Energy Resources, Economics, and Sustainability

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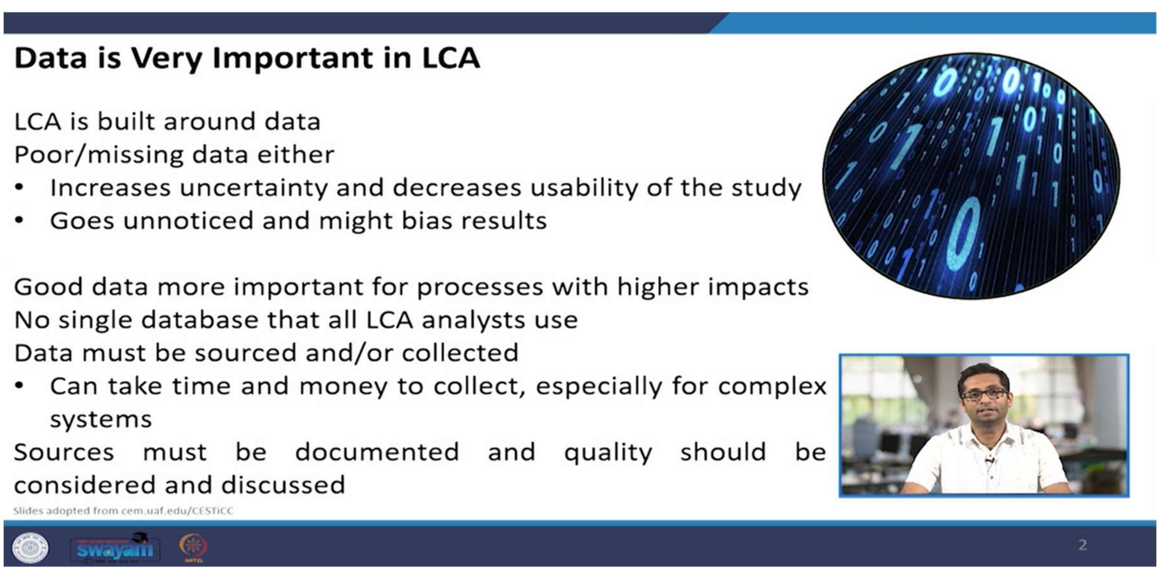
Week – 08

Lecture – 01

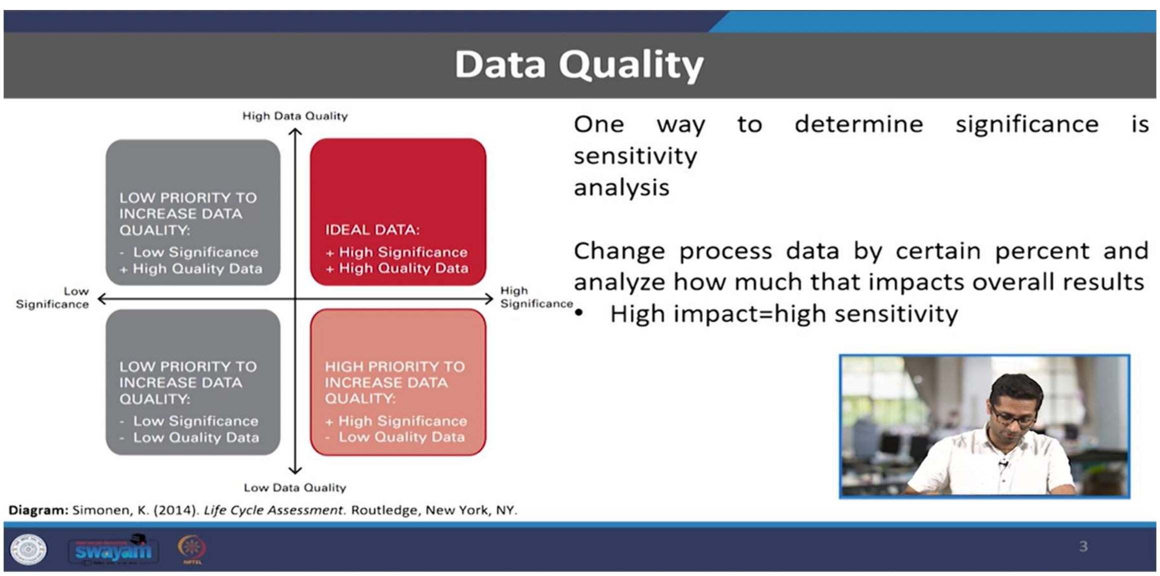
Lecture 37 - LCA: Data and Impact Assessment

Hello everyone, welcome to the course energy resources, economics and sustainability. In the previous few classes, we have been discussing the different elements of life cycle assessment. In the last class, we have been discussing the system boundary, what are the different aspects of the system that should be considered, what are the pros and cons of not considering them, what are the impacts that should be kept in mind. We will be taking the discussion further and today's discussion will be more focused on gathering the data which is a prominent feature of life cycle assessment and what to do with the data. Once you have gathered the data, how would that be converted into different kinds of impacts. So, this is something that we will try to focus in today's class.
So, starting with the availability or gathering of data, we would have or you would have understood by now that LCA is essentially an accounting procedure where you are accounting different types of data to different kinds of emissions and LCA is basically as good as the data is being collected or being used. Further, it is not humanly possible to get all the data that would be needed to quantify all the emissions that might come up from every single process and that is why like there is often like data is often missed or like you would not be able to account for certain data either due to unavailability of data or in some cases it might be too expensive to get the data. And what could be the reason or what could be the result of such missing data?



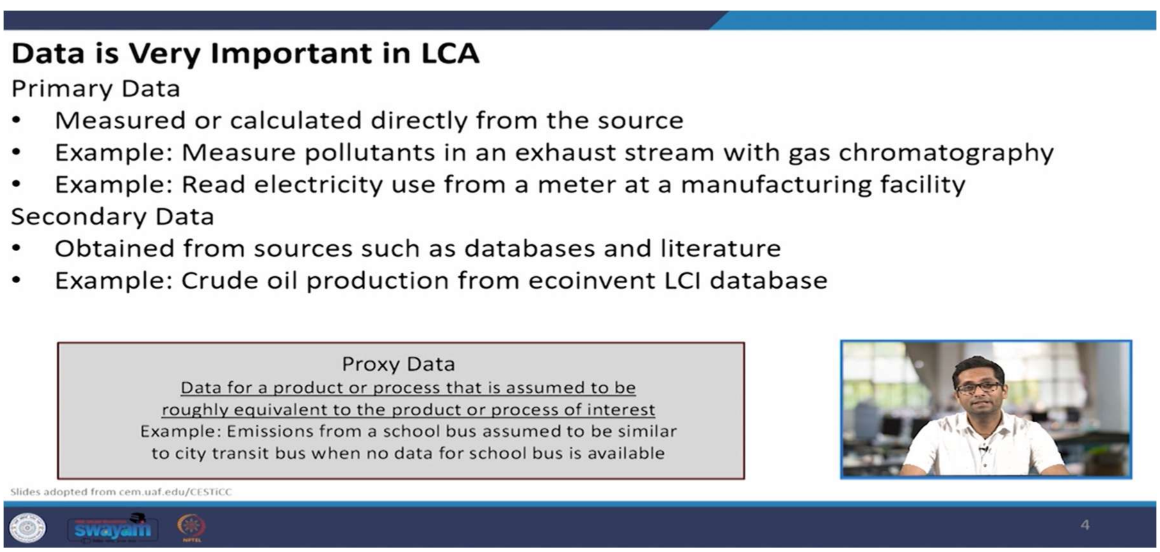
First thing is the results would have a high grade of uncertainty. We would not be very certain if the particular emission is leading to a particular environmental impact but that is true for any process. But again, another feature if we are not able to collect all the relevant data, we might end up taking in a bias into the results. We might be overlooking some of the parameters which might create a bias against some of the emissions or some of the impact categories and that is something we should try to avoid. We should try our best to get as much data as possible and high impact data or good data should be basically try to be found out for the processes which have more or the most of the impact in a process. Well, then you would question like how I am going to get the data. Now there are different ways of getting the data and this is something we will be discussing in the future or in the class in the later parts.

Plus, any data that we get would either require your time, you would have to find the data in the different sources available or you can also go for purchasing some of the standard databases which could have the data that might be available. Further, it is very important that you document the data, all the assumptions that have been undertaken while adopting the data or calculating or quantifying the data should be clearly discussed. So, as the reader knows how the data is being collected, how is it being used, whether the data was relevant to their case studies or not.

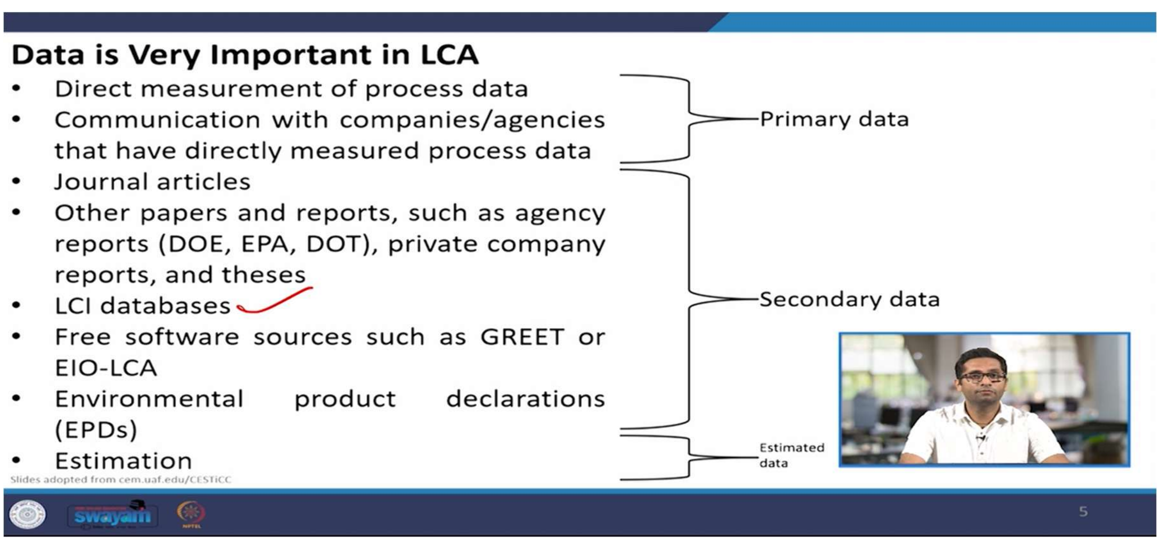


So, regarding data, we should be very careful to have high quality data for the processes which are of very high significance. Let us take an example, like again we are going towards an era of green hydrogen and for producing this green hydrogen we would need electricity. So, while doing a life cycle assessment for any green hydrogen process, the electricity footprint or the carbon footprint of the electricity is of paramount importance. That is one place which is expected to have a majority of emissions. So, this is an example where you would need a very high quality data because the process or the unit process that you are looking for has a very high significance. Further, if you would want to compare like a similar kind of data would be needed for maybe manufacturing of a de-ionizing agent or the place from where the water is stored, this might not be that important and that would follow in the category of data that is of low significance. Further, let me repeat the aim or like our impetus while doing a good life cycle assessment should be to get as high quality data as possible for the processes which have a very high significance.

The second most important thing would be to get the high significance data or like for the data for which we do not have very good data. It might happen that we are planning to produce hydrogen from a biomass source and for growth of biomass we might not have very high quality data in India. So, we should try to gather very high quality data for biomass and that should be the next significance. The processes with the highest significance should be given the most impetus while collecting the data. Further, there might be processes which have very low contribution to the final emissions and for that we might, even if we are not getting very high quality data it might suffice because anyway the impact that they are creating is not very high. How would you ascertain that these are the processes for which you need a high quality data? Probably you would have to do a sensitivity analysis wherein you would change the process parameters by a certain percentage and see the impact of those processes on the overall results. If the overall results change by a significant amount those are the processes that would need a great deal of consideration and you should be looking for good quality data for these kinds of processes.



Further data is the core of any LCA and this data can come from either primary collection wherein you yourself collect the data. It can come from simple calculations, it can come from the meter reading from electricity meter, it can come from the exhausting measurement, you can measure the flue gas concentration of the different fossil fuel based energy production processes, you can measure the pollutants yourself and these would be the sources of primary data. Then there are also secondary data wherein you might not have the ability to collect each and every emission that is happening on each and every part of the process. You can refer to understand certain standard databases as well as the published literature that is available. An example could be the crude oil production that is happening in some of the other countries could be available through one of the equipment databases. Further the electricity footprint that we might be using for different kinds of processes might come from either the government sources which are quantifying it or again it can come from different publications. It might also happen that the process that we are looking for doesn't appear in any of the publications or the processes. In such a case instead of omitting the data altogether what is proposed is that you should be using proxy data, you should try to find processes which are similar to the process that you are trying to model or trying to replicate and use the data for that case. Say for example if you would want to see the emissions that are coming out from a school bus. Now exactly the emissions coming out from the school bus might not be available in any database or in any publication. What is expected to be more readily available is maybe the emissions from a standard transit bus. So since a school bus in every aspect would be equivalent to a transit bus there is no problem using transit bus emissions in place of a school bus. Further some people might want to look at emissions that might come from the burning of biochar. Since biochar is very similar to coal and combustion you might want to consider to replace it by coal and gather the emissions that come from the combustion of coal when it comes to biochar. So these are few examples where you might want to use proxy data instead of the actual data which might not always be available to you.

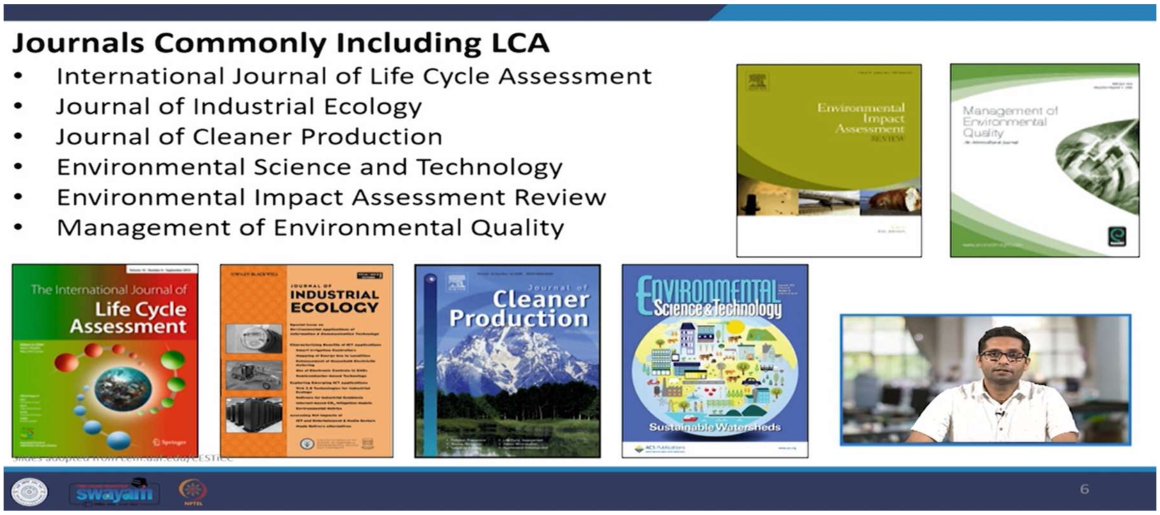


Further if we were to see some of the examples of primary data this would of course be the direct measurement that you can do. Further it can also come from the communication with the different companies, agencies which might have authorized you to do the study or you might want to collaborate with them because they have been running a particular plant or operating a process for quite some time and they would have been collecting this data for meeting the different environmental regulations and you might want to enter into some kind of agreement with them and use the data. Because of the structure of the LCA is such that you would not always be presenting the exact emissions command you are mostly presenting the end results.

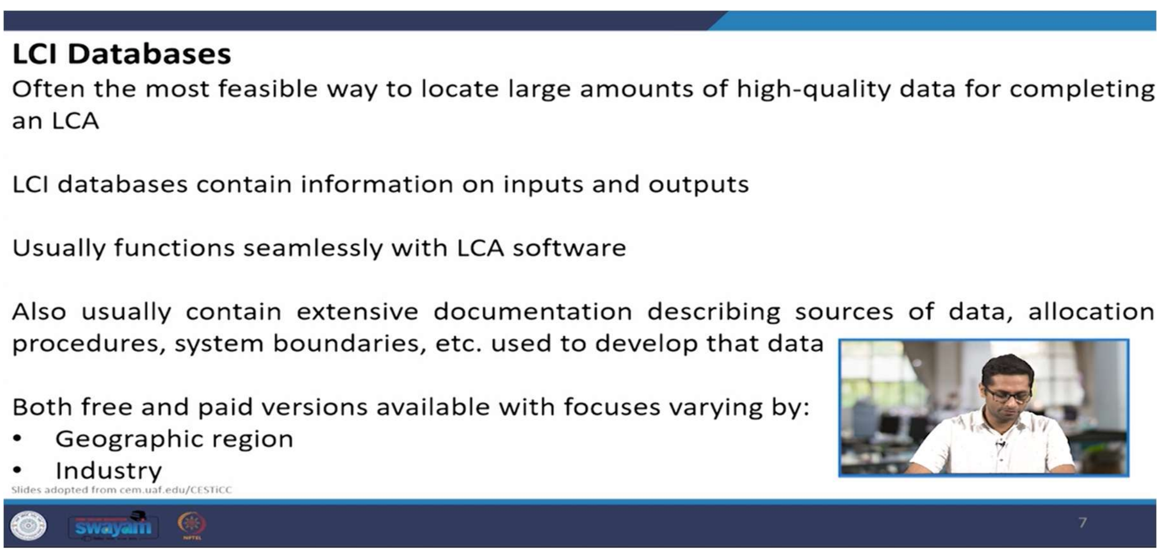
Many times the company would not have problems sharing their data because you are not putting in the exact mass flows or the elemental flows of the compounds in the processes but you are giving in the final data in the results. Further when it comes to secondary data the ideal source would be the different kinds of databases that are available. There are many different LCA databases available and these databases could be both free as well as paid. And Of course if we are looking for high quality data many of these databases charge a very good price for it. Another good source would be the different journal articles.

These journal articles again could be subscription based or open access. Not all of us would have access to subscription based articles but there are many journals who publish LCA data regularly and many of the authors would also give the inventories. If you are modeling some of the processes that has already been published by some of the authors you might want to use them directly. Another source could be the different reports that come out by the different government agencies or the agencies around the world like the Department of Energy or there could be private company reports and it could also come from academic thesis where people or students have done their masters or PhD thesis in the past for some kind of processes and you might want to use or adopt those data straight away. Further there are also certain free softwares like GREET. GREET is one software which is available for transportation emission database and then there is also economic input output LCA data which is available for free. Further because of the environmental regulations there are different corporates or entities which regularly publish the environmental product declarations which is the footprint of the product that is manufacturing. So in case you are doing a life cycle assessment for a product which is similar to one being manufactured by one of the companies which has put out its EPD in the open domain you might also want to refer to those reports. Then if the process that you are trying to model or you are trying to replicate for the LCA does not have the data available in either through primary or the secondary sources. The last resort would be if you would want to go for some kind of estimation where you would try to replicate the process with the process that is available and for which the data is available.

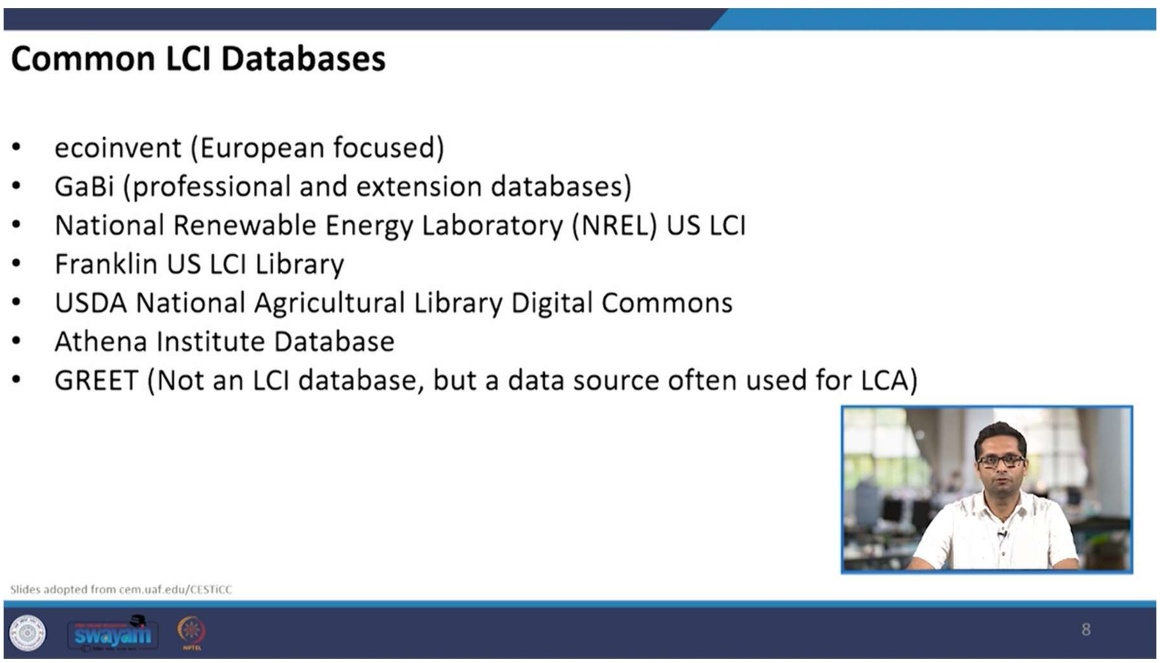
So rather than omitting the process all together it is always beneficial to have some kind of estimation that can go in. Of course this would increase the uncertainty of your process but it is also recommended to go for some kind of estimation.



Then just to give you an example of the different kinds of journals that you might want to refer to while collecting data for your life cycle assessment. So there is one particular journal which is the International Journal of Life Cycle Assessment which is based on or totally committed towards publishing the LCA studies both in terms of methodology and the LCA of different processes. Apart from them we also have reputed journals like Journal of Cleaner Production, Environmental Science and Technology, Environmental Impact Assessment Review which would regularly publish different kinds of studies which have LCA attached to it. So all these journals are reputed journals which you might want to refer to when you would want some kind of data to be available. And also these are the prospective journals where you can also try to publish your results as well as your interpretations from the LCA that come out.



Now coming to the different kinds of databases. So it's often it is seen that like whenever you are doing LCA for a very comprehensive process you would not be able to collect all the data by yourself. You would have to refer to some kind of databases for the background data that exists. And there are many databases available and there is no single database that you can say that is available. And these databases have been used by all the LCA community and different people would want to use different data because different databases have their regional as well as impact limitations. And in the future in the coming few slides we'll try to discuss a few of the prominent databases that are available and what are the major databases that are available. And these normally many of these databases are also linked to some kinds of softwares. So in many of the softwares that you might be using might come with their own databases. So you can also use also databases directly. Further the professional databases when you refer to also come with a lot of information in terms of the metadata which basically lists down the source of data, the allocation procedures that they have adopted, the system boundaries that have been used. All of these terms we have discussed in the past and we also try to understand the type of impact that it could have on the final results. And again many of these databases would be limited to a few geographical regions and it might happen they are also limited to a particular industry.

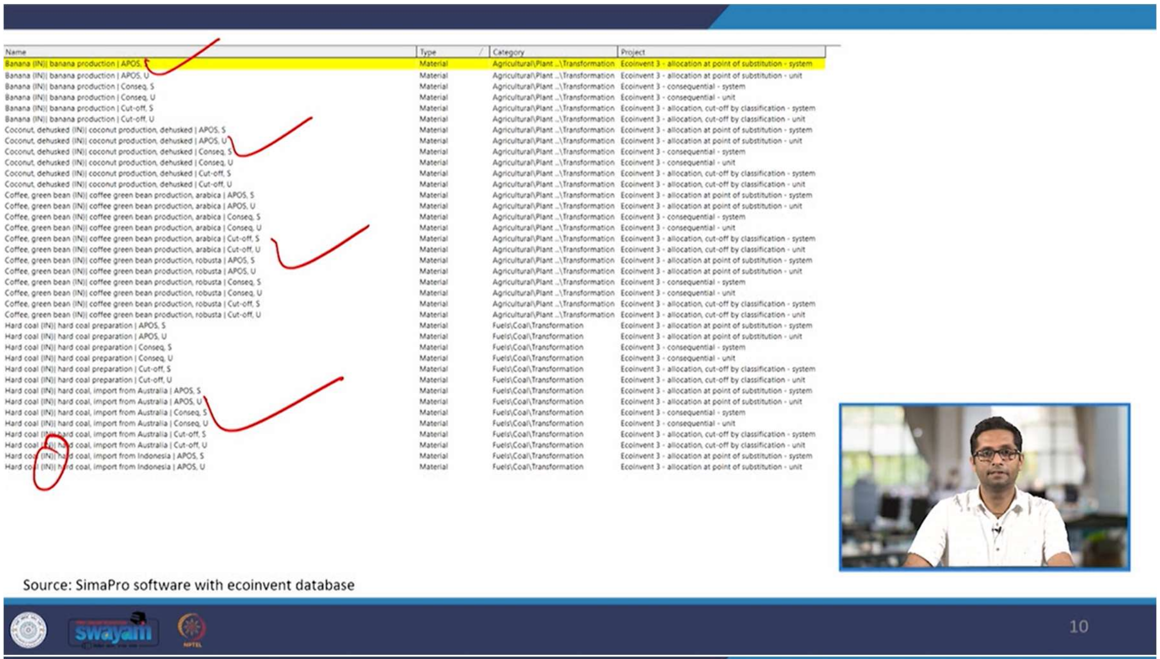


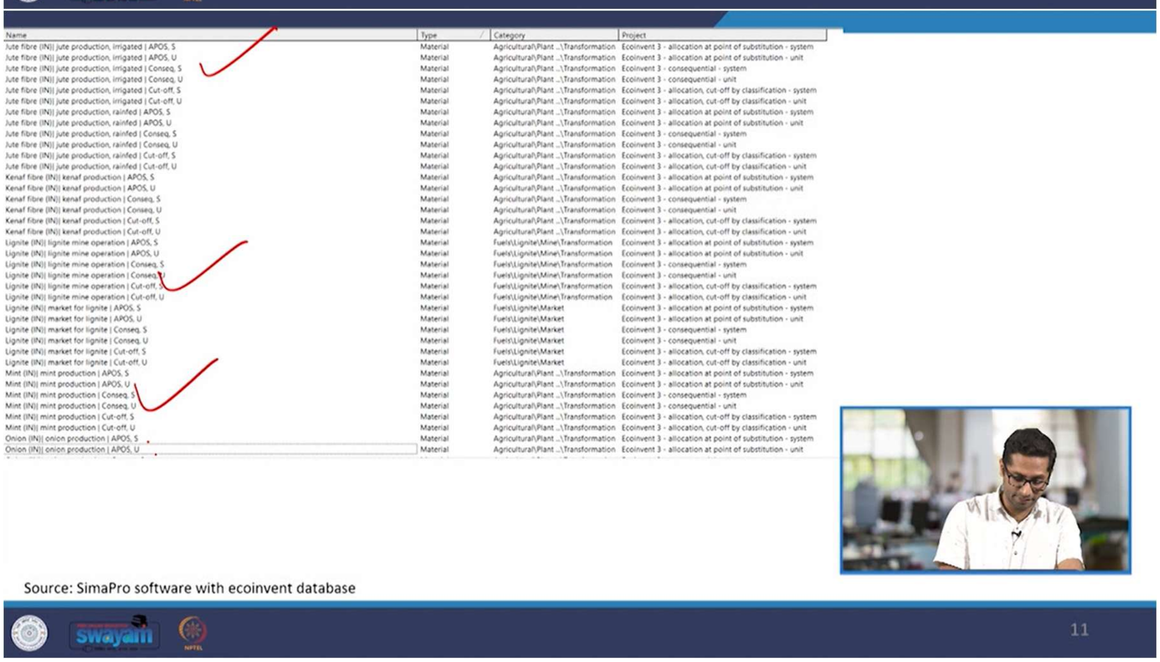
So let us try to analyse few of the prominent databases that are available and try to see what they are. So I would just like to acquaint you with a few prominent ones. One of the earliest databases and one of the most widely used databases is the EcoInvent database that was originally developed in Switzerland and used to be European based but again it has been increasing its geographical content and it now also has a significant amount of India based processes. Another database that you might want to refer to as far as India is concerned is the Gabi database. Gabi again comes in close proximity with the Gabi software but again it has a pretty decent India based database. Then other databases could be a database by the National Renewable Energy Labs in the US which is the USLCA database which is mostly freely available but the processes are much more focused on the US. Then another US based database would be the Franklin US database. And we also have databases like Athena, Institute database as well as Greet. Many of them are focused on the US or the Europe and have close proximity with the developed world.

Let me take you through one by one the different databases. So first one is of course the EcoInvent database which is the most widely used database.

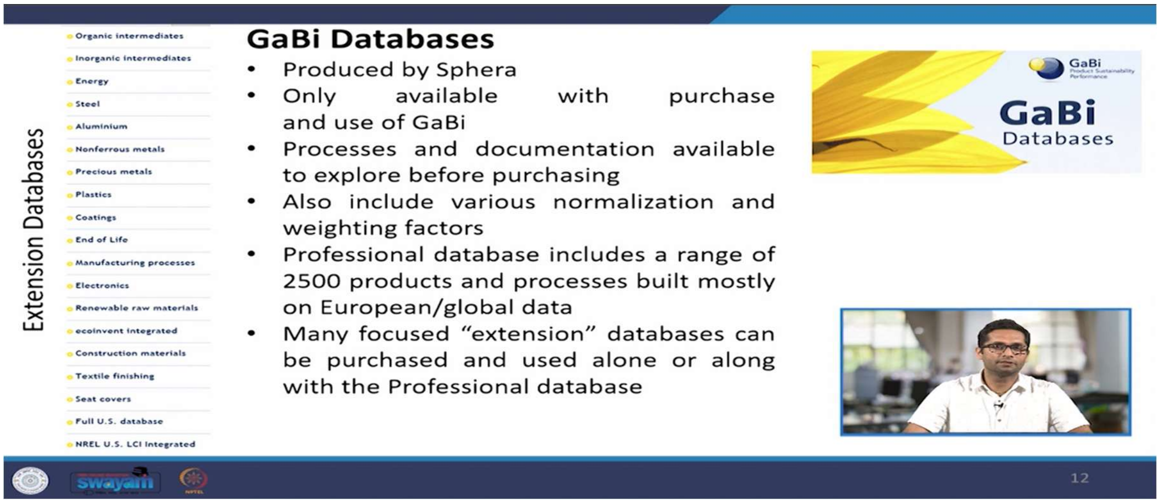
It was originally conceived in Switzerland and it's basically operated by a non for profit association which is a consortium between five different entities which is basically the Swiss Federal Institute of Technology, EPFL, Paul Schurr Institute, EPMA and ART. And they all together have put in a lot of data. All together it has more than 10,000 datasets pertaining to different geographies and also the different time scales. They have pretty good coverage over the different energy related processes, specifically the electricity production, the different chemicals that are used, biomass based processes, agricultural processes and this is one of the most extensive database that is available. And also the database is available in the EcoSpold format which means it could be readily be used in different kinds of software available.

Few prominent software being Gabi, SimaPro, OpenLCA is a free software. So you can easily link this database with software and are you good to use the database for your processes. This normally is a paid service and it comes with the subscription fees and so you would have to pay for if you want to accept this database.

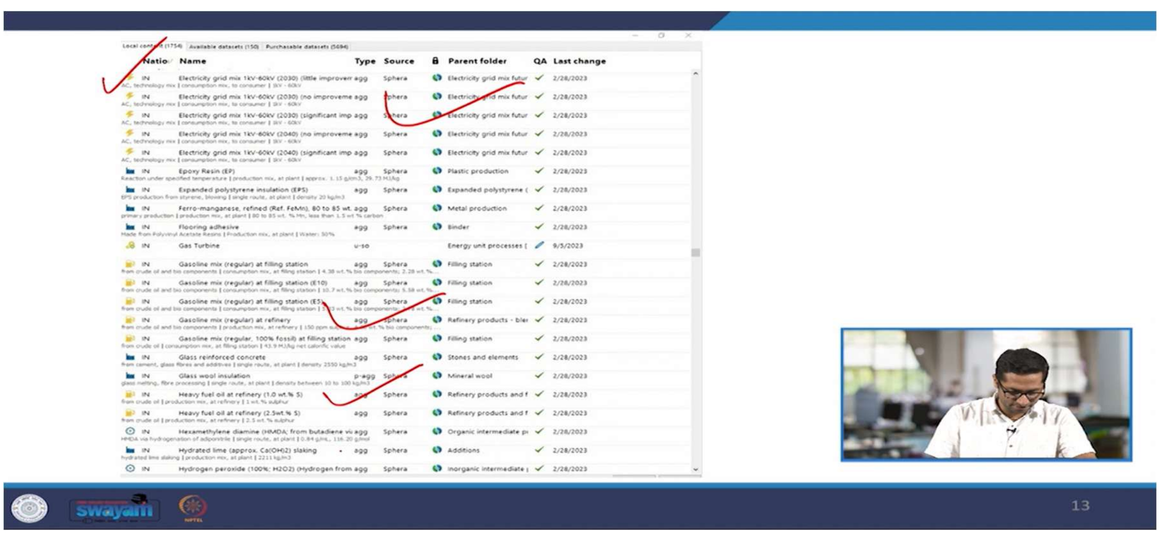




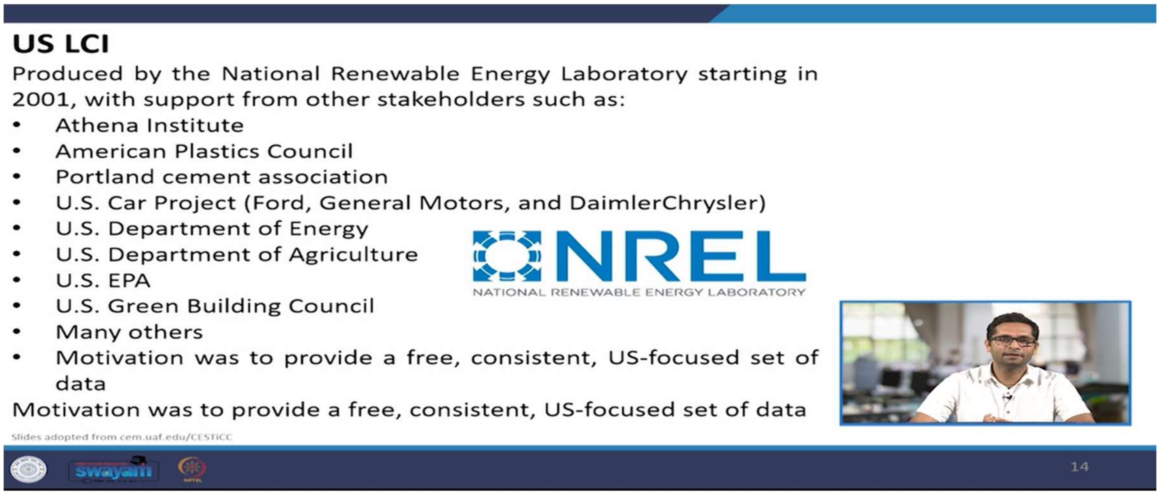
Further, just to give an example, this is the EcoInvent database as seen in the SimaPro software. So you can see in here the India related inventors that are available, might not be very clear in the screen. So what we can see here are few inventors related to the production of bananas, coconuts, coffee as well as hard core. And the term that you see IN basically refers to the Indian context. So the data has been collected with respect to the Indian context and that is available for you to use. Some other examples could be the production of jute or lignite, mint, onions. So they have a pretty extensive database that is available for the Indian conditions.



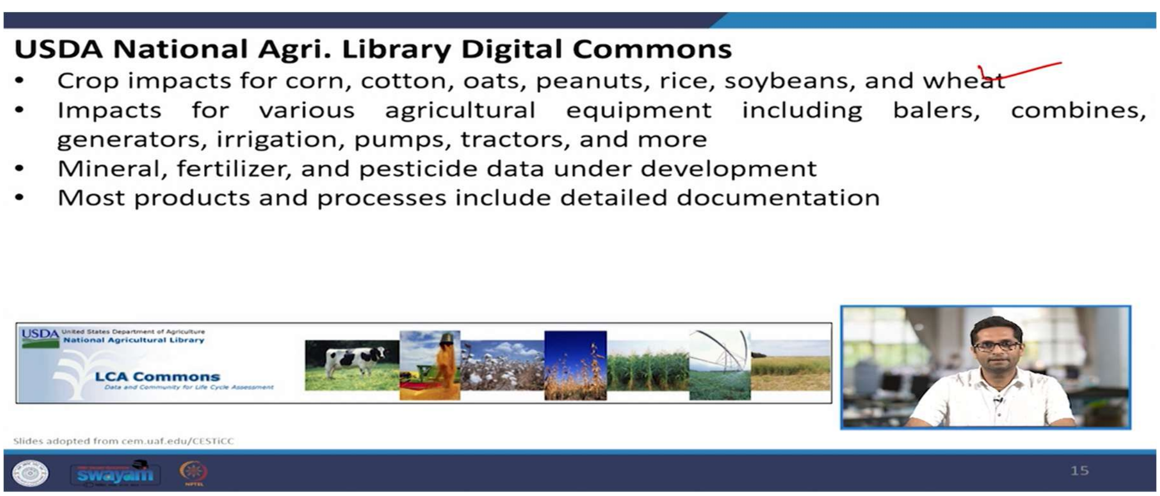
Then another global database that is used by the research community or the LCA practitioners is the Gabi database. This is basically produced by Sphera company, earlier it was known as ThinkStep or PE International. So they again have a pretty extensive database covering different geographies. As such the database consists of more than 2500 different products. It used to be European centred but again it has been increasing its boundaries and now it has a good amount of India specific database as well. One of the major issues with this database is that this can only be used in the Gabi software which is again a paid software. So if you would want to use the Gabi databases it has to be necessarily be used in the Gabi software which can come for different types of subscription fees. And again you also have the advantages that they give you many liberties in terms of the different normalisation and the weighing factors and other types of graphical user interface where you can visualize the process much more in detail.



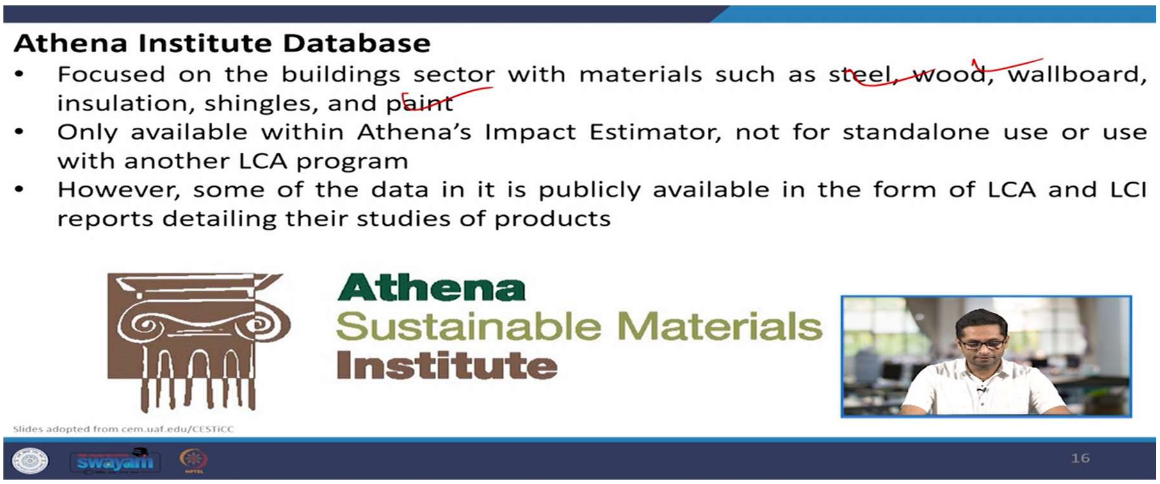
Again to give you an example, so these are some of the India specific databases that are available in the Gabi software. So you can see like we have the nation India in here and then you can see different kinds of electricity being produced. The gasoline mixtures which is the petrol that is available, you would have the different kinds of heavy fuels that are available, different kinds of chemicals like hydrated lime, hydrogen peroxide. So all in all it has a good amount of India specific database with respect to energy also available in it.



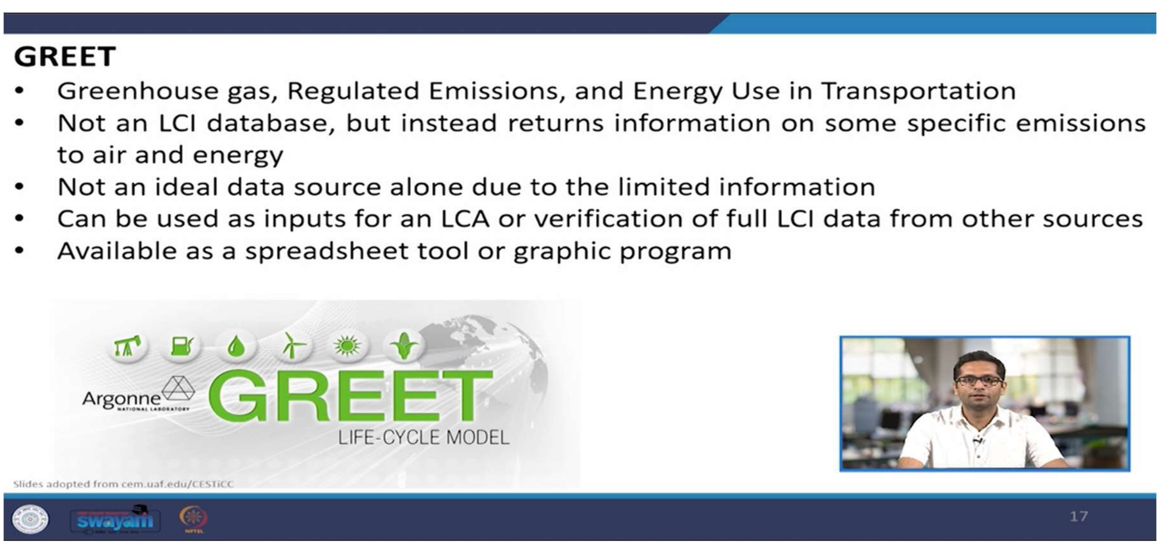
Another option could be the USLCI database which is maintained by the National Renewable Energy Lab and this is a free database. So the reason why this database was created was to help the LCI practitioners to access the data freely and come up with the results that are consistent. And again it had contributions coming from a whole lot of different institutes. Some of them are mentioned here like the American Plastics Council, the US Department of Energy, the US Department of Agriculture and many others. And it again is a US specific database. So if you are looking towards some processes for which you are certain that the emissions would not change between the Indian and the US scenario, probably it would be safe to use this database in the software or the tool that you are employing.



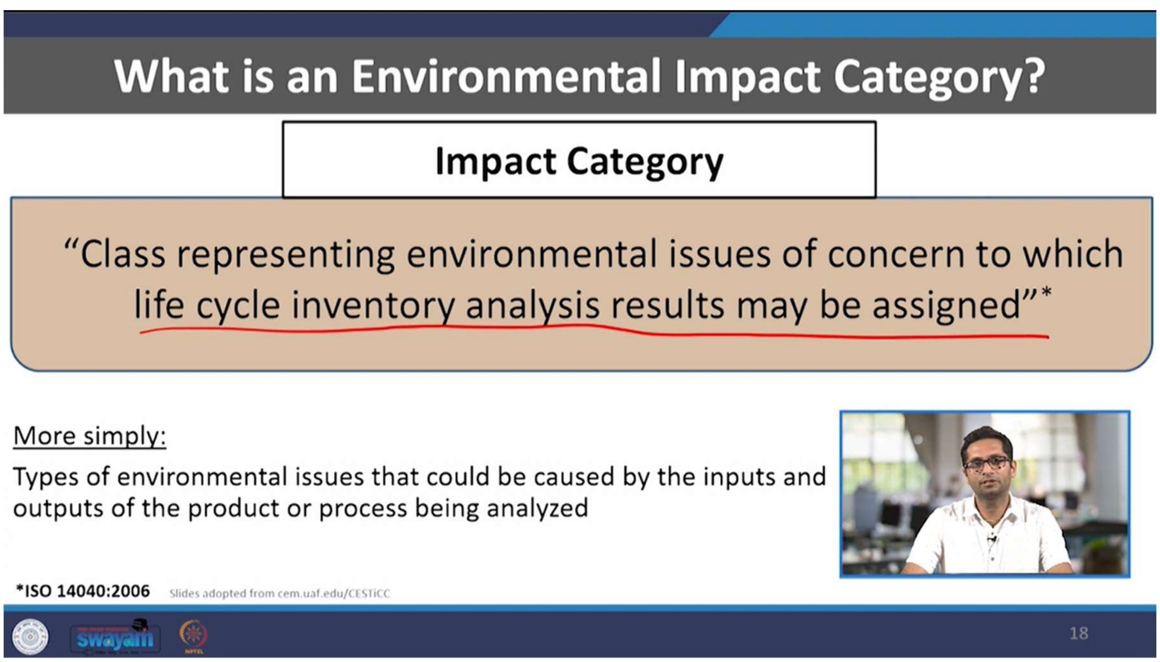
Another database that you might want to refer to is again a US based database which is the National Agricultural Library Digital Commons database and this is more to do with the agricultural production, the agricultural crops like corn, cotton, peanuts, rice, soybean, wheat. It also provides a good amount of estimation for the fertilizers and the pesticides data that would be used and many of the processes have detailed documentation available. And again this is a sort of free database that is available if you are looking towards research into biofuels or biomass based energy production processes. This is one of the database that you can refer to and can gain meaningful insights.



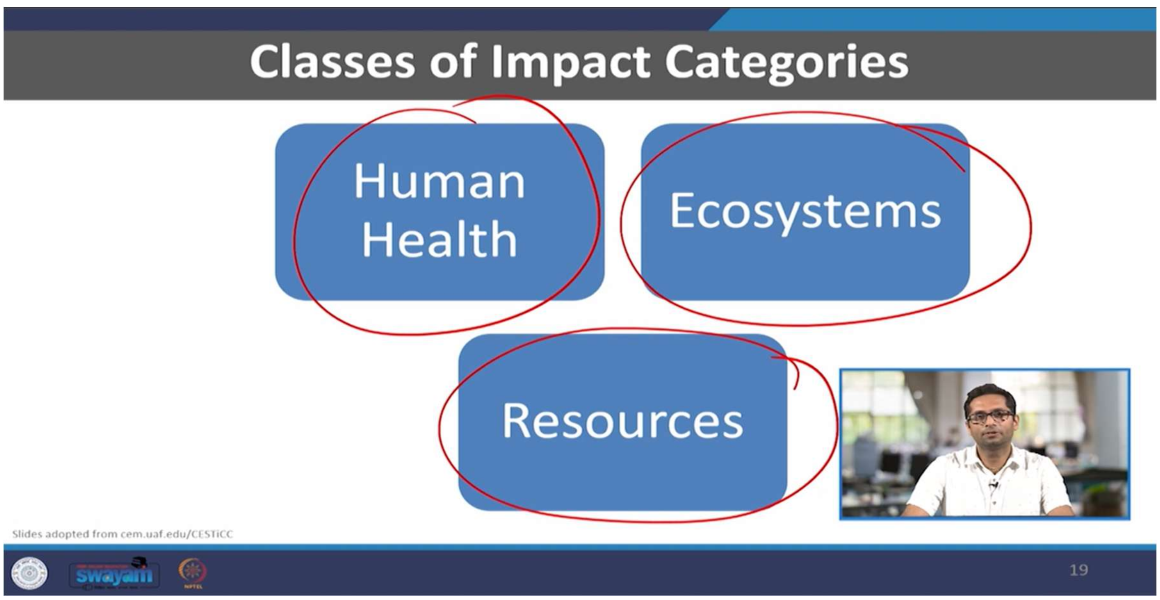
Another database that could be of interest is the Athena Institute database which is mainly to do with the building sector. So if you are trying to quantify the sustainability of the different types of buildings or that might come up in the future in terms of the materials that are used for its construction in terms of steel, wood and other types of ingredients, this is one particular database that you might want to refer. Again This database has been specific to the US so it has a leaning towards the US based inventories but with certain modifications you might be able to use this for the Indian conditions as well. And again this is not a standalone database, it also comes along with its own LCA program where you would want to use it.



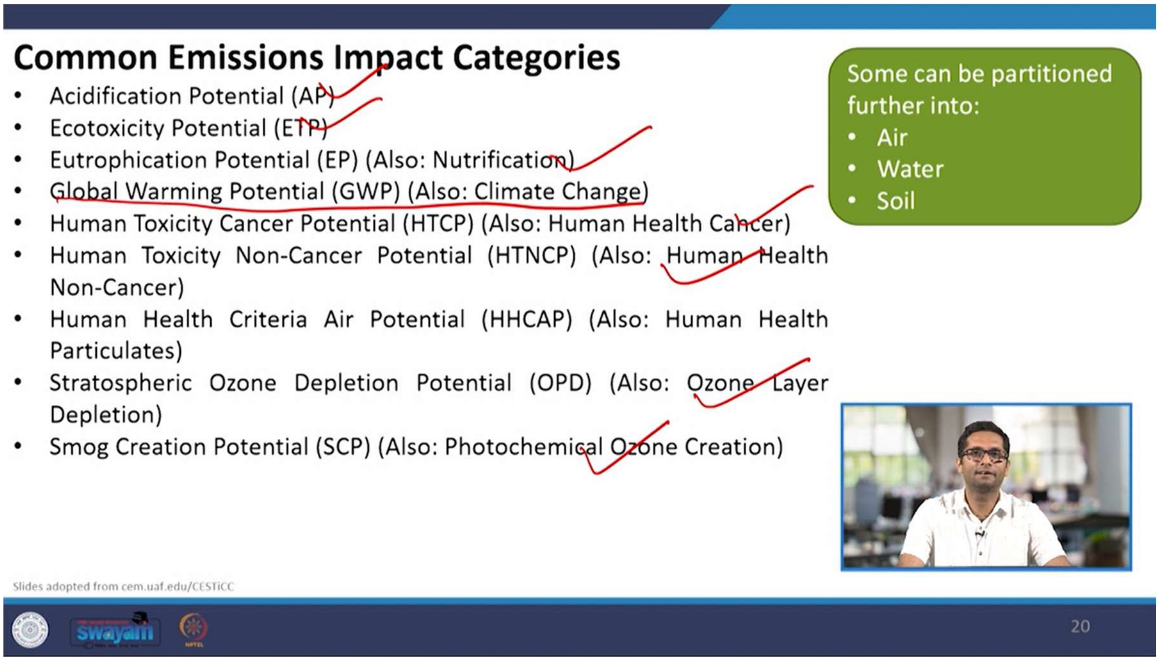
Then there is another commonly used database or tool I would say which is called the GREET tool, it stands for greenhouse gas regulated emissions and energy use in transportation. So basically this is a transportation sector tool. In the recent past you might have seen different reports coming out by the different types of agencies which have tried to compare electric vehicles with biofuels to IC engine vehicles and there are different kinds of results that are out and most of these studies you will find are using this tool which is called GREET. It was developed by the Argonne National Laboratories in the US. It is basically trying to quantify selected emissions that come from the different functions of a transportation fuel. So it is not a complete LCA in that respect because it is only considering few select emissions and it is also available in terms of a software that could be used online or you can also download the spreadsheets. So in case you are interested in comparing the different types of transportation options that are available to you and you would want to gain some meaningful insights with respect to the Indian conditions, this could be one tool that you might want to use. So with this we have tried to discuss the different kinds of databases that are commonly used and of course like there are many other databases that are available. I have just introduced some of the prominent ones and I feel you guys are free to discuss or go through the different kinds of databases that might be available and use that for your analysis in the future. Now once the data is available to you, what to do with the data is the next question. So let us proceed to that part of the discussion.



So once you have the data available with you, you have the inventories that you would be using for the different process categories, you would go for the impact category or the impact assessment step. So for the impact assessment, first thing is you would have to choose the different impact categories that you would want to analyse. So if I go with the definition of impact category, it goes as a class representing environmental issues of concern to which the lifecycle inventory analysis results may be assigned. So basically what it means is like you have now quantified the different kinds of inputs and outputs that come in or go out of the process. Now you would want to assign these emissions to different kinds of possible impacts and this is where you need to select different impact categories which would be of interest to you. So this was basically the types of environmental impacts that could be caused by the inputs and outputs of the product and the process being analysed. It might happen that the process that you are analysing only has emissions in terms of the greenhouse gases, so global warming potential is the only thing that you are concerned about. Further there could be some processes where you are not concerned much about the emissions with respect to the global warming potential but eutrophication is a major concern.



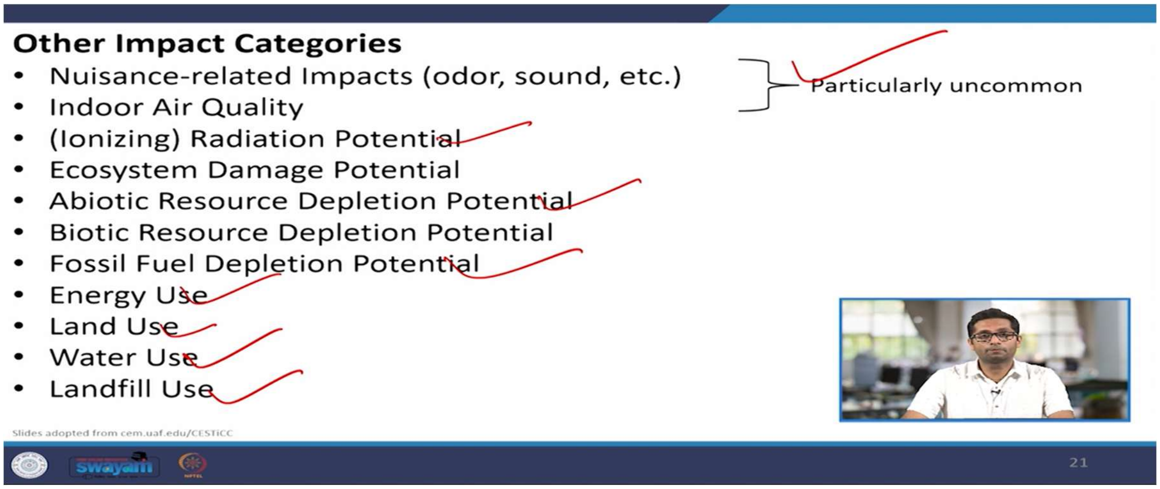
So there could be different processes which could have different kinds of impacts and overall these impacts could be divided into three major sections. There could be impacts to the human health, there could be impacts to the ecosystems and there could be impacts to the resources. The different kinds of methodologies might want to group the different kinds of individual impacts in these three broad categories. This is not that you would always have to look for impact categories which is a part of human health, ecosystems and resources but these are the three major impact categories that have been formulated and a majority of methodologies would want to quantify the impacts in either one of the three. So the different midpoint indicators that would be calculating would be coming in either these three and this also sheds the light that LCA essentially is not just an environmental assessment tool, it caters to much bigger domain where it is also looking at the human health as well as the resources.



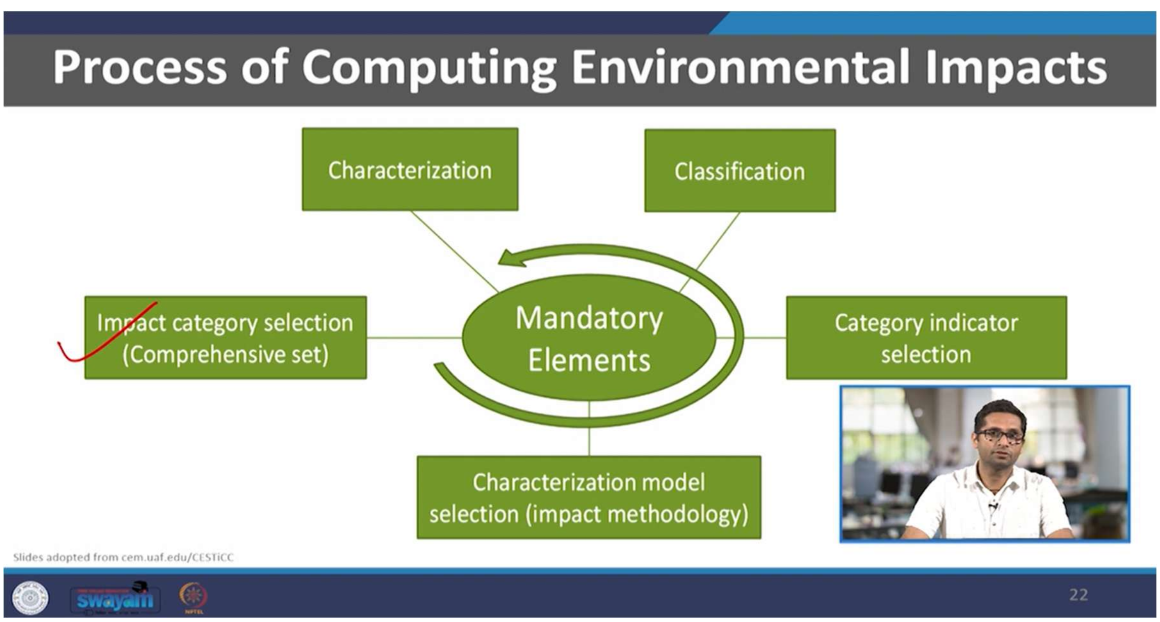
So some of the common impact categories that you might come across in the different studies have been listed in front of you. Of course the most common one that you would come across in different kinds of literature would be the global warming potential also referred to as climate change. But other important ones would be the acidification potential which is basically the release of the toxic gases into the atmosphere which might end up causing acid rains. Ecotoxicity, eutrophication which is also called eeutrification wherein you are increasing the nutrient concentration into the water bodies which might lead to algal blooms. There could be human toxicity which could be for cancer based or non-cancer based.

Further there could be stratospheric ozone depletion potential or it is also called as ozone layer depletion. There could be a smoke creation potential or photochemical ozone creation. There could be slightly different names used for the same types of indicators. And further there could be subdivisions in terms of whether these impacts are partitioned into the impacts to the air, water or soil. So often you might come across the eutrophication for fresh water or marine environment or there could be acidification with respect to soil, air, water.

So the different types of methodology that you might choose might have different kinds of partitioning. Further beyond this there could be other impact categories. Some of them are listed in front of you.



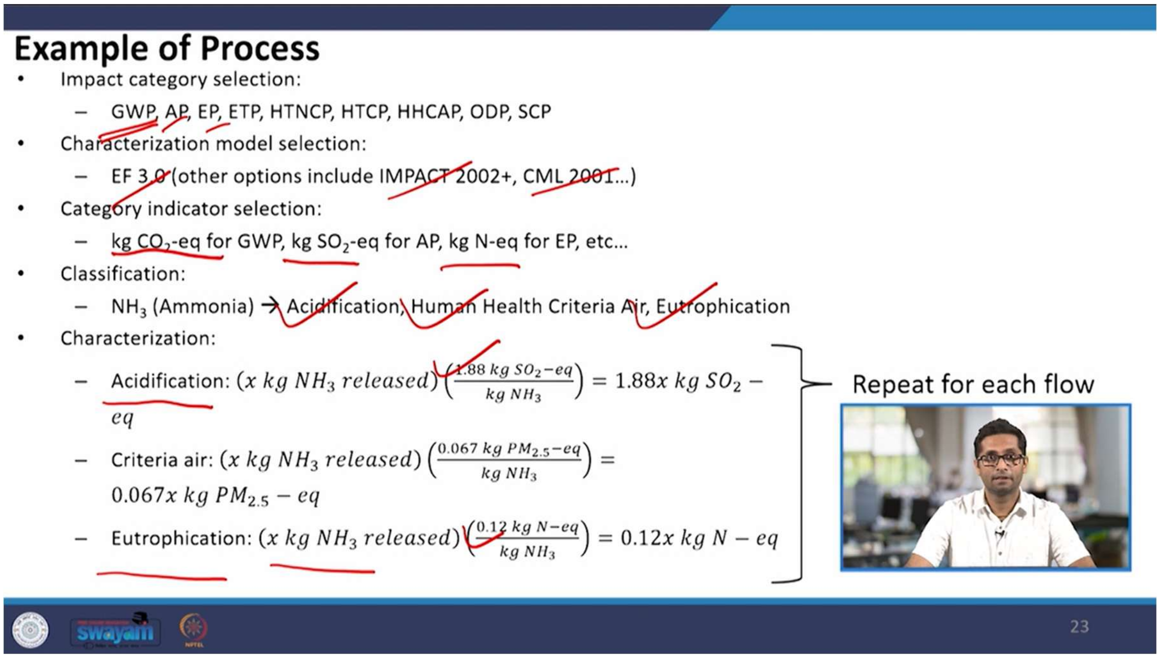
The important ones could be the ionizing radiation, the resource depletion potential, the fossil fuel depletion, energy use, land use which where you are trying to quantify the land footprint of a particular process that you are trying to analyze, water use which is again gaining prominence. Then there could be the waste which might end up in the landfills or landfill use. Then there are other some of the parameters which are not very often used, something called like nuisance related impact with respect to the sound or the odor or the indoor air quality. These are particularly not very common to be used in an LCA but again there might be a few studies that might be using it. So with this I believe you got an understanding that when we are doing a life cycle assessment we are not just referring to the CO2 emissions, the global warming potential or the climate change. It is much more than that. We are trying to look at the complete environment or the complete like planet as a whole what could be the different sorts of impact that might be possible for the process that we are trying to understand.



Let us try to understand how do we compute the different environmental impacts when we have the data available. So once you have the data available in terms of the different inputs and outputs you would first want to choose the different kinds of impact categories that are of interest to you. It might be a single impact category, there are many LCA that would just try to quantify the CO2 emissions but there could be other LCA studies which might want to quantify as many as 18 impact categories. So again this could be a very comprehensive set and it depends upon the LCA practitioner. Then once you are aware like these are the impact categories that I would want to work on this next time could be the characterization model that would be used to converting for converting the emissions into the final impact.

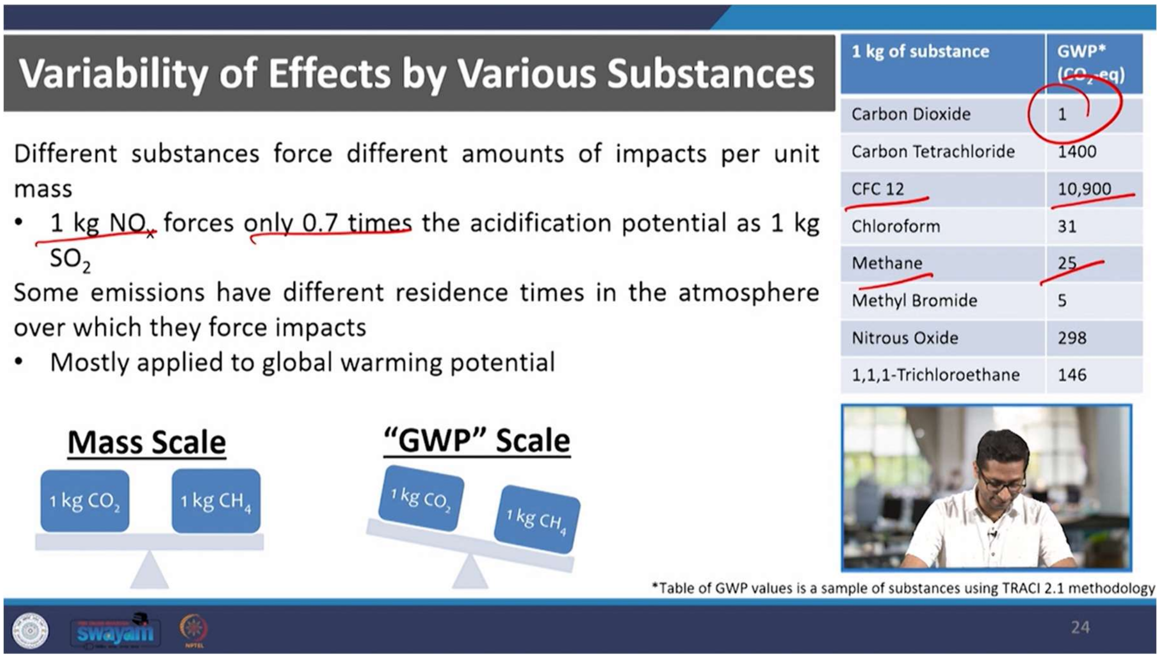
How do you ascertain the relationship between the emission that is happening from the process with the final impact? How would you ascertain the relationship between the CO2 that is emitted with the global warming that is happening? So that is what I call a characterization model and again there could be a consensus of a model or there could be different models available for a particular impact category where you can choose one model that serves your purpose. Once the model has been chosen it would normally come with a category indicator which basically tells you in what would be the factor which would be used to normalize the different kinds of emissions. Suppose when I am talking about the global warming potential the category indicator that I would normally be using would be CO2 equivalent. Similarly if I am talking about acidification it might be SO2 equivalent. So once those kinds of category indicators have been selected again there might be certain impact categories where you have the choice of selecting different impact category indicators and there in it is a matter of choice.

So once that is selected you would want to see what are the emission that contribute to a particular category or to a particular impact category. Suppose for example you are releasing a certain kind of chlorofluorocarbon into atmosphere. Now this chlorofluorocarbon would of course lead to ozone depletion but it also would have a very high global warming potential. So in this case a simple chemical or a single CFC would have a contribution both towards global warming and ozone depletion. And this is something that you would be doing in the classification section where you would want to see which emissions would contribute to the different kinds of categories that you have selected. And finally there would be characterization where you would be putting in the characterization weights or with respect to the standard indicator and adding them up. Let us try to understand this with the help of the examples.



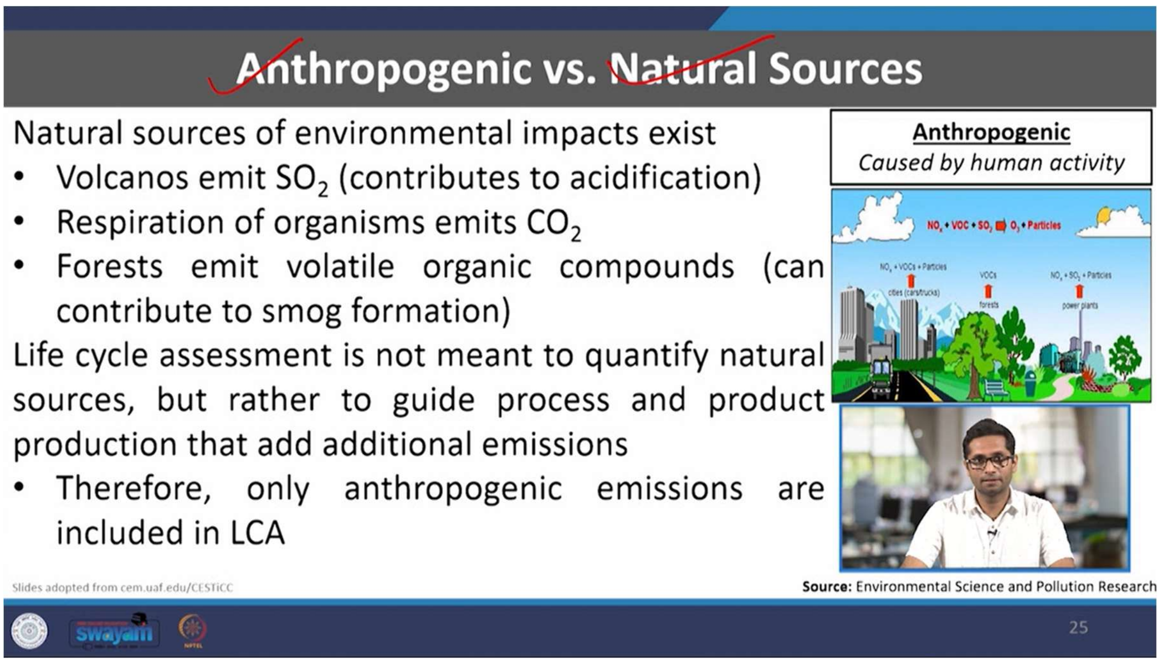
So the first thing is for the process that is under study you would want to select the impact categories which could be many different. The most common one of course is the global warming potential then there could be acidification, eutrophication, ecotoxicity potential, human health, carcinogenic and non-carcinogenic. Then for quantifying these impact categories you would have to select some kind of characterization models. The common ones that you might come across could be the CML, the impact 2002 or the EF 3.0 which is the environmental footprint 3.0 which is a European based and another one that is very readily used is the recipe methodology. So once that is done these methodologies would normally come with the category indicators. Now you would want to quantify all the different emissions which lead to global warming potential in terms of a single indicator and this indicator could be kgs of CO2 equivalent.

Similarly for acidification potential this could be the kgs of SO2 equivalent, kgs of nitrogen equivalent for eutrophication. Now you would want to quantify what all emissions lead to what all impact categories. So suppose ammonia is one of the emissions that are coming from their process. Now ammonia could have an impact on the acidification, human health, eutrophication. So here we are trying to quantify what would be the impact categories where a particular emission could have a considerable impact. And finally there would be the characterization where you would want to convert the emissions or normalize the emissions with respect to the category indicator that you have chosen. So suppose I am looking at the acidification I am having X kgs of ammonia being released. So this X kgs of ammonia would then be converted into the SO2 equivalent. So in this case I am multiplying that with a factor of 1.88. I would have a different factors when I am using or when I try to understand the impact of ammonia for eutrophication. So when I am talking about eutrophication the same X kgs of ammonia would have to be multiplied by another factor maybe 0.12 to convert into nitrogen equivalent and to see its effect on eutrophication. So again to repeat a single emission could have different impacts and we would have to try to convert that into the different impacts by the different kinds of characterization factors.

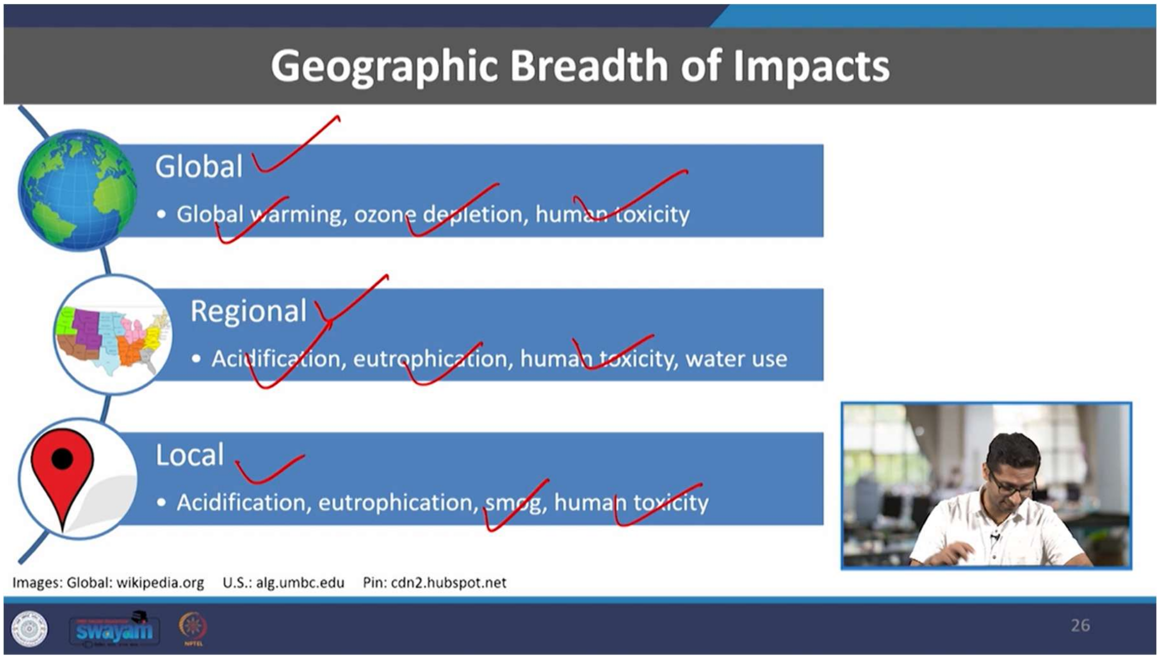


We also need to understand that the equivalence in the mass again there could be different emissions come out from the different processes but it does not mean that if we have 1 kg of different emissions coming out the impact would always be the same. What is the reason for that? The reason could be the different chemicals could have their own different reaction potentials. Certain chemicals would react much more readily than the others and the some kinds of emissions might break down quite easily can have a very low residence in the atmosphere so the impact could be somewhat lesser. An example could be if I am talking about the acidification potential 1 kg of NOx emission would not always be equal to 1 kg of SO2 emission. So if I am using one particular characterization model 1 kg of NOx and NOx emission would normally be equal to 0.7 times the emissions of 1 kg of SO2. Similarly many of you might have heard about the emission factors of CO2 and methane which is CH4 so methane is a much more potent greenhouse gas as compared to CO2 and it is normally the number normally varies between 25 to 30 so 1 kg of methane normally has an impact which is 25 to 30 times more than that of CO2. So if I am talking about CO2 equivalent 1 kg of methane would be equivalent to almost 25 kgs of CO2. So you might wonder why that is happening again the different gases have their own chemical relationships in terms of the reaction being considering and also they have their own residence time. So on the right hand side what you see are the global warming potentials of the different prominent greenhouse gases.

Of course the normalization factor here is the carbon dioxide so that is always attributed by the number 1. If we see the global warming potential for typical CFC it comes out to be around 10000 for methane again it is 25 and again we need to understand that these numbers are typical for a 100 year global warming potential. That is we were trying to quantify the effect of a particular gas over 100 years of span. If this span was 25 years or 500 years so there are GWP values that are available for 25 years and 500 years these values would be much more different because in the time in which a particular gas would break down in the atmosphere and would be reducing its radiative forcing with respect to the which is leading to global warming potential might be different over the life span over the gas.



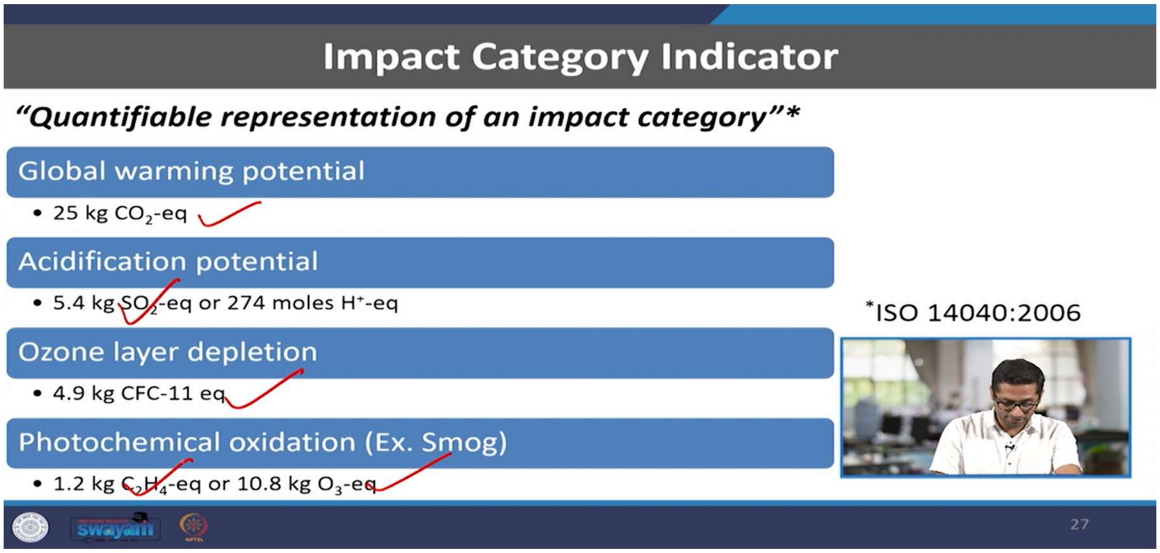
Further it is also very important to understand that when we are doing the LCA we are mainly concerned with the anthropogenic emissions and we would normally emit the emissions that are coming from the natural sources. Suppose we as human beings have been emitting CO2 ever since our birth and will continue to do it. So it does not mean that we are going to quantify every like ml of CO2 that we are emitting because that is a natural process and we will omit that and similar would be the CO2 emission that might come out from the natural cycles between the different organisms. Further we are also aware that volcanoes would be emitting different kinds of sulphur oxides and that again a natural process. So that is something again we would try to omit in a typical LCA. There could be different forest which would be emitting different kinds of volatile organic compounds. Again these kinds of emissions are normally not taken into account while we are doing a life cycle assessment. So to repeat life cycle assessment in the most common form is normally only concentrated on the anthropogenic emissions. Although there are some kinds of variations which are also called like the life cycle assessment technological synergy and some other variations that might want to quantify some of these emissions but they are like a slightly different kind of LCA.



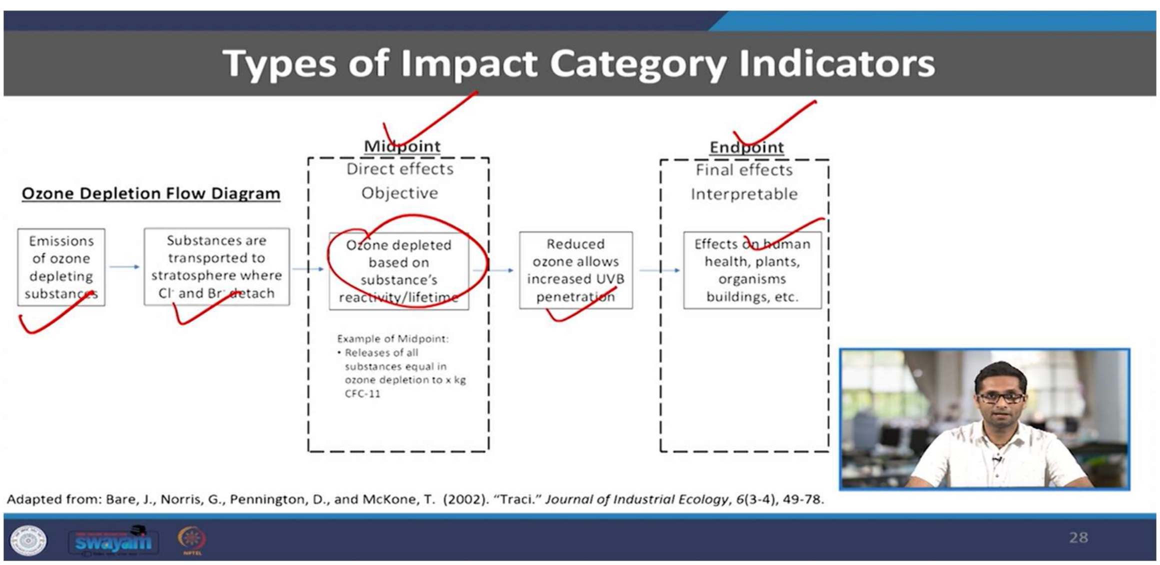
Again we need to be aware of the fact that not all the impacts that are being created would be equally applicable to all the people around the world. There could be some impacts that are local in nature then there would be others which are regional in nature spanning to a one country or maybe a couple of countries and then there will be certain impacts which would be truly global in nature.

So when I am talking about the global impacts the typical example would be CO2. So any molecule of CO2 emitted anywhere would have same kind of impact on the total population of the earth in terms of the global warming. So that is one impact that is considered as global. Other impacts could be ozone depletion. Then there could be certain impacts which are just regional in nature which could be the acidification, eutrophication because the impact of the acid or the different kinds of weak acid that are created might travel to almost 300-400 km and then this is where the effect would be felt. It is not happening that an emission that is happening in India would cause an acid rain in the US so that is very unlikely and that is why they are attributed as regional.

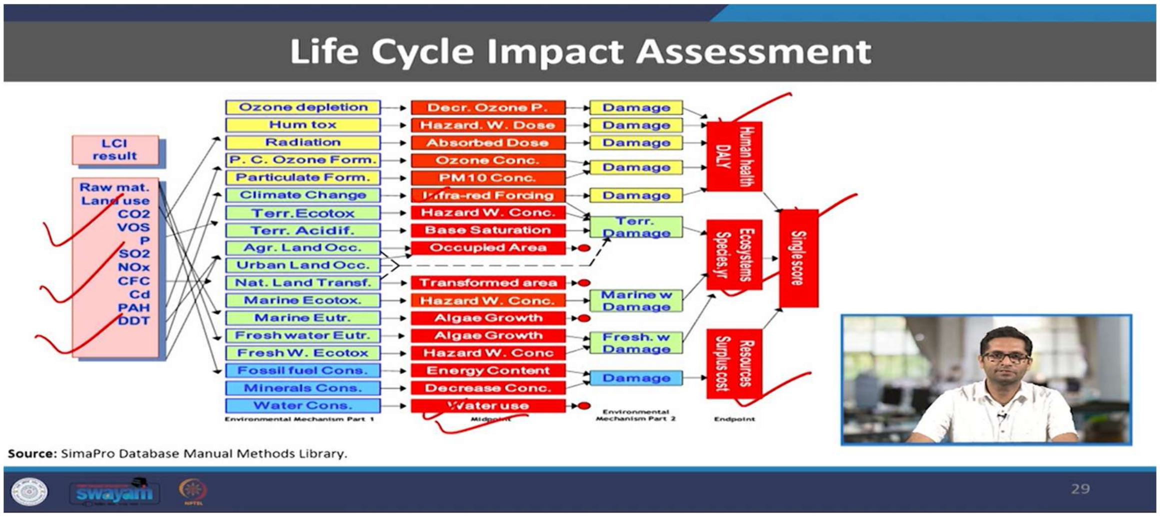
And similarly there could be certain impacts which could be totally local in nature something smoke which is basically a result of the different kinds of vehicle emissions or human toxicity again is something that could be on all the three levels local, regional and global. So different impacts could be seen at different spatial scales.



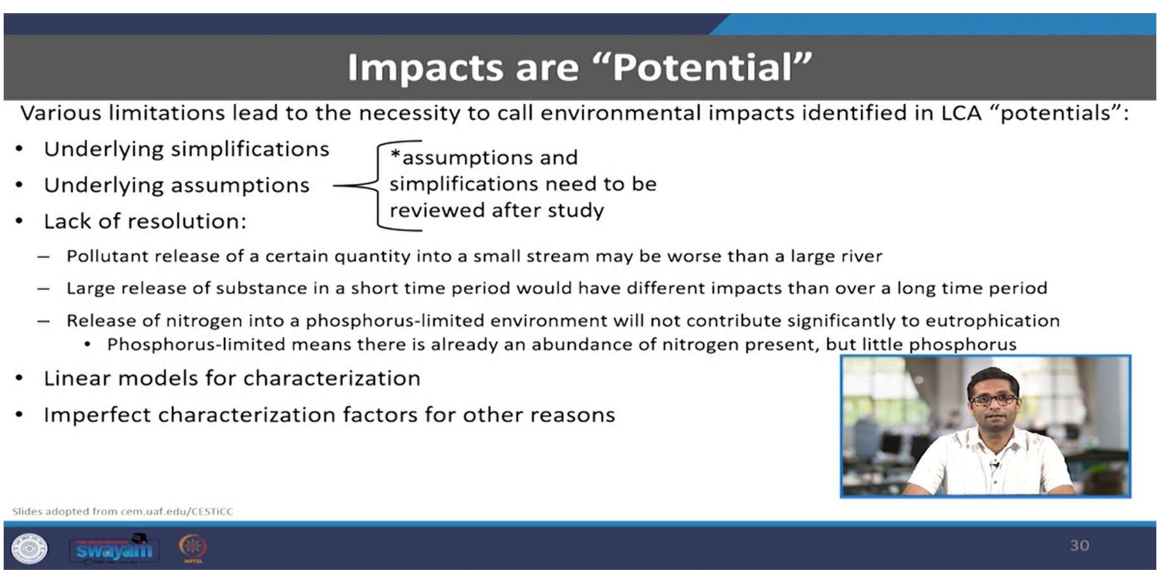
Further we would have to categorize the impacts in terms of an impact category indicator. This is what we have tried to understand in the earlier slides as well. So if you are looking towards global warming potential the normal impact category indicator that we would be using would be CO2 equivalent. So you would want to quantify all the emissions in terms of the CO2 equivalent. Similarly if you are looking towards acidification potential we would want to quantify the emission in terms of the SO2 equivalents or H plus ions equivalents. So there are two different options available and the practitioner can use either one of them. A common unit that is used for ozone layer depletion is CFC11. So what I mean by CFC is the chlorofluorocarbon. So it is the CFC11 molecule equivalent that we would want to quantify. If I am talking about the problem of photochemical oxidation or also known as smog I might have the indicator in terms of O3 equivalent or it might be ethylene equivalent. So again there are options available to us.



We also need to understand the basic difference between midpoint and endpoint indicator. So let us first try to understand how do we quantify the emissions. So suppose I have a process that might be emitting some kind of emissions like chlorofluorocarbons. So this is a process that would be emitting some kind of ozone depleting substances. Now these emissions would be transported to the stratosphere where the chlorine or the bromine elements or the molecules would react with the ozone and break down the ozone. What is the direct effect? There would be a thinning of the ozone layer, the reduction in the concentration of the ozone layer and this would be the direct effect that would be felt. The ozone layer gets depleted and this is what is called the midpoint indicator. What is the result of this depletion? Because the concentration has not depleted more of the UV radiations would be able to penetrate the atmosphere and reach the surface of the earth and what would be the effect of these UV radiations reaching the surface of the earth? It could be the different kinds of diseases like cancers, it could be the different effects on the plants or the buildings that are being caused and this is what I mean by the endpoint. So when I mean the midpoint indicator it is a much more scientific basis to it. I know how many molecules of a particular emission might lead to decrease in the concentration of ozone layer by this much amount. Whereas if I am talking about the endpoint it's a bit has a good amount of uncertainty into it because it's very difficult to quantify that if I am emitting 1 kg of CFC 11 into the atmosphere what is the exact number of people who might be having or being troubled with the cancer because of this particular issue. So when I am talking about the midpoint indicators the relationship between the emissions and the final result is very scientifically laid down and it has very low uncertainty attached to it. When I am talking about the endpoint indicators in terms of the effect on the human health, the ecosystems or the resources of course the relationship has been laid down but it has a great deal of uncertainty attached to it. When I am presenting my data to the decision makers and if I tell them that I have a particular emission which might lead to thinning of the ozone layer by so much so ppm he or she might not be interested in it. He or she or the decision maker might be more interested in understanding what is the probability increase in the disease like cancer. So when I am presenting the data to a policy maker or decision maker or authority it might be much more worthwhile if I present the data in terms of the endpoints because it is something that is going to make much more sense. Whereas if I am trying to get the data or the interpretation for my own self and I would want a good amount of certainty attached to it I would normally stop at the midpoints because the relationship has much more scientific basis as compared to the endpoints. So this is the tradeoff between endpoints and the midpoints. Midpoints we are much more certain about the relationship it is easier to understand it but while communicating the results to the common people the people might not be able to appreciate the result of it. Whereas if I am talking presenting the results in terms of the endpoint if I am able to tell a particular person that because of this particular emission his or her life would be reduced by maybe X years that is going to make much more sense to it. But again if I talk about the relationship between the emission and the endpoint it has a lot of uncertainty attached to it.



This is an example of a typical life cycle assessment methodology which is the recipe methodology that is used quite often so you would have the different kinds of emissions that can come out of a process and these emissions could lead to different kinds of midpoints so you see almost 18 midpoint indicators in here. You also see the infrared forcing which is basically the climate change potential also the water footprint and the different kinds of midpoints and these midpoints would eventually lead to either the degradation in the human health, the degradation of the ecosystems or the depletion of resources. This is something that I mean by the endpoints and finally this could be coupled in a single indicator as well. So this is something we can try to understand that what is the difference between the midpoint and the endpoint indicators and based upon the audience we might want to present the results in terms of midpoint and endpoints. Majority of the LCA that you would come across in the open literature would want to stop at the midpoint indicators.



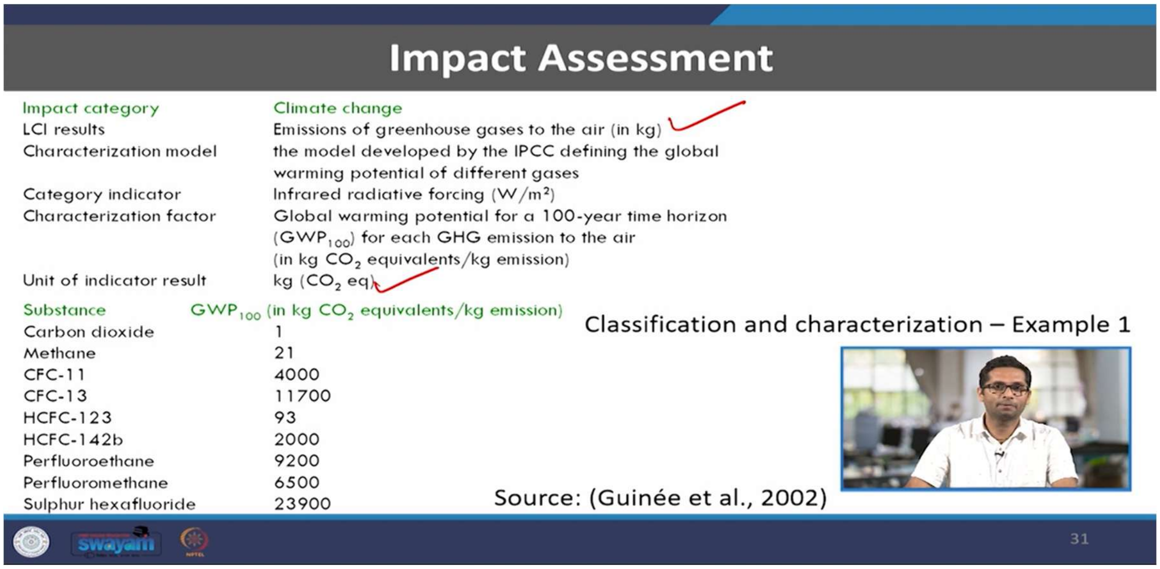
Again I would like to press upon the point that we have discussed in the previous classes as well that these impacts are potential. LCA as a methodology has certain simplifications, assumptions and which can lead to some kinds of errors and that's why the results are always potential. So, any LCA that you would do would have different kinds of assumptions and simplifications going into it and also the LCA studies would have a lack of resolution. So just may give you an example, if I am emitting a certain kind of pollutant into a water body, so the same kgs of pollutant if that enters into a small water body might have a very drastic effect as compared to the same pollutant being released into a big water body.

So suppose emitting one kind of pollutant to a small lake and the same quantity of pollutant is released into an ocean body, the impact would not be the same and the LCA is incapable of taking an impact like this. Also the same kind of emission if that is released in a very short amount of time might have a much greater impact if the same emission was happening say over a year or maybe couple of years and in that case the concentration would be much more spread out.

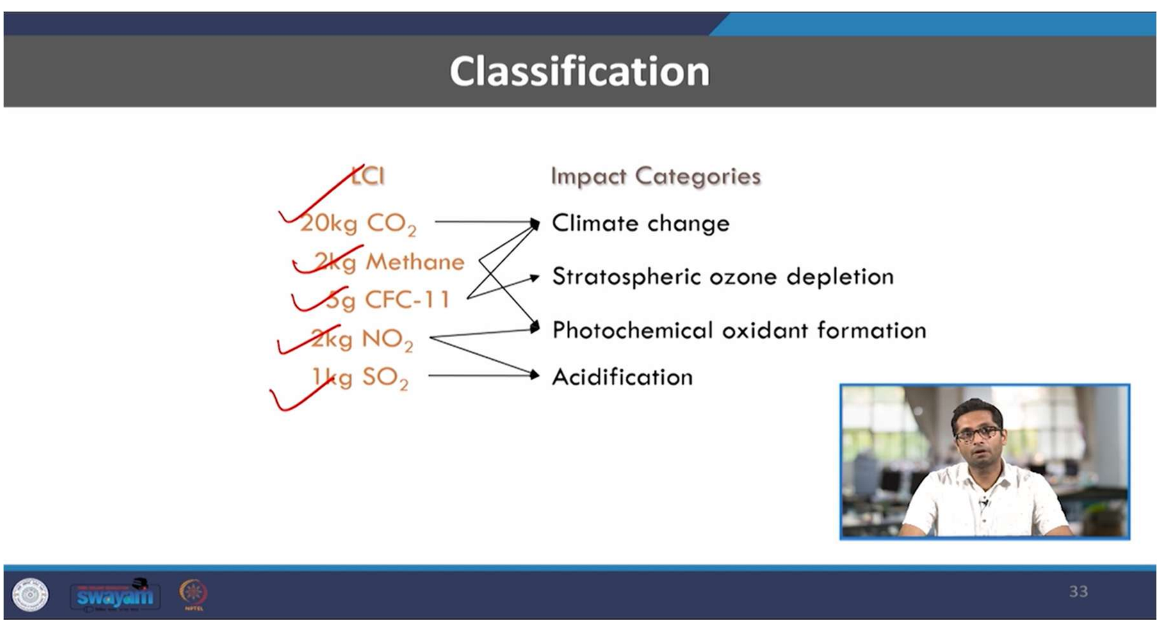
Again this is something that an LCA fails to account for, it normally doesn't take the temporal impacts into account. Of course there are other variations of an LCA which have tried to bring in this aspect but a typical LCA methodology would normally overlook these kinds of impacts. Further there could be some kind of emissions which can create an impact only when there are some other emissions available. Typical example could be like if I am releasing nitrogen into a phosphorus limited environment, the impact might not be as high as if I am releasing phosphorus into an environment like where the nitrogen is present.

So these are again some things that LCA models are incapable of doing. Further Most of these models are linear in nature whereas the results or the impacts for example human toxicity is not linear if you study it more carefully. So this linearization also increases the uncertainty or simplification as I would say in the LCA results and this is again one of the shortcomings of the LCA models.

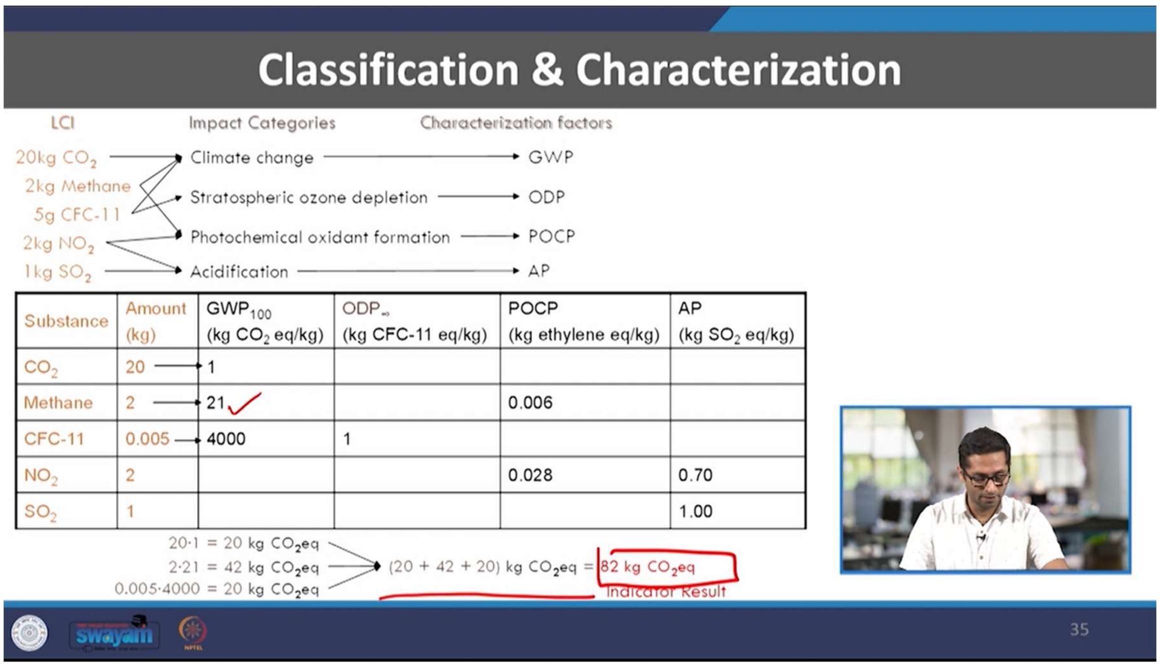
Further the characterization factors are not always exact. The characterization factors have been updated since the time, since like the different studies keep on coming and we have better and better characterization factors available. So there is always an improving phenomena that is going on.



So let us try to understand the conversion of this data into the impact categories with the help of an example. So again let me repeat the same thing. So like suppose I have, I am looking towards an impact category that is climate change and the emissions that would be causing would be the different greenhouse gases. A characterization model that I would be choosing for this would be the IPCC model which is the most widely used model that is available. The indicator would be the infrared radiative forcing which is dictated in terms of CO2 content and different gases would be having the different characterization factors associated with them. And you can see the characterization factors that I am showing in this slide were a bit different from the slides that I have shown earlier because there are different studies which will come up with the different types of characterization factors.

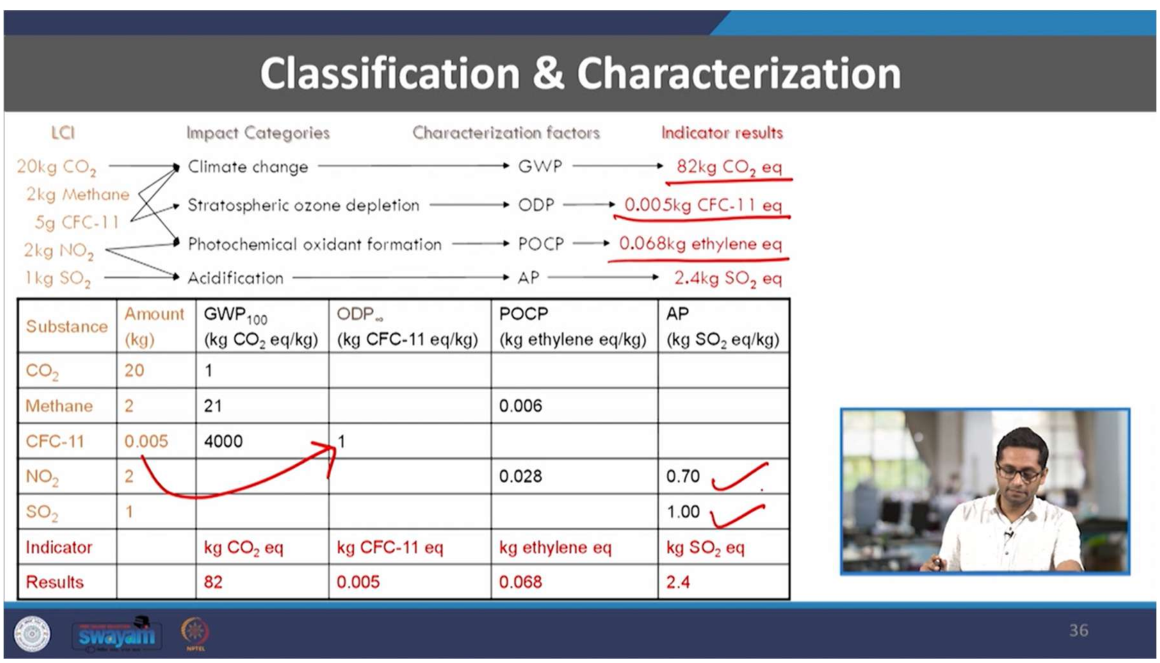


So let us try to understand how do I convert these emissions into the final impact categories. Let us look at a hypothetical process which would be emitting almost 20 kgs of CO2, 2 kgs of methane, 5 grams of CFC11 which is an ozone depleting chemical, 2 kgs of NO2 and 1 kg of SO2. So the first thing would be I would want to select the impact categories that would be important to me. So for this I would select climate change which is being caused by two chemicals which is CO2, methane as well as CFC11. Then If I am talking about stratospheric ozone depletion that would normally be caused by CFC11. Photogramical oxidation of oxygen formation would be a result of methane and NO2. Acidification would come out from NO2 and SO2.



So once these impact categories have been selected I would select the different characterization models or characterization factors. So for the climate change I would normally be going for global warming potential. For ozone depletion it is the ozone depletion potential. Similarly photochemical ozone creation potential as well as the acidification potential. Of course these names might be slightly different with respect to the models that you would be using. So the first thing I would be putting all the individual amounts in terms of a table like this. So this is just for the understanding. If you are using an LCA software this all is done in the background. So we have all the emissions that are coming from the complete process. Then these are the respective amounts of the emissions. I have given all the emissions in terms of kgs. Now the global warming is being caused by three chemicals or the three of the emissions out of these five which is the CO2, methane and the CFC11. And then I would have the different characterization factors. So for CO2 of course it is 1, for methane it is 21 and for CFC11 it is 4000. The ozone depletion is just caused by one chemical which is CFC11 and that is why I just have one in here. The photochemical oxidation or ozone formation would be caused by two chemicals which is methane and NO2. And the characterization model that I am using gives the photochemical ozone creation potential in terms of ethylene equivalent.

And I do not have an emission of ethylene here. So you do not have the value of 1 attributed to any of the emissions. So it is converted into ethylene equivalent in here. And finally we would have the acidification potential in here which is in terms of SO2 equivalent. So we have SO2 as well as NO2 emissions in here. Now the next thing that you would be doing would be multiplying these individual emissions with the characterization factors. So I would be multiplying 20 which is the 20 kgs of CO2 being released into 1. I would multiply 2 kgs of methane into 21 which would be the global warming potential for methane. And similarly I will be multiplying 5 grams of CFC11 with 4000. So once I have done that you can see at the bottom of the slide I am multiplying the two things the three. You would add the three together and finally you would have the results in terms of the total CO2 equivalent of emissions in for the global warming potential. Again an important point to note down in here is that the emissions or the global warming potential of 20 kgs of methane is equivalent to 5 grams of CFC11. So even if there is a very small emission that is occurring for a particular compound sometime it might not be good to neglect it because it can have an emission that could be very high in nature that depends upon the characterization factor. So something similar you would be doing for the ozone depletion potential where you will multiplying with the respective characterization factors for the impact categories.



Substance	Amount (kg)	GWP_{100} (kg CO_2 eq/kg)	ODP_{∞} (kg CFC-11 eq/kg)	POCP (kg ethylene eq/kg)	AP (kg SO_2 eq/kg)
CO_2	20	1			
Methane	2	21		0.006	
CFC-11	0.005	4000	1		
NO_2	2			0.028	0.70
SO_2	1				1.00
Indicator		kg CO_2 eq	kg CFC-11 eq	kg ethylene eq	kg SO_2 eq
Results		82	0.005	0.068	2.4

Add them up and you would have the final results. So if I am talking about the global warming potential this would be 82 kgs of CO2 equivalent. Something similar you will be doing for ozone depletion potential where you will be multiplying 5 grams into 1 and this would be 0.005 kgs of CFC11 equivalent. You would do that for photochemical ozone creation potential as well where you will be multiplying 2 kgs of methane with 0.006 and 2 kgs of NO2 with 0.028 add the two things and the total results will be in kgs of ethylene equivalent. Finally in terms of acidification potential you will be adding the emissions of NO2 as well as SO2.

So with this we have tried to gain some basic understanding of how would I convert the emissions into the final impact categories. In this particular class we have paid emphasis on the different types of databases available how would I get the data for my processes and also try to understand once this data is available the different emissions are available how would I convert that into the different kinds of impact categories. In the future classes we will try to understand how would what are the different impact categories in much more detail. With this we end today's class. Thank you.