

SUSTAINABLE MINING AND GEOINFORMATION

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Week – 10

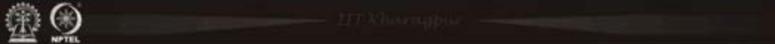
Lecture 50: Life Cycle Analysis for Mining Industry

Welcome, students, to our NPTEL Online Certification course on the topic of Sustainable Mining and Geoinformation. Today, it is lecture number 50, and the topic is Life Cycle analysis for the Mining Industry. In the previous class, we discussed the concept of life cycle analysis, how the life cycle analysis is carried out, and what the different components are. Today's class is a continuation of last class, and in today's class, we shall discuss how the concept of environmental life cycle analysis can be applied to the mining industry, and we will discuss this by taking a case of a coal mine. Again, just to give a brief introduction, the mining industry is an important industry that provides the raw material used by the manufacturing industry. So, it has a very important stake in the national economy. But the mining industry has significant adverse impacts on the environment and ecosystem.



INTRODUCTION

- Mining industries is an important industry providing raw materials for manufacturing sector.
- Mining operations have significant adverse impact on the environment.
- Important to identify and predict environmental impacts of mining operations.
- Life-cycle assessment (LCA) can be used to carry out a comprehensive environmental analysis.
- We take a case study of coal mining to demonstrate application of LCA in mining industry.
- We review a recent journal paper for this case study.



So, it is very important to identify, to determine, to estimate what the different environmental impacts are likely to be. Then also to suggest mitigation measures so that the adverse environmental impact can be minimized. One way to do this is to conduct an environmental impact assessment study. But in recent times, the concept of life cycle assessment, or what we call environmental life cycle assessment, can be used to carry out a comprehensive environmental analysis of the mining project, in which the different environmental impacts will be ascertained, and the critical environmental impacts will be identified. We can suggest remedial measures so that the environmental impact caused by various processes and activities can be identified, and it can be minimized by taking suitable mitigation measures. So, we have discussed the concept of life cycle analysis in the last class. Today, we demonstrate the application of the LCA technique, in a mining case study.

There is a recent journal paper that discusses the application of LCA for a coal mining project. We will discuss that paper, which gives a very good review of how an LCA can be applied to a coal mining project. The objective, the paper name, and the title of the paper are already mentioned in the reference list. So the study, which was presented in the paper, had the objective of carrying out the environmental LCA for a coal mining project. As we have discussed, the LCA study can be done using the ISO method, ISO 14040. This standard which came in the year 2006, and subsequently this standard have been modified. This study was conducted following the ISO 14040 protocol. So, What are the different steps to conduct the LCA study as per ISO 14040? One is identify system boundary, then determine the life cycle inventory analysis (LCI), that means you quantify the various input elements and also the output elements.

LCA of Coal Mining

- Objective of the paper was to carry out Environmental LCA for hard coal mining.
- LCA study was conducted as per ISO 14040: 2006.

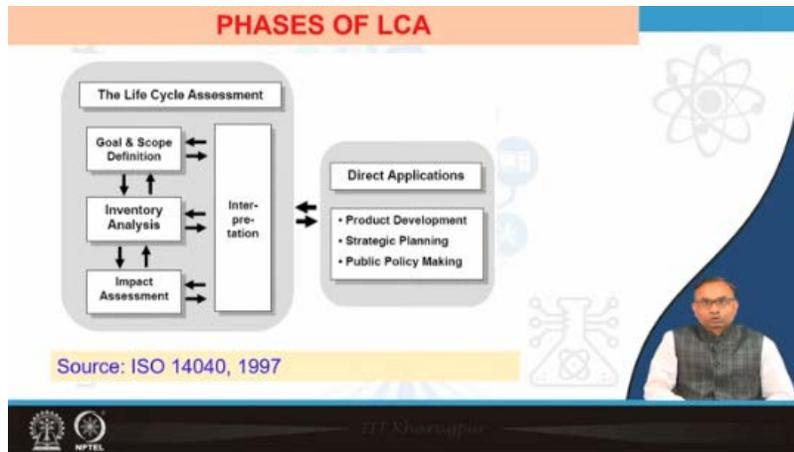
Steps to conduct LCA study:

- Identify System boundaries;
- Life cycle inventory analysis (LCI) – Quantify Input and output elements (material, water, chemicals, energy, waste).
- Life cycle impact assessment (LCIA)
- Interpretation
- Function: coal production
- Functional unit: 1 ton coal

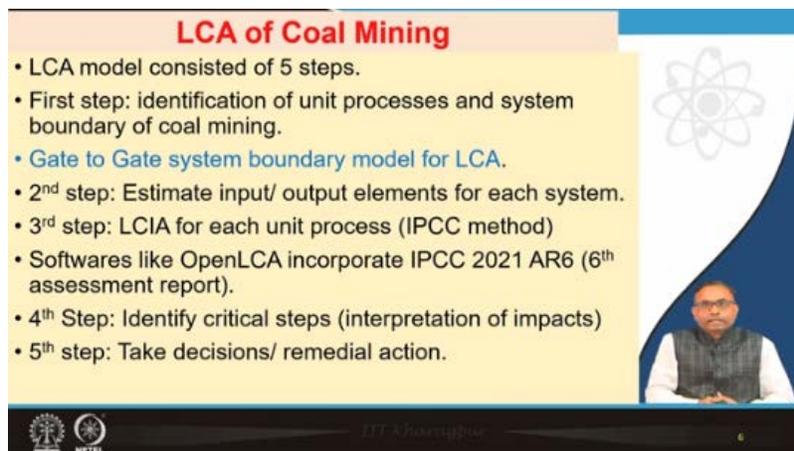
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In the input, you can have the material input, energy input, water, chemicals, things like that, and in the output element, the processed product, the desired product, and then all the waste products: solid waste, liquid waste, and gaseous waste. These are the outputs. Once we do the inventory for each unit process, then we proceed to the next step, which is the Life Cycle Impact Assessment (LCIA). So, in LCIA, we carry out the assessment following some of these methodologies that are available, such as the ISO methodology or the RECIPE methodology, whichever is applicable. Once we have the impact data, we then interpret the data by analyzing the impact results, identifying which process is causing more environmental damage. And then, through suitable modifications of that process, we can reduce the environmental impact. That is the utility part.

Now, as you know, when we are doing the life cycle analysis for a coal mining project, the function is that we produce coal, and the functional unit we can take is 1 ton of coal. Normally, coal production is expressed in units of so many million tons per year. So, we can take the functional unit as 1 ton, and with respect to 1 ton of coal production, we will establish what the material input is, what the environmental outputs are, waste outputs, and pollution outputs, by carrying out a life cycle analysis study. So, this is as per ISO 14040: the phases of life cycle analysis are goal and scope definition, inventory analysis, impact assessment, and interpretation. We already know this; we have discussed it in the previous class.

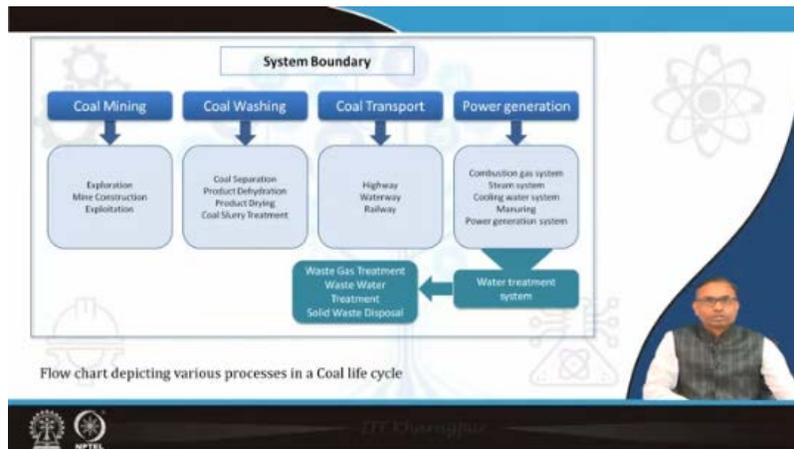


For this particular case study, the LCA for coal mining, as discussed in the paper, the LCA model consists of five steps. The first step is the identification of the unit process and system boundary for different processes, different unit processes of coal mining. Then the scope, i.e., cradle to grave, cradle to gate, or gate to gate, as we have discussed in the previous class, since mining is not the entire life cycle of the product. Mining is only a part of the entire lifecycle. So, when you do the lifecycle analysis for mining, it is normally gate-to-gate. You can expand it to gate-to-grave. Or from cradle to grave, provided you have all the information, because once the coal is produced, it leaves the boundary of the mine. So, probably, if the user company is some other company, you don't have more information about where the coal is going, how it is being processed, and in each process, what the inputs and outputs are; that information may not be available to the coal mining company.

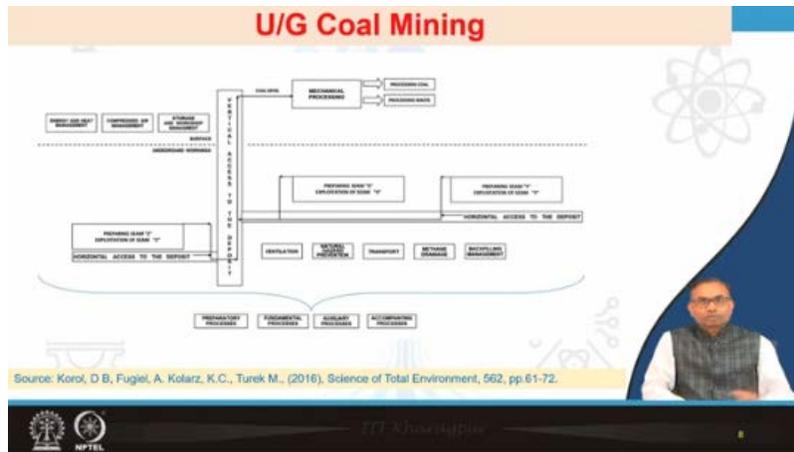


If it is an integrated company that produces coal and then power generation takes place, then probably it can be done; otherwise, for mining projects, mostly the gate-to-gate approach is taken. The second step is to estimate the input-output elements for each

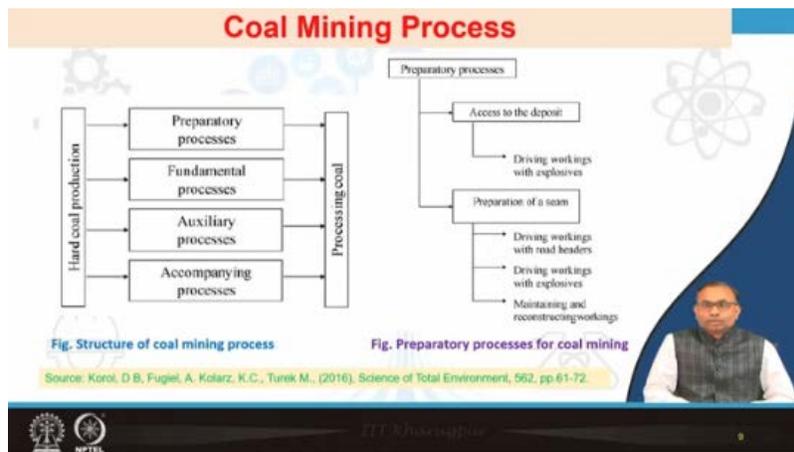
system. The third step is life cycle impact analysis for each unit process using the IPCC method. Nowadays, software like OpenLCA is also available, which incorporates the IPCC 2021 AR6 report, and this is open-source software, freely downloadable. So, anyone can use it. Using this software or otherwise, we can identify and estimate the Life Cycle Impact Assessment (LCIA), and then identify the critical steps where maximum impact is taking place. We identify the critical processes, and then, the fifth step or last step is to take remedial action to modify those critical processes so that our environmental impact is minimized, or you take your decision depending on the impact result that you have gotten from the study.



So, for coal mining, you can see this is the unit process roughly; it is not a comprehensive process, you can break it into small groups as well. But, we can say coal mining, coal washing, coal transport, then it goes to power generation, and then in the power plant, it generates solid waste, liquid waste, and gaseous waste. And this waste material is collected; it is treated or disposed of. So, this is the full diagram depicting the life cycle of coal from mining to the power plant and beyond. So, in the case study in the paper, this is the reference of the paper, which is Koral, Fugiel, and Turek 2016 Science of Total Environment. This is the paper where they are talking about underground mining. In underground mining, there are some processes that take place on the surface, and there are some processes that take place underground.



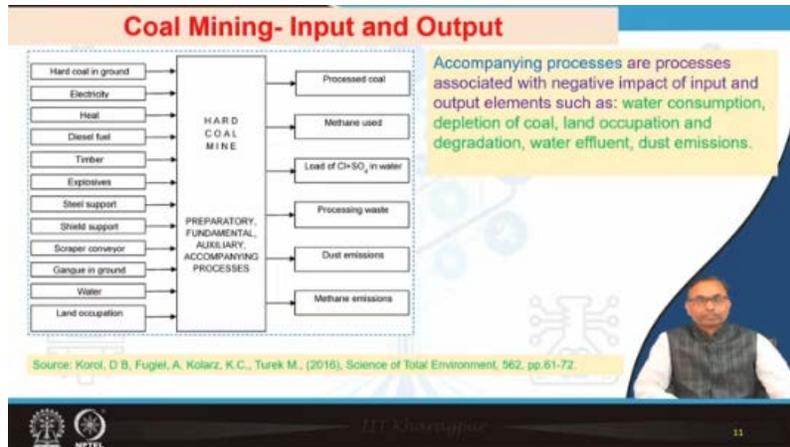
So, the authors have classified the coal mining into four processes. One is the preparatory process, preparation for the mining, the fundamental process. Those are the very essential mining processes, underground mining processes. Then you have the auxiliary processes, and the fourth is the accompanying process. So, this is the structure of the coal mining as per the authors, and when we say preparatory process, it is basically how you are going to access the deposit, either by digging a shaft or by driving an incline. So, driving an incline, or driving a shaft. That is the preparatory process, and that is the access. The second part is the preparation of the seam. So, driving of workings in the seam, driving of galleries, then driving of workings with explosives, maintaining and reconstructing these galleries, and working. These are the preparatory processes of coal mining.



Then, the fundamental process: once you access the deposit by sinking a shaft, you drive the galleries. Then what do you have to do? You extract the coal from the coal seam either by a long wall method or a bord and pillar method. In the paper, they have used a long wall method and are using explosives, machinery, electricity, support, etc. There are so many requirements, so many input materials that you are using. Once you are

extracting the coal, producing the coal, that coal has to be collected and transported. They have to be transported to the surface. And once the coal is transported, you will be storing the coal in a siding in a heap. So that is the processing part, the mechanical processing part, and these are fundamental processes in coal mining. That is underground coal mining. The main processes of coal mining are drilling, blasting, and transporting. These are the fundamental processes, and around the mine, you require so many other processes that are known as auxiliary processes.

For example, ventilation, transport, energy and heat management, maintaining a suitable working environment, providing compressed air, methane drainage from the coal mining, backfill management, filling and stowing, storage, and workshop management. These are the auxiliary processes that help in the mining, and lastly, you have the accompanying process. These are processes associated with the negative impact of the input and output elements. For example, when you do the mining, you are consuming some water. The coal resource itself is getting depleted. You are occupying the land which otherwise could be used for some other purpose. You are occupying the land by creating an overburdened dump. That land has been blocked for a long time, water effluent is coming, and dust emission is taking place. These are accompanying processes.



Mostly, these are the environmental outputs. So, we had all these four processes: the preparatory process, the fundamental process, the auxiliary process, and the accompanying process. Now, you look at this diagram, which provides, or which you can see diagrammatically, what the inputs are and what the outputs are for carrying out these four processes. You can see the inputs on the left side: electricity, heat, diesel, timber, explosives, steel support, shield support, scrapper conveyor, gangue material on the ground, water, and land. These are required for mining and the production of coal. What

is the output in each of these processes? So, the output is coal, processed coal. The output is methane that is coming out. The output is effluent water with a higher concentration of chlorine and sulphate. The output is processing waste, which includes overburden waste material, dust emission, and methane emission. So, these are the input and the output for the coal mining. Now, we have classified the coal mine process into four types of processes.

LCI of Coal Mining – Preparatory Process

Partial processes	Unit processes	Input/output	Unit	Amount
Access to the deposit	Driving workings with explosives	Electricity	kWh	0.0400
		Explosives	kg	0.0088
		Steel support	kg	0.6370
Preparation of a seam	Driving workings with road header	Gangue	Mg	0.0087
		Electricity	kWh	0.8660
		Explosives	kg	0.0013
	Driving workings with explosives	Steel support	kg	1.7537
		Gangue	Mg	0.0941
Maintenance and reconstruction of workings	Driving workings with explosives	Electricity	kWh	0.0621
		Explosives	kg	0.0072
	Maintenance and reconstruction of workings	Steel support	kg	0.0988
		Gangue	Mg	0.0112
		Electricity	kWh	0.0105
		Explosives	kg	0.0010
		Steel support	kg	0.1318
		Gangue	Mg	0.0350

Functional Unit: 1 ton of coal

So, now we have to go back to each process and see what the input is, what the output is, how much the input is, and how much the output is, and then we have to reduce the input and output per ton of coal produced. So, here the functional unit is one ton of coal. So, for one ton of coal production in the preparatory process, how much input is required, and how much output is required? So, you look at this table. For example, driving working with explosives, how much electricity is required per ton, explosives required per ton, steel support required per ton, and filling material that is required per ton. So, like that for each Preparatory process also. Preparatory processes are subdivided into four different processes. And for these sub-processes, how much electricity is required, how much explosive is required, how much steel support is required, and how much waste material is required? That is quantified. So that is the life cycle inventory we are calculating for each process and each sub-process. Similarly, this is for a fundamental process. They have five sub-processes.

LCI of Coal Mining - Fundamental process

Partial processes	Unit processes	Input/output	Unit	Amount	
Seam exploitation	Longwall reinforcing	Electricity	kWh	0.1519	
		Explosives	kg	0.0001	
		Shield support	kg	5.6403	
		Scraper conveyor	kg	0.8208	
		Exploitation	Electricity	kWh	4.7619
		Explosives	kg	0.0036	
		Timber	m ³	0.0010	
		Gangue	Mg	0.2487	
		Decommissioning longwalls	Electricity	kWh	0.1328
		Explosives	kg	4.98E-05	
Mechanical processing	Hard coal processing	Gangue	Mg	0.0007	
		Electricity	kWh	9.2348	
		Processed coal	Mg	1.0000	
		Processing waste	Mg	0.5256	
	Heaping coal and waste	Electricity	kWh	0.5317	

Functional Unit: 1 ton of coal




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Long wall reinforcing, exploitation of coal, decommissioning of long wall, processing of the coal in the processing plant, and then the storage of coal and overburden. So, again here, also input electricity, explosives, shield support, scrapper, conveyor, like that, we are calculating that per ton of coal, how much of these inputs we are requiring, and how much output also per ton of coal it is coming out. So, we are calculating for the fundamental process. Similarly, for auxiliary processes such as ventilation, how much electricity is required, how much methane is generated, that is the output, how much methane emission is taking place, how much heat is energy is required for heating. How much energy is required for compressed air, how much energy is required to drain methane drainage, how much energy is required for backfill, and how much energy is required for the workshop? So, all these things for each process, each sub-process. How much input is required? How much output is produced? If you are using electricity, how much electricity do you use? If you are using water, how much water used? If you are using chemicals, how much chemical is used?

LCI of Coal Mining - Auxiliary Process

Partial processes	Unit processes	Input/output	Unit	Amount
Ventilation	Ventilating workings	Electricity	kWh	6.1913
		Methane emissions	kg	4.299
Natural hazard prevention	Methane hazard	Methane emissions	kg	0.0235
Transport	ROM haulage and hoisting	Electricity	kWh	8.1869
		Electricity	kWh	0.1789
		Diesel fuel	m ³	1.64E-04
Energy and heat management	Processing and generating electricity and heat	Heat	GJ	0.0698
		Electricity	kWh	11.5867
Compressed air management	Producing and supplying compressed air	Electricity	kWh	1.0101
Methane drainage	Methane drainage of deposit	Electricity	kWh	0.1626
		Methane used	kg	0.495
Backfill management	Hydraulic backfill	Electricity	kWh	0.0180
Storage and workshop management	Repairs, overhauls, storing machines, equipment and materials	Electricity	kWh	0.4104

Functional Unit: 1 ton of coal




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Sometimes this water can be an output also. So, in some process, how much water are you producing? That would be an output. How much methane are you producing? Sometimes, methane is an input, and sometimes, methane is an output. Output in a methane drainage: methane is an output. Sometimes, the waste material that we are producing is output, and sometimes the waste material we are using for backfilling becomes an input. So, for each process and subprocess, you have to identify what the input is and how much input is required per ton of coal. What is the output, and how much output is coming out per ton of coal? Lastly, for the accompanying process, particularly water is produced, and effluent water is produced. Coals are coming out from the processing plant, the coal washery. Then, waste material comes in the form of overburden material, or it comes in the form of coal washery rejects. That is the gangue; they have used the term gangue. In the European mines, they use the term gangue.

LCI of Coal Mining – Accompanying Process

Accompanying processes	Unit	Amount
Water	m ³	0.1961
Load of Cl + SO ₂ in water	kg	0.6425
Hard coal in ground	Mg	1.0000
Gangue in ground	Mg	0.3984
Dust emissions	kg	0.0061
Land occupation	ha	1.1E-05

Functional Unit: 1 ton of coal

Dust emission, land occupation, that is also an output, and sometimes it is an input. How much land are we using, and how much land are you utilizing? So, it is also an input, because land will be required for: where you will be placing your overburden dump. Land will be required, where you will be placing your washery reject. So, these are the lands that are degraded, which is also input. Now, once you have done the inventory, for each process you have calculated how much input per ton of coal, and how much output per ton of coal, that is called the life cycle inventory for each process, sub-process. Then you can do an aggregation of that. What is the total input required? What is the total output required? Then you can do that for each process; what is the total input required? What is the total output coming out for each process? Now, the next step is the life cycle impact assessment (LCIA). Now, for this impact assessment, there are two things: one is the impact indicator as per the ISO; they have specified so many impact categories.

Life Cycle Assessment Methods

There are two types of impact indicators.

Midpoint indicator (problem oriented)

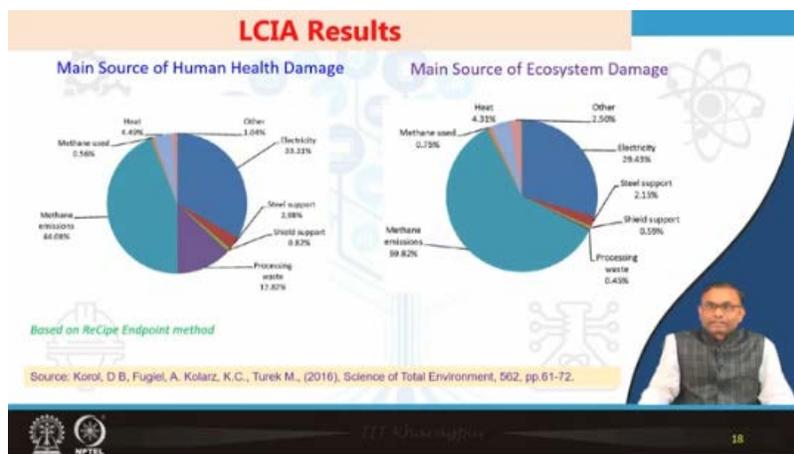
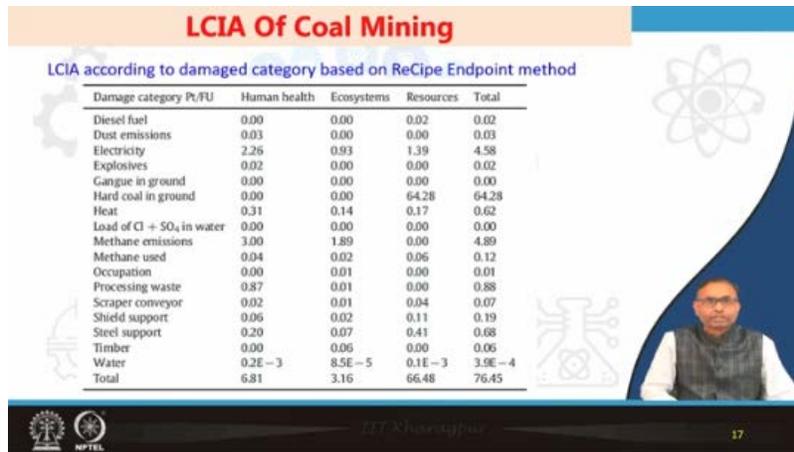
- HH (Human Health)
- CC (Climate Change)
- Eutrophication
- Acidification Potential
- Resources Depletion
- Ecotoxicity

End-point indicator (damage oriented)

- Climate change
- Human health
- Ecosystems
- Resources.

For example, you have human health, climate change, eutrophication, acidification, potential resource depletion, ecotoxicity, and desertification. Some are mentioned in this slide. Some are there, some more impact categories are also present. Now, we have to do the impact prediction on these impact categories. As per the ISO, they have classified two types of impact assessment. One is the problem-oriented, that is, what kind of problem? Secondly, that is, the ultimate damage that is taking place. They call it end-point impact, and the other is the middle point. Midpoint impact, as I have told you, the second category is the damage category. The end point is finally what impact is happening? For example, climate change, human health, the ecosystem, and the health of the ecosystem, then damage to resources. So, these are the end-point damage types of impact damage on climate change, damage to human health, damage to ecosystems, and damage to the resources.

There are different types of methods available in the LCA literature, so the RECIPE method is one. Using these methods, we can calculate what is the damage. For example, for this particular case study. They have taken the endpoint damage category, and the categories are damage to human health, damage to the ecosystem, and damage to the resources, and then they have added them together, which is the total damage. So, life cycle impact analysis calculates the total damage. So, input-wise, what is the total damage that is taking place? So you can see how the damage category, and the different types of input starting from diesel fuel, dust emission, electricity, explosive gas, or waste material coal, which is stored in the ground, heat, effluent, methane emission, and then water. So, all these things, what is the total damage that is taking place? So, this is presented in the table. All this impact data, which they have calculated using the endpoint method.



So, what are the causes? And which causes are creating the highest damage? You can see the main source of human health damage. For each category, they have calculated the contribution. You can see that methane emissions in coal mines are causing the highest damage, contributing to 44 percent of the human health damage. Similarly, the next is the electricity used in the mine for different mining processes, which is responsible for 33 percent of human health damage. So, methane emissions and the electricity used in the mine together contribute to around 77% of the human health damage. The rest contribute to only 23%. Here, if I want to reduce the environmental impact or take remedial measures to reduce the impact caused by coal mines, I must focus on these two activities or processes.

What are they? Methane emissions—how can we reduce them from underground coal mines? If I take measures like methane drainage or degasification, the impact will be significantly reduced. The second main cause is electricity use. If I can use less electricity or reduce consumption, the impact on human health damage will be significantly reduced. This is how we interpret our life cycle impact analysis data. Similarly, I will

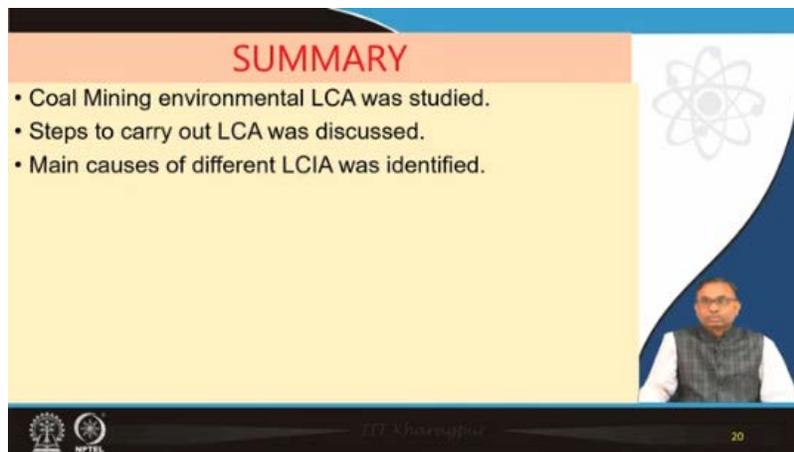
show the second diagram on the right side, which highlights the main source of ecosystem damage. Here again, methane emissions contribute to roughly 56 percent of ecosystem damage. Climate change and global warming are now major threats to ecosystems, largely due to greenhouse gases. Climate change is driven by greenhouse gases, and methane is a major one. In underground coal mining, significant methane emissions occur, contributing to 60% of ecosystem damage.

Secondly, the next important process is electricity use, contributing roughly 29 percent. If you reduce electricity consumption, ecosystem damage will decrease. By taking measures to reduce methane emissions and electricity use, our impact on ecosystem damage will be significantly reduced. Using life cycle impact analysis, we can identify which processes contribute most to environmental damage. Our focus should be on mitigation measures to minimize damage from these critical processes. Interpretation: Electricity use and methane emissions are the two main causes of human health and ecosystem damage. Efforts should focus on reducing methane emissions and electricity use in underground coal mines. This brings us to the end of this class. We have demonstrated how life cycle analysis, discussed earlier, was applied to underground coal mining.

INTERPRETATION

- Electricity, methane emissions, are 2 main causes contributing to human health and eco-system damage.
- Efforts should be directed to how to reduce methane emission and electricity use in mining.

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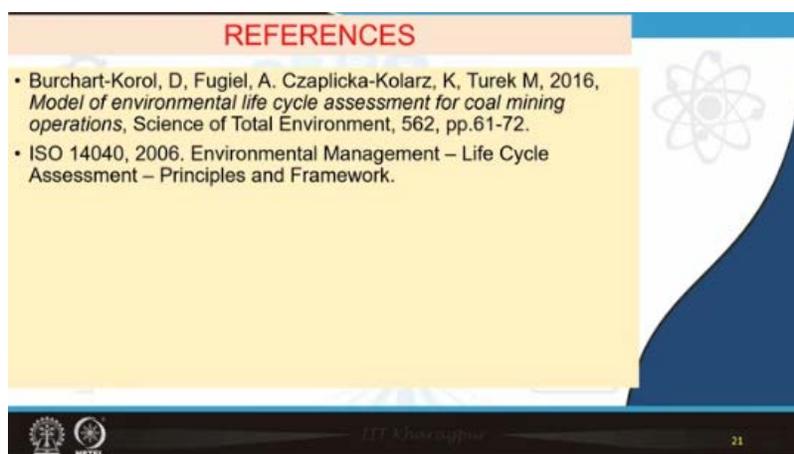


SUMMARY

- Coal Mining environmental LCA was studied.
- Steps to carry out LCA was discussed.
- Main causes of different LCIA was identified.

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What are the different steps that were part of the life cycle analysis for the coal mine? We calculated the life cycle inventory, and from the life cycle inventory, life cycle impact analysis was done using the suggested methods. Once that was done, we identified major processes. Critical processes that contribute to the environmental impact categories. Here, we have two cases: human health damage and ecosystem damage. So, we identified the processes that are contributing to the environmental impact assessment. Once we have identified the causes, then we can suggest remedial measures, mitigation measures in those processes, so that the overall environmental impact assessment for the mining can be minimized. So, these are the references that we have taken. Particularly, the first reference is a very recent paper that presented the life cycle assessment study for coal mining, and we reviewed that paper to demonstrate how the life cycle assessment study can be used for a coal mining project. So, with the last class and this class, the life cycle analysis study chapter is over. And in the next class, we will discuss a new topic. Thank you very much!



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