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# Spreadsheet tool for Life Cycle Assessment (LCA)

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20-10-2020

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# Overview

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- Introduction
- Development of Spreadsheet tool
- Sample: Case Study

# Introduction – Definition and methodologies

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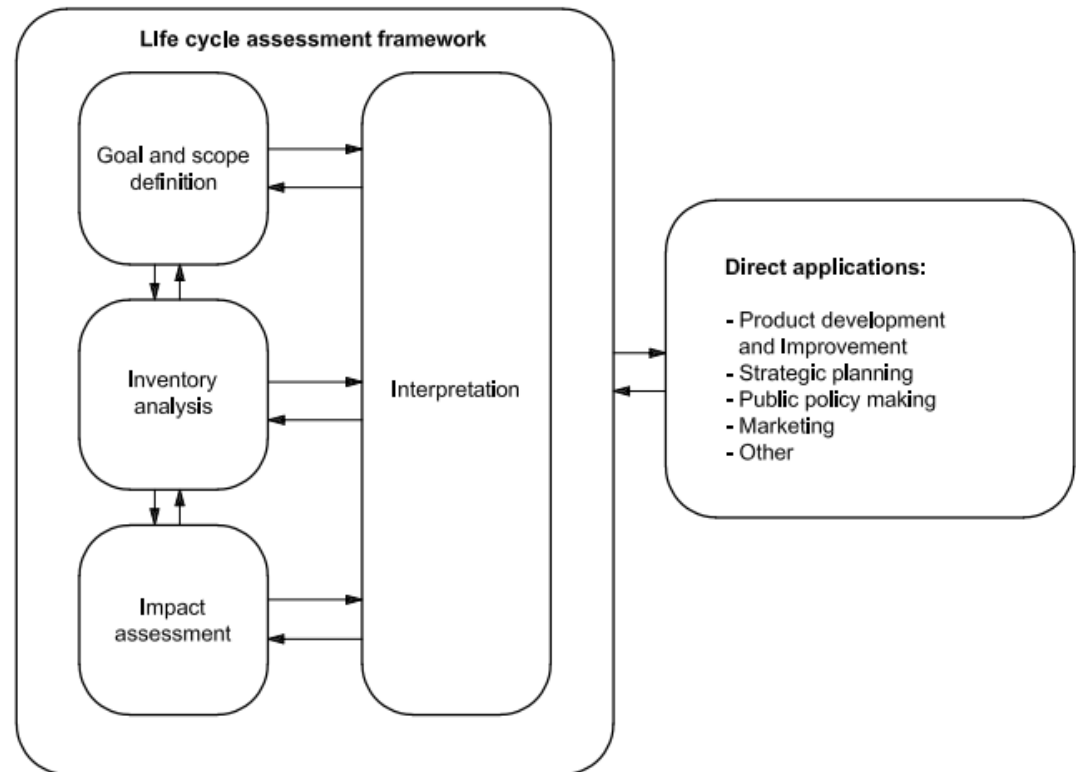
- Life Cycle Assessment (LCA) definition
  - ISO 14040 – “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”
- LCA Methodologies
  - International Life Cycle Database (ILCD)
  - UNEP report – Life Cycle Assessment – What it is and how to do it
  - ISO 14040 series
  - Guidelines for Special application: Greenhouse gas protocol, PAS 2050 and ISO 14067

- Life Cycle Assessment

- LCA is a widely used sustainability assessment concept

- It basically has 4 stages

- Goal and scope
- Life Cycle Inventory (LCI)
- Life Cycle Impact Assessment (LCIA)
- Interpretation



# Goal and Scope

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- Goal
  - Objective:
  - Application:
  - Intended Audience:
  - Public disclosure:
- Scope
  - Product system :
  - Function:
  - Functional unit:
  - System boundary :
    - Criteria, List of unit processes, data associated with unit processes, deleted processes
  - Data requirement :

# Goal and Scope (*Continued*)

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- Scope (Continued)
  - Data quality :
    - Time period, technological coverage, geographical coverage, precision, completeness, consistency, reproducibility, source of data and uncertainty.
  - Allocation method :
  - LCIA methodology :
  - Interpretation : Identify significant issue, different analysis, and summary (Conclusions, limitations and recommendations)
  - Assumptions
  - Limitations
  - Type of reporting
  - Critical review

# Life Cycle Inventory (LCI)



- Planning of data collection -
  - Case study, Database and Govt. reports
- Data collection, formatting and compilation
  - Completion of data collection. Formatting and compiling the data from multiple source (interview, internal monitoring files hard copy reports, soft copy reports, photo, and samples) to a single source
- Data validation
  - Data is valid with requirement in goal and scope, matching with literature, follow mass and energy balance and so on
- Data analysis
  - Normalizing validated data to functional unit
- Data aggregation
  - Consolidating results based on data type, incase of confidentiality
- Redefining system boundary
  - Opportunity to alter system boundary based on study

- Defining LCIA methodology
- Classification
  - The selection of required input/output value for characterization based on its contribution towards and environmental issue.
- Characterization
  - The identification of suitable characterization factors for the inputs/outputs selected. By suitable it is meant the factor which converts the input/output to impact indicator
  - Characterization



- Identification of the significant issue
  - Structuring result
  - Analysis – contribution, anomaly, uncertainty, sensitivity, dominance and influence.
- Evaluation
  - Consistency check and completeness check
- Summary
  - Conclusions – From analysis
  - Limitations – Completeness check, and consistency check
  - Recommendation – application, recommendation based on conclusion and measures to overcome limitations

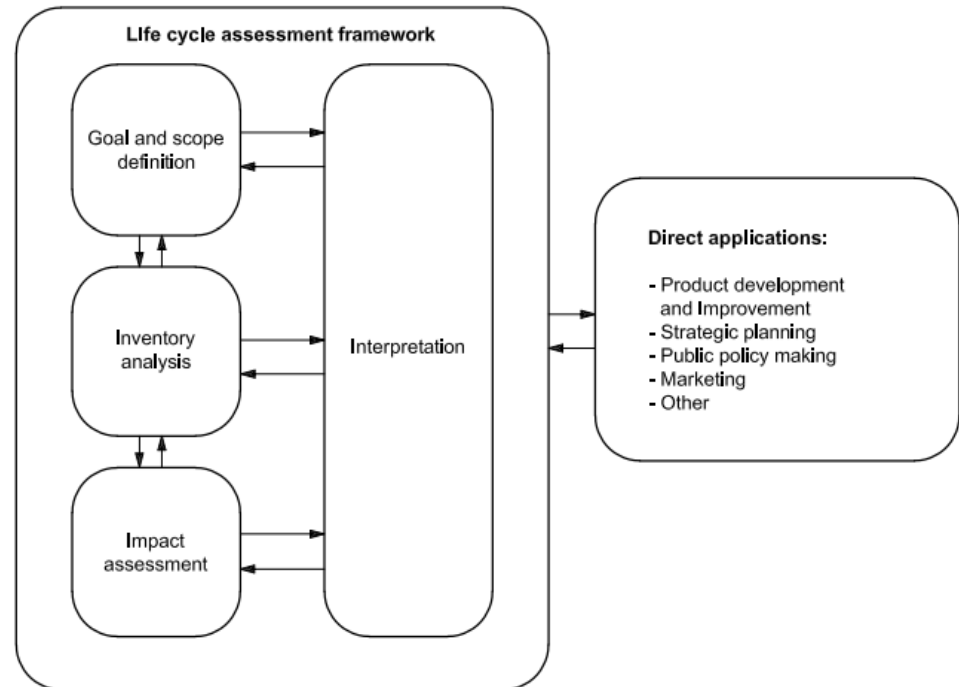
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# Developing spreadsheet tool

# LCA framework (ISO 14040/44)



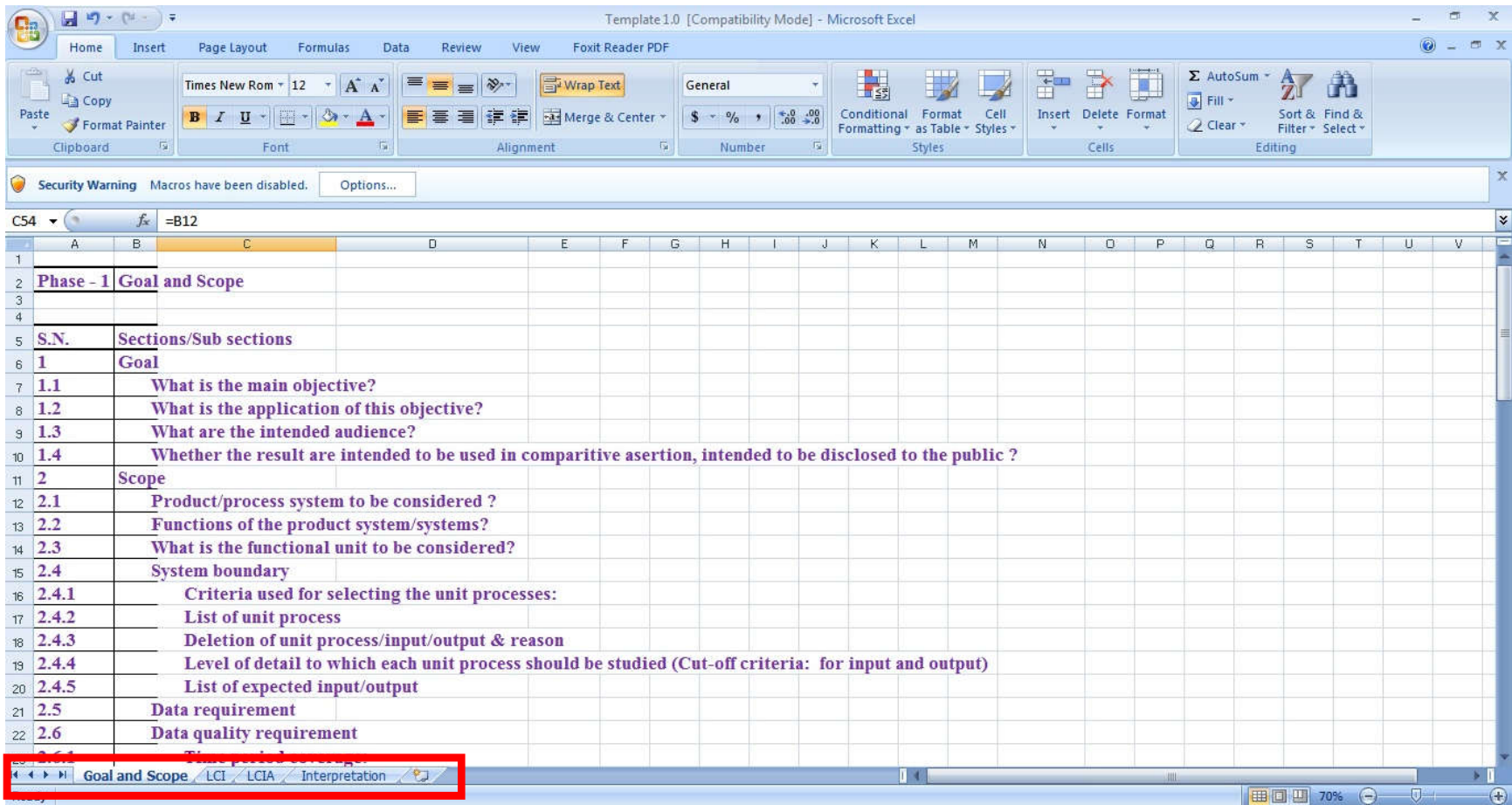
- Life Cycle Assessment
  - It basically has 4 stages
    - Goal and scope
    - Life Cycle Inventory
    - Life Cycle Impact Assessment
    - Interpretation



# LCA framework (ISO 14040/44)



- Screenshot of LCA spread sheet template



# Goal and Scope (*Continued*)

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- Goal
  - Objective:
  - Application:
  - Intended Audience:
  - Public disclosure:
- Scope
  - Product system :
  - Function:
  - Functional unit:
  - System boundary :
    - Criteria, List of unit processes, data associated with unit processes, deleted processes
  - Data requirement :

# Goal and Scope (*Continued*)

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- Scope (Continued)
  - Data quality :
    - Time period, technological coverage, geographical coverage, precision, completeness, consistency, reproducibility, source of data and uncertainty.
  - Allocation method :
  - LCIA methodology :
  - Interpretation : Identify significant issue, different analysis, and summary (Conclusions, limitations and recommendations)
  - Assumptions
  - Limitations

# Goal and Scope



## • Goal and scope - Index

Template 1.0 - for screen shot [Compatibility Mode] - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K
2	<b>Phase - 1</b>	<b>Goal and Scope</b>									
3											
4	<b>S.N.</b>	<b>Sections/Sub sections</b>									
5	<b>1</b>	<b>Goal</b>									
6	<b>1.1</b>	<b>What is the main objective?</b>									
7	<b>1.2</b>	<b>What is the application of this objective?</b>									
8	<b>1.3</b>	<b>What are the intended audience?</b>									
9	<b>1.4</b>	<b>Whether the result are intended to be used in comparative asertion, intended to be disclosed to the public ?</b>									
10	<b>2</b>	<b>Scope</b>									
11	<b>2.1</b>	<b>Product/process system to be considered ?</b>									
12	<b>2.2</b>	<b>Functions of the product system/systems?</b>									
13	<b>2.3</b>	<b>What is the functional unit to be considered?</b>									
14	<b>2.4</b>	<b>System boundary</b>									
15	<b>2.4.1</b>	<b>Criteria used for selecting the unit processes:</b>									
16	<b>2.4.2</b>	<b>List of unit process</b>									
17	<b>2.4.3</b>	<b>Deletion of unit process/input/output &amp; reason</b>									
18	<b>2.4.4</b>	<b>Level of detail to which each unit process should be studied (Cut-off criteria: for input and output)</b>									
19	<b>2.4.5</b>	<b>List of expected input/output</b>									
20	<b>2.5</b>	<b>Data requirement</b>									
21	<b>2.6</b>	<b>Data quality requirement</b>									
22	<b>2.6.1</b>	<b>Time period coverage:</b>									

Goal and Scope LCI LCIA Interpretation

Ready

# Goal and Scope



- Goal and scope - Index

Template 1.0 - for screen shot: [Compatibility Mode] - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K
21	2.6	Data quality requirement									
22	2.6.1	Time period coverage:									
23	2.6.2	Geographical representation:									
24	2.6.3	Technological coverage:									
25	2.6.4	Precision:									
26	2.6.5	Completeness:									
27	2.6.6	Consistency:									
28	2.6.7	Reproducibility:									
29	2.6.8	Sources of data:									
30	2.6.9	Uncertainty of the information:									
31	2.7	Allocation procedure									
32	2.8	Impact category, impact category indicator and characterisation factors/model.									
33	2.9	Value choices and optional elements									
34	2.10	Interpretation to be used?									
35	2.11	Limitations									
36	2.12	Assumptions									
37	2.13	Type of reporting?									
38	2.14	Critical review?									
39											
40											
41											

Goal and Scope LCI LCIA Interpretation



# Goal and Scope

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- Goal
  - Objective:
  - Application:
  - Intended Audience:
  - Public disclosure:

# Goal and Scope (Continued)



- Sections in goal

Microsoft Excel window showing a template for Goal and Scope analysis. The ribbon includes Home, Insert, Page Layout, Formulas, Data, Review, View, and Foxit Reader PDF. The Security Warning states: "Macros have been disabled. Options..."

The spreadsheet content is as follows:

SN	Elements	Description	Remark (description of question in detail, generic comment or answers, example)
1.1	What is the main objective?		Generally the main objective of the LCA is to find the product or process which has least effect on environment and human health or to guide the develop
1.2	What is the application of this objective?		The practical application of the objective should be described here, generally development of inventory database, to understand the impact of a product
1.3	What are the intended audience?		Academicians, industrialists, public policy maker, Intergovernmental Organisation (environmentalists E.g. WHO), Non-governmental Organisations etc, a
1.4	Whether the result are intended to be used in comparative asertion, intended to be disclosed to the public ?		If yes, more clarity and transparency should be provided to the LCA (Example: Proper definition of the data quality requirement). And in the interpretation

The spreadsheet also includes sections for "Critical review?" and "Goal", and a "Scope" section. The bottom status bar shows "Saving AutoRecover info: 80%".

# Goal and Scope (*Continued*)



- Scope
  - Product system :
  - Function:
  - Functional unit:
  - System boundary :
    - Criteria, List of unit processes, data associated with unit processes, deleted processes
  - Data requirement :
  - Data quality :
    - Time period, technological coverage, geographical coverage, precision, completeness, consistency, reproducibility, source of data and uncertainty.
  - Allocation method :
  - LCIA methodology :
  - Interpretation : Identify significant issue, different analysis, and summary (Conclusions, limitations and recommendations)
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  - Limitations
  - Type of reporting
  - Critical reviews

# Goal and Scope (Continued)



- Sections of scope

(17-04-29) Template 1.0 [Compatibility Mode] - Microsoft Excel

Functional unit : Quantified performance of a product system for use as an reference unit. The functional unit should be a measurable quantity which serves the purpose of process. E.g. (1) 1 tonne of clinker is considered as the functional unit for clinker production. (2) 1 truck lorry of sand, because the sand is practically available on truck unit.

S.N.	Elements	Description	Remarks
2.1	Product/process system to be considered ?		Process System : A collection of unit process with elementary and product flow, performing one or more defined functions ,and which models the life
2.2	Functions of the product system/systems?		It is a statement of performance characteristics, or in simple words it is the process performed by the process system. It is usually required if two or mo
2.3	What is the functional unit to be considered?		Functional unit : Quantified performance of a product system for use as an reference unit. The functional unit should be a measurable quantity which
2.4	System boundary		
2.4.1	Criteria used for selecting the unit processes:		Set of criteria which specifies out of all the unit processes, which unit processes are to be considered as a part of a product system for LCA. There are
2.4.2	List of unit process	1) Name of unit process 2) Name of unit process	The processes to be considered according to the system boundary criteria should be provided along with a brief description of the activities undergo
2.4.3	Deletion of unit process/input/output & reason	1) Name of unit process - Reason for o 2) Name of unit process - Reason for omission	This step is to mention processes which should be considered according to system boundary but avoided due to some other reason. Along with the
2.4.4	Level of detail to which each unit process should be studied (Cut-off	Mass limit: Energy limit: Environmental significance:	The input/output should satisfy a cut-off % of the total mass input modelled. Or % cutoff of a reference mass input value (from literature) E.g. The inp The input/output should satisfy a cut-off % of the total energy input or Cut off % of a reference energy value input. E.g. The input should be atleast 1 The input/output should satisfy a minimum additional % of the estimated environmental significance of the product system. E.g. Any output gas with
2.4.5	List of expected input/output	1) Name of unit process - Input : ..... 2) Name of unit process - Input : ..... Output : .....	Here the list of expected inputs and outputs related to each unit processes should be provided. Every unit process considered according to the system
2.5	Data requirement	1) Name of unit process - Input : ..... 2) Name of unit process - Input : ..... Output : .....	Here the list of inventory required for the study should be reported process wise. This is to ensure that atleast these inventory will be collected, which

Goal and Scope LCI LCIA Interpretation

# Life Cycle Inventory (LCI)

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- Planning of data collection
- Data collection, formatting and compilation
- Data validation
- Data Analysis
- Data aggregation
- Redefining system boundary

# Life Cycle Inventory (Continued)



## • LCI index

(17-04-29) Template 1.0 [Compatibility Mode] - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1																			
2	Phase - 2	Life Cycle Inventory (LCI)																	
3																			
4																			
5	S.N.	Sections/Subsections																	
6	1	Preparation of data collection																	
7	1.1	Preparation of rough process flow chart																	
8	1.2	Fixing modes of data collection																	
9	2	Data collection, formatting and compilation																	
10	2.1	Data collection																	
11	2.2	Data formatting and compilation																	
12	2.2.1	LCI compilation (Input/output wise) - Data in terms of absolute value																	
13	2.2.2	LCI compilation (Input/output wise) - Data with respect to reference flow																	
14	2.2.3	LCI compilation (Input/output wise) - Miscellaneous data																	
15	3	Data validation																	
16	3.1	LCI data (validation)																	
17	3.2	LCI data (validated result)																	
18	4	LCI analysis																	
19	4.1	LCI analysis - Using data in terms of absolute values																	
20	4.2	LCI analysis - Using data with respect to reference flow																	
21	4.2.1	Calculation using reference flow																	
22	4.2.2	Results of LCI analysis using reference flow																	
23	4.3	LCI analysis using miscellaneous data																	
24	4.3.1	Miscellaneous data for calculation																	
25	4.3.2	Calculation																	
26	4.3.3	Result																	
27	4.4	LCI analysis result (Input/output wise for clinker)																	
28	4.5	LCI analysis result (Process wise for clinker)																	
29	5	LCI data aggregation																	
30	6	Refining the system boundary																	
31																			
32																			
33																			

Ready



# Life Cycle Inventory (Continued)



## • Sections of LCI

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E37 A process flow chart should be prepared based on the process considered which is already described in the Goal and Scope. The expected input and output should be also mentioned in the process flow chart. It can be made based on the information from any reliable sources such as literature, books, reports, preliminary site visits etc. This process flow chart should give a complete understanding on the data which should be collected in the study. Flow chart also enables the data providers an easy comprehension on data requirement. Or even it will help the LCA practitioner to find the data from literature in an ordered manner. This will smoothen the data collection process. In description column It can be mentioned whether a flow chart is made or not and if made please provide some description or the image can be provided, E.g. The process flow chart is made.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
31														
32														
33														
34	1	Preparation of data collection												
35														
36		S.N.	Sub process	Description of the Sub process	Remark									
37		1.1	Preparation of rough process flow chart		A process flow chart should be prepared based on the process considered which is already described in the Goal and Scope. The expected input and output should be also men									
38		1.2	Fixing modes of data collection		There are numerous ways of data collection based on the data accuracy requirement suitable method can be chosen. Use the process flow chart and the expected input/output									
39														
40	2	Data collection, formatting and compilation												
41														
42		S.N.	Sub process	Description of subprocess	Remark									
43		2.1	Data collection		This step should be started after the completion of data collection with the help of process flow chart and prepared modes of data collection. In description box information on data									
44		2.2	Data formatting and compilation		The data collected using different modes and from different sources will have inconsistent format. These data needed to be compiled and formatted to a uniform manner. Usually t									
45														
46	2.2.1	LCI compilation (Input/output wise) - Data in terms of absolute value												
47														
48		S.N.	Sub process	Description of subprocess	Remark									
49		2.2.1	LCI compilation (Input/output wise) - Data in terms of absolute value		Here the data in the form of absolute value should be reported. By absolute value it is meant that it is the raw and cumulative data which corresponds to the time period defined in th									
50														
51		Template Table												

Goal and Scope LCI LCIA Interpretation

Ready

- Defining LCIA methodology
- Classification
- Characterization



# LCIA (Continued)



## • LCIA Index

Template 1.0 [Compatibility Mode] - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1																								
2	Phase - 3	Life Cycle Impact Assessment (LCIA)																						
3																								
4																								
5	S.N.	Sections/Sub sections																						
6	1	Impact category, impact category indicator, and characterization model/factors used																						
7	1.1	Impact category																						
8	1.2	Impact category indicator																						
9	1.3	Characterization model/factor																						
10	2	LCI result assigning for Classification																						
11	2.1	Classification of LCI result for characterization																						
12	2.2	Reporting of the classified inventory result (input/output categorywise)																						
13	2.2.1	Classified inventory result for characterization (Input/output categorywise)																						
14	2.2.2	Rejected inventory results for characterization (Input/output categorywise)																						
15	2.3	Reporting of the classified inventory result (Processwise)																						
16	2.3.1	Classified inventory result for characterization (Processwise)																						
17	2.3.2	Rejected inventory results for characterization (Processwise)																						
18	3	Characterization																						
19	3.1	Characterization factor																						
20	3.2	Calculation of impact indicator or Characterization																						
21	3.2.1	Characterization calculation (input/output categorywise)																						
22	3.2.1.a	Characterization results (in detail for every data)																						
23	3.2.1.b	Characterization results (aggregated for each input/output category)																						
24	3.2.1.c	Characterization result (final result)																						
25	3.2.2	Characterization calculation (process wise)																						
26	3.2.2.a	Characterization results (in detail for each data of process)																						
27	3.2.2.b	Characterization results (aggregated for each process)																						
28	3.2.2.c	Characterization result (final result)																						
29																								

Ready

# LCIA (Continued)



## • Sections of LCIA

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E507 Here the characterization of the LCI results is carried out. The LCI results reported processwise in the LCI phase should be reported here, but care should be taken in order to incorporate only the classified inventory and to remove the rejected inventory. If processwise LCI results are not available, try to report the classified data results in the unit processes considered in the system boundary of scope phase. This processwise sorted LCI results are then multiplied with the characterization factors. Sum of all the characterised results gives us the impact indicator of the corresponding process system. This way of doing characterization helps to understand the contribution of different processes on characterization. A sample of the information to be provided in the description cell is as follows "The LCI results are multiplied with suitable characterization factors. The calculation is carried out process wise. The classified LCI results are reported processwise and multiplied with the suitable characterization factors. This enables us to understand the process wise contribution toward the impact category considered".

3.2.2 Characterization calculation (process wise)

S.N.	Process/Sub process	Description of process	Remark
3.2.2	Characterization calculation (process wise)	Here the characterization of the LCI results is carried out. The LCI results reported processwise in the LCI phase should be reported here, but care should be taken in order to incorporate only the classified inventory and to remove the rejected inventory.	

Template table

Process	Value	Unit	Mathematical operator	Characterization factor	Unit	Characterization result	Unit
<b>Inputs</b>							
Name of classified input belonging to this process	Numerical value of input	unit of input/functional unit	x	Numerical value of the suitable characterization factor	Unit of characterization factor or (unit of impact indicator/unit of input)	=	Numerical value of characterised input Unit of impact indicator/functional unit
<b>Output</b>							
Name of classified output belonging to this process	Numerical value of output	unit of output/functional unit	x	Numerical value of the suitable characterization factor	Unit of characterization factor or (unit of impact indicator/unit of output)	=	Numerical value of characterised output Unit of impact indicator/functional unit
<b>Total</b>							<b>Sum of all characterised values Unit of impact indicator/functional unit</b>

Goal and Scope LCI LCIA Interpretation

Ready 57%

# Interpretation

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- Identification of the significant issue
- Evaluation
- Summary

# Interpretation (Continued)



## • Interpretation Index

Template 1.0 [Compatibility Mode] - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	<b>Phase 4</b>	<b>Interpretation</b>										
3												
4	<b>S.N.</b>	<b>Sections/Sub sections</b>										
5	<b>1</b>	<b>Identification of significant issues</b>										
6	<b>1.1</b>	<b>Structured information</b>										
7	<b>1.2</b>	<b>Analysis</b>										
8	<b>1.2.1</b>	<b>Contribution analysis</b>										
9	<b>1.2.2</b>	<b>Dominance analysis</b>										
10	<b>1.2.3</b>	<b>Influence analysis</b>										
11	<b>1.2.4</b>	<b>Anomaly analysis</b>										
12	<b>1.2.5</b>	<b>Uncertainty analysis</b>										
13	<b>1.2.6</b>	<b>Sensitivity analysis</b>										
14	<b>2</b>	<b>Evaluation</b>										
15	<b>2.1</b>	<b>Completeness check</b>										
16	<b>2.2</b>	<b>Consistency check</b>										
17	<b>3</b>	<b>Conclusion, Limitation and Recommendation</b>										
18												

Ready



# Interpretation (Continued)



## • Sections of Interpretation

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E27 Here the results from the LCI or/and LCIA is been structured. The information will be structured in the form of tables. In the table the columns can be Unit process (basic and most detailed structure), life cycle stages (a set of unit process indicating the life stage of a product or process system E.g. Extraction, production, use phase others etc), group of processes (A set of process of similar kind energy production, transportation, others etc), group of process with similar managerial influence (Categorising the process based on the managerial influence E.g. A- Completely

**1.1 Structured information**

S.N.	Process	Description of	Remark
1.1	Structured information		Here the results from the LCI or/and LCIA is been structured. The information will be structured in the form of tables. In the table the

**Template table for LCI**

A \ B	A1	A2	A3	Total
B1 (Unit)	Value	Value	Value	Sum of values in the row
B2 (Unit)	Value	-	Value	Sum of values in the row
B3 (Unit)	-	Value	Value	Sum of values in the row

The value indicates the numerical LCI result corresponding to the respective row and column. If there is no value corresponding to the cell mark a hyphen.

A = {Unit process, Life cycle stages, Group of similar type process, group of similar managerially influenced processes}

{A1, A2, A3 etc} = {Name of Unit process 1, Name of unit process 2, Name of unit process 3 etc (Example : Extraction of limestone, limestone crushing, raw meal preparation, clinkerisation etc)}, {N

B = {Inputs and Outputs list}, {Input and output category/type} etc

{B1, B2, B3, etc} = {Limestone, Coal, electricity, truck, cement, CO<sub>2</sub>, radiation etc}, {Energy - fuel, Energy - electricity, Raw material, ancillary material, other physical inputs, others, Product, Co-pro

Goal and Scope LCI LCIA Interpretation

Ready

# Interpretation (Continued)



- Sections of Interpretation

Template 1.0 [Compatibility Mode] - Microsoft Excel

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E449 The goal met through the study should be mentioned in a quantitative or qualitative way. The significant issues found in the structured information, and observations of analysis is reported here. From standard structured information and contribution analysis the major and minor contributing LCI or LCIA, data or unit process can be identified. If any ranking system is there based on the contribution, it can be reported from the dominance analysis results. The result can be reported in terms of the managerial influence, from the observations of the Influence analysis. If any new data is observed or if any data value seems to be anomalous those details can be reported from the result of anomaly analysis. If possible provide the sensitivity of different input,output and processes on the LCI and LCIA results. The uncertainty of the LCI and LCIA results can also be reported.

	A	B	C	D	E	F	G	H	I	J	K
434		8	Data Allocation	Consistent	Mass allocation						
435		9	Impact category	Consistent	Mid point impact categories like Energy consumption, CO <sub>2</sub> emission						
436		10	Impact category indicators	Consistent	Energy in MJ, and emission of CO <sub>2</sub> in kgCO <sub>2</sub>						
437		11	Characterisation model	Consistent	Cement plant data, experiment results and database.						
438		12	Value choices	Consistent	No value is defined						
439		13	Assumption	Consistent	All the assumptions defined in the goal and scope is consistently used throughout the study						
440		14	Classification	Consistent	Every data which directly contribute to the impact considered is classified.						
441											
442	3	<b>Conclusion, Limitation and Recommendation</b>									
443											
444		<b>S.N.</b>	<b>Process</b>	<b>Description of</b>	<b>Remark</b>						
445		3	Conclusion, Limitation and Recommendation	In this section the conclusions and limitation observed in the study is been documented. Also recommendation based on these two are							
446											
447		<b>Template table</b>									
448		<b>S.N.</b>	<b>Element</b>	<b>Description</b>	<b>Remark</b>						
449		1	Conclusion	The goal met through the study should be mentioned in a quantitative or qualitative way. The significant issues found in the structured							
450		2	Limitation	As the LCA study progress, the limitation experienced would have been reported in the limitation section of goal and scope phase. H							
451		3	Recommendation	The application of the goal will be mentioned in the goal and scope phase. Start the recommendation with mentioning how to use the							
452											

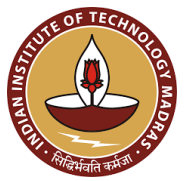
Goal and Scope LCI LCIA Interpretation

Ready 100%

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# Sample Case study :LCA of clinker (an ingredient of cement)

# Goal and Scope



- Goal
  - Objective: The goal of the study is to assess the energy consumption related to the production of clinker
  - Application: It can be used in estimating embodied energy of cements
  - Audience: Academician and industrialist
  - Public disclosure: No



# Goal and Scope (Continued)



- Goal definition – Case study

Template 1.0 - for screen shot [Compatibility Mode] - Microsoft Excel

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	A	B	C	D	E	F	G	H
43	1	<b>Goal</b>						
44								
45		SN	Elements	Description	Remark			
46		1.1	What is the main objective?	To quantify the energy consumption related to production of clinker in an typical integrated cement factory in India	Generally the main objective of the LCA is to f			
47		1.2	What is the application of this objective?	1) To understand the life cycle inventory of clinker production in an typical Indian cement plant. 2) To understand the current energy consumption of clinker production and to compare it with respect to other reported values.	The practical application of the objective shoul			
48		1.3	What are the intended audience?	Academician and industrialist are the intended audience. Academicians can understand the energy related clinker production in detail, which enable them to assess the possibilities for improvement and propose solutions for improvement. Even the hypothetical methods for improvement can be assessed. The industrialist can understand the area of potential improvement from the study (and take managerial decisions, formulate policies etc. to improve the same).	Academicians, industrialists, public policy mak			
49		1.4	Whether the result are intended to be used in comparative asertion, intended to be disclosed to the public ?	No	If yes, more clarity and transparency should be			
50								
51	2	<b>Scope</b>						
52								
53		S.N.	Elements	Description	Remarks			
54		2.1	Product/process system to be considered ?	The processes related to clinker production in an integrated cement plant using dry processing for clinkerization. The plant use 5 stage preheater precalciner unit along with the	Process System : A collection of unit process			
55		2.2	Functions of the product system/systems?	Production of clinker	It is a statement of performance characteristics			
56		2.3	What is the functional unit to be considered?	1 tonne of clinker is considered as the functional unit.	Functional unit : Quantified performance of a p			

Goal and Scope | LCI | LCIA | Interpretation

Ready

# Goal and Scope



- Scope
  - Product system : Clinker production unit with dry processing system
  - Function: Clinker production
  - Functional unit : 1 Ton of clinker
  - System boundary :
    - Criteria : Ground to gate – The processes related to the clinker production from the extraction of inputs, to transportation of clinker to the out gate of cement plant
    - Unit process considered –
      - Raw material extraction – Extraction of raw material (limestone, clay, etc)
      - Fuel extraction - The process includes, extraction of fuel consumed in different processes like, clinkerization, thermal power plant, diesel for transportation etc.
      - Limestone crushing – The crushing of limestone chunks to small size
      - Raw meal preparation – Mixing of the raw meal ingredients in the required proportion, grinding and blending uniformity
      - Fuel preparation – Preparation of fuel for the application of the same in kiln
      - Clinkerization – the process of thermal treatment of the raw meal to produce clinker
      - Others (services etc) – All miscellaneous processes excluded in the previous processes or happening simultaneous in a non-continuous way eg: Diesel consumed for onsite transportation, electricity consumed by factory lighting, colony lighting, transformer losses etc.
      - Transportation – The transportation of raw material and fuel in terms of truck and diesel
- Data requirement : All the inputs and outputs related the processes in Gate to gate

- Scope (*continued*)

- Data requirement : All the inputs and outputs related the processes in Gate to gate
  - Raw material extraction – Explosives, water consumed, fuel consumed for equipment, electricity consumed, lubricant consumed for equipment, equipment consumables, equipment, the limestone extracted, the emissions generated, etc
  - Fuel extraction - Raw material (for fuel production E.g. crude oil, petroleum etc), energy (explosives, diesel for extraction equipments, diesel for transportation equipments, electricity for mines etc), oil for equipments, equipments, infrastructure, fuel, waste, PM, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, etc.
  - Limestone preparation: Limestone consumed, electricity, lubricant for related equipment, limestone produced, noise, emission etc
  - Raw meal preparation: Limestone, clay (etc ingredients of raw meal), Electricity for related equipment, raw meal produced, emissions etc.
  - Fuel preparation: Fuel consumed, Electricity (including embodied energy from the heating value of fuel burned), Lubricants for related equipment, fuel produced, emissions.
  - Clinkerization: Raw meal consumed, water(for cooler), fuel consumed for thermal treatment, Electricity(related equipment), Consumables for the equipment, Carbonate content in raw meal, clinker produced, emission, etc.
  - Others (Services etc): Electricity for factory lighting, colonies lighting, transformer losses etc.
  - Transportation: Distance, amount of material transported, diesel required by truck, train, transportation in terms of truck, train etc.

# Goal and Scope (Continued)



- Scope (*continued*)
  - Data quality :
    - Time period – 1 year data (2014-2015); Technological coverage: Dry technology – 5 stage preheater precalciner; Geographical coverage: situated in the limestone mines; Completeness: full completeness; Consistency: The calculation should be completely consistent: reproducibility: till regional level; source of data: Cement plant; Uncertainty: No.
  - Allocation method : Single product (No allocation)
  - Embodied energy methodology : Direct energy and embodied energy is calculated using suitable factor
  - Interpretation :
    - Identify significant issue – Structured result, Contribution analysis
    - Evaluation - Completeness check and consistency check
    - Summary: Conclusions, limitations and recommendations
  - Limitation
    - The plant is not a clinker production unit but an integrated cement plant unit, of which process till clinkerization is been studied to simulate clinker production unit
  - Assumption
    - The electricity is assumed to be produced completely in plant
    - The fuels are assumed to be bought from locality with a distance of 5 km between the fuel source/fuel supply source and cement plant

# Goal and Scope (Continued)



## • Sections of scope – Case study

Template 1.0 - for screen shot [Compatibility Mode] - Microsoft Excel

The processes related to clinker production in an integrated cement plant using dry processing for clinkerization. The plant use 5 stage preheater precalciner unit along with the rotary kiln.				
	A	B	C	D
51	2	Scope		
52		S.N.	Elements	Description
53				Remarks
54		2.1	Product/process system to be considered ?	The processes related to clinker production in an integrated cement plant using dry processing for clinkerization. The plant use 5 stage preheater precalciner unit along with the rotary kiln.
55		2.2	Functions of the product system/systems?	Production of clinker
56		2.3	What is the functional unit to be considered?	1 tonne of clinker is considered as the functional unit.
57		2.4	System boundary	
58		2.4.1	Criteria used for selecting the unit processes:	All processes starting from extraction of raw material and fuel, till and including production of clinker is considered in the study. This condition for selecting unit processes is called Ground to gate.
59		2.4.2	List of unit process	1) Raw material extraction - Extraction of raw materials (limestone, clay etc)
60				2) Fuel extraction - The process includes, extraction of fuel consumed in different processes like, clinkerization, thermal power plant, diesel f
61				3) Limestone Crushing - The crushing of limestone chunks to small size
62				4) Raw meal preparation - Mixing of the raw meal ingredients in the required proportion, grinding and blending uniformly
63				5) Fuel preparation - Preparation of fuel for application in kiln activities.
64				6) Clinkerization - The process of thermal treatment of the raw meal to produce clinker
65				7) Others (services etc) - All miscellaneous processes excluded in the previous processes or happening simultaneous in a non-continuous way
66				8) Fuel extraction or production - Extraction or preparation of fuels consumed for different processes in the production of clinker
67				9) Transportation - The transportation of raw material and fuel E.g. vehicles consumed in tkm.
68		2.4.3	Deletion of unit process/input/output & reason	Electricity production (including heating value of fuels) - The production of electricity using inventories like fuel, electricity consumed, water, infrastructure, electric wires and emissions etc. Inorder to avoid the confusion, the electricity alone is been considered as input in this study.
69		2.4.4	Level of detail to which each unit process should be studied (	Mass limit: NIL
70				Energy limit: NIL
71				Environmental significance: NIL

Goal and Scope LCI LCIA Interpretation



# Life Cycle Inventory (LCI)



- Planning of data collection

- A process flow chart is developed, with unit processes and data flow
- Data is planned to collect through case study

- Data collection, formatting, and compilation

- 2 visits were conducted to the cement plant,
- The process map developed is modified to a realistic process map based on the interaction with cement plant officials
- Based on the process map and interaction with the officials, the input and output of materials, energy etc related to the clinker production is been collected.
  - The data was collected in the form of interview, questionnaire, internal monitoring files (soft copy, hard copy, images, etc), public survey sheets, samples, photos etc.
- All the data from different source files is compiled to a uniform format for an easy comparison of value and validate the data

- Data validation

- Check whether data qualities are met
- Check values with literature

# Life Cycle Inventory (LCI)



- Data validation (*continued*)
  - Eliminate suspicious data, bad quality data etc
  - If data redundancy is present choose the value, which is similar to those reported in literature or, from the source which is more reliable
  - Energy mass balancing.
  - Conversion of unit to unique value for similar data type.
- LCI analysis
  - Depending on the data (absolute values, reference values, estimated values, assumed values, and multiple values) available different methods are used for calculation
- LCI data aggregation:
  - Conducted
- Redefining system boundary :
  - Most of the expected data is collected thus no alteration in system boundary

# Life Cycle Inventory (LCI), Continued



- LCI results

Sample - (17-03-16) Clinker - Microsoft Excel

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LCI result (Process wise for clinker)

	A	B	C	D	E
701	4.5 LCI result (Process wise for clinker)				
702					
703		Process	Value	Unit	Remark
704		Raw material extraction			
705		Input			
706		Limestone and marl	1.453	tons/ton of clinker	Formula = The limestone and marl yearly consumption value/yearly clinker produced. TI
707		White clay	0.034	tons/ton of clinker	Formula = The white clay yearly consumption value/yearly clinker produced.The white c
708		Diesel (Limestone extraction and transportation process)	0.002	tons/ton of clinker	Formula = (Diesel consumed for extraction and transportation/ clinker produced) * Dens
709					
710		Output			
711		White clay	0.034	tons/ton of clinker	Formula = The white clay yearly consumption value/yearly clinker produced.The white c
712		Limestone and marl	1.453	tons/ton of clinker	Formula = The limestone and marl yearly consumption value/yearly clinker produced. TI
713					
714		Fuel Extraction			
715		Input			
716		Petcoke (imported)	0.035	tons/ton of clinker	Formula = (Petcoke yearly consumption value/yearly clinker produced). Petcoke consum
717		Petcoke (indigenous)	0.025	tons/ton of clinker	Formula = (Petcoke yearly consumption value/yearly clinker produced). Petcoke consum
718		Coal	0.001	tons/ton of clinker	Formula = The coal yearly consumption value/yearly clinker produced.The coal yearly co
719		Lignite	0.037	tons/ton of clinker	Formula = The lignite yearly consumption value/yearly clinker produced.The lignite year
720		Diesel	0.000	tons/ton of clinker	Formula = The diesel yearly consumption value/yearly clinker produced.The diesel year
721		Diesel (Limestone extraction and transportation process)	0.002	ton/ton of clinker	Formula = (Diesel consumed for extraction and transportation/ clinker produced) * Dens
722		Diesel oil	0.001	ton/ton of clinker	Formula = (Diesel consumption for onsite transportation / clinker production). The yearl
723					

Goal and Scope

LCI

LCIA

Interpretation

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# LCIA - Embodied energy calculation



- The inventory result is converted in to embodied energy (MJ) by multiplying with suitable energy factors. The energy factors are experimentally found and calculated using ecoinvent database and Cumulative Energy Demand (CED).
- The selection of required input/output value for energy calculation.
  - Embodied energy and emission of input/output will be beyond the scope of the study
  - Not all need to be considered as the input/output values will be traces
- Energy calculation
  - The identification of suitable energy factors for the inputs/outputs selected
  - Factors were selected from different sources based on the suitability to the inputs

# LCIA - Embodied energy calculation, (Continued)

- Characterization section (Embodied energy calculation)
  - Case study

Sample - (17-03-16) Clinker - Microsoft Excel

Process and inputs	Input/Output value	Unit	Chemical characterisation	Unit	Characterisation re	Unit
<b>Raw material extraction</b>						
Input						
Limestone and marl	1.453	ton/ton	x	4.8	MJ/ton	= 7.016 MJ/ton
White clay	0.034	ton/ton	x	45.8	MJ/ton	= 1.547 MJ/ton
Diesel (Limestone extraction and transportation process)	0.002	ton/ton	x	42.7	MJ/kg	= 73.512 MJ/ton
					<b>Total</b>	<b>82.074 MJ/ton</b>
<b>Fuel extraction/production</b>						
Input						
Coal	0.001	ton/ton	x	1.29	MJ/kg	= 1.421 MJ/ton
Lignite	0.037	ton/ton	x	0.252	MJ/kg	= 9.220 MJ/ton
Diesel	4.98E-05	ton/ton	x	3.93	MJ/kg	= 0.196 MJ/ton
Diesel (for extraction and transportation of limestone)	0.002	ton/ton	x	3.93	MJ/kg	= 6.770 MJ/ton
Diesel (for onsite transportation)	0.001	ton/ton	x	3.93	MJ/kg	= 3.078 MJ/ton
					<b>Total</b>	<b>20.685 MJ/ton</b>
<b>Limestone Crushing</b>						
Input						
Electricity	1.017	kWh/ton of clinker	x	15.09533	MJ/kWh	= 15.351 MJ/ton
					<b>Total</b>	<b>15.351 MJ/ton</b>
<b>Raw meal preparation</b>						
Input						
Electricity	23.157	kWh/ton of clinker	x	15.10	MJ/kWh	= 349.570 MJ/ton
					<b>Total</b>	<b>349.570 MJ/ton</b>
<b>Fuel preparation</b>						
Input						
Electricity	5.950	kWh/ton of clinker	x	15.10	MJ/kWh	= 89.813 MJ/ton
					<b>Total</b>	<b>89.813 MJ/ton</b>

Goal and Scope / LCI / **LCIA** / Interpretation

- Identification of the significant issue
  - Structuring result
  - Analysis – contribution
- Evaluation
  - Consistency check and completeness check
- Summary
  - Conclusions – From structured results and analysis
  - Limitations – Completeness check, and consistency check
  - Recommendation – application, recommendation based on conclusion and measures to overcome limitations

# Interpretation

- Identification of significant issues
  - Structured result
  - Analysis

Sample - (17-03-16) Clinker - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
24	1.1	<b>Structured information (Energy)</b>												
25		The rows can be either input or input category, whereas the columns can be unit process, process categories, life cycle stages, process grouped based on influence.												
26		<b>Characterisation result</b>												
27		Inventory results input category wise \ Unit processes	Raw material extraction	Fuel extraction/ production	Limestone Crushing	Raw meal preparation	Fuel preparation	Clinkerization	Others (services etc)	Transportation	Total			
28		Raw material	8.56								8.56			
29		Fuel (for kiln)		10.84				3079.56			3090.40			
30		Fuel (for transportation and ext	73.51	9.85					33.42		116.78			
31		Electricity			15.35	349.57	89.81	449.76	65.50		970.00			
32		Truck								9.07	9.07			
33		Total	82.07	20.68	15.35	349.57	89.81	3529.33	98.93	9.07	4194.81			
34		Unit : All values are in MJ/ton of clinker. In raw material extraction the fuel for transportation includes extraction and transportation of limestone												
35														
36	1.2	<b>Analysis (Energy)</b>												
37		<b>Contribution analysis</b>												
38		Inventory results input category wise \ Unit processes	Raw material extraction	Fuel extraction/ prod uction	Limestone Crushing	Raw meal preparation	Fuel preparation	clinkerization	Others (services etc)	Transportation	Total			
39		Raw material	0.20								0.20			
40		Fuel (for kiln)		0.26				73.41			73.67			
41		Fuel (for transportation and ext	1.75	0.23					0.80		2.78			
42		Electricity			0.37	8.33	2.14	10.72	1.56		23.12			
43		Truck								0.22	0.22			
44		Total	1.96	0.49	0.37	8.33	2.14	84.14	2.36	0.22	100.00			

Ready

# Interpretation, *(Continued)*



- Structured embodied energy result
  - The embodied energy of clinker is calculated within ground to gate system boundary. The result obtained is 4194.81 MJ/ton of clinker
- Analysis
  - Contribution analysis
    - The main contributors are fuel for clinkerization (73.41%), electricity for clinkerization (10.72%) and electricity for raw meal preparation (8.33%). All these three inputs contribute around 92.47% of total energy.
    - The embodied energy results show that the most contributing process is clinkerization with 84.14% of the energy consumption followed by raw meal preparation 8.33%.
    - In terms of input the major contributors are the fuel for kiln with 73.67% and electricity with 23.12% contribution.

# Interpretation, (Continued)

- Evaluation
  - Completeness :
  - Consistency:

Sample - (17-03-16) Clinker - Microsoft Excel

The inventory related to the extraction or production of fuel was not available and ecoinvent database is been used. The energy and emissions conversion factor for the fuel is also obtained using impact assessment methods like Cumulative Energy Demand and IPCC 2013 (direct CO2) GWP 100a method respectively

	A	B	C	D	E	F	G	H	I	J	K	L	M
82	<b>2 Evaluation</b>												
83	The objective of this element is to establish and enhance confidence in, and the reliability of, the results of the LCA or the LCI study. Basically this phase is to check whether the analysis has met the requirements.												
84													
85	<b>2.1 Completeness check (Energy)</b>												
86													
87		Element	Description	Remark									
88		Completeness	Here the completeness check is to ensure that data requirement for the LCA is met. If any relevant information required for the determination of the significant issues, is missing										
89													
90		Unit process	Completion of analysis/ data available meet requirement	Discussion	Remarks								
91		Raw material extraction	Completed		If complete mention the same, if not complete mention the same as incomplete, partially complete etc and give some remarks on the same.								
92		Fuel extraction/production	Partially complete		The inventory related to the extraction or production of fuel was not available and ecoinvent database is been used. The energy and emissions conversion factor								
93		Limestone Crushing	Completed										
94		Raw meal preparation	Completed										
95		Fuel preparation	Completed										
96		clinkerization	Completed										
97		Others (services etc)	Completed										
98		Transportation	Partially complete		The data related to fuel consumption was not available, values is been calculated based on assumed millage of truck.								
99	Note: The energy factor for limestone, clay, coal, lignite, diesel, electricity and truck uses a combination of factor value collected during site visit and calculated using software												

Goal and Scope / LCI / LCIA / Interpretation

Ready



# Interpretation, (Continued)



## • Evaluation

- Completeness :
- Consistency:

Sample - (17-03-16) Clinker - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K
113											
114	2.3	<b>Consistency check (Energy)</b>									
115											
116		<b>Element</b>	<b>Description</b>	<b>Remark</b>							
117		Consistency	Here the compl	The objective is to ensure the data, methods and assumptions are consistent as in goal and scope. If consistent, provide so							
118											
119		<b>Check</b>	<b>Consistency</b>	<b>Discussion</b>	<b>Remark</b>						
120		Data source	Partially Consistent	cement plant and	Data includes the inventory data, characterisation factor etc. If consistent, provide source of the data or p						
121		Data Accuracy	Partially consistent	The cement plant	Data includes the inventory data, characterisation factor etc. If consistent say provide a description saying						
122		Data age	Partially consistent	1 year for cemen	Data includes the inventory data, characterisation factor etc. Age includes the timing of the data e.g. time						
123		Technological coverage	Partially consistent	Dry processing w	Type of technology used e.g. State of art, pilot plant etc. If consistent, provide type of technology. If not						
124		Time related coverage	Partially consistent	2014-2015 is the	The time period considered e.g. Recent, 2015 etc. If consistent, provide time period, If not consistent pro						
125		Geographical coverage	Partially consistent	Central tamil nad	Provide the name of geographical area of study. If consistent report the location, if not report the differe						
126		Data Allocation	Consistent	Mass allocation	For product system with 2 or more products the allocation can be done in different ways e.g. mass, econ						
127		System boundary	Consistent	Ground to gate	For comparing 2 or more product system the system boundary considered should be consistent. IF consi						
128											
129											

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# Interpretation, *(Continued)*



- Evaluation

- Completeness :

- All data except transportation was obtained as defined in goal and scope
    - The energy factor for limestone, clay, coal, lignite, diesel, electricity and truck uses a combination of factor value collected during site visit and calculated using ecoinvent and Cumulative Energy Demand (CED) method

- Consistency:

- All the element like data source, data accuracy, data age, temporal coverage, technological coverage, and geographical coverage are partially consistent, and system boundary is consistent with respect to the defined goal and scope

# Interpretation



- Conclusion, Limitation and Recommendation

Sample - (17-03-16) Clinker - Microsoft Excel				
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				General Number
				Conditional Formatting as Table Styles
				Insert Delete Format Cells
				Editing
C131				
A	B	C	D	E
121	Data Accuracy	Partially consistent	The cement plant data on inventory and the characteri	Data includes
122	Data age	Consistent	1 year	Data includes
123	Technological coverage	Consistent	Dry processing with 5 stage preheater precalciner syst	Type of techno
124	Time related coverage	Consistent	2014-2015	The time perio
125	Geographical coverage	Consistent	Central tamil nadu	Provide the na
126	Data Allocation	Consistent	Mass allocation	For product sy
127	System boundary	Consistent	Gate to gate	For comparing
128				
129				
130				
131	3 Conclusion, Limitation and Recommendation			
132				
133	Sub elements	Description	Remark	
134	Conclusion	The inventory study results (raw material, fuel, electricity etc) match with the values reported in the literature. So the data shows the values lies in same range reported in other countries. The impact category results shows that the process raw meal grinding and clinkerization contribute to 93% of the energy consumption. In terms of input the major contributors are the fuel for kiln and electricity which contributes around 97% of total energy. Certain inputs are present in one or more processes so the sensitivity results are not having linear relationship. The sensitivity of the input fuel data is the highest with sensitivity of 7.5%, It means the 10% variation of the input fuel data can cause 7.6% variation in the total energy consumption.	The significant issues found in the structured information, say most contributing LCI or LCIA data or unit process. If possible provide the sensitivity of the same.	
135	Limitation	The data related to the fuel extraction process was taken from ecoinvent database. Another limitation was the inventory data for the transportation is calculated based on assumed distance.	The limitation to meet the elements in goal and scope is provided here, completeness check and consistency check is also discussed here	
136	Recommendation	So it is recommended that during LCA of clinker production an inventory collection of electricity and fuels alone itself can provide a coverage of 97%. Or if the data collection is process wise the raw meal preparation and clinkerization process will be more than enough to have a coverage about 93%.	Recommendations are provided based on the logical and reasonable consequence of the conclusion. It can also be measures related to the significant inputs or unit process, which the intended authors should take in to consideration.	
137				
Ready				

- Summary

- Conclusion:

- The embodied energy of clinker is calculated with in ground to gate system boundary. The result obtained is 4194.81 MJ/ton of clinker
    - The main data contributors are fuel for clinkerization (75.98 %), electricity for clinkerization (9.85%) and electricity for raw meal preparation (7.66%). Most contributing process in clinkerization (85.83 %) and most contributing data type is fuel (75.95%)
    - The embodied energy of clinker corresponding to different geographical area are varying from (2970 – 3810) MJ/ton of clinker <sup>[1]</sup>. Compared to it the energy obtained in the study is higher than the expected range.

- Limitation

- Completeness : All data except transportation was obtained as defined in goal and scope
  - Consistency: Element like data source, data accuracy, technological coverage, temporal coverage, geographical coverage are partially consistent with respect to the defined goal and scope

[1] – Based LCI from Ecoinvent database V3 and calculated using method Cumulative energy demand (1.09). The value is calculated using software SimaPro. The geographical areas considered are Canada (3720 MJ), Switzerland (2970 MJ), Europe without Switzerland (3810 MJ), US (3760 MJ), and Rest of the world (3710 MJ)

- Recommendation

- It can be used in the estimation of embodied energy of different types of cement
- If the required accuracy of the result is  $\pm 10\%$ . The study can be limited to process raw meal grinding and clinkerization as it has a coverage  $>92\%$ .
- The reiteration of data collection on transportation can improve the accuracy of result for transportation process

Thank you