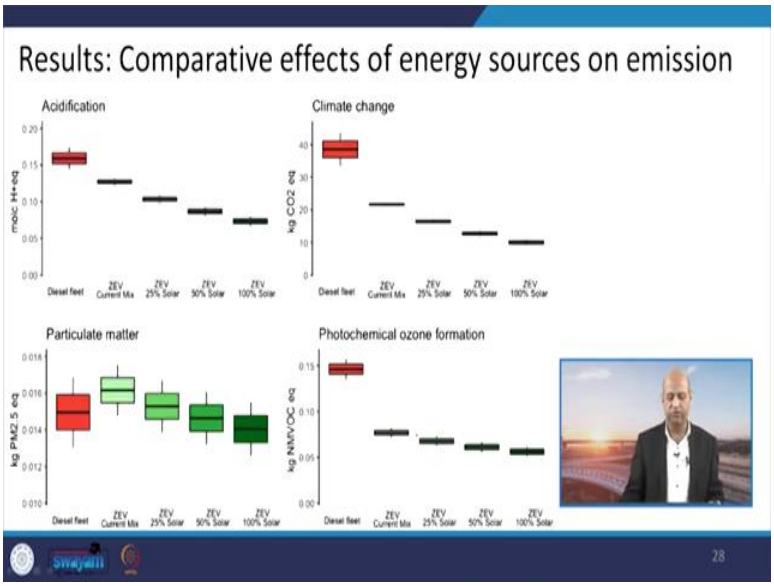

Then when we see the comparative effects of energy source on emissions, so see, like this acidification related, hydrogen ion equivalent. So the diesel fleet, it gives around this much of emission, but if we go for zero emission vehicles or electric vehicles of different capacities, and then where this electricity is coming from, that also plays role.

So if it is 25 % solar battery charging, electricity coming then it is more reduction, those emissions of acidification related emissions and 50 % solar then it is further reduction. So you can see as we go the electricity from more renewable sources, then the impact becomes less and less. But here very interesting you can see, particulate matter PM 2.5 so diesel vehicle is, emission is there, but this current mix where coal based power plants are there for electricity production, so in that case this emission is more.

That is very counter intuitive, because emission is there but if we are using coal based power plants to produce the electricity. When 25 % solar is there, then further emission reduces, and up to 50 % is there then it also kind of equivalent to the diesel, but if 100 % solar or renewable energy resources are there to produce electricity and to charge the battery, only then benefit is there, but there is some kind of key indicator or some kind of issue which need to be taken care of, because these are the total emissions, but if see like diesel vehicles are emitting whole emissions in the city only.

But these battery operated vehicles not emitting any kind of tailpipe emissions. Their emissions are far away, where this power plant is located. So when emissions will come from the chimneys or stags, the dilution will be there and the impact will not be same. So this is not only the emission kind of game but the air quality impact, which we have to see. So this kind of analysis sometimes can be a little bit deceptive or not the objective assessment kind of a thing, but overall reduction is there in each kind of potential indicators of environmental impacts.

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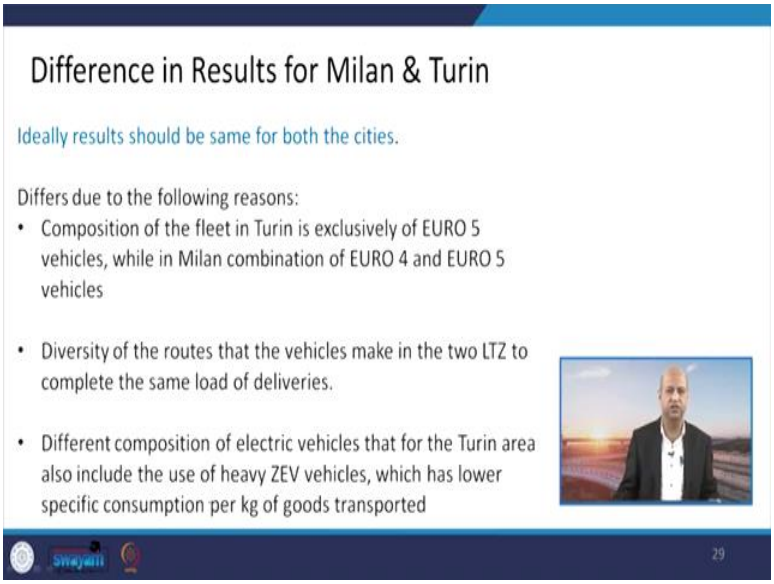

Then different results are there, so you can see different kind of fleets like Euro V and Euro IV, those kind of fleets are there, therefore in both cities impacts are not similar, they have some differences.

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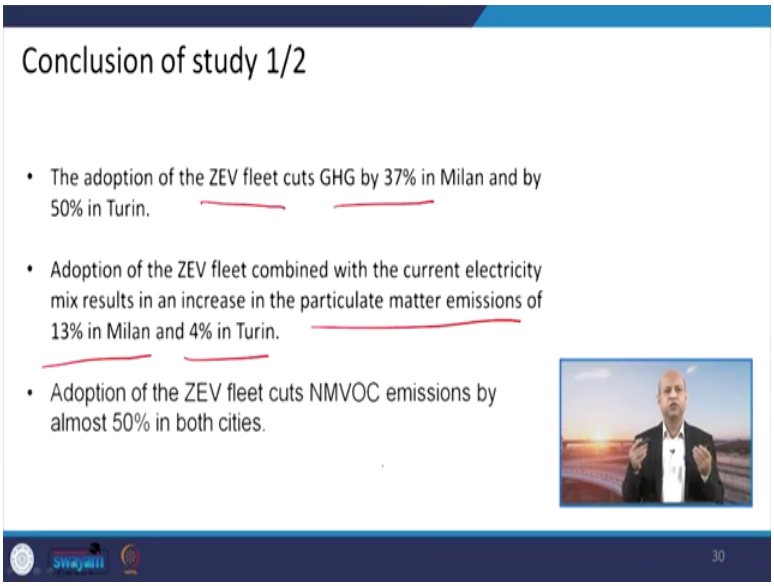

When we conclude about these studies, so you can see that adoption of this ZEV fleet reduces the GHG or greenhouse gas emissions by 37 % in Milan and 50 % in Turin city. But as we have earlier discussed that if we compare regarding particulate emissions then there is a slight increase, like 13 % in Milan and 4 % in Turin and that is because of those power plants which are based on coal based electricity generation.

Well there is another kind of reduction like non-methane VOCs emissions are reduced around 50 percent in both the cities. So that is a good sign, means greenhouse gas emissions and these NMVOC or non-methane VOCs, volatile organic compounds, they are reduced significantly. Particulate matters are slightly increased and if we go for like production of electricity with the help of renewable resources then this increase, slight increase like 14 %, 4 %that can also be properly addressed.

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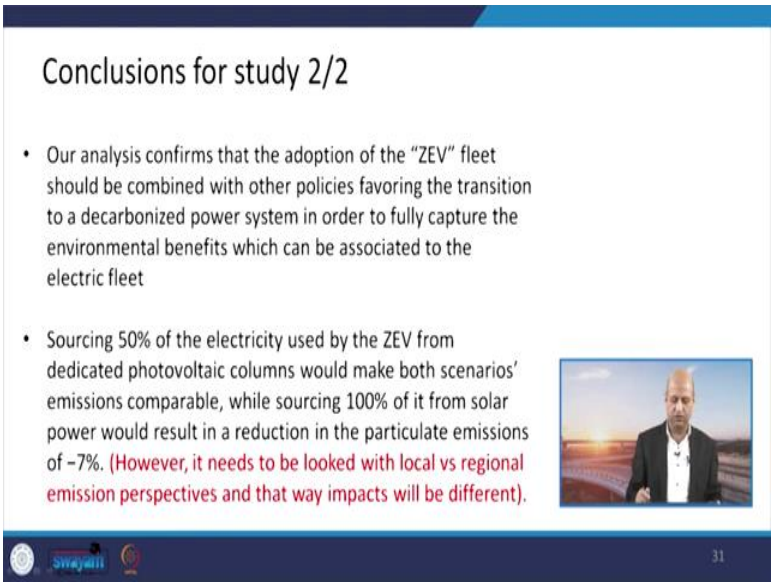

This is where we can see the comparison similarly as I said earlier also that only when we go for 100 % fleet based on solar powered, battery recharging capacities only then there is reduction in particulate matter, otherwise there is no significant reduction in particulate metal in total.

But as I said we have to see it in perspective of regional or local emissions if you are combining regional emissions then this is okay, but if you are focusing on local emissions then this is not the right thing. In local emissions we are not having tailpipe emissions. So benefits to the local people is enormous in that way.

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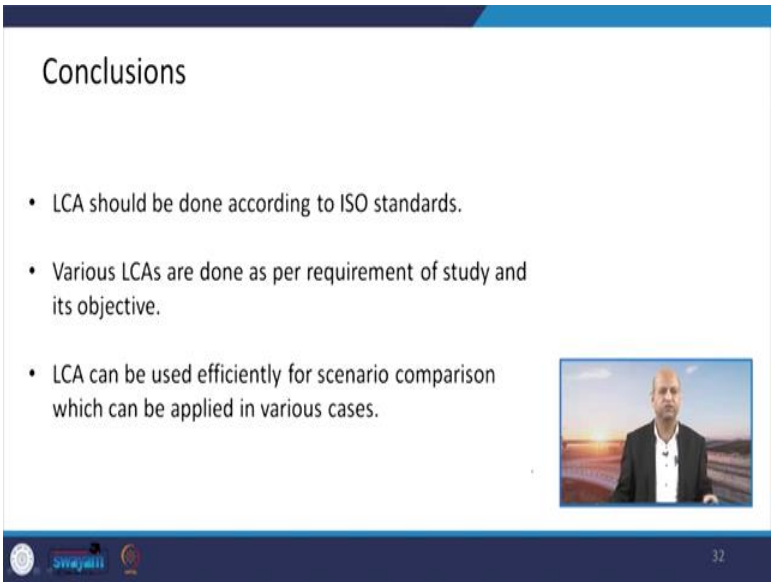

So in conclusion we can say that LCA should be as per the prescribed guidelines by ISO, ISO standards, and there are various methodologies like conceptual, simplified or detailed and that depends on the context and the objective of the study, which methodology we should go for and then different scenarios maybe there, and that can give us a real picture whether the reduction is occurring or not in pollutants or in the impacts, negative impacts, okay?

So we have to do the real life exercise, good data collection analysis. Only then better picture emerges and as I also said that sometimes data analysis also gives partial picture, as this regional and local kind of things if we ignore then something, half kind of conclusion we arrive at. So those things we should be careful about, right?

So this is all for today's lecture like part theory, part practice. I hope it is more clear for you, that how LCA is implemented as a case study. We will see another case study to give you more better perspective about the implementation of LCA in real life scenario. So this is all for today.

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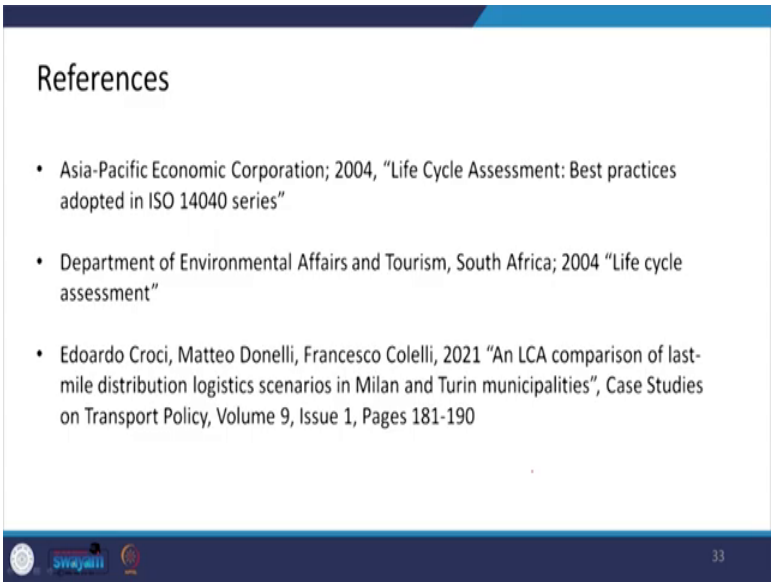

These are the references which you can go through for more information so that is all and I thank you again for your kind attention. See you next time with more case study, thanks.