Life Cycle Assessment
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Lecture – 36
Summary and Case Studies

Welcome back. So, we are in the last week of this course now. So, this is the week-8. And as I mentioned towards the end of the previous week, so during this week-8, we will be mostly focusing on kind of revising the material whatever we have covered earlier. Then I will give you a lot of examples that is the plan for this week is to go over several examples from different fields, some research projects, some industrial projects in terms of how this LCA tool is used in real world projects.

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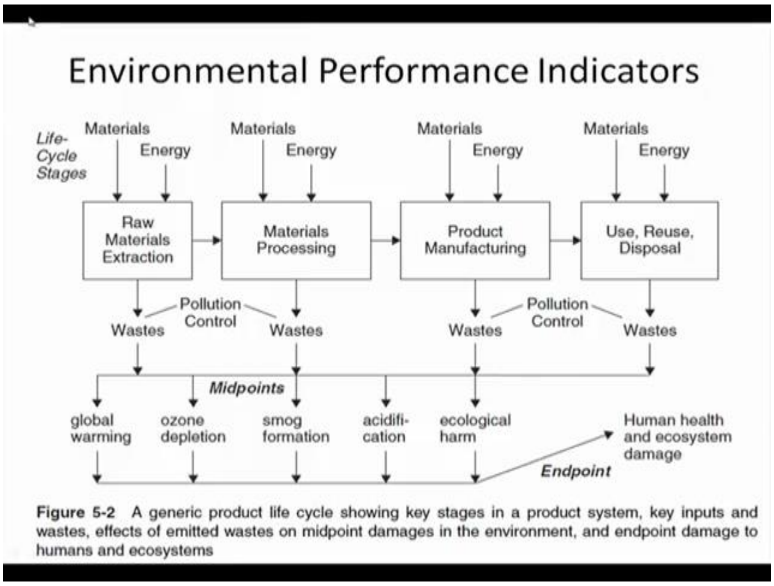

So, if we get started, let us take a big picture where we have been looking at in terms of this is kind of the summary of what we have talked so far in a very simple form. If you remember we looked at life cycle stages, we talked about the system boundary. So, here what you see in this picture is from different boxes that are very simple as schematics. Again whenever you are doing any of these pictorial descriptions, you do not have to be an artist to do that even if you make the boxes like this and put all these different inputs and outputs as you can see over different arrows for the material and energy coming into the each of the unit process as well as whatever is the whatever is the output in terms of the waste product. So, all these if you just depicted in this particular form that is more than enough to give a good pictorial description of any process.

So, as you can see here we start from raw material acquisition, raw material extraction, then material processing, product manufacturing use, reuse, disposal. And we have talked about this many times in this course so far. So, this being this being the last week you should have been you I am pretty sure you must be very, very conversion with this material so far if you have gone through each and every of the video that we have produced. So, for each of this process, we have the material and energy input and we have the waste has output. So, this is what we had looked at earlier.

We had this input parameters which was a material energy when we say material it could be the raw material, metals, nonmetals, it could be the organic material, it could be even it also includes water. So, we talked about the water as well the water footprint. So, for all these stages we need certain materials going into the system and certain waste being produced. And we took this waste being produced and what we did that what if you remember what we did with that is we produced, we had several we looked at ok, what are the emissions coming out. So, what would be the environmental impact, what would be the human health impact related with these emissions. And they lead to these what we call them the midpoint indicator as you see towards the bottom of this particular sketch, if you look at the that this sketch again if towards the bottom of this sketch, you can see that what we call them the midpoint indicators.

Midpoint indicated means whatever is the exhaust coming out. Exhaust when I say exhaust if these are not it is not vehicular exhaust we are talking about we I am using it in a more general term. It is any emissions coming out from the process and that emission could be air emissions, could be water emissions, could be waste emissions and all these had certain environmental and human health impacts and that is what we have categorized towards the end of this sketch which we call this midpoint indicator. And the midpoint indicator lead into global warming, ozone depletion, smog, acidification, ecological harm and there are several more with only few are listed here.

And then from this midpoint, we go to the end point which is a human health and ecosystem damage. Because at the end of the day, but we are interested is any industrial activity any process that we are proposing or we are undertaking or we have been using for last several years, what is the human health impact, what is the ecosystem impact and how to reduce that. So, this whole LCA exercise helps us to identify the impact and then once we have identified the impact, we can always go for how to mitigate that. So, before you go for the mitigation step, you need to understand and this is what you need this particular sketch in a very like a nutshell gives you the big picture of this whole codes that we have been talking about for last seven weeks and this would be the last week of the course.

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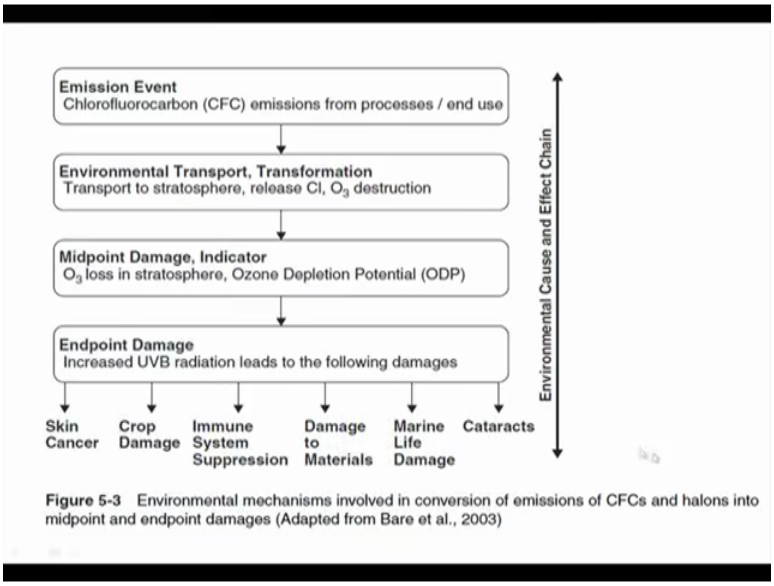

Figure 5-3 Environmental mechanisms involved in conversion of emissions of CFCs and halons into midpoint and endpoint damages (Adapted from Bare et al., 2003)

So, whenever you look at any of these emission event there is one example here that if you are looking at the emission event one very, very common example that we have been using is chlorofluorocarbon. Chlorofluorocarbon if you remember from this old refrigerator that we have where do we have been using in our houses, the fridge that we call in more common language refrigerator is used to have chlorofluorocarbon. Now, we do not use it anymore the CFCs, CFCs have been kind of you can say phased out from use in refrigerators. And why they were phased out because we were concerned about ozone depletion.

So, CFC how, but how it was you how you used to happen if that is what has been explained in this particular sketch over here. You have this chlorofluorocarbon emissions from process, and that goes into it gets into the environment it gets transported in the environment transform and it goes to the stratosphere. And what it does it releases chlorine, it is a chlorofluorocarbon. So, it has chlorine there. So, it releases chlorine, and the chlorine leads to ozone destruction. So, chlorine reacts with the ozone, and it basically reduces the ozone layer.

So, what is the importance of ozone layer in our stratosphere, all the UV rays or their harmful rays that is coming from the sun, but the ozone layer does it either absorbed those harmful rays or it reflects it back. So, if this is the ozone layer that you are looking at, so the light ray coming in from the sun. So, if all the harmful effect will be absorbed in this layer or it will be send it back in to the atmosphere. So, when it does not come in to that to the lower part of the atmosphere, where we live or where the plants are. So, we are not getting the harmful effect of all those harmful UV rays.

But if the ozone layer the if this is the thickness of the ozone layer, if it gets thinner and thinner and thinner what is happening that harmful rays is able to penetrate through that and it will come out at the bottom. And when it comes out at the bottom, we will have more skin cancer, we will have impact on our plants and all those, so that is where. So, with the depletion of ozone it we are losing ozone in the stratosphere and because of the loss on ozone in the stratosphere, we calculate that as a ozone depletion potential that is we call it as a ozone depletion potential.

What is the ozone depletion potential because of the CFC release? So that is our midpoint indicator. But midpoint indicator is basically all these midpoint indicators that we have talked about that basically gives us to a kind of a way to calculate what is the kind of immediate impact or what is the impact which is happening to the different species available in the atmosphere. But ultimately, we are going from this midpoint to the end point. And this end point as you can see in the next box below that end point damages increased UV radiation leads to the following damage and what kind of damage skin cancer, crop damage, immune system, damage to material, marine life, cataracts. So, these are our end point damages. So, think about that.

Because of the CFC release in to performed from the refrigerators going in to the atmosphere creating ozone delayer depletion and leading to potentially leading to having more skin cancer, more crop damage, immune system separation, so this is what we are we are able to calculate. Of course, there are a lot of I would say guesstimates there are lots of modeling which went into all these exercises. But this tools like LCA gives us that is a very powerful tool, because even if it may not be 100 percent perfect no tool, no environmental model is 100 percent perfect. But at least it gives us some idea of what could be the potential in environmental impact and the human health impact and that leads to kind of better design we can go for more eco design, more green engineering, pollution prevention and all those things can come into picture. So, on the right hand side you can see the arrow kind of shows you the environmental cause and effect change. So, what we can do now we once we reduce this we will have less impact over there. So, we can go for mitigation of these kind of exercise.

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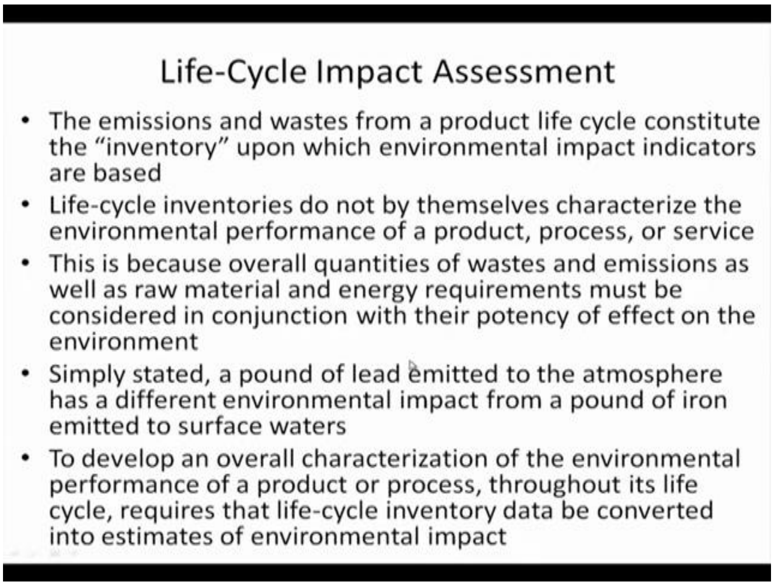

So, what I have said so far in this video kind of summarized in couple of slides over here. So, do not worry too much about going through the line by line on these slides, you can read it later on we will have this material available for you on as you can see from the previous weeks as well you have seen that the materials are available for you. This is for your reading material, do not worry too much going line by line of these slide. Essentially what we are trying to say here is we look at the emissions, we look at the input and output and that is the inventory which based on which we do the environmental impact indicators. So, this inventory do not what when we got this inventory, they do not characterize their environmental performance of the product we have to look at what kind of because overall quantity, we have to look at what is what it happening in terms of effect on the environment.

Say one if you get an example say if we have a 1 kg of led or certain amount of led is emitted to the atmosphere, it will have a different kind of impact as opposed to 1 kg of iron being emitted to the atmosphere. So, 1 kg of led going in to the atmosphere or to the water versus 1 kg of iron going to that after the effect is different. Because the way this iron or led or say arsenic or cadmium or any organic chemical, how they will react in the environment, what will be it is fate and transport in the environment, what is it is toxicity in terms of for that of the particular chemicals or elements present there that is dictates what will essentially happen in terms of it is impact on environment as well as the human health. So, what we have, so we have to have a overall characterization of the environmental performance of a product or process and we use this life cycle inventory data for doing that.

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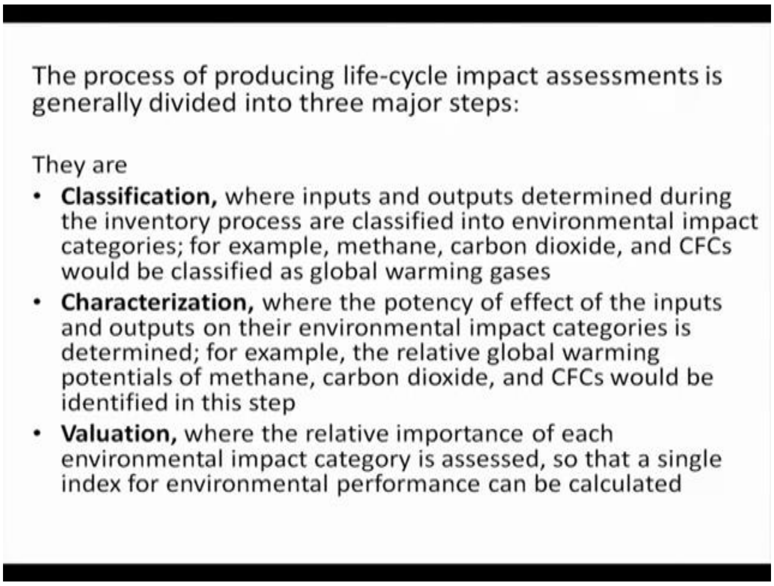

So, that is we. So, this is divided, when we try to do this classification or this impact assessment, they are usually divided in to three major steps, one is we have to do the classification. Classification means where input and output whatever is during the inventory process, which I have explained earlier, we classify them into different environmental categories. For example, methane, carbon dioxide, CFCs, they have been classified as global warming gases. So, not each gas has global warming potential. So, like it not be, whichever gas has a global warming potential we will put them as global warming gases which ever can cause acidification we will put them in a acidification column, eutrophication, similarly damage to in terms of like a salinity.

So, you can pick different categories as we had those environmental impact categories and we can club these emissions in those categories what happens in some of the cases where you may have one particular emissions which may have impact oN 2 Or three different categories. So, how will you do that, in that case what we do we take a weighted average, we kind of decide based on this emissions coming out of this 40 percent will go there, 30 percent will go there, another 30 percent will go there and we decide based on that particular category. So, classification is when you have the input and output whatever is coming out we put we classify them in to different categories and you will see some examples of that.

Then after you have done we have to have the characterization because what is the relative potential. And if you look at the global warming potential exercise what is it, say carbon dioxide is also global warming gas methane is a global warming gas as well CFC has global warming potential, nitrous N 2 O has global warming potential. So, but how much how much is the global warming potential of each one of these. So, to solve our problem what we have done is we have taken one particular gas or one particular element or one particular component of these different like a emissions coming out for different categories as one unit.

So, what does that mean, so for example, in global warming potential we have assumed that whatever is the global warming potential coming out of carbon dioxide gas that is one, so that is one is the global warming potential for CO 2. So, based on the CO 2 what would be the global warming potential of methane CFC nitrous oxide? So, we have a number. So, CO 2 becomes our baseline for global warming potential. So, that is how we have done this characterization. So, we come calculate the relative global warming potential.

Then you go for valuation where the relative importance of each environmental impact categories is assessed and a single. Because again as I said earlier as well we in the one some of the previous videos that if you give all these different numbers to a I would say to a policy makers and say you are doing a presentation in front of the environment minister either at the state level or at say in Delhi or it at the federal level in any country where you may be. And if you are doing this presentation and you come up with all these complex equations and so all these complex graphs and then the whole the people put the scientific community will probably understand what you are talking about if you presented well.

Think about the minister who may not have that that much of a scientific background, so to make him or her understand the significance of that we need to bring it down to a number, in number which makes certain sense and that number should be relative. So, that we can say this is better than like if among the two if you are comparing we can put the number. And again this is similar to air quality number or the water quality index or to certain extent even the stock exchange index. So, we come up with this valuation where the relative importance of each environmental categories assessed and a single index for environmental performance can be calculated.

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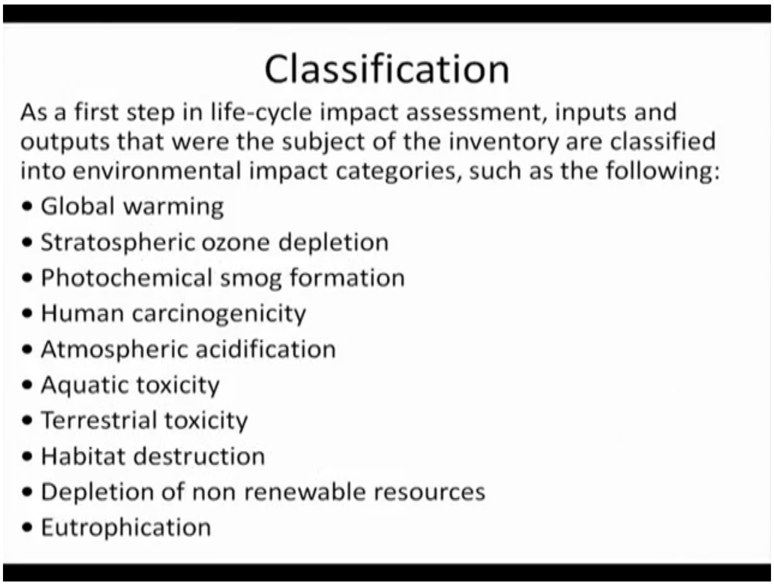

And will look at some of these examples in a minute. So, in terms of classification there are as I said there are different impact categories, global warming we talked about then you have the stratosphere we talked about ozone depletion as well, there could be photochemical smog, human carcinogenicity, atmospheric acidification, aquatic toxicity terrestrial, habitat destruction depletion of. So, there are a lot of categories which is there, which based on what kind of emissions coming out we can find out whether they are going to impact either one of these categories, so that is.

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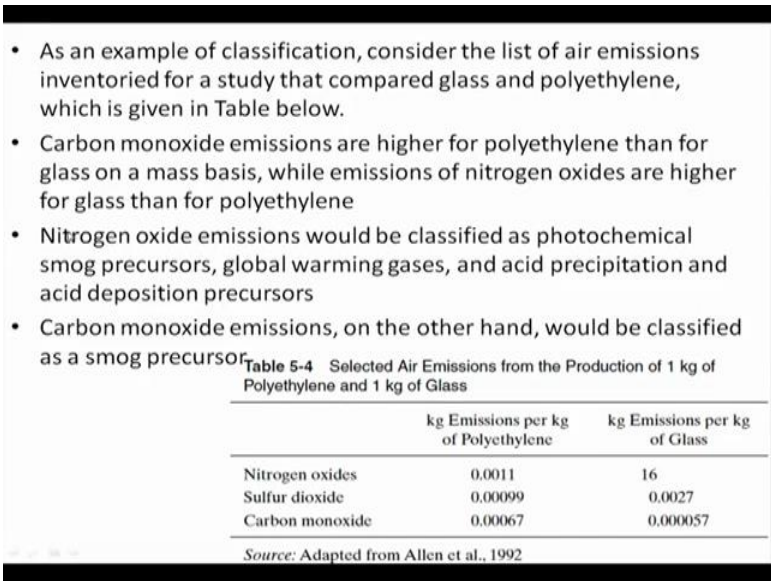

Table 5-4 Selected Air Emissions from the Production of 1 kg of Polyethylene and 1 kg of Glass

	kg Emissions per kg of Polyethylene	kg Emissions per kg of Glass
Nitrogen oxides	0.0011	16
Sulfur dioxide	0.00099	0.0027
Carbon monoxide	0.00067	0.000057

Source: Adapted from Allen et al., 1992

So, now let us look at an example. So, if you have a as an example of classification say if you take a air emission. So, for a study that cope if you take a air emissions for from a study which compared glass and polythene which is given in the table below. This is the selected emissions from the product of 1 kg of polythene and 1 kg of glass polyethylene. So, what are the emissions coming out per kg of polyethylene, we have the nitrogen oxide, sulfur oxide, carbon monoxide. So, these three material again these are not the total list this is the list coming like a just some example parameters. So, these are the k g emissions per kg of polythene then.

So, let us look at an example for classification where we will be looking at the air emissions from two process. So, say for the production of polythene versus production of glass. So, as you can see in the table on the right hand side at the below here, the expected presents as kg emissions per kg of polythene of in one column and the other column is g of emissions per kg of glass. And we are looking at three selected air emissions as I said these are not the exhaustive list this is the three emissions that we are looking at nitrogen oxide, sulfur dioxide and carbon monoxide.

As you can see from the figures for nitrogen oxide and sulfur dioxide, we see more emissions in glass as opposed to per kg of polythene. Where in carbon monoxide it is different we have less coming out from glass and more from the production of polythene. And these here if you look at nitrogen oxide, nitrogen oxide is will create photochemical smog, will create global warming acid precipitation, acid deposition, so that is what nitrogen dioxide is pre predominantly involved in. See carbon monoxide on the other hand was especially for the smog it is not a greenhouse gas so that is.

So, you can you can look at, so different types of emissions comes out from industrial process it does not mean that one particular type of industry emissions will be same irrespective of the different industrial process we will look at. Some of the emissions will be more depending on the type of operations they are there. And as opposed to other as we saw over here nitrogen dioxide and sulfur dioxide was higher for polythene sorry higher for glass as opposed to carbon monoxide which is lower.

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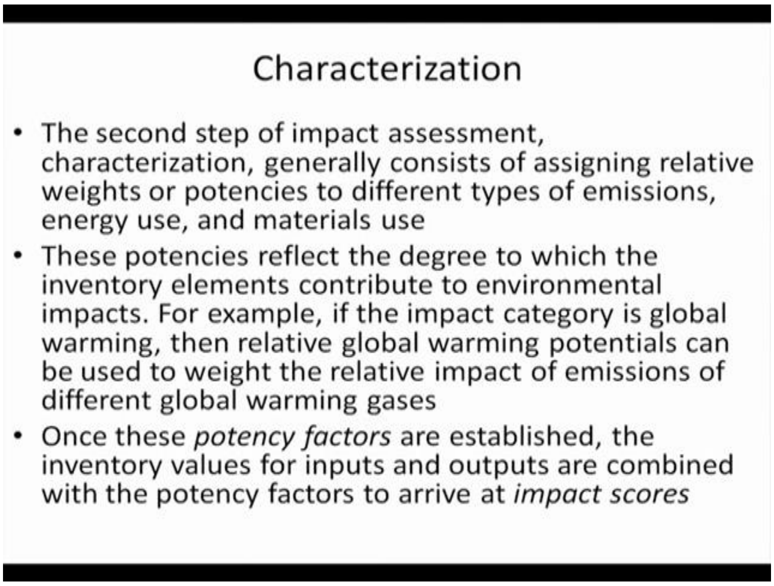

So, what does that is all these mean. So, if we take the all these data and then we put we want to have some relative weights to them, we assign some relative weights, so that and based on that potency of different types of emissions, energy use material use. So, we put some we give them a potency factors and this potency factors needs to be established. So, these potencies reflect the degree to which the inventory elements contribute to environmental impact. For example, if it is empowerment impact is global warming potential and so we look at different relative impact of emissions of different global warming gases. And I said earlier in this video and for global warming potential, we have used carbon dioxide as the baseline. So, for carbon dioxide, we take it one; and for other gases based on carbon dioxide how much more or how much less, so that is what we kind of. So, once this potential factors are established, we can take this inventory values for input and output and combined with this potency factors and we reach to impact its course.

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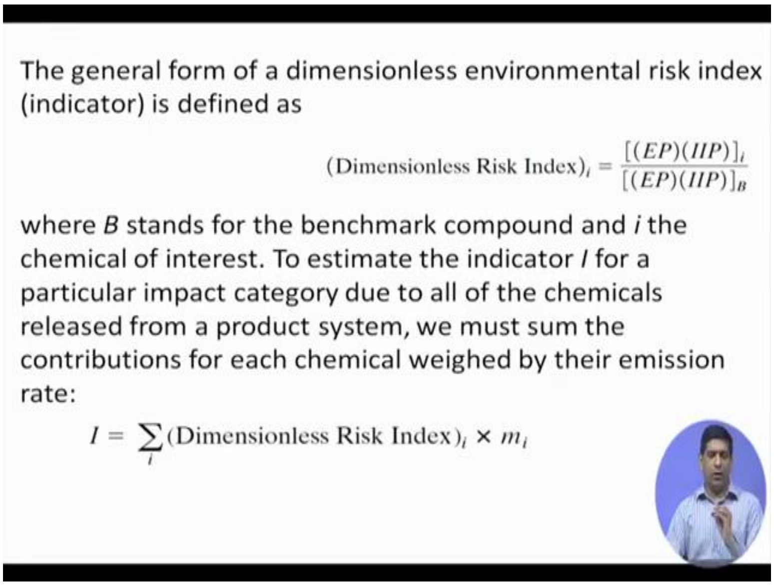

And also you in how this is done in a mathematical way. So, the gentle form of for the dimensional is environmental risk index, we calculate that based on whatever is the emission factors, what is the emission potential plus they the inventory emissions coming out and from for different processes. Here B stands for the benchmark compound. So, here and I is the chemical of interest. So, to estimate the indicator I for particular impact categories due to all the chemical release from the product system, we must sum them. So, we take this dimensional risk index and risk index here is, here i is for the particular i chemical, the chemical number I or we can have and the B is for your baseline. So, you divide. So, here in terms of global warming gas this would be our carbon dioxide. And whatever is the emission potential and the impact coming out from the other emissions, for example, say nitrous oxide for methane and that will go on top and there we take this ratio and that ratio multiplied by the mass of that particular chemical being released so that is what you see over here.

So, if you do total impact categories when we go for total impact categories of course, we have to do the summation and what will sum these dimensional risk index multiplied by the mass of that. So, it is like a weighted average, you can think about. So, if you have a group of chemicals out there, and you are looking at one particular impact, so from that group of chemicals say global warming potential several gases are out there. So, if you want to quantify the total global warming potential, we will take the impact from each of these gases multiplied by the mass of the gas or mass of that particular stuff coming out, so that is how we do the summation. So, that is what it is being shown here as in this equation at the bottom over here.

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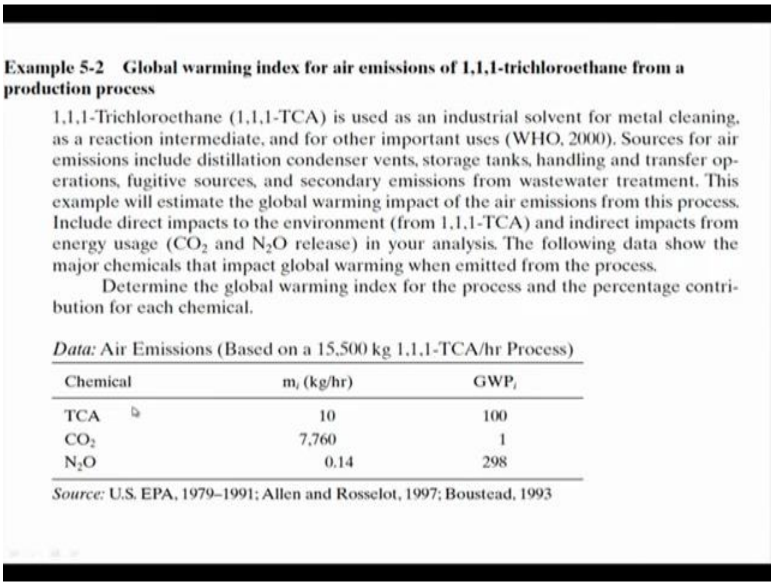

Example 5-2 Global warming index for air emissions of 1,1,1-trichloroethane from a production process

1,1,1-Trichloroethane (1,1,1-TCA) is used as an industrial solvent for metal cleaning, as a reaction intermediate, and for other important uses (WHO, 2000). Sources for air emissions include distillation condenser vents, storage tanks, handling and transfer operations, fugitive sources, and secondary emissions from wastewater treatment. This example will estimate the global warming impact of the air emissions from this process. Include direct impacts to the environment (from 1,1,1-TCA) and indirect impacts from energy usage (CO_2 and N_2O release) in your analysis. The following data show the major chemicals that impact global warming when emitted from the process.

Determine the global warming index for the process and the percentage contribution for each chemical.

Data: Air Emissions (Based on a 15,500 kg 1,1,1-TCA/hr Process)

Chemical	m_i (kg/hr)	GWP_i
TCA	10	100
CO_2	7,760	1
N_2O	0.14	298

Source: U.S. EPA, 1979–1991; Allen and Rosselot, 1997; Boustead, 1993

So, let us look at well we will do a math and that will make it a little bit more clear. So, if you have to do this global warming index for say 1, 1, 1-trichloroethane from a particular process. So, we have been with say 1, 1, 1-trichloroethylene production process. So, it is we uses the industrial solvent we know that it is a react and for cleaning as a reaction intermediate other important use, but when we try to make them there are certain things which gets emitted into the atmosphere. So, here at the bottom the data that has been given to us for this particular problem, we have three chemicals are provided. Again these are most of the times you see this list or only just an example list, they are not the complete list of chemicals which gets emitted do not code that only these three will get emitted when you are producing trichloroethylene there will be some more, but this these are the important ones.

So, we have these three emissions which is trichloroethylene, carbon dioxide and nitrous oxide, we have the mass of being released, so kg per hour of say 10, 7,760, nitrous oxide

0.14. And we have been given greenhouse gas potential this is the ratio see is the carbon dioxide we have number 1. So, here this means hundred times more potent than CO 2 and N 2 O is 298 times more potent than CO 2. So, these numbers are based on with the CO 2 as the baseline as you saw in the previous slide.

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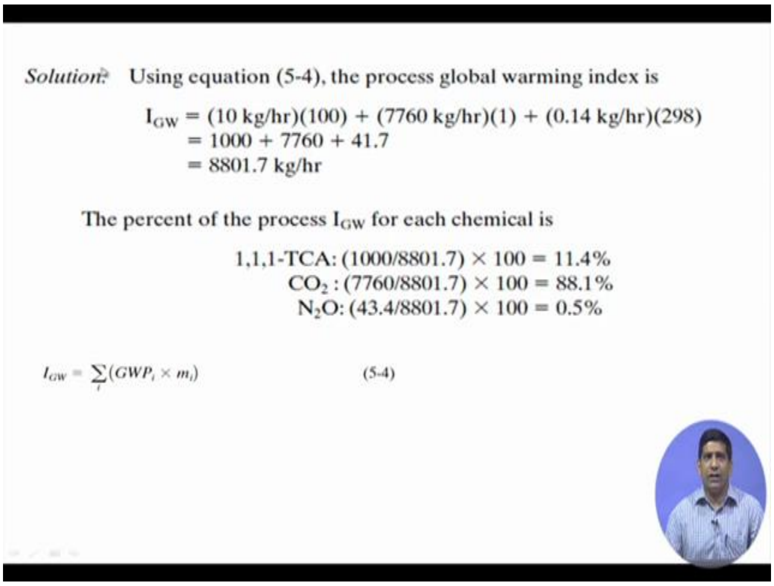

So, now if you have to calculate the global warming opportunity index for that how will do that, which we use the equation which we just mentioned earlier which is you take this ground what greenhouse potential that is index times the mass and sum it up. So, here 10 kg per hour and for 140 CA then for CO 2 and this is for our N 2 O and if you add them up. If you look at here although both TCA and N 2 O has much higher greenhouse gas potential as opposed to CO 2. But CO 2 just think so much of a mass the most significant out of 8800 number that you got for the total greenhouse gas potential for this process the predominantly 7760 came from CO 2, so that is almost nearly 90 percent 90 percent of the impact is just coming from CO 2 and rest is coming from others.

And it is although N 2 O has a very high greenhouse gas potential 298, but the impact is much lower even like less than 1 percent of the impact coming from CO 2 that is why N 2 O although in many processes N 2 O gets release including in the composting process. But we do not see that much of an issue in terms of that much of a discussion on N 2 O when we talk about greenhouse gas potential. The reason being that is the impact is much less has been calculated over here if you take the proper center process for each chemical CO 2 is 88 percent, TCA is 11 percent, and N 2 O is only 0.5 percent, so that is why although their impact is much higher, but since the mass is much less. The total impact comes out to be much smaller.

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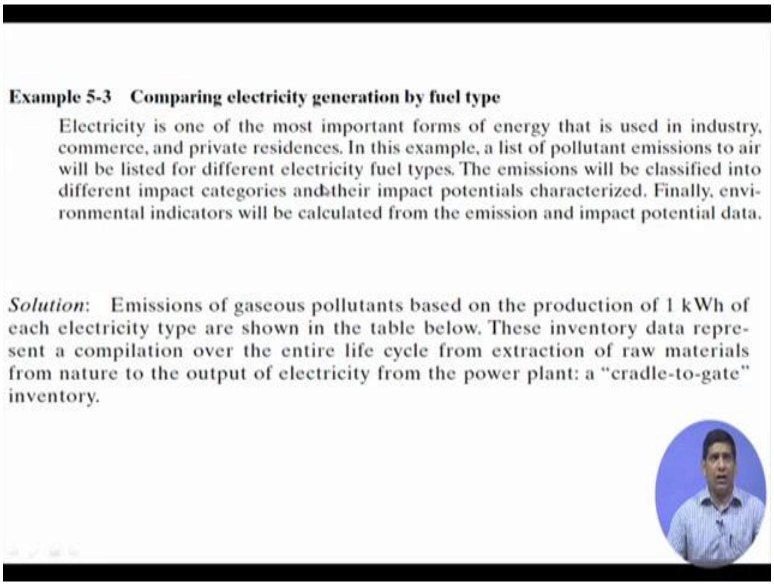

So, similarly and let us look at another example. Say if you compare electricity generation, but the fuel type there will be some emissions of gas or gases pollutants coming out. And we can take emissions of the gases pollutants, different fuel types that is coming out. And we can calculate and classified them in to different impact categories and their potentials characterized finally, the environmental impact can be calculated from emissions and the impact potential data. So, if you look at it with the next slide, we will look at for production of one kilowatt hour of each electricity type.

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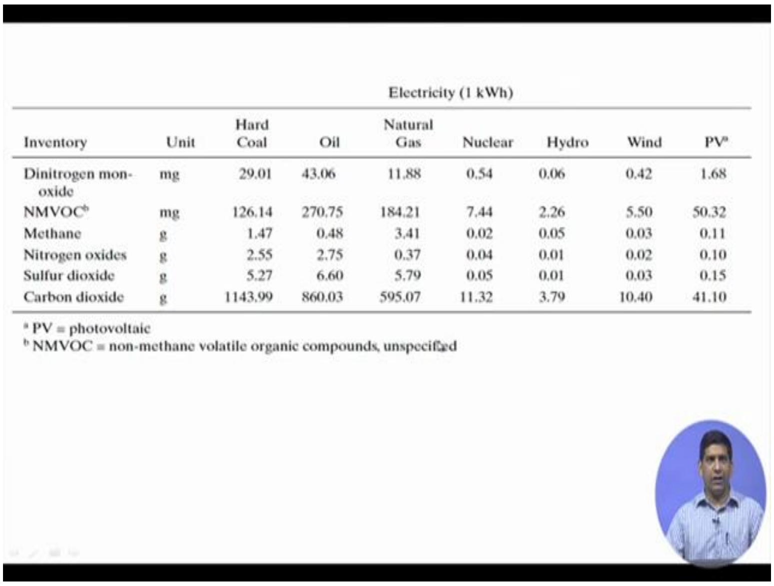

Inventory	Unit	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV[a]
		Electricity (1 kWh)						
Dinitrogen mon-oxide	mg	29.01	43.06	11.88	0.54	0.06	0.42	1.68
NMVOC[b]	mg	126.14	270.75	184.21	7.44	2.26	5.50	50.32
Methane	g	1.47	0.48	3.41	0.02	0.05	0.03	0.11
Nitrogen oxides	g	2.55	2.75	0.37	0.04	0.01	0.02	0.10
Sulfur dioxide	g	5.27	6.60	5.79	0.05	0.01	0.03	0.15
Carbon dioxide	g	1143.99	860.03	595.07	11.32	3.79	10.40	41.10

[a] PV = photovoltaic
[b] NMVOC = non-methane volatile organic compounds, unspecified

So, if you look at here from cradle to gate, so we have a hard coal, oil, natural gas, nuclear, hydro, wind and photovoltaic cells which is the solar power. So, for all these different types of potential energy sources, if you look at again these are not the complete list. So, this is a kind of some emissions. So, here dinitrogen monoxide and these are your unit is for hard and for you see the emissions coming out for production of 1 kilowatt hour of electricity. So, here we can say if you remember from the previous class what we talked about that functional unit. So, this is a good example of functional unit here. So, if you have to compare the different types of electricity production, you can take a functional unit of 1 kilowatt hour or you can take a functional of 1 gigawatt hour, whatever, but it has to be the same for each of these electricity different types of electricity production system.

So, for say 1 kilowatt hours of electricity being produced, so we have different emissions coming out we have nitrogen monoxide, non methane volatile organic compound, methane, nitrogen oxide, sulfur dioxide and you look at all these different numbers coming up. So, how what will do with this numbers? So, what will do with this number is will calculate and this is what happens in today’s when you when you do the real LCA most of these work is actually done by the software. But as a researcher, as a student, as a practitioner of LCA, you should understand what else what the software is doing for you. So, you just not take the because software can always make a mistake and if you input something wrong if you selected some wrong process, it will give you a garbage coming little will that result will not be correct. But you should be able to know what is actually going on in to the software at least you should have a good idea of that.

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Global warming index: $I_{GW} = \sum_i (GWP_i \times m_i)$

		Electricity (1 kWh)						
$(GWP_i \times m_i)$	Unit	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV
Dinitrogen monoxide (GWP = 298)	g	113.52	91.11	132.15	7.10	5.01	18.59	37.53
Methane (GWP = 25)	g	36.86	12.00	85.26	0.52	1.29	0.76	2.74
Carbon dioxide (GWP = 1)	g	1143.99	860.03	595.07	11.32	3.79	10.40	41.10
I_{GW}	**g**	**1294.37**	**963.15**	**812.48**	**18.94**	**10.09**	**29.75**	**81.37**

The inventory values for each pollutant are multiplied by the appropriate GWP_i. For example, the table entry (above) for hard coal dinitrogen monoxide is calculated as:
(298 *29.01 mg)/(1000 mg/g) = 113.52 g.

So, how we can go about this calculating that? So, if you want to do this global warming index, again this will be these calculations usually done by software these days. You can even use excel spreadsheet to do this kind of calculations if you have a smaller type of LCA being done. So, here if you look at we know the dinitrogen monoxide global warming, it is N 2 O 298, methane was 25, carbon dioxide is 1. So, these are the three which will contribute to global warming.

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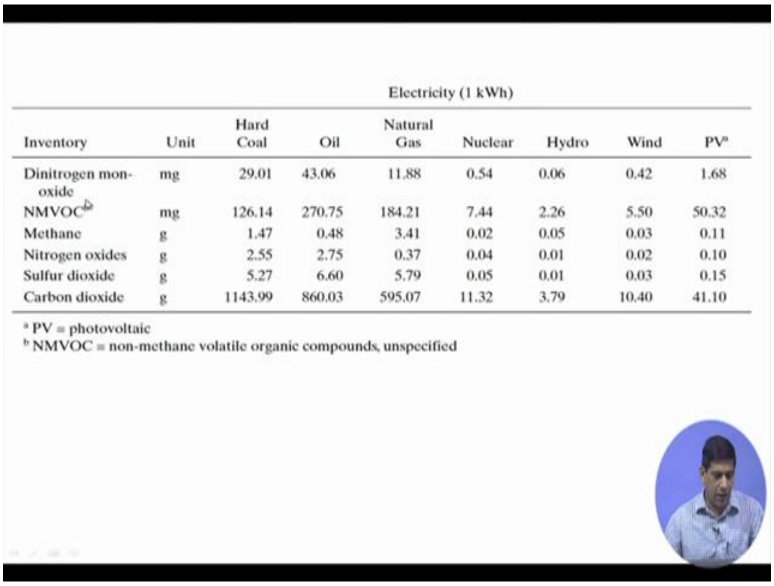

Inventory	Unit	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV[a]
		Electricity (1 kWh)						
Dinitrogen mon-oxide	mg	29.01	43.06	11.88	0.54	0.06	0.42	1.68
NMVOC[b]	mg	126.14	270.75	184.21	7.44	2.26	5.50	50.32
Methane	g	1.47	0.48	3.41	0.02	0.05	0.03	0.11
Nitrogen oxides	g	2.55	2.75	0.37	0.04	0.01	0.02	0.10
Sulfur dioxide	g	5.27	6.60	5.79	0.05	0.01	0.03	0.15
Carbon dioxide	g	1143.99	860.03	595.07	11.32	3.79	10.40	41.10

[a] PV = photovoltaic
[b] NMVOC = non-methane volatile organic compounds, unspecified

And so that is a as opposed to like NMVOC, sulfur dioxide, they do not contribute to the global warming. So, the only these three will contribute and we have this data. So, the inventory value for each pollutant will multiply due using this equations, we know that greenhouse gas potential we multiplied by mass. What we have been given in this particular table is the mass. So, we can do that and if you do for ever hard coal, we found that for table entry we can calculate it for the hard coal and we get 113.52 and sorry. So, that is 29.01 times 298 and then converting from milligram to gram we got hundred 113.52. Similarly, you can do it for the others as well.

So, you can calculate for others in terms of the greenhouse gas and then you can add them up. So, here finally, we got for hard coal this much, oil. So, if you compare the hard coal was is the with the highest global greenhouse gas global warming potential. As if you say if the only category that we are worried about is the global warming potential and in terms of comparing these different types of electricity production, so this hard coal comes out to be the words, because that is the highest value. You see over here that is your 1.29, 1295 almost 1294.37. And then you go to oil then you have natural gas and then we have photovoltaic cell then we have wind, nuclear and then hydro. So, hydro comes out to be much, much better in terms of global warming potential, but this is for global warming potential, it may not be the same for other impact categories.

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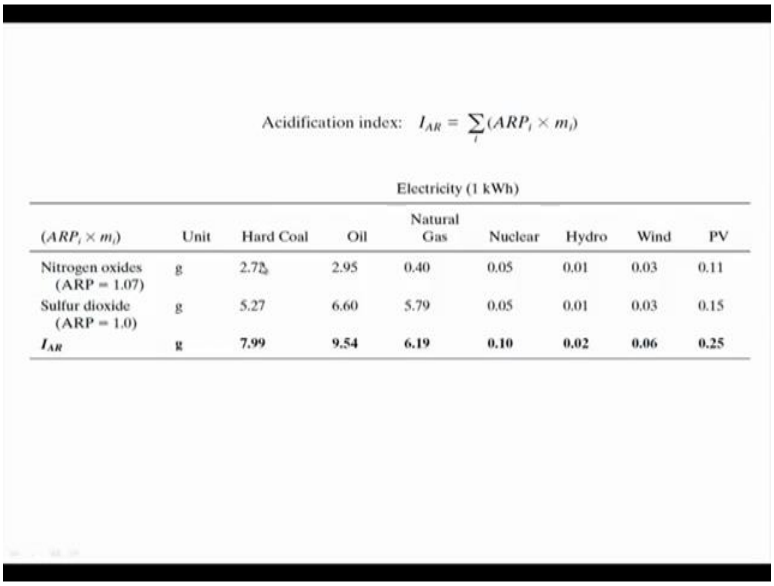

Acidification index: $I_{AR} = \sum_i (ARP_i \times m_i)$

Electricity (1 kWh)

$(ARP_i \times m_i)$	Unit	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV
Nitrogen oxides (ARP = 1.07)	g	2.72	2.95	0.40	0.05	0.01	0.03	0.11
Sulfur dioxide (ARP = 1.0)	g	5.27	6.60	5.79	0.05	0.01	0.03	0.15
I_{AR}	g	**7.99**	**9.54**	**6.19**	**0.10**	**0.02**	**0.06**	**0.25**

So, let us look at the other impact categories. So, in the other impact category for the acidification index, similar calculation, you get this acidification index potential 1.07 and 1. And these two nitrogen dioxide and sulfur dioxide is what will cause that and you do the same kind of a math over here you get the numbers, and here you see oil actually comes out to be the worst. So, earlier our hard coal was bad for global warming, but for acidification oil is bad. So, we have to make a decision and on which would like how to do that. And the best one here is hydro in the earlier one also the hydro was the best. So, based in terms of lowest acidification index was hydro and as low as to global warming potential is also hydro.

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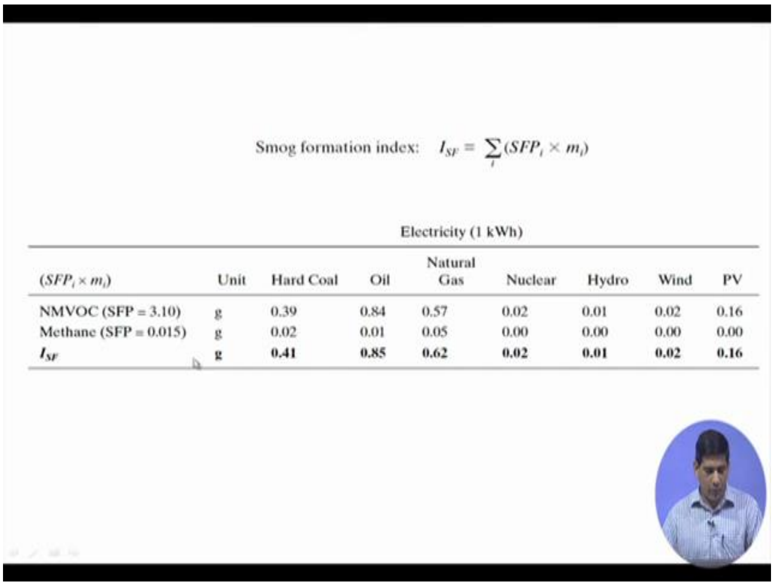

Smog formation, similar calculations can be done using this the factor, and for a smog production again the worst one is oil followed by gas, hard coal comes out to be the third one. So, it is not the worst one, it is actually the third worst, hydro is the best and nuclear and wind is put potentially the same, and photovoltaic cell comes up with after the hard coal. So, again you can see for the different types of impact categories different process comes out to be better or less or less. So, what does that mean that means, that as a practitioner or as a policymaker, we have to decide which impact categories is more critical for me.

So, about among the different impact categories out there which one is the most critical which one which gives more weightage and based on that we will decide which one is good for us. So, you do a weighted average and then you come up with which one is better. So, this again it does not mean that oil is always better than hard coal depends on what type of impact you are looking at.

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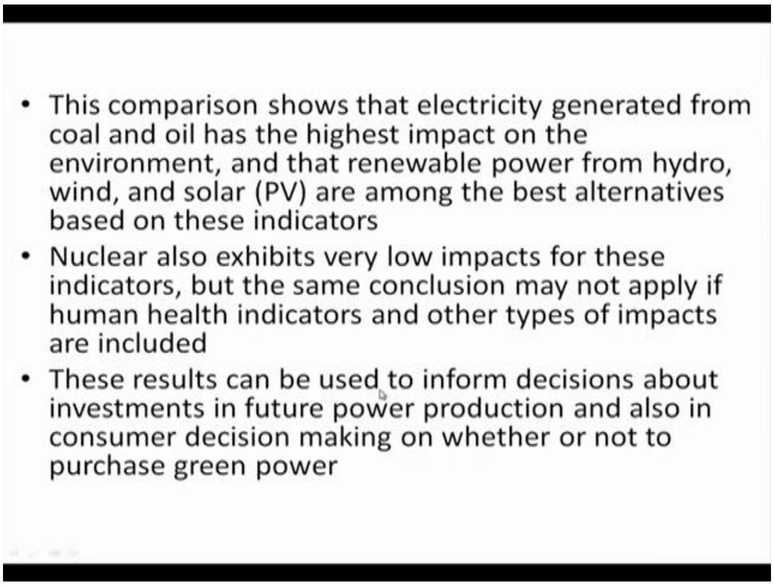

So, this comparison shows the electric generation is the highest impact we have already talked about that and hydro solar are the best alternatives. Nuclear also exhibit is low impact the problem with nuclear is the nuclear waste disposal we have to be really careful about that, but other types of this. So, these results can be used to make the informed decision whether to not purchase whether you can go for that.

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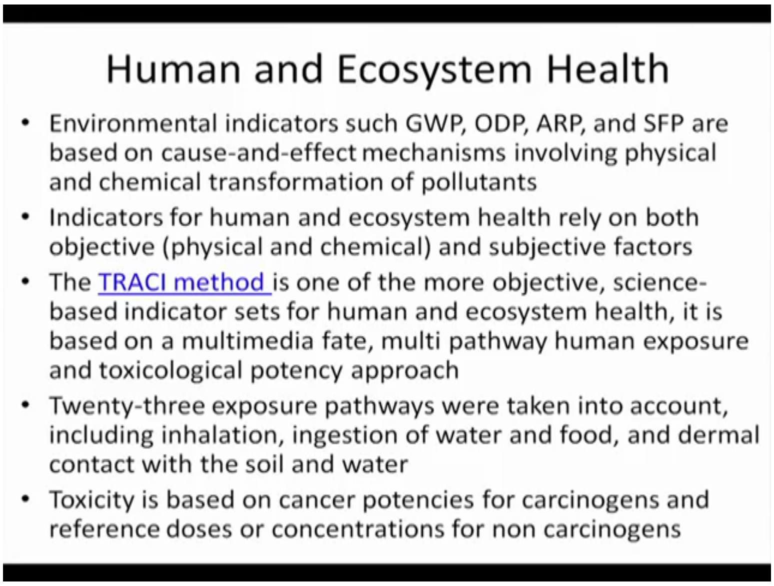

So, these are different environmental impacts the categories are there greenhouse gas, ozone depletion, acidification and other things. These based on the cause and effect we talked about that. And we look at our objective like physical and chemical and subjective factors, there are some methods out there which gives us science based indicator set for human and ecosystem health. This TRACI method which is a EPA, USEPA develop method that is used and there are other methods out there which is done as well we talked about that recipe 2002 and other. So, there are different pathways twenty three exposure pathways are taken help and with based on that this method has been developed. Toxicity is based on the can cancer for the carcinogen, and for and reference doses concentration for the non-carcinogen.

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Table 5-5 Rankings of 1993 Releases of Chlorinated Organic Compounds in the Great Lakes Basin for Several Potency Factor Schemes

Compound[a]	EPA Huma Risk[b]	Dutch Human Tox[c]	Dutch Aquatic Tox[c]	EPA Eco Risk[b]	MPCA Tox Score[d]	Dutch Terr Tox[c]
Tetrachloroehtylene	8	4	5	10	6	3
Dichloromethane	13	5	8	10	2	9
Trichloroehtylene	8	12	12	10	10	10
1,1,1-Trichloroethane	8	1	6	10	7	4
Chloroform	6	8	4	6	1	6
1,2-Dichloroethane	8	6	7	8	4	7
PCBs	1	2	2	1	5	1
Endosulfan	2	7	1	2	11	2
Carbon tetrachloride	3	10	10	2	3	11
Vinyl chloride	6	9	13	6	9	13
Chlorobenzene	8	14	14	8	13	14
Benzyl chloride	13	15	15	10	14	15
Hexachlorobutadiene	3	13	11	4	12	8
2,4-Dichlorophenol	13	11	9	10	15	12
2,3,7,8-TCDD	3	3	3	4	8	5

[a] Listed in descending order of quantity released.

[b] U.S. EPA, Waste Minimization Prioritization Tool, used to rank pollutants.

[c] Dutch: Guinée et al. (1996) considers environmental fate and transport, developed specifically for life-cycle assessment.

[d] MPCA: Pratt et al. (1993), Minnesota Pollution Control Agency system for ranking air pollutants. May be based on human or animal effects.

So, here is some of these rankings. So, the different types of compounds out there and this EPA human risk, Dutch human risk, Dutch aquatic toxicity, Eco risk, tox Dutch. So, based on their different risk factors have been given for different types of chemicals and based on different types of types of impact that we are looking at.

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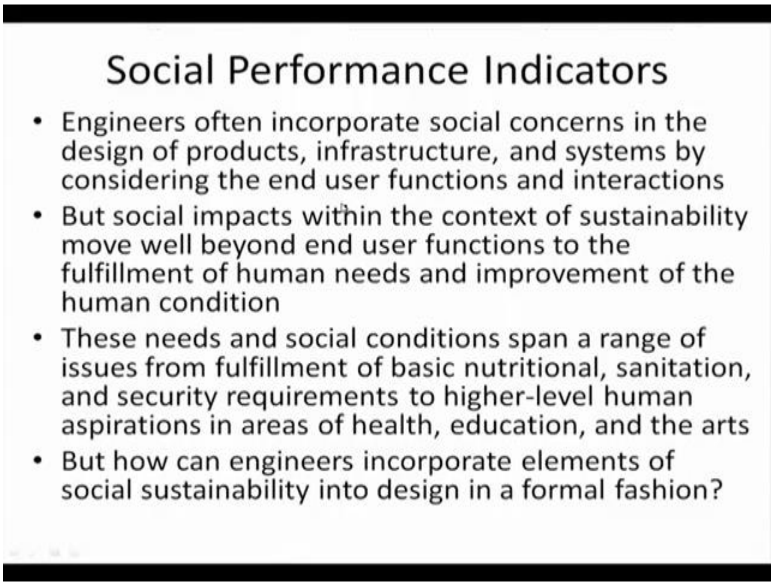

Then we also have to look at the social performance indicator which we have not again LCA does not can take care of the social aspect. When we talk about big picture lifecycle a very big picture sustainability there the social comes in picture, LCA is mostly environmental. So, we have focused mostly in this course on the environmental aspect. We have talked about social little bit, but we have to look at the social concern in terms of the infrastructure, end user function and the sustainability what are the in terms of the in how human aspirations in health, education. So, in terms of ingenious incorporating this social responsibility in a formal fashion, it is always a challenging, there is a new methodology still being developed.

First draft is out there the United Nations environmental program and SESTAC they have come together and put and come and come up with a seat social LCA document out there. I encourage you to look at the document if you are interested. And I think I initially in the in some of the lectures I kind of mentioned that document as well, but still it is in preparation stage, we do not have the out there.

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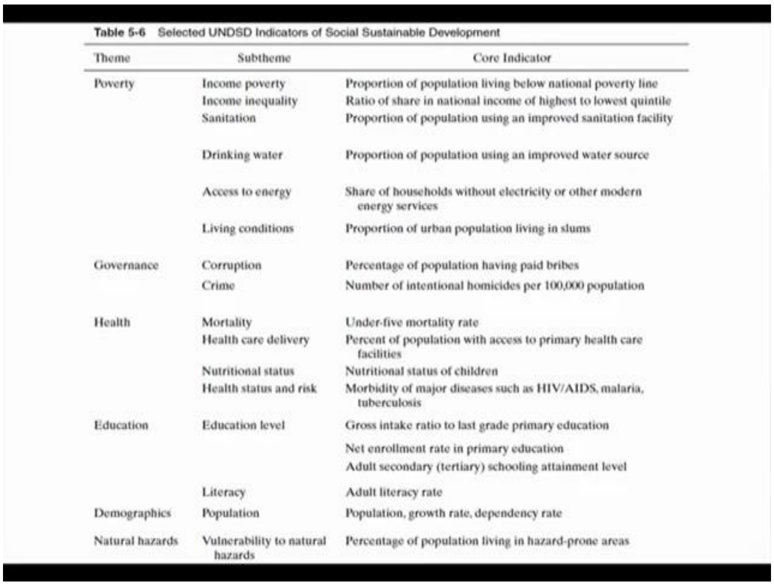

Table 5-6 Selected UNDSD Indicators of Social Sustainable Development

Theme	Subtheme	Core Indicator
Poverty	Income poverty	Proportion of population living below national poverty line
	Income inequality	Ratio of share in national income of highest to lowest quintile
	Sanitation	Proportion of population using an improved sanitation facility
	Drinking water	Proportion of population using an improved water source
	Access to energy	Share of households without electricity or other modern energy services
	Living conditions	Proportion of urban population living in slums
Governance	Corruption	Percentage of population having paid bribes
	Crime	Number of intentional homicides per 100,000 population
Health	Mortality	Under-five mortality rate
	Health care delivery	Percent of population with access to primary health care facilities
	Nutritional status	Nutritional status of children
	Health status and risk	Morbidity of major diseases such as HIV/AIDS, malaria, tuberculosis
Education	Education level	Gross intake ratio to last grade primary education
		Net enrollment rate in primary education
		Adult secondary (tertiary) schooling attainment level
	Literacy	Adult literacy rate
Demographics	Population	Population, growth rate, dependency rate
Natural hazards	Vulnerability to natural hazards	Percentage of population living in hazard-prone areas

So, and then there are some social development indicators which have been used from there are different types of poverty, governance, health, education, demographics those things are used for that. So, if you look at and this is again from the social sustainability stakeholders in terms of employee working condition, international community, future generation consumer, so there are based on the different types of activities.

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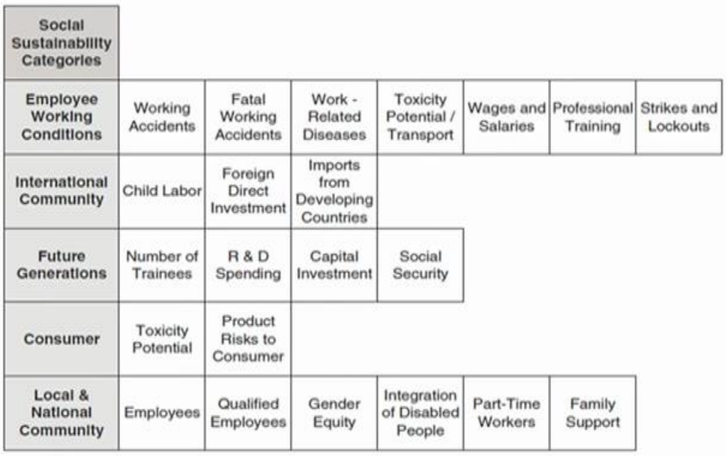

Figure 5-4 Social sustainability stakeholders (categories) and indicators within each category (Adapted from Kölsch et al., 2008)

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So, this is more of for you as a reading material you go over that we did not cover much of the social LCA here because that was not part of this course, but there is there something like social LCA out there I just wanted to introduce you to that. So, this is the summary slide.

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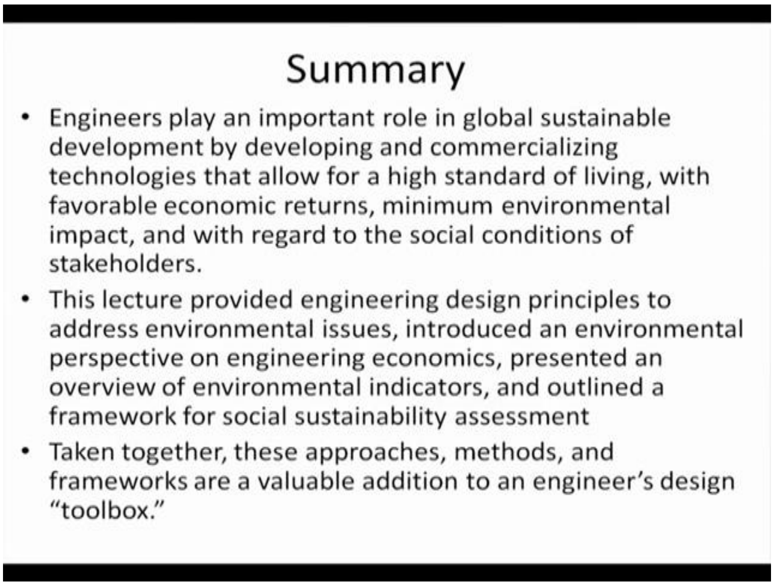

And after this saying that from the next video onward, we will be focusing more on I will give you example after example. So, we have several examples lined up, which I want to go over in the next video. So, kind of a summary for this particular course, as an engineer or we play an important role in global sustainable development, by developing and commercializing technology and we are trying to improve the standard of living. And our goal is to have favorable economic it returned, but the same time we have a goal to minimize the environmental impact and as well as improve the social conditions of the stakeholder

So, this particular course, we provided some of these principles to address the environmental issues we have a we even talked about some environmental economics aspect little bit and give you a different environmental indicators and also touched upon the social sustainability aspect, we did not went in to detail of that. So, taken together what I have tried to do in this particular course for this particular is try to give you a tool. So, this is one of the tool in your toolbox which can help you as a future engineer to design things more responsibly especially from an environmental perspective. So, with that I will close this particular video and then from the next video onwards, we will start looking at examples of how this LCA is used in real world projects.

Thank you.