Air Pollution and Control
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Lecture 22
Emission Inventory for Industrial Sector

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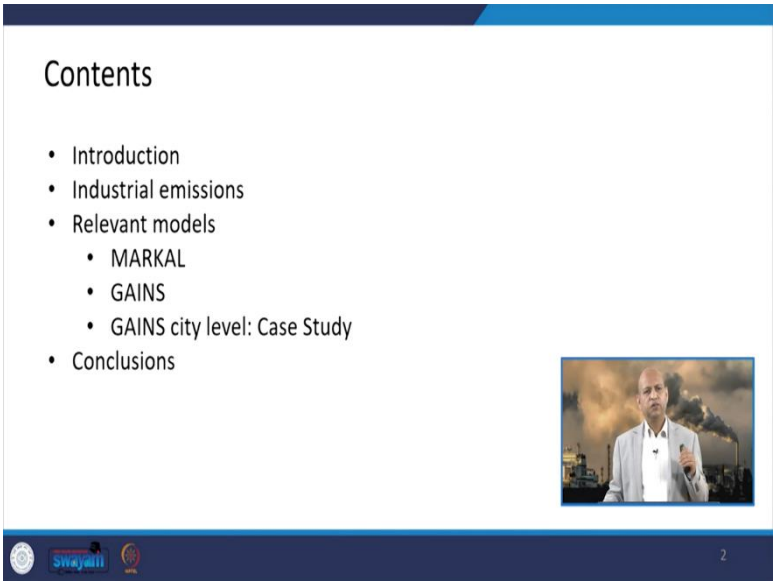

Hello friends. You may recall last time we discussed about how to develop emission inventory of transportation sector. And today, we will discuss about emission inventory for industrial sector, because emissions are released by several activities anthropogenic activities, whether it is transportation sector, industry sector, agriculture, power plants, any kind of activity where we burn some fuel and combustion occurs, then some emissions come out of these activities.

So, after brief introduction, we will look at what kind of emissions are there from industries and then what are the different models, which are available to estimate the emissions, that means to develop emission inventories for industries.

Although these models like MARKAL, GAINS, these are the general models means they can develop emission inventory for all possible sectors, but we will focus only on the industry sector, which they also cater. Otherwise, you can also develop some spreadsheet models especially related to industrial activities or any activity, that is very simple when you use certain relationships of those activities which emit some sort of air pollutants and greenhouse gases etc. And after case study at the city level using GAINS model, we will conclude.

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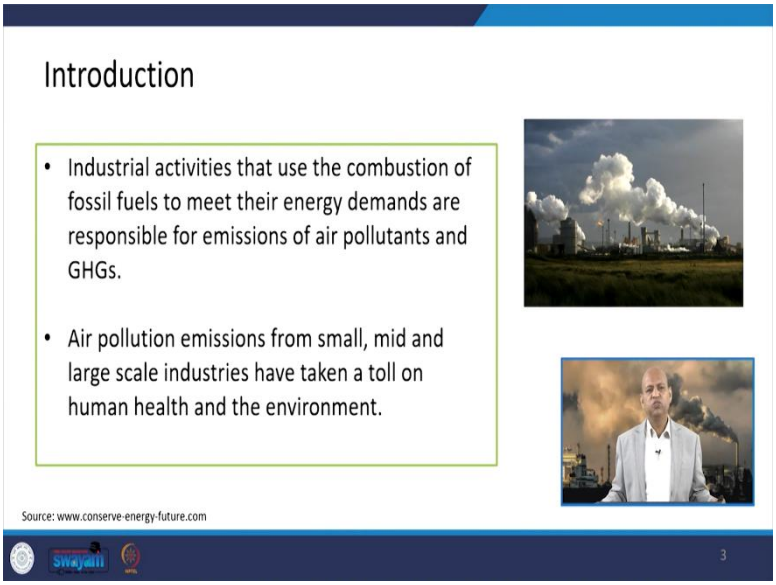

So, when we talk about industrial activities with use combustion of fossil fuels. So, the burning activity of fossil fuels and fossil fuels are basically hydrocarbons and they also have certain other elements like Sulphur and other things. Then nitrogen comes from even air also. Some nitrogen may be present in fuel also and other things may also be present impurities may be there. So, they are oxidized and then some emissions of air pollutants and greenhouse gases comes out of those particular burning activities.

And these emissions, when we focus only on industrial activities, so there are several smaller small, mid or large scale industries, which have different kinds of emissions depending upon what kind of processes they are tackling, or they are using for manufacturing for operating some other elements.

So, according to those processes, there are several kinds of air pollutants emissions are there and the emissions when they come into the air, then naturally whether they come from any other sector not only the industrial sector, when people are exposed to those pollutants, then there are negative health impacts, environmental impacts are also there. So, those kinds of impacts are there.

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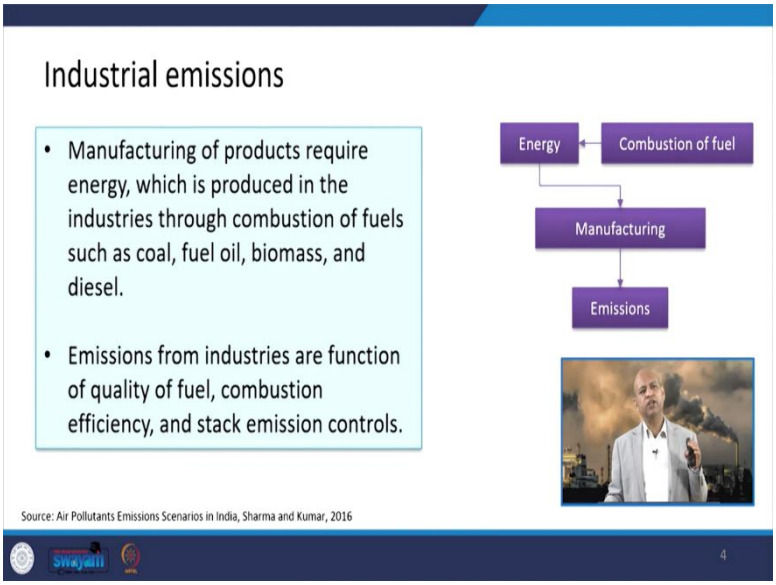

And as you know, because whatever manufacturing activity you do, whatever product you are manufacturing, there is a use of energy. Energy comes out of from some source, whether it is coal burning, or oil burning, or some other act like electric power is also a source of energy, but where electricity is produced if it is not from renewable resources, then it is coming from some like coal or oil-based power plants. So, again air pollution emissions are there. Biomass may also be there some source, diesel, petrol anything.

Well, these emissions are the functions of different kinds of factors like quality of the fuel, then the combustion efficiency, if it is more efficient then CO_2 is more rather than other pollutants like CO etc. And stack emission control strategies and technologies, because even if some emission is coming out of some activity, when it passes through the stack, if you are providing some controlling mechanism, air pollutants controlling equipment's like ESPs or scrubbers etc, they will capture those pollutants, and the cleaner air will come out will come out of the stacks.

So, it will depend I mean the fuel quality as well as the state control like equipment's and the efficiency of the combustion process, all those kind of technological interventions can influence the total emissions out of those industrial activities.

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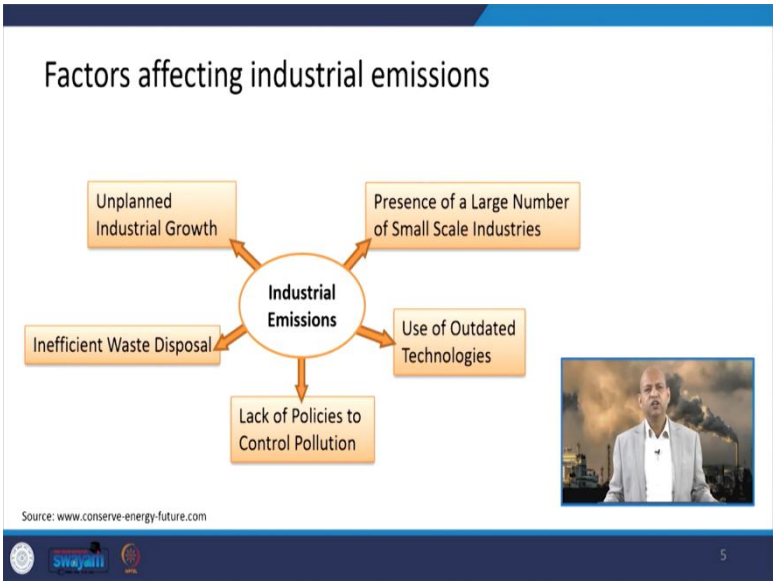

Well, then, when we talk about other factors, then also there are additional factors like presence of a large number of small-scale industries maybe responsible for total high emissions. The reason is because small scale industries do not have much resources to install air pollution control equipment. So, that may be one reason, that their emissions are more polluting and when collectively we look at that, then high emissions may be from small scale industries.

Then use of outdated technologies are also one factors for example, someone is using that oil for furnaces. And somebody is using electric furnaces, then naturally oil based furnaces will emit more pollutants in comparison to the electric furnaces at the local level. Although someone can argue that, if electricity is produced from the coal-based power plants, that will also emit pollutants, but that will be far away where the electricity is being produced. Well, when we talk about like different policies matter,

So, if there are not proper appropriate policy interventions, then also emissions may be more. Inefficient waste disposal can be one reason for more industrial emissions, unplanned industrial growth can be there responsible for large scale emissions. The reason is because if the plant industries are there, it is easy to control them to implement some policies or to implement certain technological intervention. Unplanned growth, they also kind of deter these kind of policy and technological interventions.

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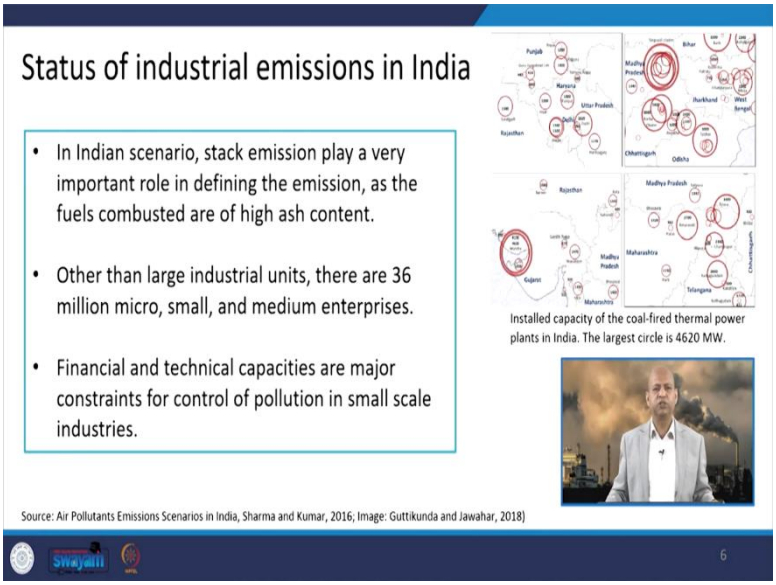

Then if we talk about the status of industrial emissions in case of India, then stack emissions play very, very important role in defining the industrial ambitions in case of India, because the fuel which is combusted having very high ash content and that is responsible for high amount of particulate matter. So, we have to provide either good ESP electrostatic precipitators or bag house filters etc. Otherwise, particulate matters will be released in very high quantity at the stack level, because of those impurities in the coal.

Well then other than large industrial units there are 36 million micro small and medium enterprises. And many as I said many small-scale industries do not have sufficient resources to install very expensive air pollution control equipment. So, that is also one very large or important factor. Then financial and technical aspects are major constraints for the control of pollution in small scale as well as micro and medium enterprises also.

So, sometimes industries pool and then they have certain technological interventions, especially like a wastewater treatment plant, it is easy for them, but for air pollution control each industry has to install their own equipment's, otherwise it will be very cumbersome and complex issue to control emissions of the air pollutants.

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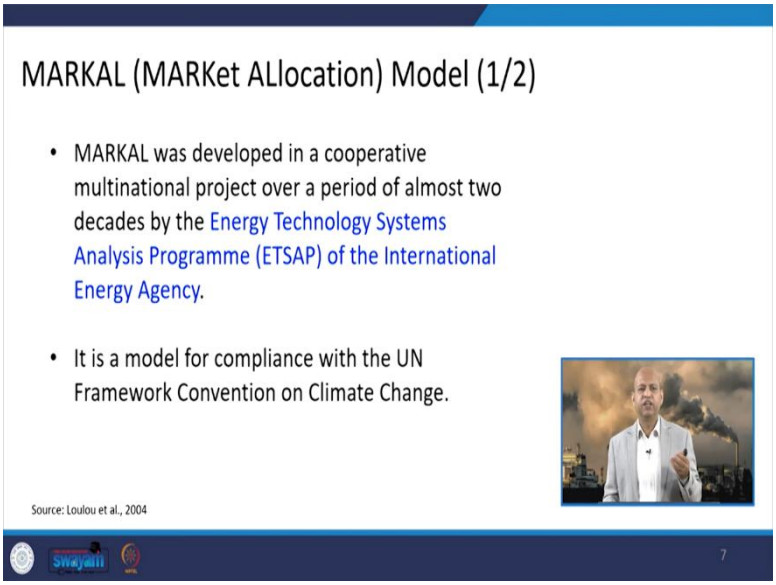

Well, now, we come to those kinds of models which are available which can help us to estimate emissions from industrial sector. One of them is MARKAL model, the market allocation model shortly known as MARKAL model. So, this was developed in a cooperative mode by a project which was multinational project over a period of almost two decades and it was by Energy Technological System Analysis Programme, of the International Energy Agency (IEA), so that was the sponsor of this project and over two decades the research development went on and this very refined model came into existence.

So, this is a model which is basically used for compliance with the United Nations Framework Convention on Climate Change, because energy related emissions it can estimate very nicely.

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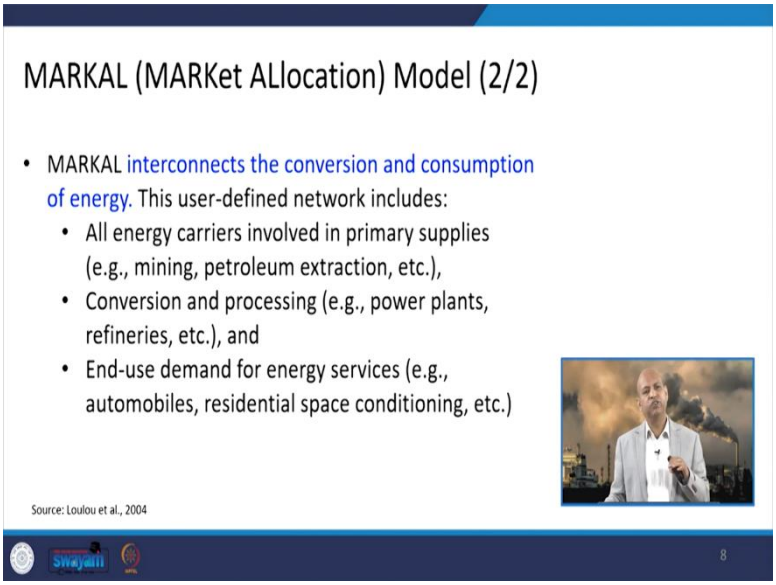

Well, this incorporates the conversion of consumption of energy and the user-defined network includes in this particular model, like all energy carriers involved in primary supplies, for example mining, petroleum extraction etc. Then conversion and processing like power plants, refineries, they are also means this model can handle those kinds of sources also. Then end-use demand for energy services, for example, automobiles or residential space conditioning, commercial activities, all those kinds of things, this is very versatile model in that sense, it can incorporate all these things.

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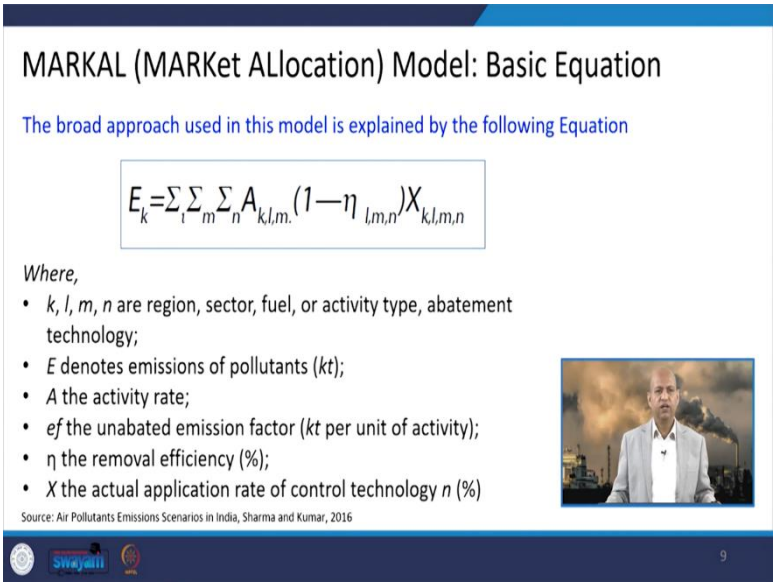

And this is the basic equation basic approach you can say, the broad approach which is used in this model like this E_k and summation of different activities and 1 minus η, that is η is nothing

but the removal efficiency. So, because if you minus it you deducted then the emissions will be calculated. X, the actual application rate of control technology is there and A is the activity rate.

$$E_k = \sum_t \sum_m \sum_n \left(1 - \eta_{l,m,n}\right) X_{k,l,m,n}$$

So, basically you have this activity rate for all kind of like regions or sectors or fuel. So, accordingly it can vary and you can then sum up. So, all those kind of activities depending upon the sector fuel etc. you calculate and then you integrate or you sum up, then the total emissions come for that particular k, that is the region you can say in that sense. So, that is the summation of all calculations.

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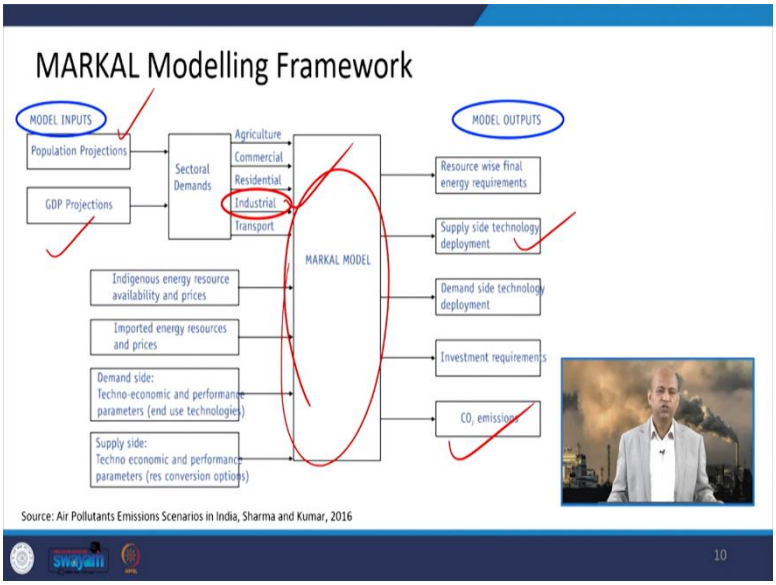

Well, when we talk about this framework, so you can see like these are the model inputs like population projections, GDP projections of that particular region and if you are calculating at the country level, then the country, then sectoral demands like agriculture, commercial, how much energy is being demanded by these sectors. So, we are basically focusing on industrial, so we can focus only on industrial demand-related issues.

Then you can see other things then this all these things come into the model, model processes according to the equations and the output comes in different ways. For example, it can have resource wise final energy requirements, it can calculate, supply side technology deployment, it can also suggest, it is a very good thing in that sense. Demand side technology deployment also it can give investment requirements, because it has all these unit costs etc.

So, that is also possible then emissions of carbon dioxide or other pollutant depending upon what kind of pollutants and greenhouse gases you are planning to estimate those emissions. So, you can play with that model and you can get those values.

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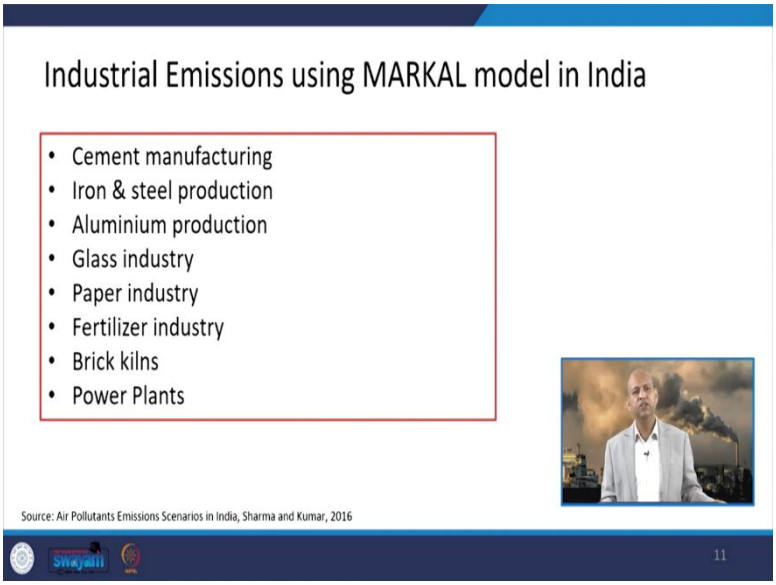

Well, the industrial emissions using MARKAL model in India, several calculations has been made like cement for manufacturing of the cement, iron and steel production or aluminium production related industries, glass industry, paper industry, fertilizer industry or brick kilns, power plants, all those kinds of industrial emissions have been calculated using this MARKAL model.

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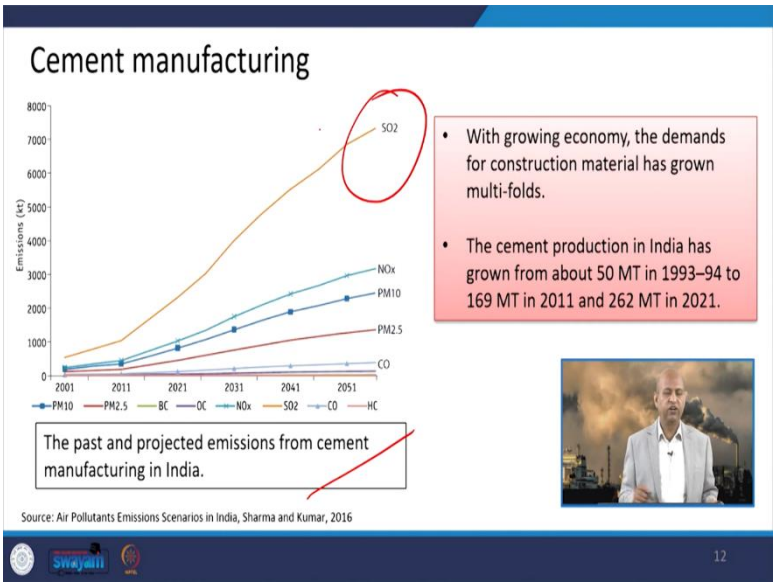

When we talk about cement manufacturing, so this economic growth has given or raise the demand of the cement, because several infrastructure projects are going on. Then construction activities are going on. So, they need lot of cement. So, from cement manufacturing activity, you can see these are the production-based emissions of different kinds of pollutants like SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO etc. You can see here and the past and projected emissions are shown for cement manufacturing in India.

So, it is shown that SO_2 emissions may increase, if you do not deploy the proper technologies, which can control these emissions. NO_x emissions are the second growth of the otherwise this SO_2, sulphur dioxide is the predominant emissions, which are coming from cement manufacturing activity.

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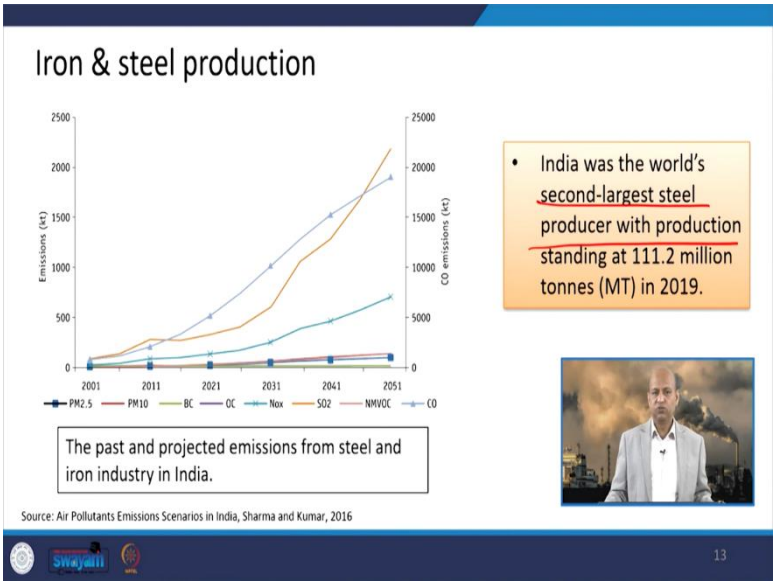

When we talk about iron and steel production, then the scenario is like SO_2 is also increasing, but the CO, CO is also very much increasing. So, these are the two dominating pollutants which are coming out of iron and steel production and like in India, this is the second largest steel producer with production extending around 111 million tonnes in 2019. So, India produces lot of iron and steel. So, that way the growth is taking place in this industry. So, accordingly the emissions of different pollutants are also increasing.

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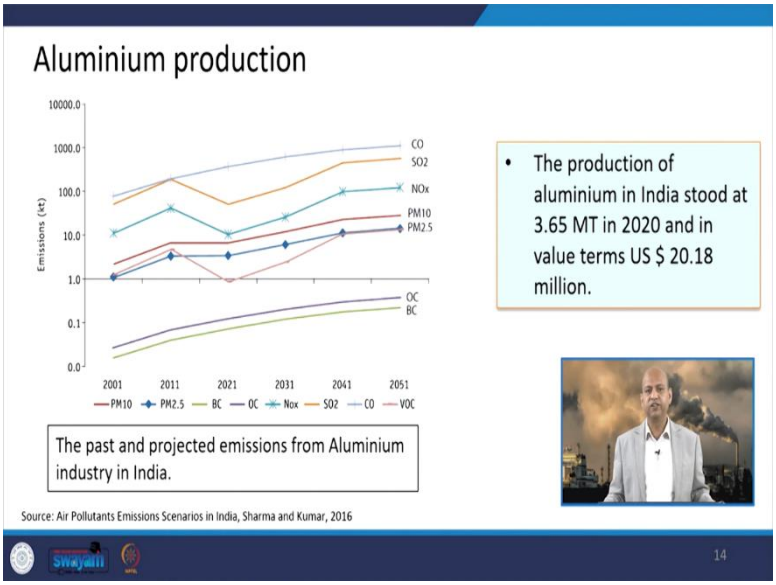

So, you can see this production of aluminium in India stood at 3.65 million tonne in 2020 and in values, if you see the monetary value, then it is around 20.18 million of US dollar. So, that kind of scale of aluminium production is occurring here. But if you compare with other iron or steel or cement, the increase of the CO and SO_2 emissions is not as sharp as in those particular industries in this case.

So, this is interesting to see what are those reasons means, either the growth is not that much sharp in comparison to those industries or maybe some better fuel consumption, or better efficiency of the technology, those kinds of things may be responsible.

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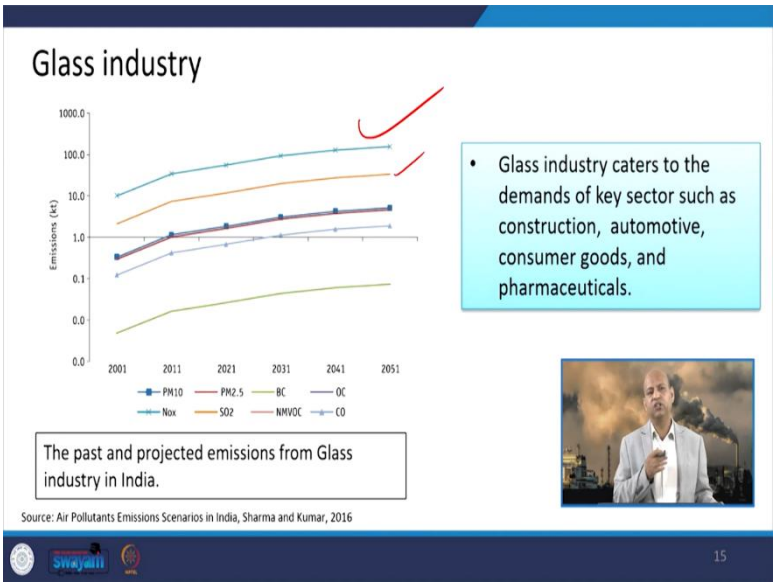

Well in glass industry also the growth is there, it is not so sharp as cement and iron and steel industries, but glass industry, because it caters lot of demands for sectors like construction, automobile and consumer goods etc. The growth is taking place as per the GDP and the emissions of different pollutants are also increasing. In this particular you can see this NOx emissions is and the SO_2 emissions are more in this case, CO emissions is not so much, that means the production-related and the combustion-related processes are better in efficiency, that is why CO is less, CO_2 maybe more.

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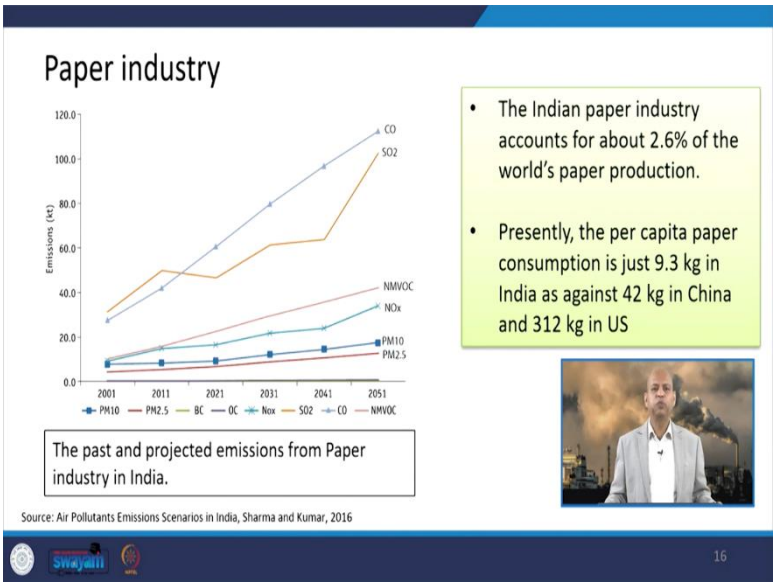

Well in case of paper industry again CO and SO_2 emissions are more in this case and this Indian paper industry accounts about 2.56 percent of the world's paper production and presently per capita paper consumption is less than the China and US like it is only 9.3 kilogram in India per capita consumption, against 42 kg in China and 312 kg in US. And the reason is very simple in developed economies, a lot of packaged things get transported and in India, that segment is still a smaller one which has all those kind of packaged food and then the transportation of different goods etc, in packages, those kind of the usage of paper maybe there.

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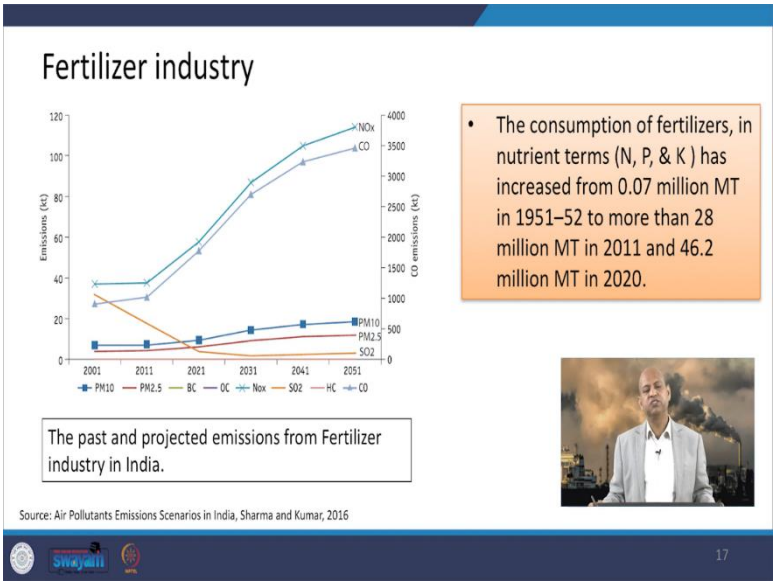

Now, you can see in fertilizer industry, the emissions of NO_x and CO is increasing very fast and because the production of fertilizers is also very high in case of India agriculture sector is growing, the usage of fertilizer is increasing. So, that is why you can see the emissions of NO_x and CO is increasing, but interestingly, the SO_2 emissions are decreasing. So, that means some processes are different in comparison to other industries, but we have to control the emissions of CO and NO_x.

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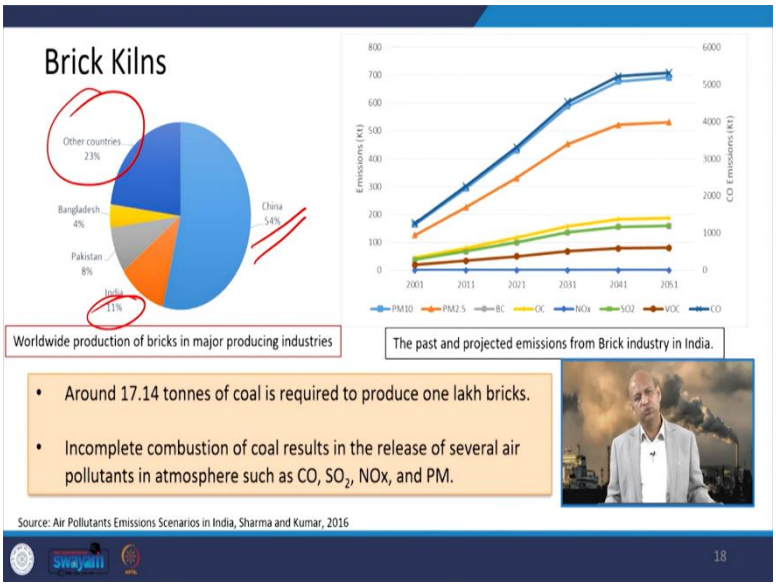

Well, when we talk about the brick kilns, then again the emissions of different kinds of pollutants are increasing, for example, this CO and this is like PM_{10}. So, these are the predominating pollutants and you see the comparison with different countries like China is

responsible for 54 percent production of the bricks, and 4 percent Bangladesh, India is around 11 percent, so that second largest are the other countries if you see in total otherwise, India is producing around 11 percent.

So, like approximately 17 tonnes, you can see of coal is required to produce one lakh bricks. So, incomplete combustion of the coal results in the increase of or release of the several pollutants in the atmosphere like CO, sulphur dioxide, oxides of the nitrogen and the particulate matters.

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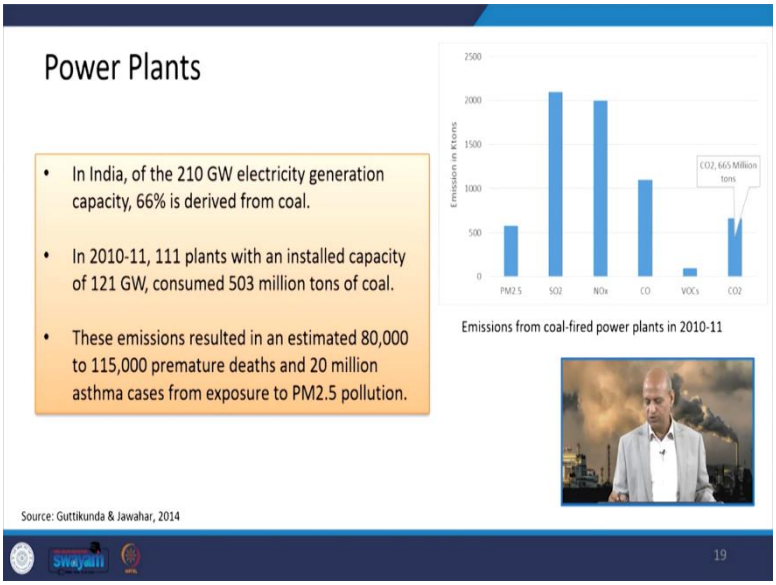

When we look at the power plants, so again you can see the CO_2 is coming and NO_x, SO_2 etc. They are coming in large quantity from the power plants and you see the need of the energy is growing, because living standard is getting better and people are demanding more energy for having better quality of life.

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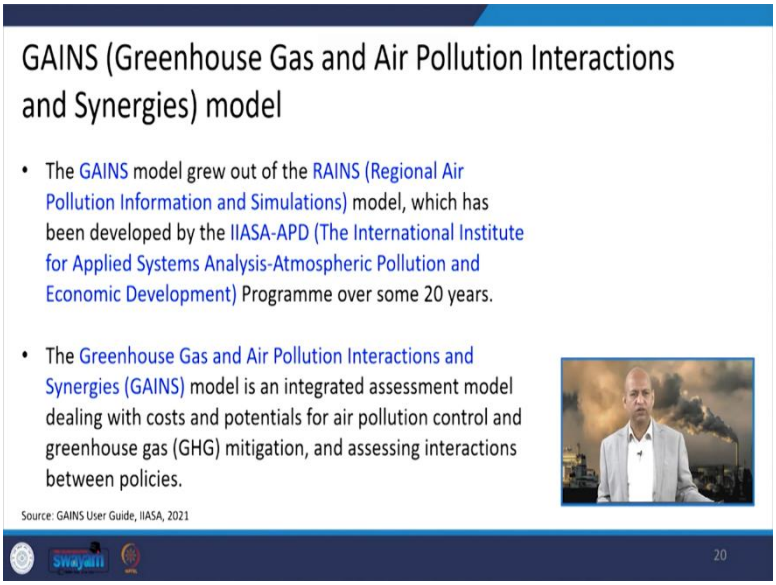

So, now, we talk about this GAINS model after MARKAL. So, GAINS model is nothing but the Greenhouse Gas and Air Pollution Interactions and Synergies Models. So, in short we call it GAINS model and this next version of the RAINS model you can say. Earlier it was Regional Air Pollution Information and Simulation model. So, this was developed by IIASA, that is International Institute for Applied Systems Analysis. And they had this program of atmospheric pollution and economic development.

So, they under this program, over the 20 years, this modelling framework has been developed, it is very exhaustive model a lot of things are there. And this can have integrated assessment of this even cost and potential of air pollution control and greenhouse gas mitigation strategies, assessing interaction between different policies. So, that way this is wonderful model, which can give you not only the quantities of the air pollutants, but also different scenarios of technological related interventions etc. We will see further in detail afterwards, after short while.

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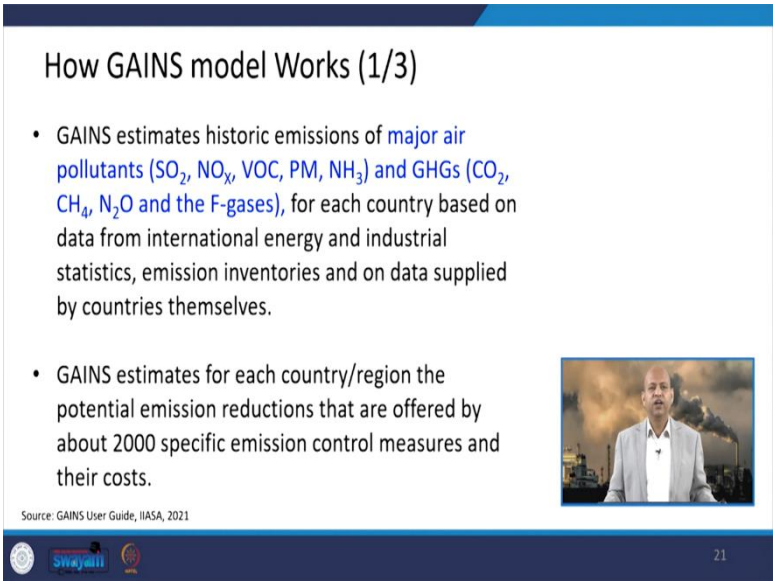

And this GAINS model can estimate major air pollutants like sulphur dioxide, or NO_x, or VOCs, volatile organic compounds, and then particulate matter ammonia. In greenhouse gases it can compute like CO_2, methane, nitrous oxide or other gases, which are responsible for greenhouse effect, for each country, it has complete database and from different sources, they have compiled those inventories and database are there.

Well, so it can estimate for each country and region all potential emission reduction strategies, mitigation strategies, technological interventions and it has around 2000 specific emission control measures and their cost involved. So it is a very kind of exhaustive data set it has plus it has a lot of possibilities for playing for different regions for different strategies, how much it will cost, how much emissions are there, what kind of strategies may be there which are possible in that particular region. So, those kinds of possibilities are there.

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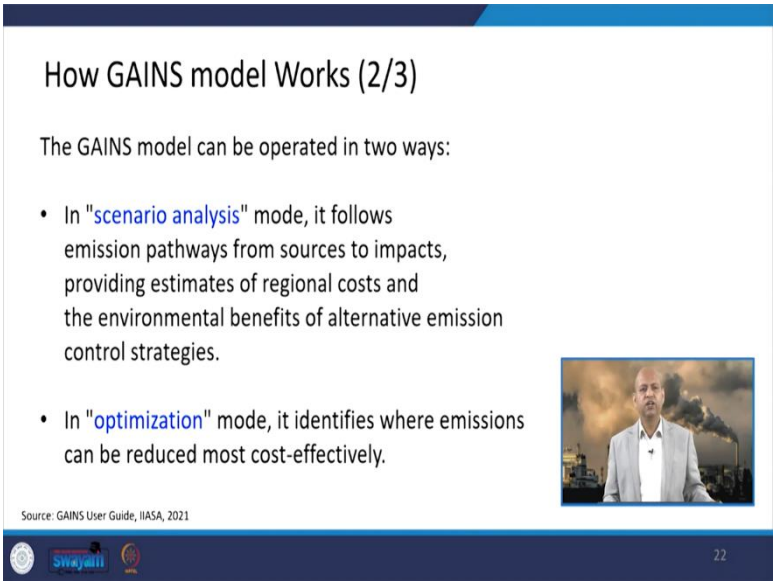

Well, when we talk about like scenarios, then in operation mode, two major scenarios are discussed like scenario analysis or you can say optimization mode. So, these are the two basic modes.

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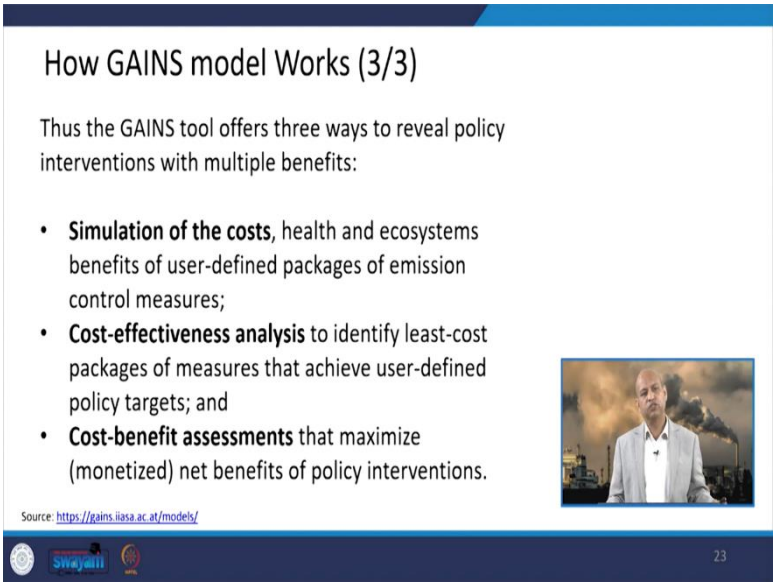

But, in three ways, three ways you can use for policy intervention calculations and multiple benefits like simulation of the cost which gives the health and ecosystems benefits for the user-defined packages of emission control measures. And the other is cost effective analysis which is used for identification of least cost packages for measuring, which can achieve user-defined policy targets. And the last one is cost benefit assessment that maximize the monetized net benefits in monetary terms of the policy interventions.

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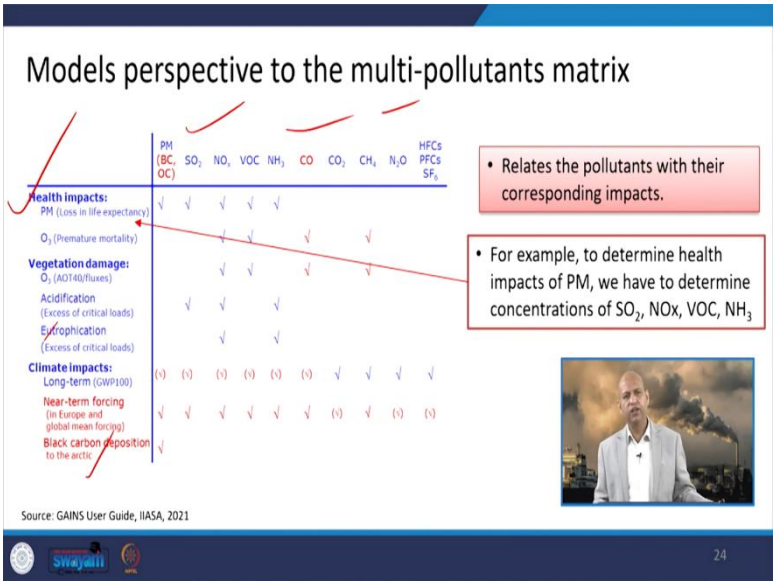

Well, when we see at this matrix, so these are the multiple pollutant matrix based on that we can have a perspective like different health impacts, because of particulate matter, we can have loss of life expectancy from Ozone we can have we can have premature mortality, all those vegetation damages, ozone, acidification eutrophication, that may be responsible by those emissions, climatic impacts maybe there, near term forcing, then black carbon deposition at the to the Arctic. Those kind of scenarios can be discussed.

And then different kinds of pollutants are covered in that particular activity you can see. So, related to those pollutants with their corresponding impacts we can assess, and then we can also determine different scenario based analyses, whether this pollutant will cause how much health impact or how much environmental damages.

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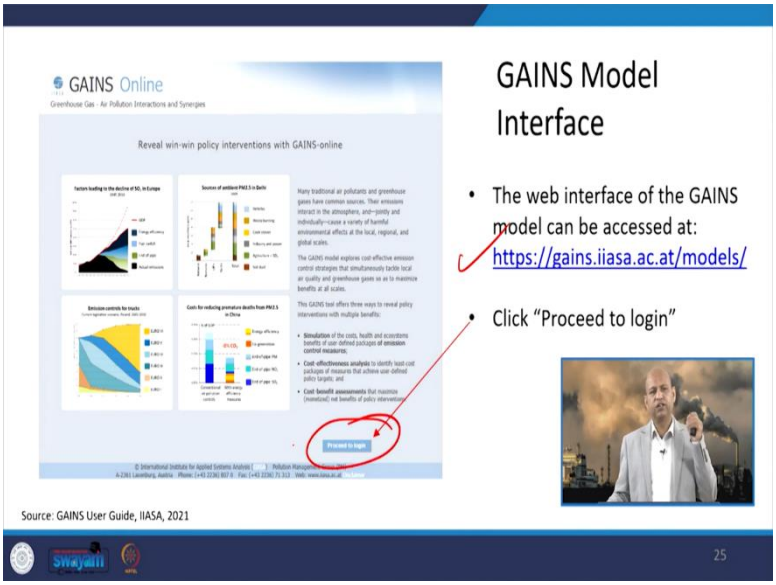

Well, this is the kind of the first interface of the GAINS model, where when you go to the site, this is online available. So, the web interface of the GAINS model can be accessed at this particular link. And then you can go to this particular point, where you can click proceed to log in, when you want to use this model.

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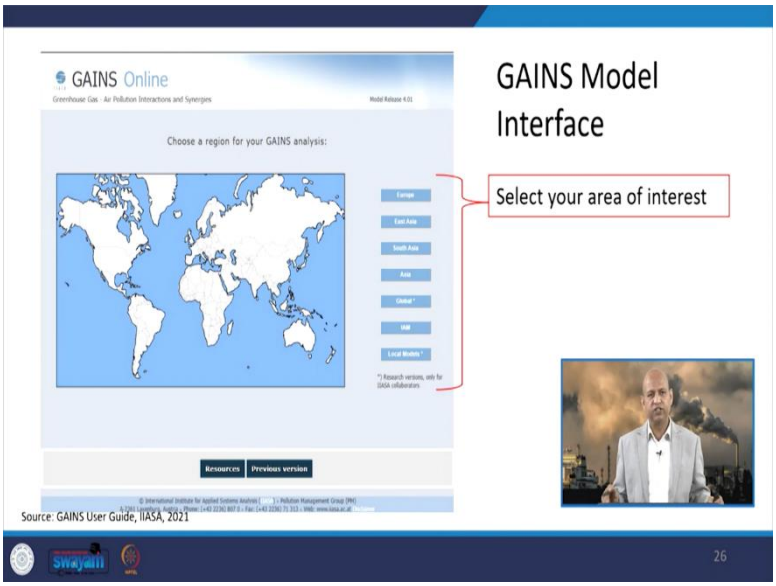

So, then this gives the choices of different areas like which area you want to calculate emissions and you want to see what kind of policies will have how much impact in different ways. So, like Europe or South Asia or Asia, global all those kinds of possibilities of different regional combinations are there.

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So, you can go, for example, we can select Asia. So, in Asia this kind of colour you will see, when we choose it, then this will give this kind of colour scheme that, you have chosen this particular area or region for which the calculations will be there by this GAINS model.

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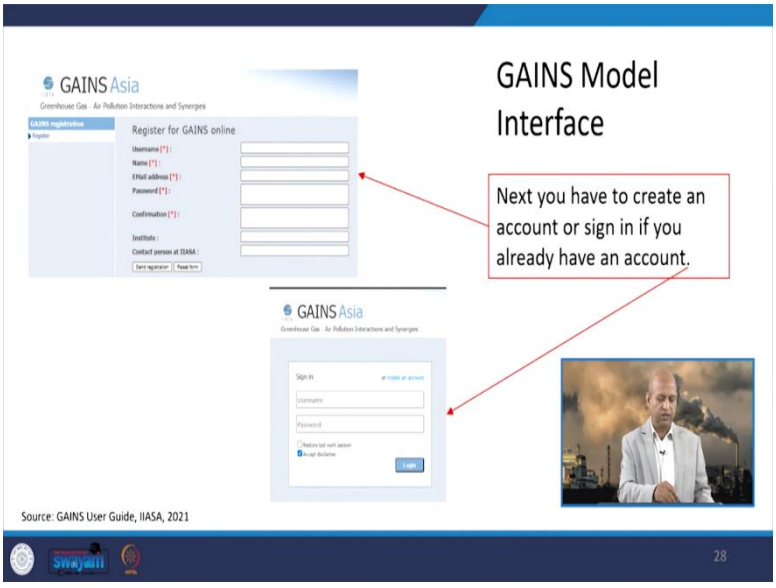

Then it gives us when we click next, then we have this particular window where we can create the account or if we have account, then we can do login or sign in means user ID and password and you can go into the model.

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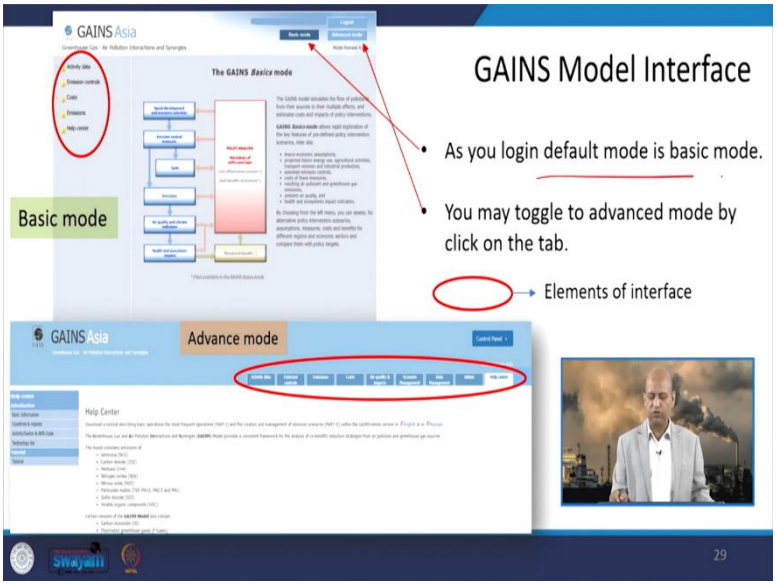

Then, we see like different kinds of things are there like some default modes of the basic model are there and then, you can toggle also with the advanced mode, where you can have various other possibilities. So, you can see here advanced mode, there are different possibilities which can you can try for calculation purpose.

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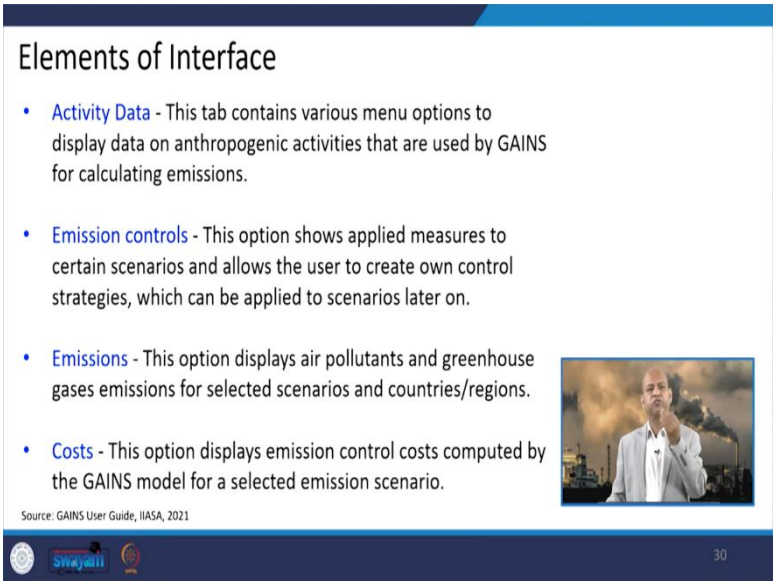

So, what are those interfaces, we can discuss like activity data are there, which the activity tab, activity data tab this gives like various kind of menu options for anthropogenic activities which are used by GAINS for calculating emissions. So, those activity data are defined.

Then if we go for emission controls tab, so this gives possibility for different scenarios that allows the user to create on control strategies, how do we want to control. Some policies may

be specific to a particular country or you want to test what kind of policies can give how much impact positive impact, so you can define your own policies, control policies, control measures.

Then emissions this option displays when you click it, then the emissions will be displayed after the calculation back at the back calculations are there. So, this option displays the pollutants and greenhouse gases. The emissions which are selected for the selected scenarios and selected region or countries. Then cost option, this gives the cost, how much cost will be there for those kind of control strategies which we have provided.

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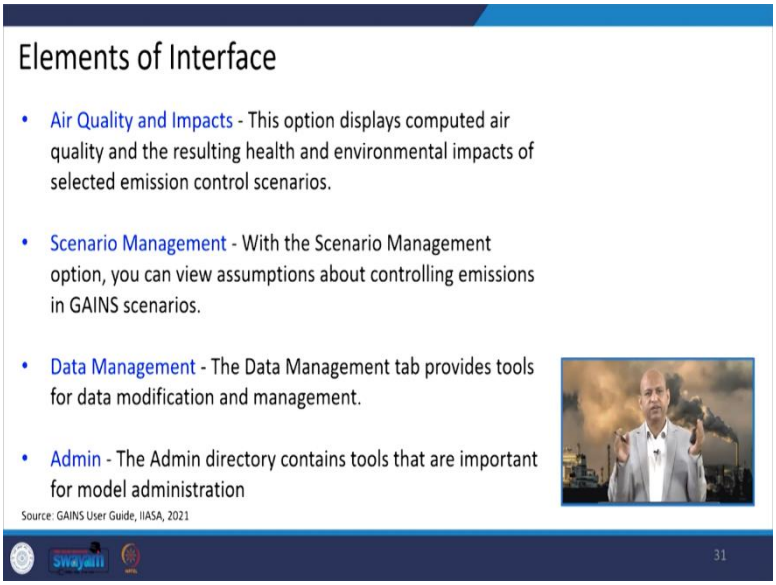

So, then we come to this type of air quality and impact. So, this gives different options to display like what is the air quality and what are the its impact in terms of health and environmental impacts for those selected emission control scenarios. So, that can be displayed.

Then when we go to the scenario management, then we can view assumptions about controlling emissions in GAINS scenario, then data management is there for providing different tools for data modification and management. Similarly, admin related the tab is there which can be used for admin related points or those kinds of possibilities.

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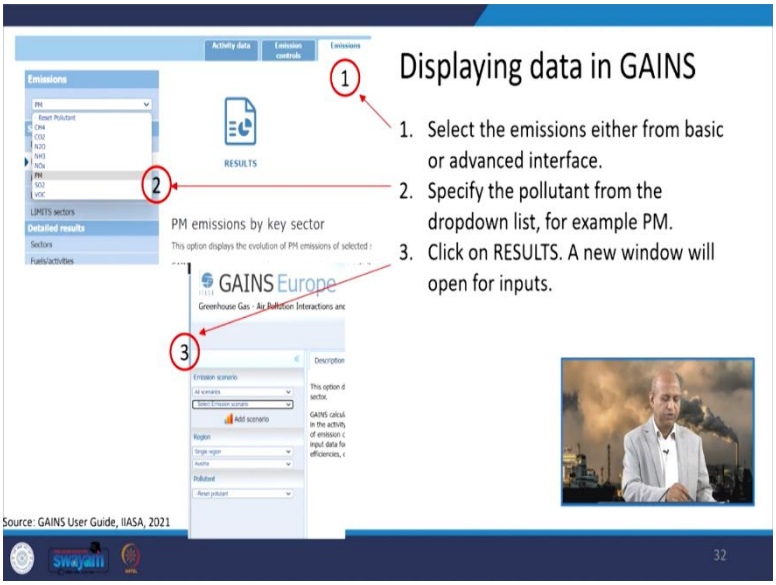

When we talk about like how this data is displayed, so you can select as we have discussed like emissions either from basic or advanced interface you can select. Then there will be these emissions like different pollutants like NO_x or PM, those kind of things. So, you can specify the pollutant which you want to calculate the emissions for.

So, let us say like for particulate matter, then you click the particulate matter, if you want to calculate for SO_2 then you click the SO_2, you can select accordingly from this second number step. The third is the result. So, when we click then the results will be there.

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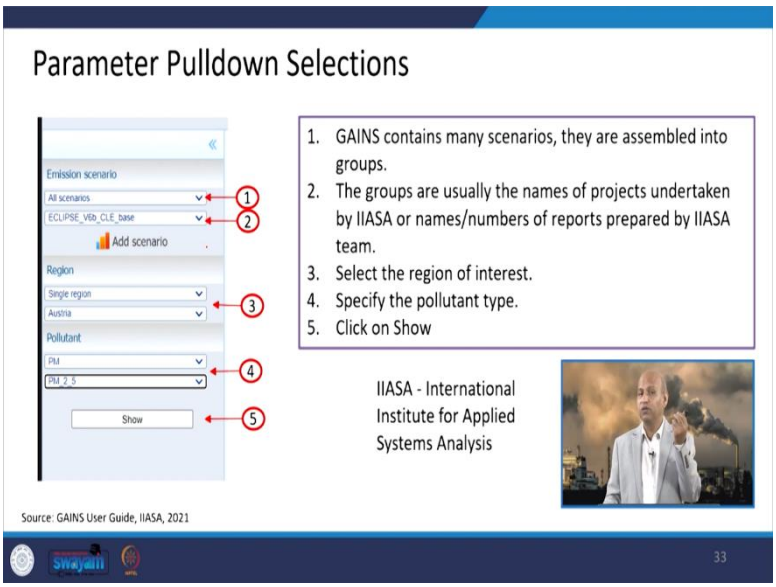

Then different parameters which can be seen for different selections like it has many scenarios, so scenarios and that is based on different kind of project activities, different group activities.

So, we know what particular scenario does. So, accordingly we can choose the specific scenario and the region of interest can be selected, then pollutant type can be selected as we have seen, then we click the Show, then it can show the results.

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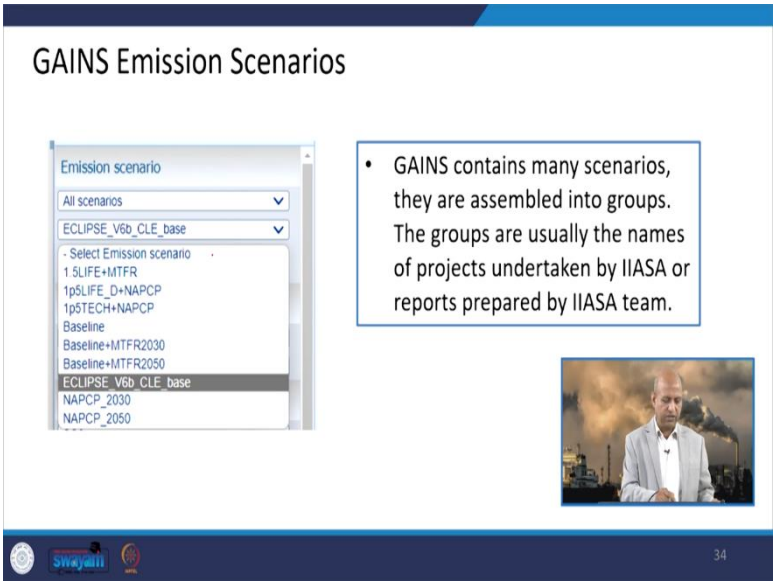

Then you can see these are the different emission scenarios as we talked. So, accordingly which scenario you are considering you can select.

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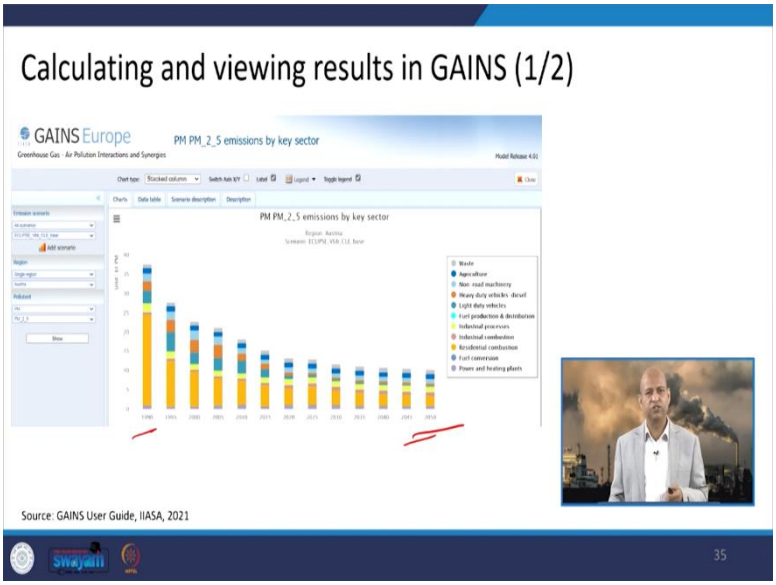

So, when we click the Show button, so these kinds of graphs are available, calculations take part in the backend and it displays. So, you can have this $PM_{2.5}$ emissions for key sectors. And for different years, like here from 1990 to 2050. So, the scenario based calculations are there and they are decreasing, because some sort of policy measures we are implementing

technological interventions we are implementing, so that is giving the lower amount of emissions, because those efficiency related scenarios, technological intervention related scenarios.

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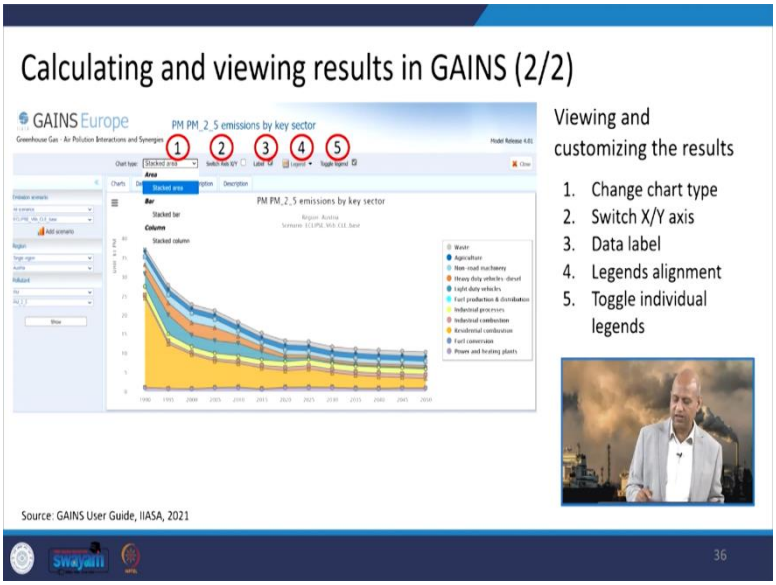

Well, when we talk about like different kinds of charts, we can select bar diagram or other kind of charts, presentations are there. So, you can select accordingly.

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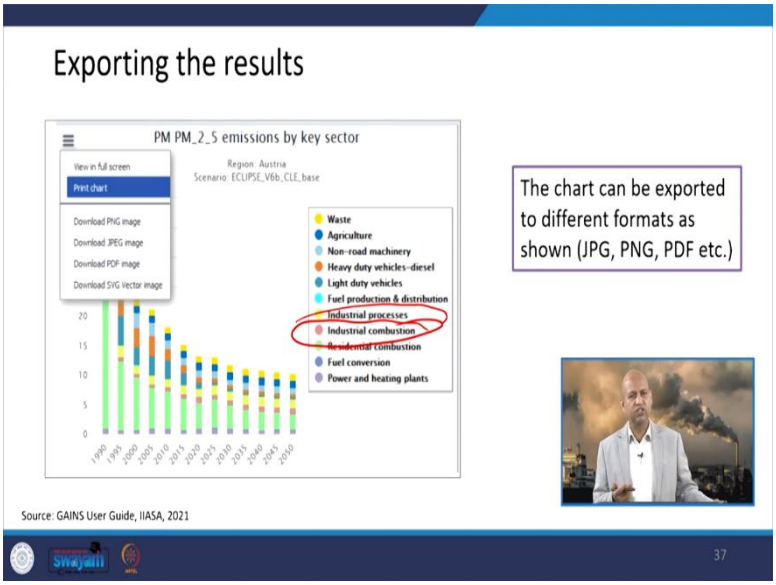

Well, you can also see these charts for you can export it for different formats like PDF or image file you can share with other people other researchers, those kinds of things are there. You can see different emissions are coming from different sectors. So, agriculture, non-road machinery, industrial combustion, so we are more interested in these industrial processes. So, these are the

models as I said it can calculate emissions for different sectors and it can also be used for industrial sector that is why we are discussing it.

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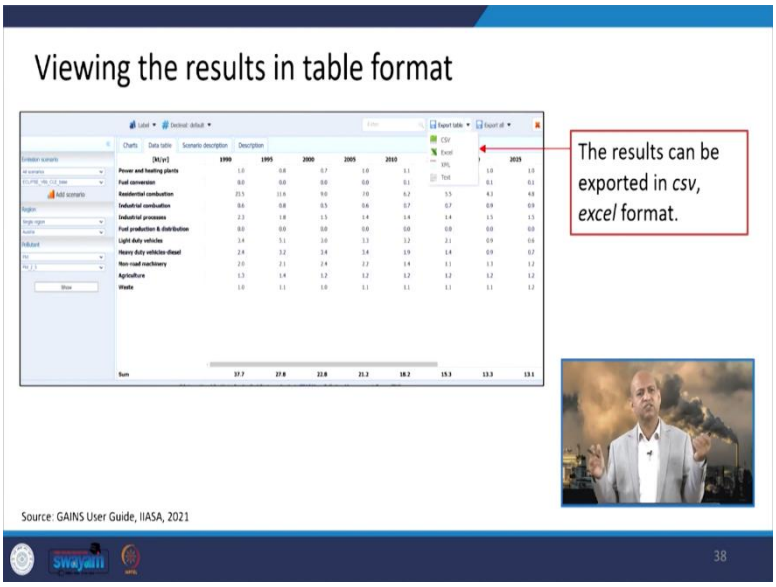

Then we can view these results in other formats like Excel sheet also. So, you can play with it, you want to generate other kind of charts other kind of comparisons beyond what is possible through this model. You can use the Excel mode or this data.

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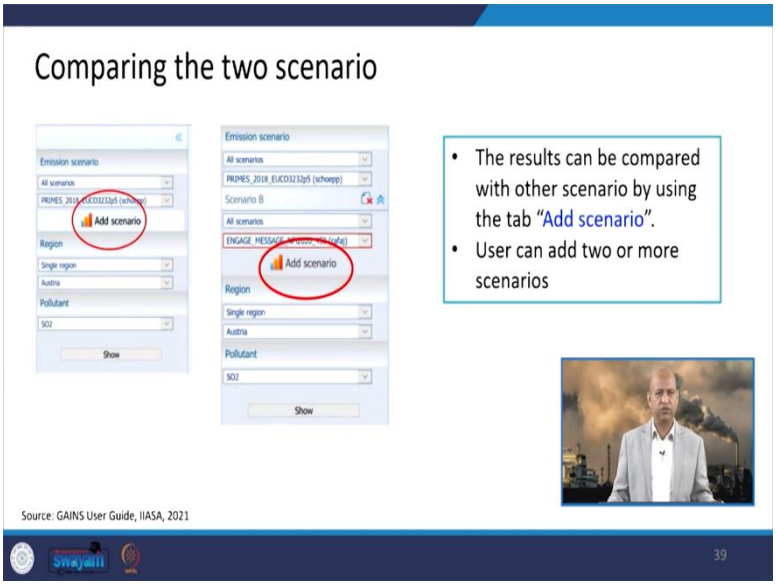

Then you can also compare two scenarios. So, you can add the scenarios with this particular tab and two, three scenarios you can compare.

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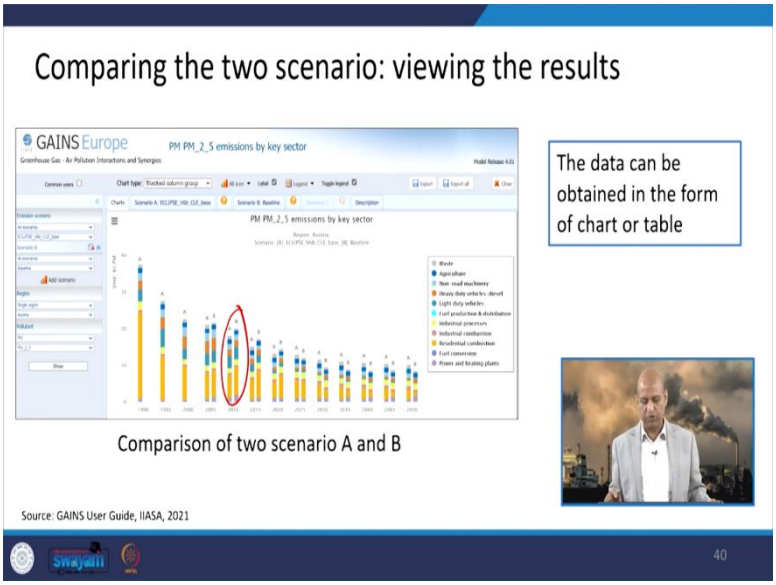

Like for example, two scenarios, if we compare A and B. So, that way you can have these like B scenario is giving more emissions in this particular year 2010 and A is giving less, so it will depend upon what kind of scenarios we have generated. So, that means A is more efficient or better technological interventions may be there. So, those kinds of comparisons we can have.

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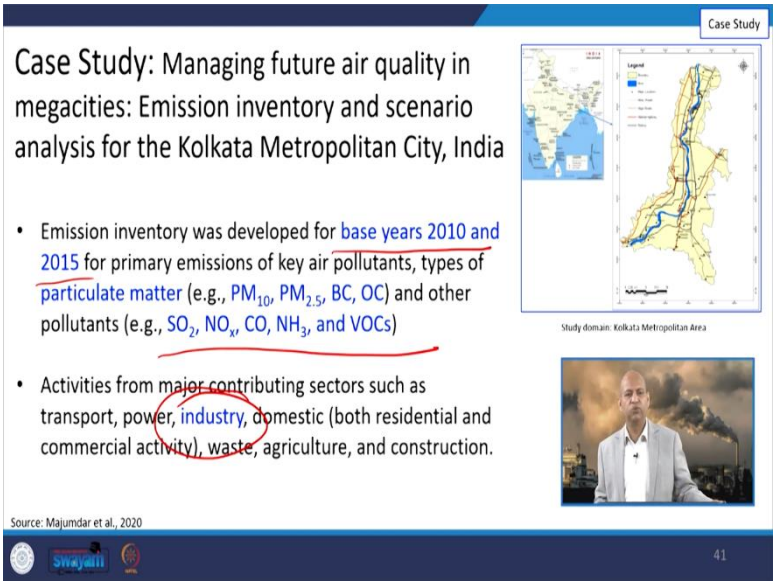

Now, if you want to understand in a better way, so we will discuss briefly this case study which was based on GAINS model basically. So, it was used for metropolitan city of Kolkata. So, emission inventory and scenario-based analysis for Kolkata city was taken as a study by some researchers. So, that particular discussion is there on this particular study.

So, they have considered these kind of pollutants like SO_2, NO_x, CO etc, particulate matter, PM_{10}, $PM_{2.5}$, black carbon, organic carbon, all those kinds of things and the base year for calculations was 2010 and 2015 and activities were for several sectors like transport power sector domestic, but we are focusing only on industry, because this is what we are looking at Emission Inventory development for industrial sector specifically.

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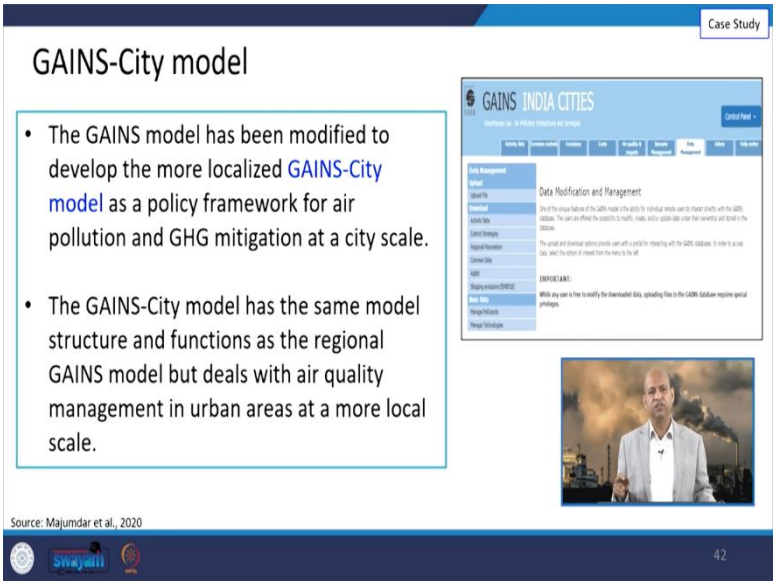

So, this GAINS city model is there basically another version of this GAINS model for a city-based study. So, that means, you can narrow down the region and that can give you different kind of scenario based analysis and you can pick up the best scenario possible.

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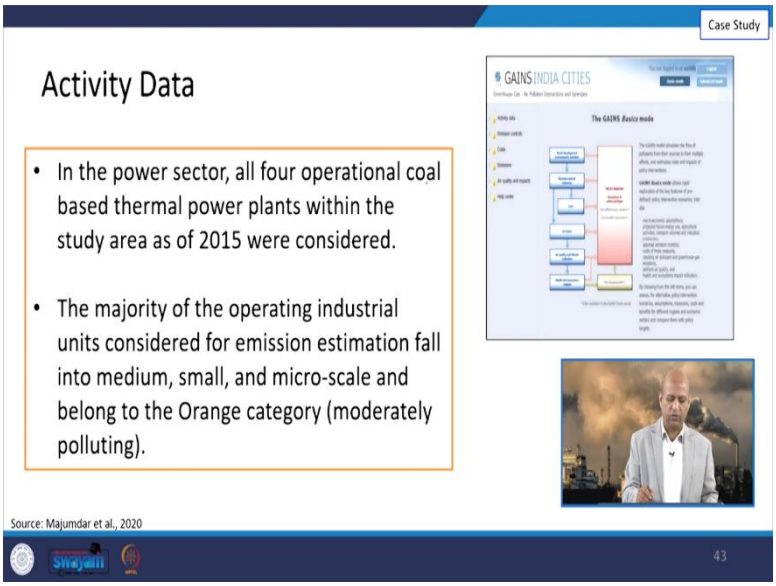

So, this we have seen the activity data in this particular case study, they looked at four optional operational coal based thermal power plants within that study area as of 2015. Those four power plants were considered. Then majority of the operating industrial units which were considered for emission estimation, they fall into medium, small and micro scale industry, hardly there were large industries. So, these were of orange category, that we moderately polluting.

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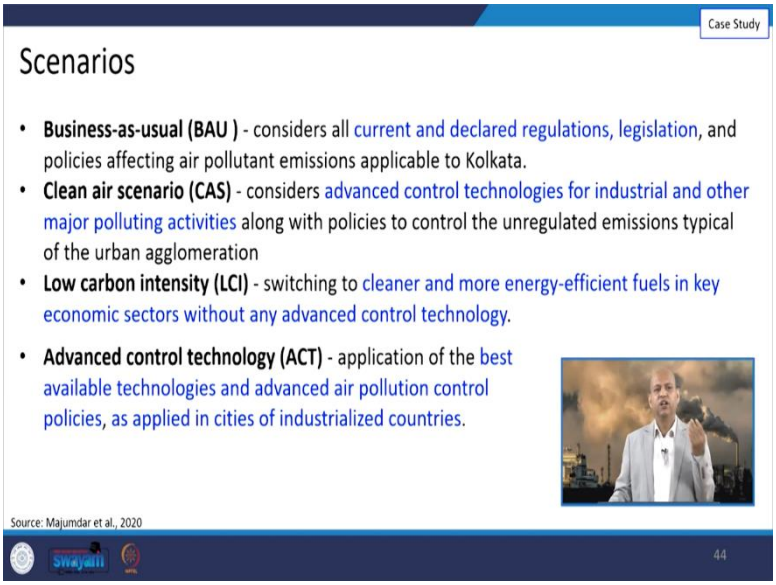

And the scenarios which were considered for this particular study were like Business-As-Usual, (BAU). So, that considers all current and declared regulations, legislations and policies which affect the air pollutant emissions applicable to Kolkata.

Then the next scenario that was considered in this study was Clean Air Scenario (CAS) and that consider some advanced control technologies for industrial and other major polluting activities, along with those policies which control unregulated emissions typically from the urban agglomerations.

The third scenario was Low Carbon Intensity (LCI), that scenario and this was like switching to cleaner and more energy efficient fuels, in key economic sectors including the industrial ones and having the advanced control technologies. Then the last scenario was advanced Control Technology (ACT) related scenario, that means the application of the best possible technologies and advanced air pollution control policies which are applied in cities and industrialized countries, means cities of the industrialized countries, so that was the best possible. So, those kind of four scenarios were considered.

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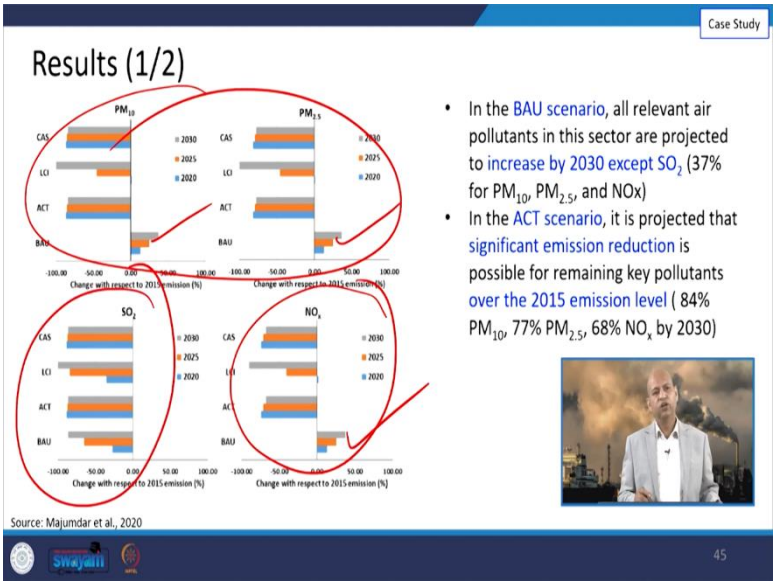

And you can see in this BAU scenario, only the positive emissions are there means growth in the emissions increasing is there otherwise, like PM_{10}, $PM_{2.5}$, SO_2. For particulate matter basically, for BAU this increasing of the pollutant was there. NO_x emissions were also accordingly increasing in the BAU scenario.

For the other three scenarios the decreasing trend was there, because of the policy interventions. But in case of SO_2 even in BAU scenario, the reduction of SO_2 emissions are there, because already some policies are there which are kind of desulfuration of the coal etc, are there. So, those are being considered.

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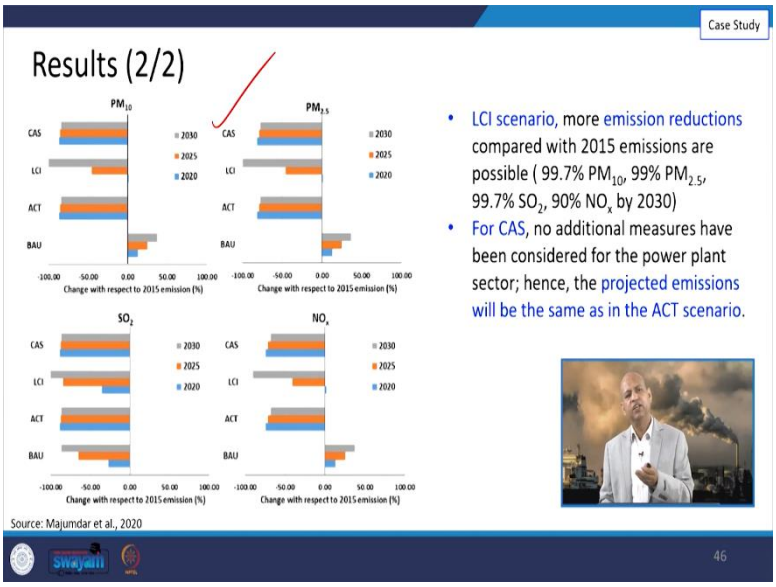

Well, well when we go for LCI scenario, then this kind of emission scenario you can see. So, different scenarios and different results according to those scenarios were discussed and seen so that is you know symbolic representation of those particular results you can appreciate that how these models can be used for comparison purpose of based on different scenario calculations.

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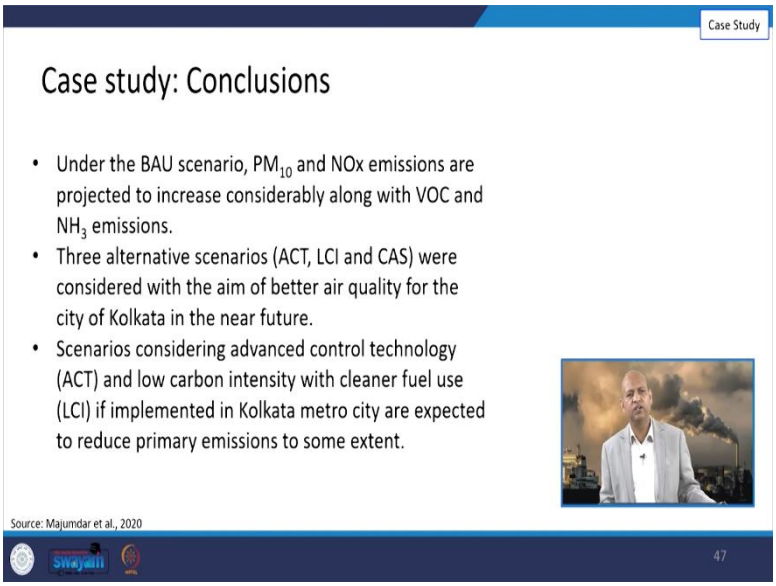

Well so the case studies conclusions are like under the BAU scenario like PM_{10} particulate matter of the 10 micrometer, RSPM also we call it. So, PM_{10} and NO_x emissions are projected to increase considerably along with volatile organic compounds and ammonia emissions.

These alternative scenarios or three alternative scenarios in addition means other than the BAU scenario like ACT, LCI and CAS, so these were considered with the aim for the battery air quality for the city of Kolkata in near future. So, those kind of policies were taken into account for those particular scenarios. And scenarios which were considering advanced control technology that is ACT and the LCI, they were implemented in Kolkata metro city and they are expected to reduce primary emissions to some extent and large extent for a particular pollutants.

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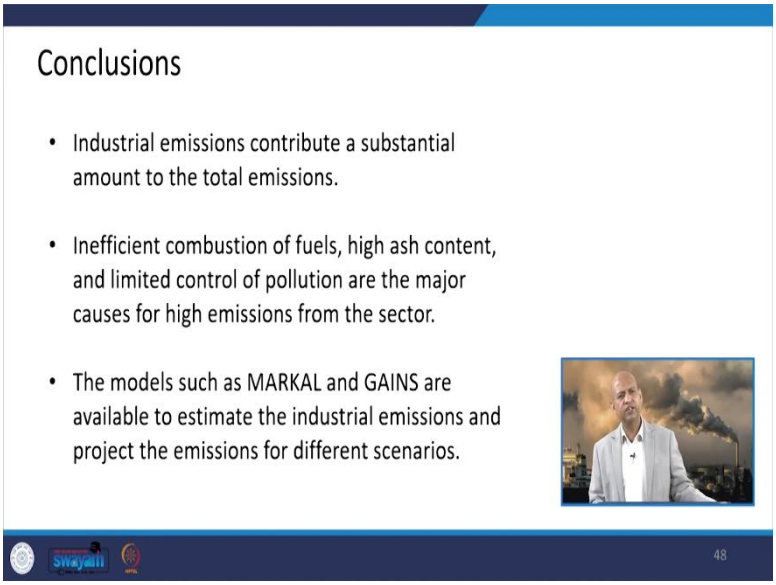

So, overall conclusion we can say that the industrial emissions contribute a substantial amount of total emissions, whether you consider air pollutants or greenhouse gases and insufficient combustion of fuels or inefficient combustion of fuels and high ash content and limited control of pollution are the major causes for high emissions from the industrial sector basically. And the models like MARKAL, GAINS, they are available they can be used for estimating the industrial emissions and you can also project by using those models emissions for different scenarios, you can define your own scenarios.

And not only these models but you can also use the excel sheet or spreadsheet models by using those equations which represent different activities. So, according to the activity data of a specific industry, you can also calculate emissions for that particular industry.

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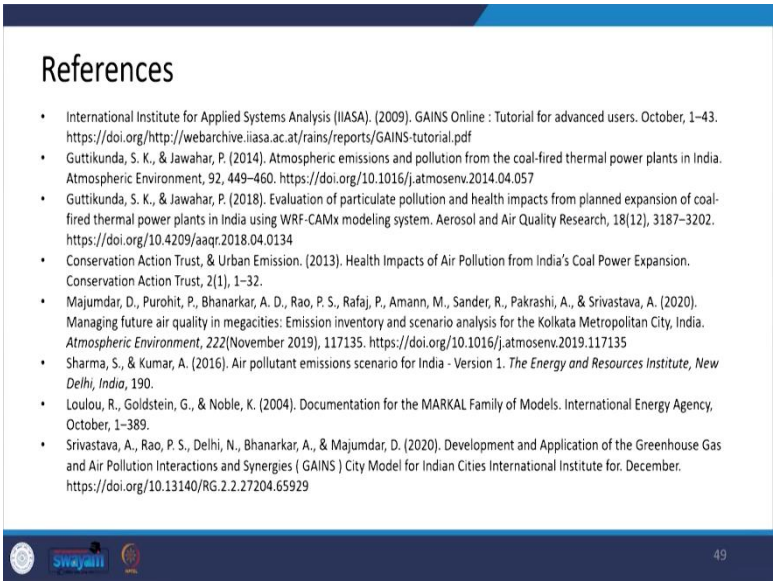

So, this is all for today for emission inventory development for industrial sector we will continue on these you know issues of emissions air quality. So, see you in the next lecture before that you can go to the references and see which are you know interesting and more informative sources can be there related to this particular chapter. So, thank you for your kind attention see you in the next lecture. Thanks a lot.