Spreadsheet tool for Life Cycle Assessment (LCA)

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Overview

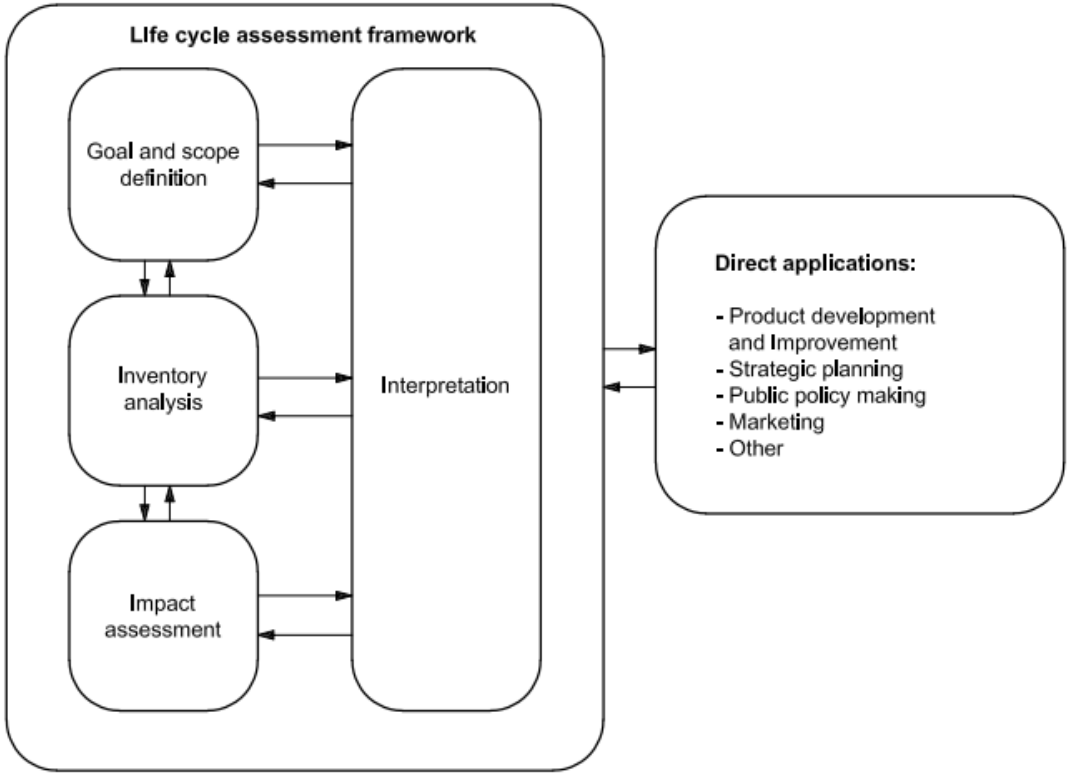
- Introduction
- Development of Spreadsheet tool
- Sample: Case Study

Introduction – Definition and methodologies

- 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

Introduction – LCA framework (based on ISO 14040/44)

- 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

- 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)*

- 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

LCIA

- 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

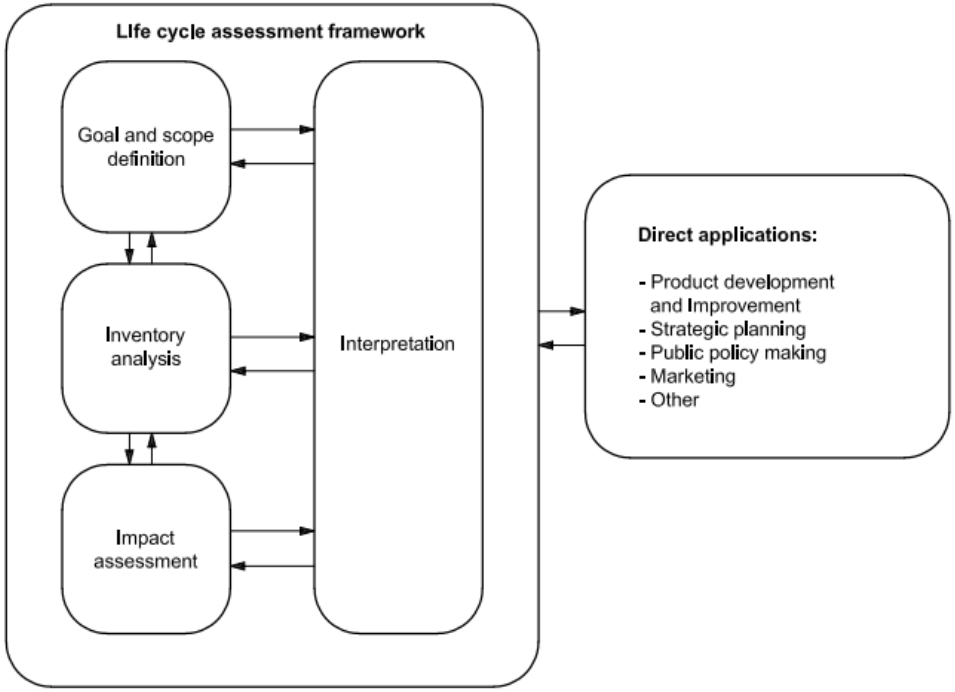
Interpretation

- 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

Developing spreadsheet tool

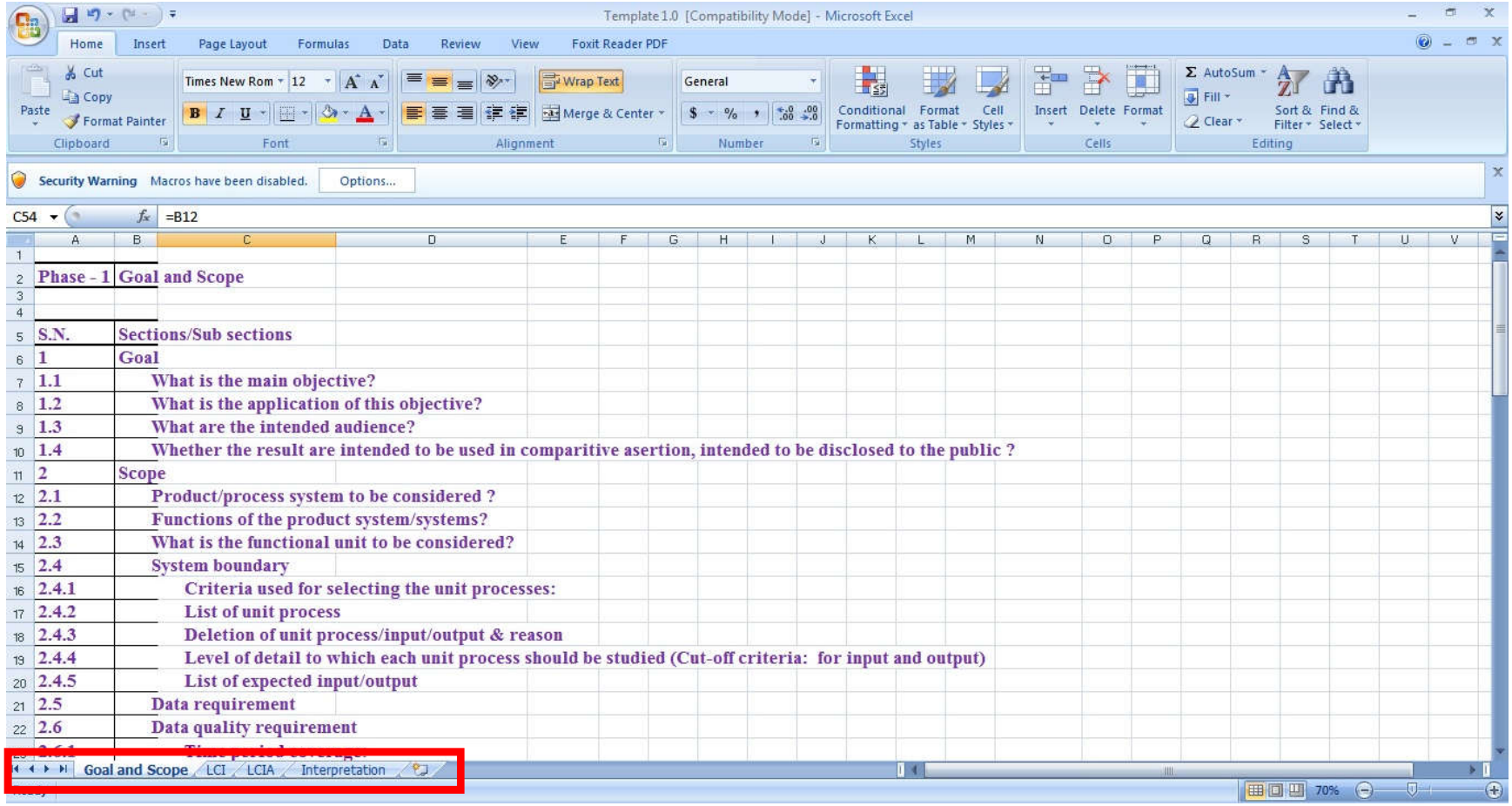
LCA framework (ISO 14040/44)

- 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



Phase - 1	Goal and Scope	
S.N.	Sections/Sub sections	
1	Goal	
1.1		What is the main objective?
1.2		What is the application of this objective?
1.3		What are the intended audience?
1.4		Whether the result are intended to be used in comparitive asertion, intended to be disclosed to the public ?
2	Scope	
2.1		Product/process system to be considered ?
2.2		Functions of the product system/systems?
2.3		What is the functional unit to be considered?
2.4		System boundary
2.4.1		Criteria used for selecting the unit processes:
2.4.2		List of unit process
2.4.3		Deletion of unit process/input/output & reason
2.4.4		Level of detail to which each unit process should be studied (Cut-off criteria: for input and output)
2.4.5		List of expected input/output
2.5		Data requirement
2.6		Data quality requirement

Goal and Scope *(Continued)*

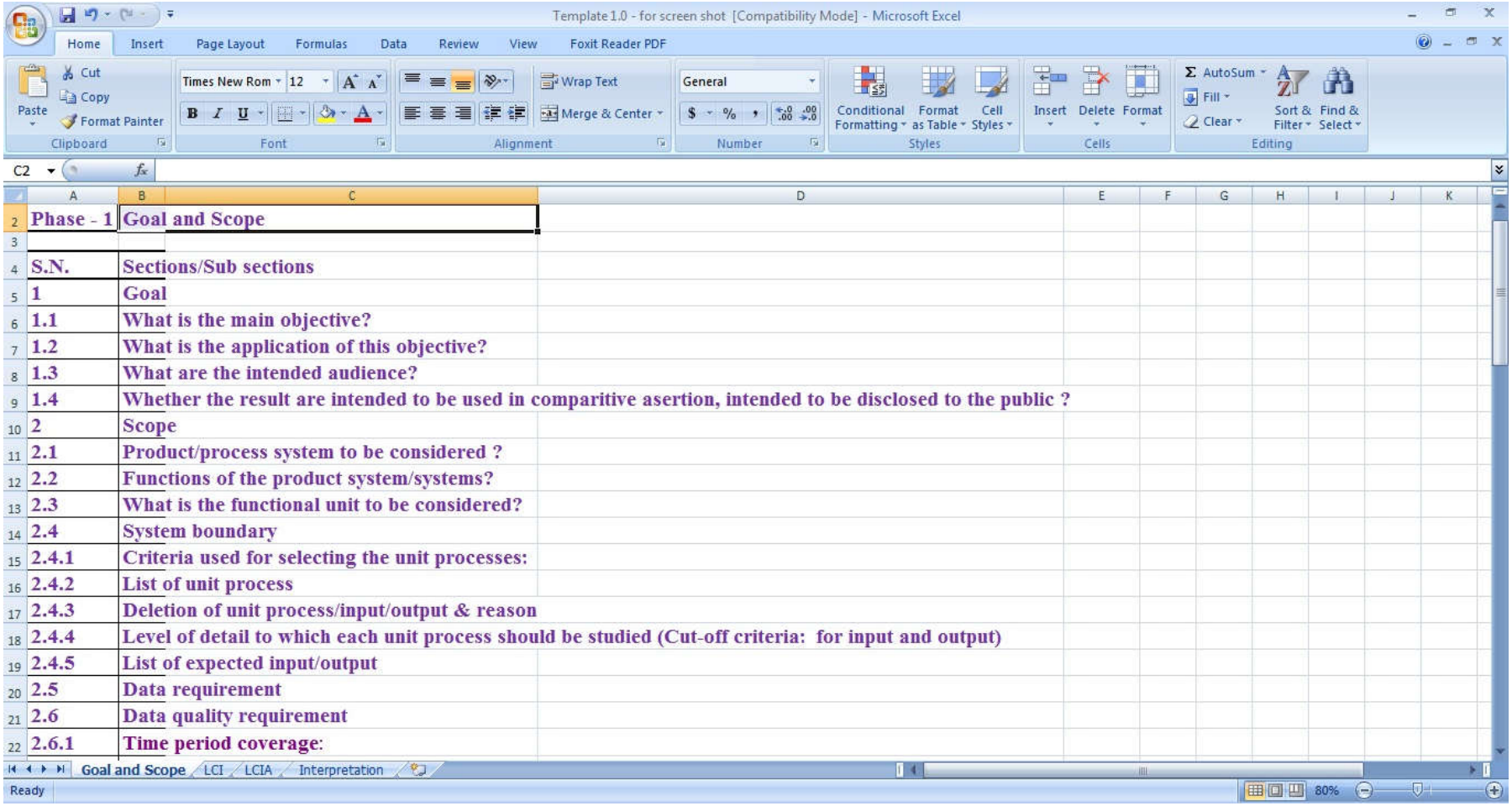
- Goal
  - Objective:
  - Application:
  - Intended Audience:
  - Public disclosure:
- Scope
  - Product system :
  - Function:
  - Functional unit:
  - System boundary :
    - Criteria, List of unit processes, data associated with unit processes, deleted processes
  - Data requirement :

Goal and Scope *(Continued)*

- 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

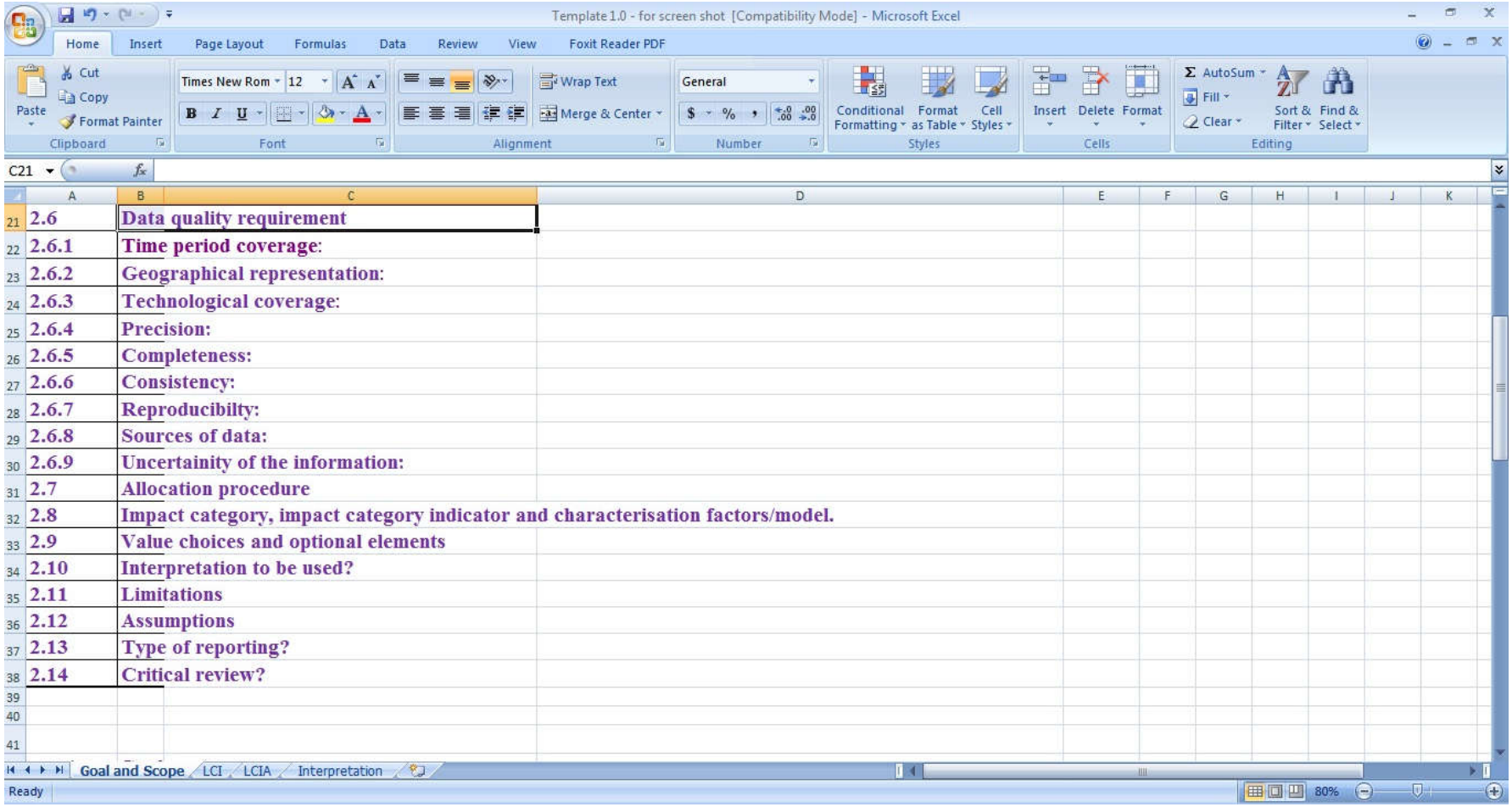
Goal and Scope

- Goal and scope - Index



Goal and Scope

- Goal and scope - Index

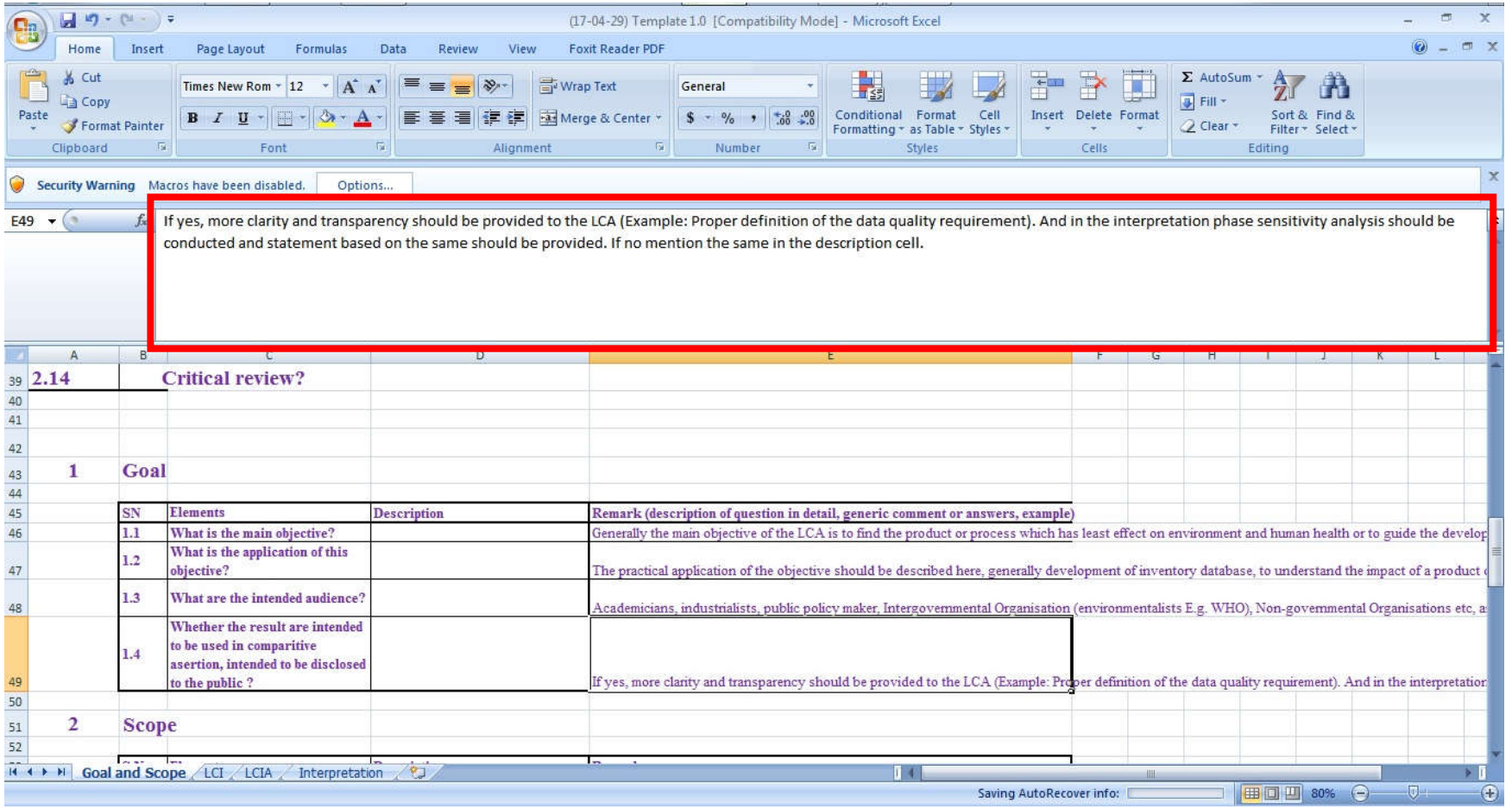


Goal and Scope

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

Goal and Scope *(Continued)*

- Sections in goal

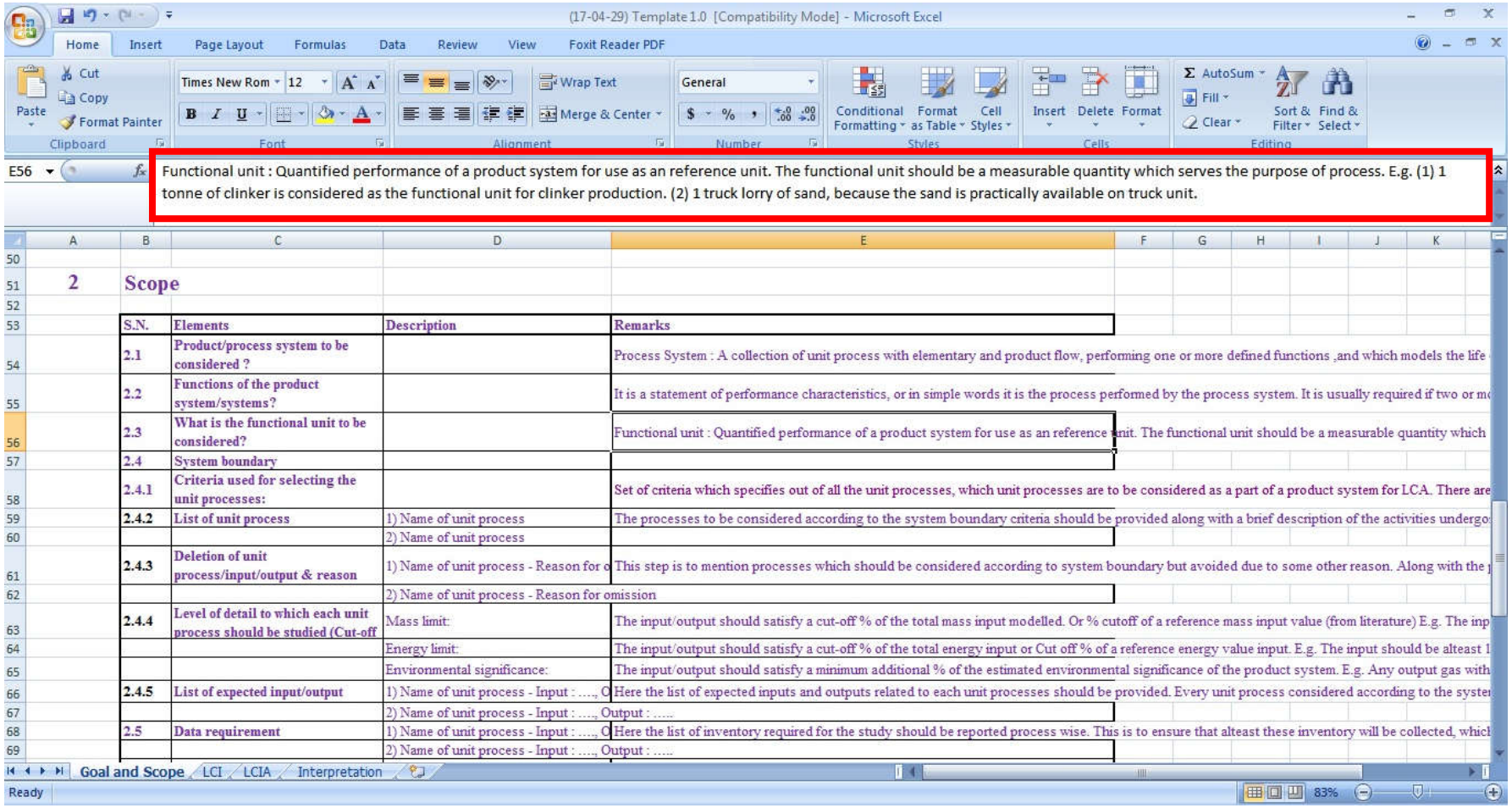


Goal and Scope (*Continued)*

- 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)
  - Assumptions
  - Limitations
  - Type of reporting
  - Critical reviews

Goal and Scope *(Continued)*

- Sections of scope



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E56: 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.

2	**Scope**			
	S.N.	**Elements**	**Description**	**Remarks**
54	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
55	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 m
56	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
57	2.4	System boundary		
58	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
59	2.4.2	List of unit process	1) 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
60			2) Name of unit process	
61	2.4.3	Deletion of unit process/input/output & reason	1) Name of unit process - Reason for o	This step is to mention processes which should be considered according to system boundary but avoided due to some other reason. Along with the
62			2) Name of unit process - Reason for omission	
63	2.4.4	Level of detail to which each unit process should be studied (Cut-off	Mass limit:	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
64			Energy limit:	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 alteast 1
65			Environmental significance:	The input/output should satisfy a minimum additional % of the estimated environmental significance of the product system. E.g. Any output gas with
66	2.4.5	List of expected input/output	1) Name of unit process - Input : ...., O	Here the list of expected inputs and outputs related to each unit processes should be provided. Every unit process considered according to the syste
67			2) Name of unit process - Input : ...., Output :	
68	2.5	Data requirement	1) Name of unit process - Input : ...., O	Here the list of inventory required for the study should be reported process wise. This is to ensure that alteast these inventory will be collected, whic
69			2) Name of unit process - Input : ...., Output :	

Goal and Scope | LCI | LCIA | Interpretation

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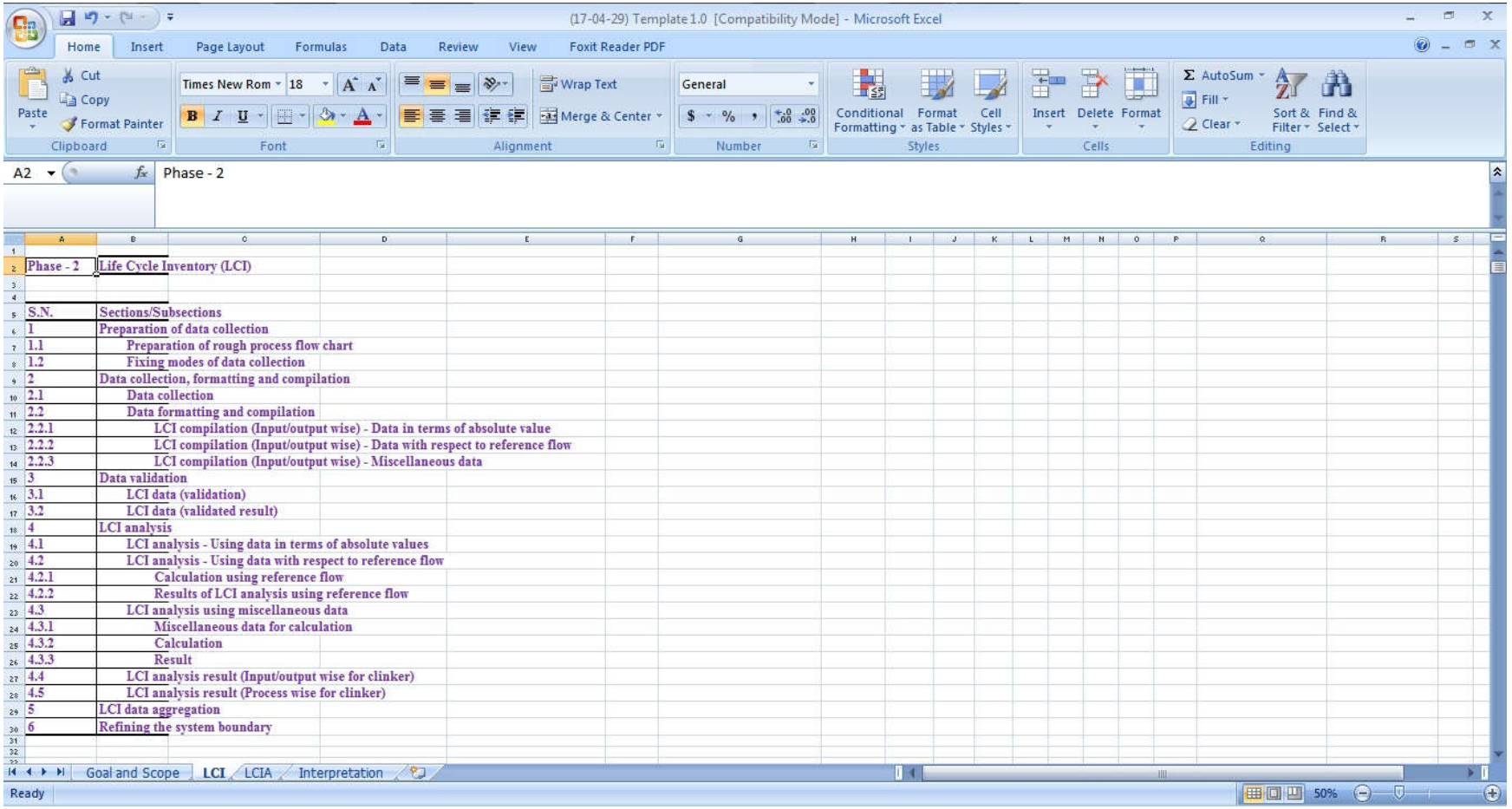
Life Cycle Inventory (LCI)

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

Life Cycle Inventory *(Continued)*

- LCI index



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A2: Phase - 2

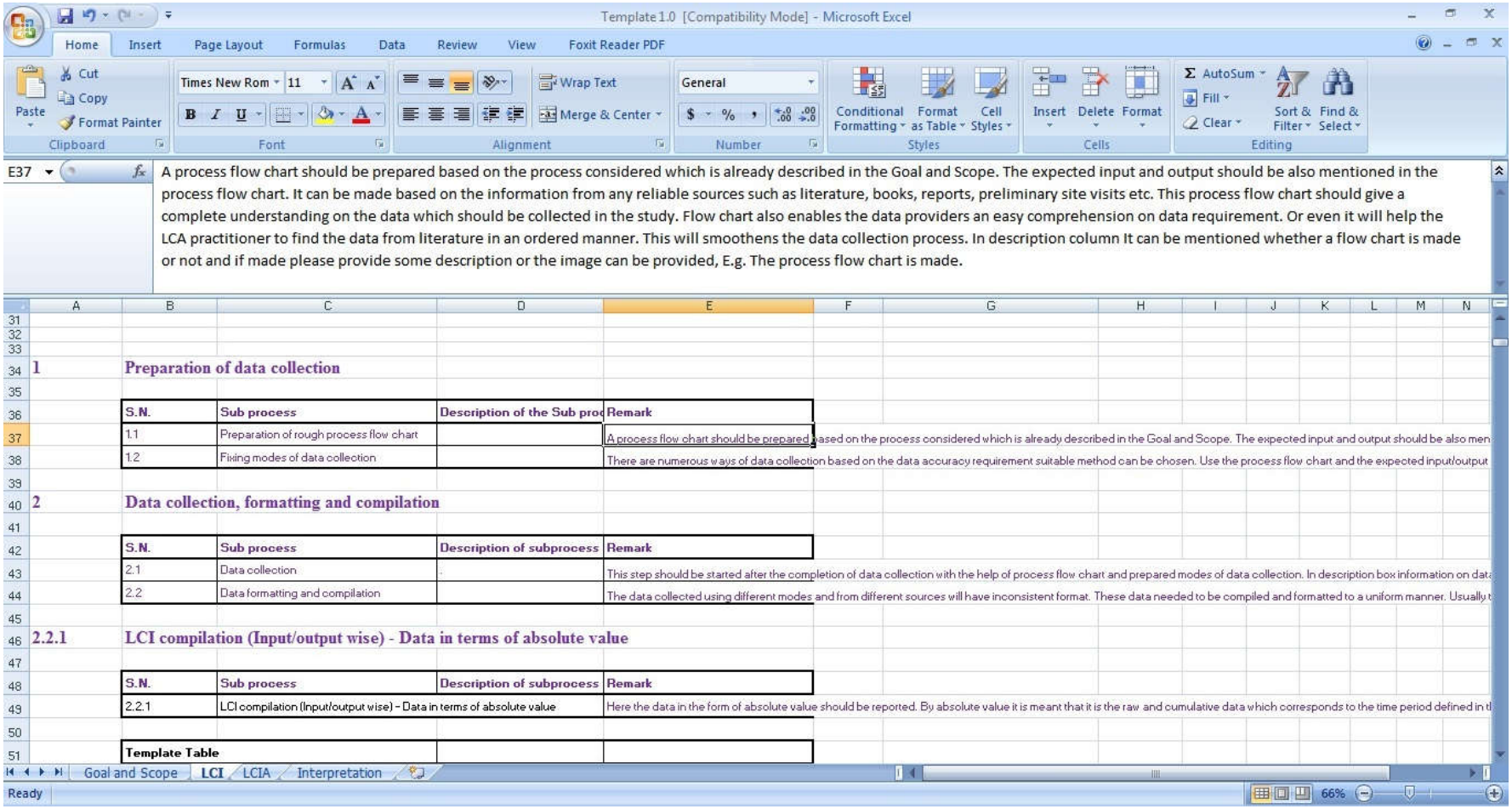
Phase - 2	Life Cycle Inventory (LCI)
S.N.	Sections/Subsections
1	Preparation of data collection
1.1	Preparation of rough process flow chart
1.2	Fixing modes of data collection
2	Data collection, formatting and compilation
2.1	Data collection
2.2	Data formatting and compilation
2.2.1	LCI compilation (Input/output wise) - Data in terms of absolute value
2.2.2	LCI compilation (Input/output wise) - Data with respect to reference flow
2.2.3	LCI compilation (Input/output wise) - Miscellaneous data
3	Data validation
3.1	LCI data (validation)
3.2	LCI data (validated result)
4	LCI analysis
4.1	LCI analysis - Using data in terms of absolute values
4.2	LCI analysis - Using data with respect to reference flow
4.2.1	Calculation using reference flow
4.2.2	Results of LCI analysis using reference flow
4.3	LCI analysis using miscellaneous data
4.3.1	Miscellaneous data for calculation
4.3.2	Calculation
4.3.3	Result
4.4	LCI analysis result (Input/output wise for clinker)
4.5	LCI analysis result (Process wise for clinker)
5	LCI data aggregation
6	Refining the system boundary

Goal and Scope | LCI | LCIA | Interpretation

Ready

Life Cycle Inventory *(Continued)*

- Sections of LCI

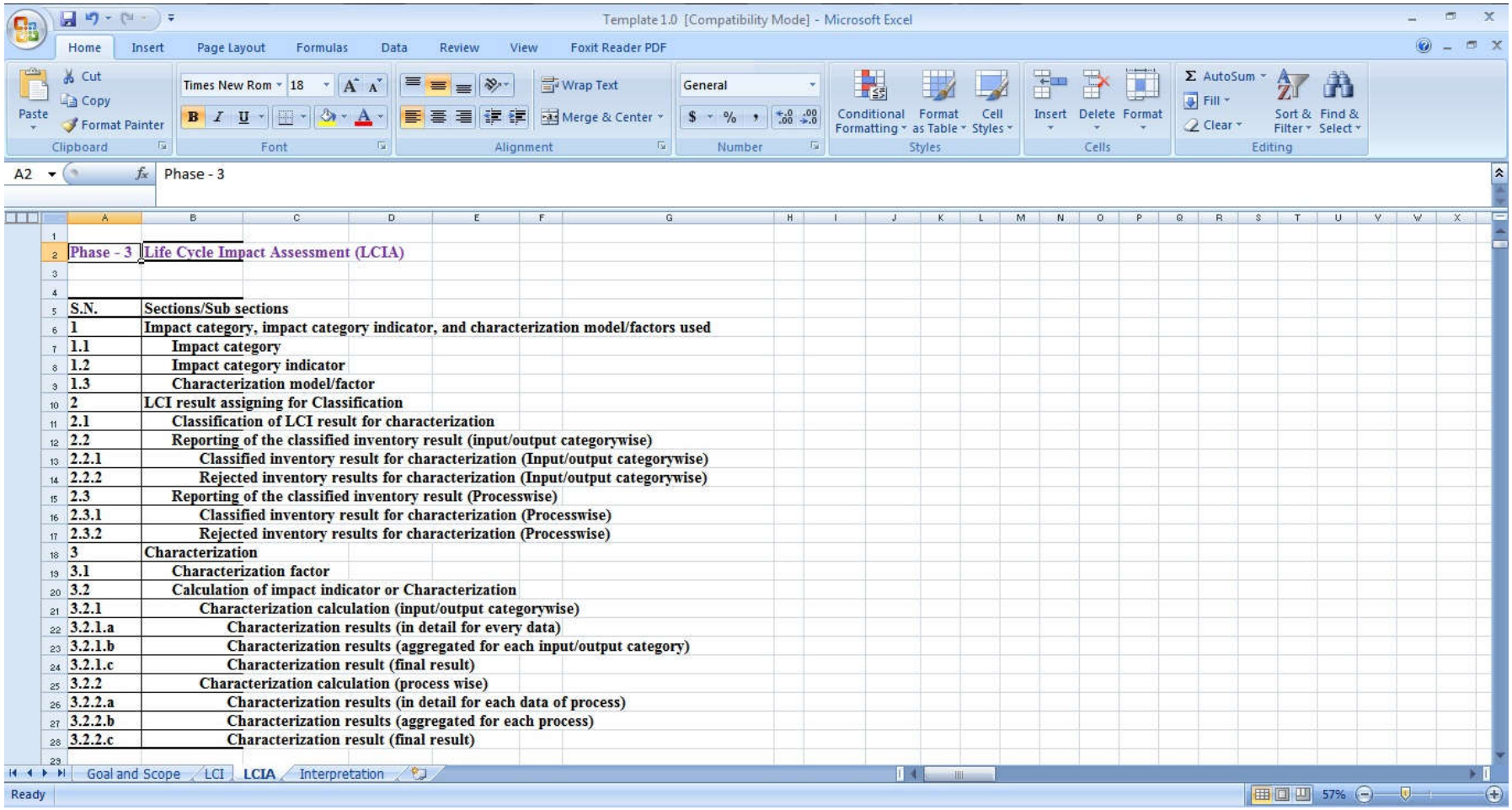


LCIA

- Defining LCIA methodology
- Classification
- Characterization

LCIA *(Continued)*

- LCIA Index



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A2: Phase - 3

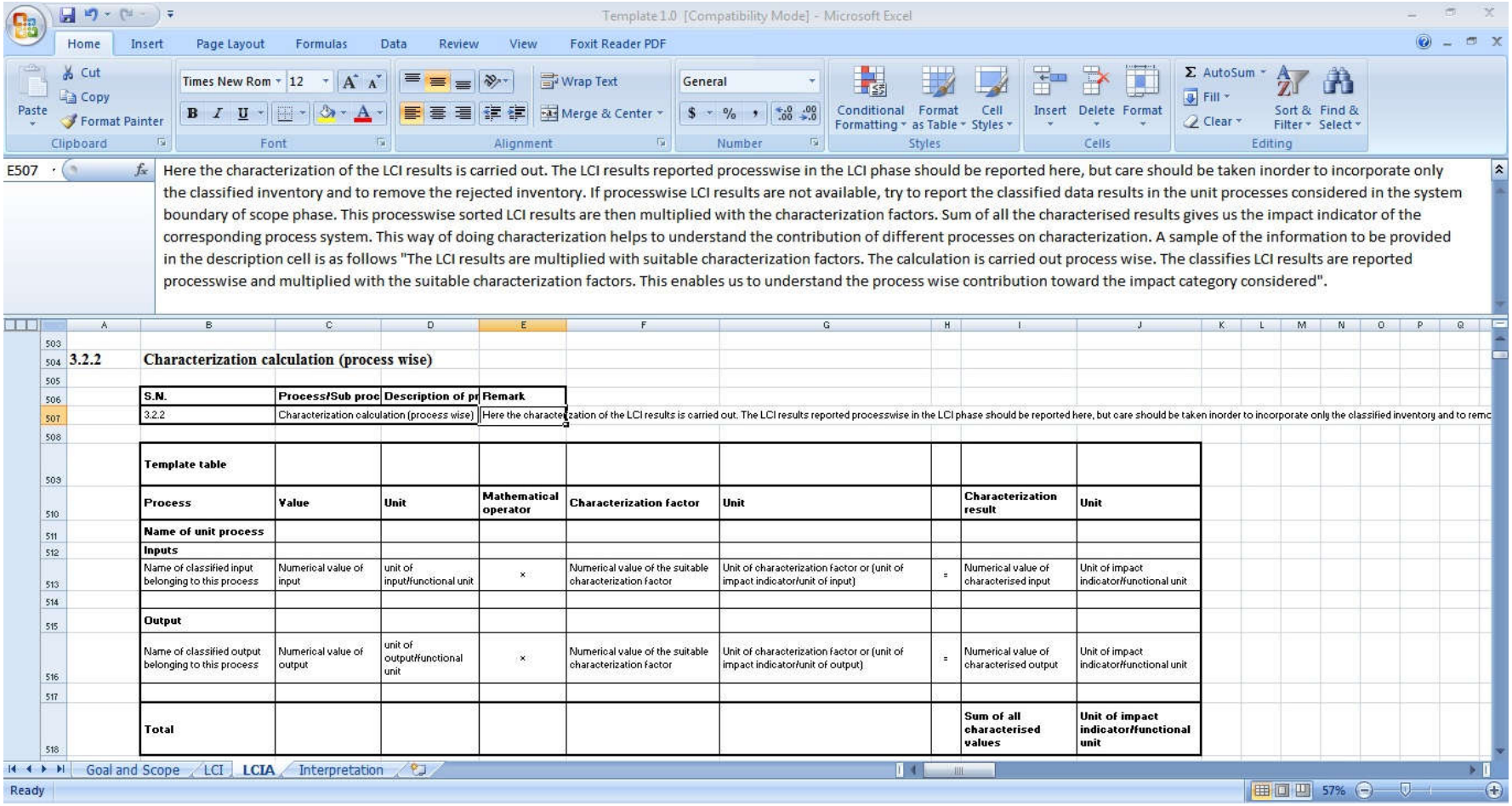
S.N.	Sections/Sub sections
Phase - 3	Life Cycle Impact Assessment (LCIA)
1	Impact category, impact category indicator, and characterization model/factors used
1.1	Impact category
1.2	Impact category indicator
1.3	Characterization model/factor
2	LCI result assigning for Classification
2.1	Classification of LCI result for characterization
2.2	Reporting of the classified inventory result (input/output categorywise)
2.2.1	Classified inventory result for characterization (Input/output categorywise)
2.2.2	Rejected inventory results for characterization (Input/output categorywise)
2.3	Reporting of the classified inventory result (Processwise)
2.3.1	Classified inventory result for characterization (Processwise)
2.3.2	Rejected inventory results for characterization (Processwise)
3	Characterization
3.1	Characterization factor
3.2	Calculation of impact indicator or Characterization
3.2.1	Characterization calculation (input/output categorywise)
3.2.1.a	Characterization results (in detail for every data)
3.2.1.b	Characterization results (aggregated for each input/output category)
3.2.1.c	Characterization result (final result)
3.2.2	Characterization calculation (process wise)
3.2.2.a	Characterization results (in detail for each data of process)
3.2.2.b	Characterization results (aggregated for each process)
3.2.2.c	Characterization result (final result)

Goal and Scope | LCI | LCIA | Interpretation

Ready

LCIA *(Continued)*

- Sections of LCIA

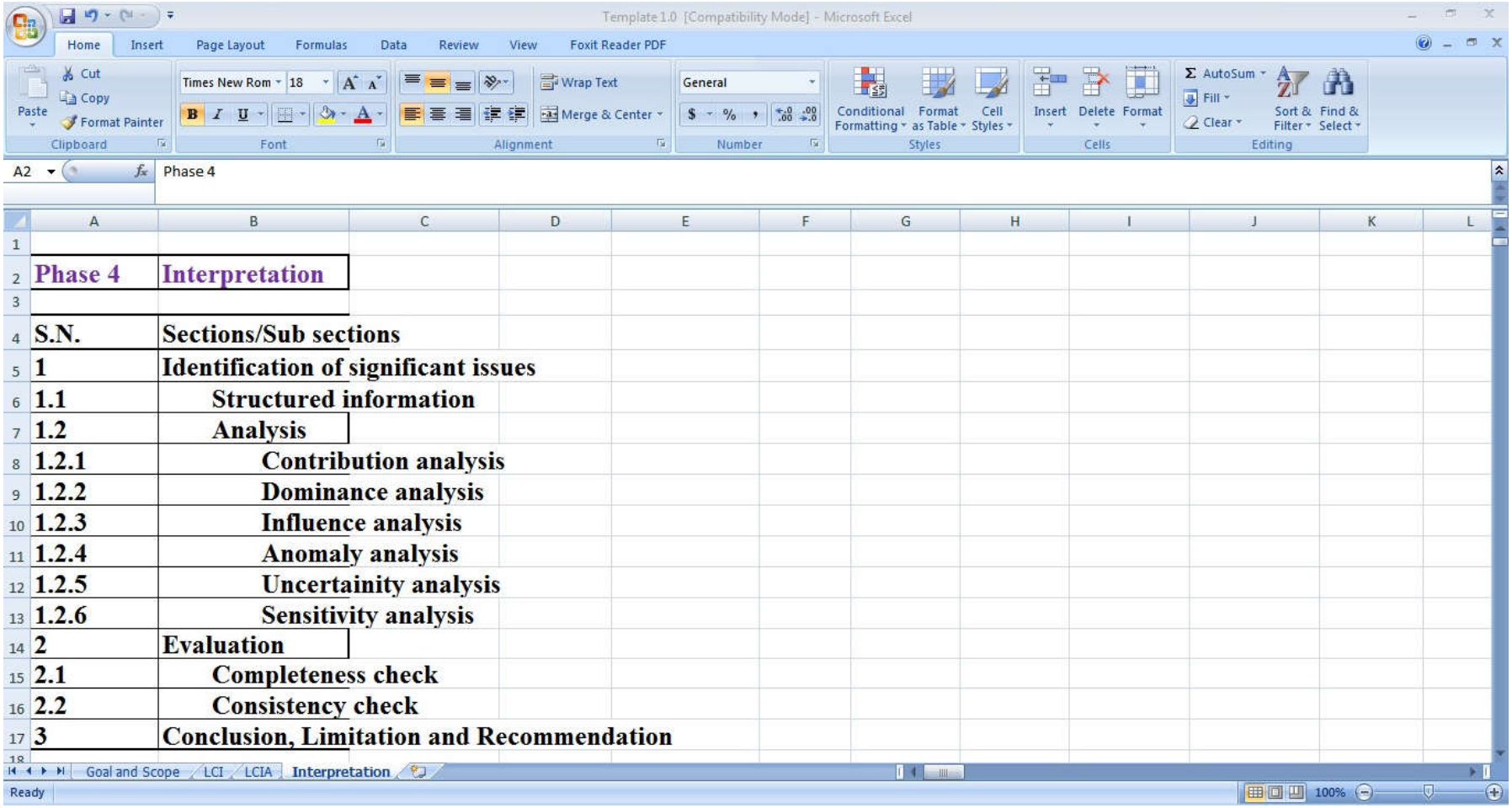


Interpretation

- Identification of the significant issue
- Evaluation
- Summary

Interpretation *(Continued)*

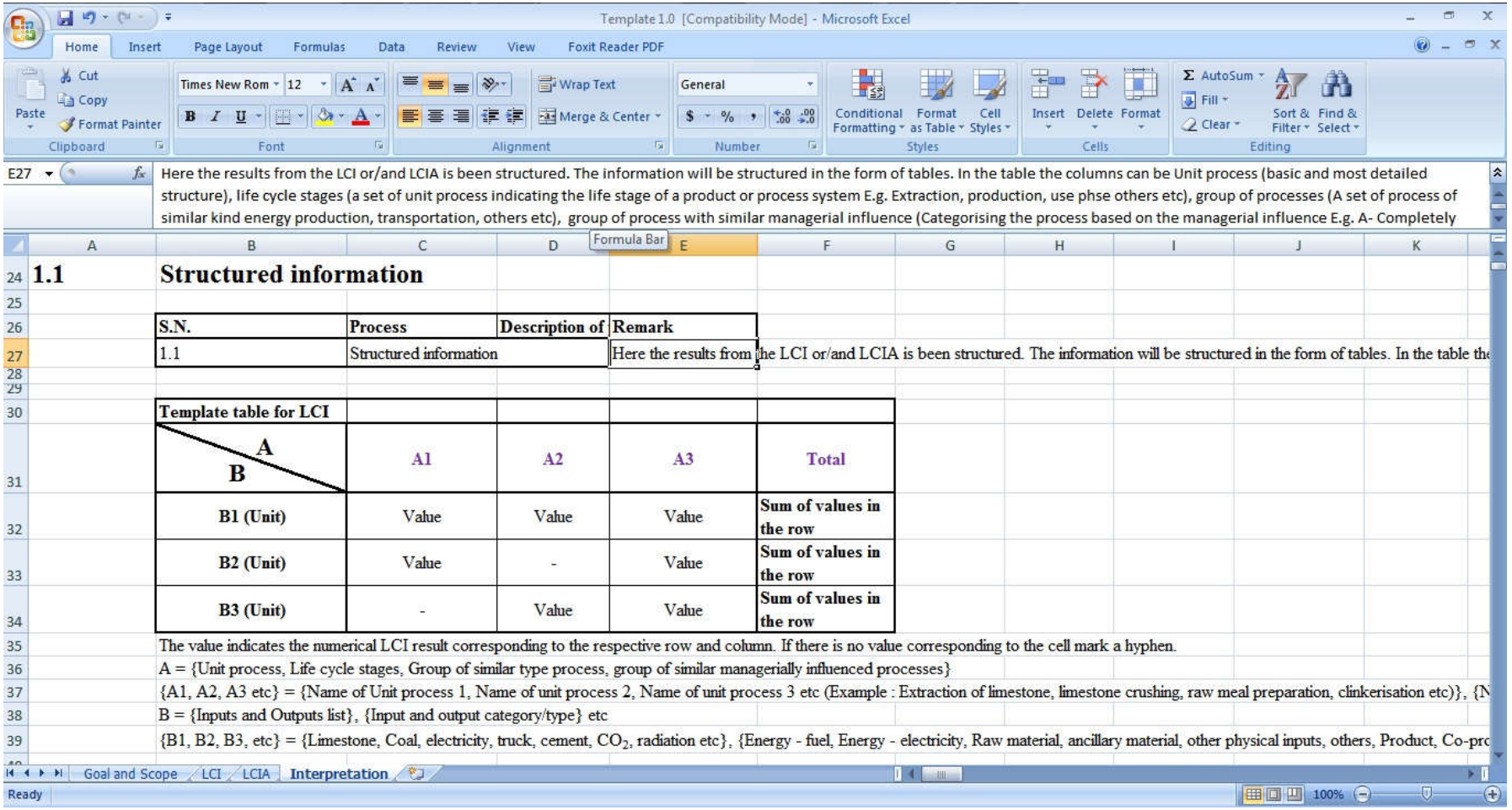
- Interpretation Index



Phase 4	Interpretation
S.N.	Sections/Sub sections
1	Identification of significant issues
1.1	Structured information
1.2	Analysis
1.2.1	Contribution analysis
1.2.2	Dominance analysis
1.2.3	Influence analysis
1.2.4	Anomaly analysis
1.2.5	Uncertainity analysis
1.2.6	Sensitivity analysis
2	Evaluation
2.1	Completeness check
2.2	Consistency check
3	Conclusion, Limitation and Recommendation

Interpretation *(Continued)*

- Sections of Interpretation



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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 phse 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

Formula Bar

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

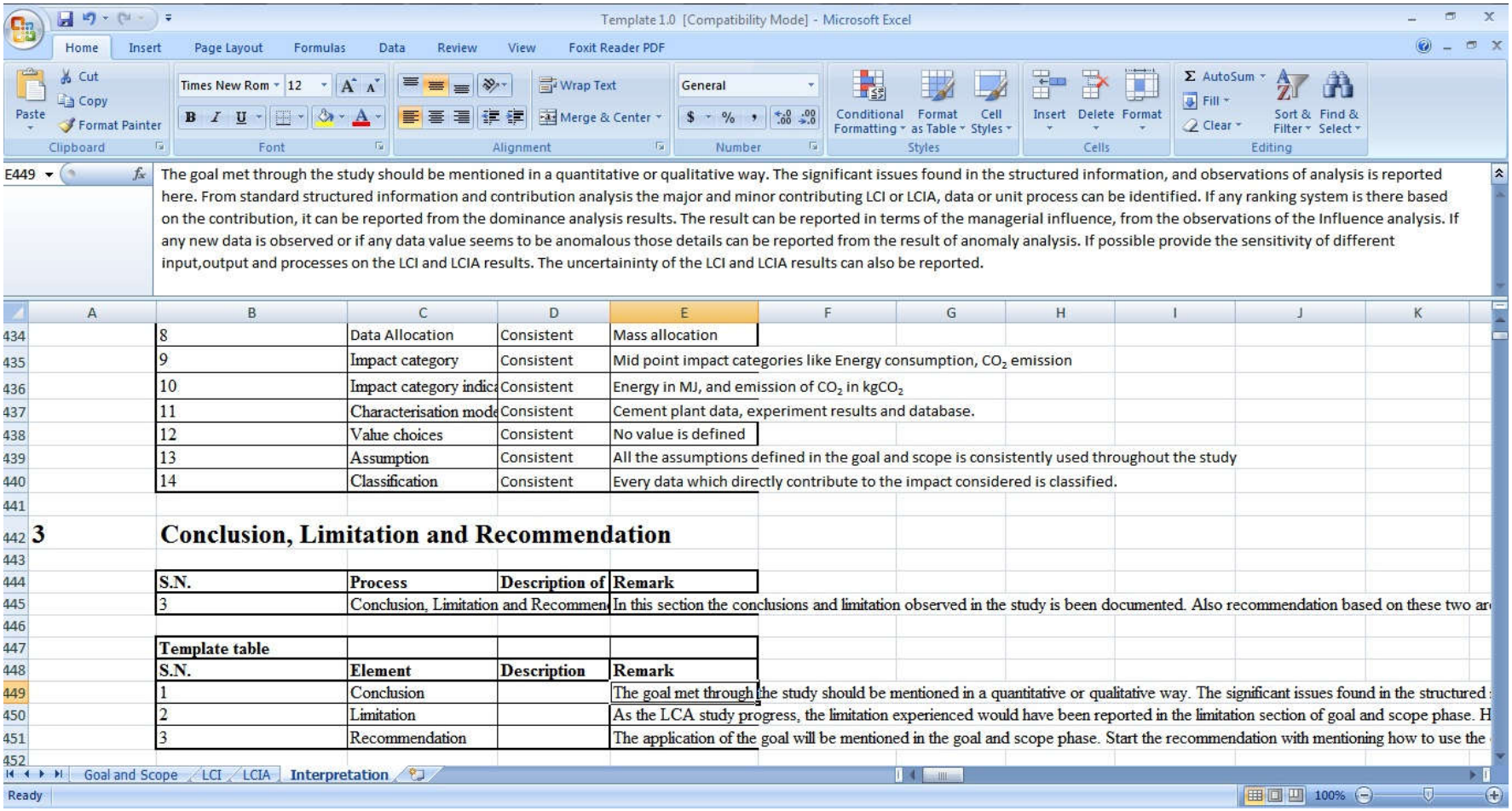
{B1, B2, B3, etc} = {Limestone, Coal, electricity, truck, cement, CO_2, radiation etc}, {Energy - fuel, Energy - electricity, Raw material, ancillary material, other physical inputs, others, Product, Co-pro

Goal and Scope | LCI | LCIA | Interpretation

Ready

Interpretation *(Continued)*

- Sections of Interpretation



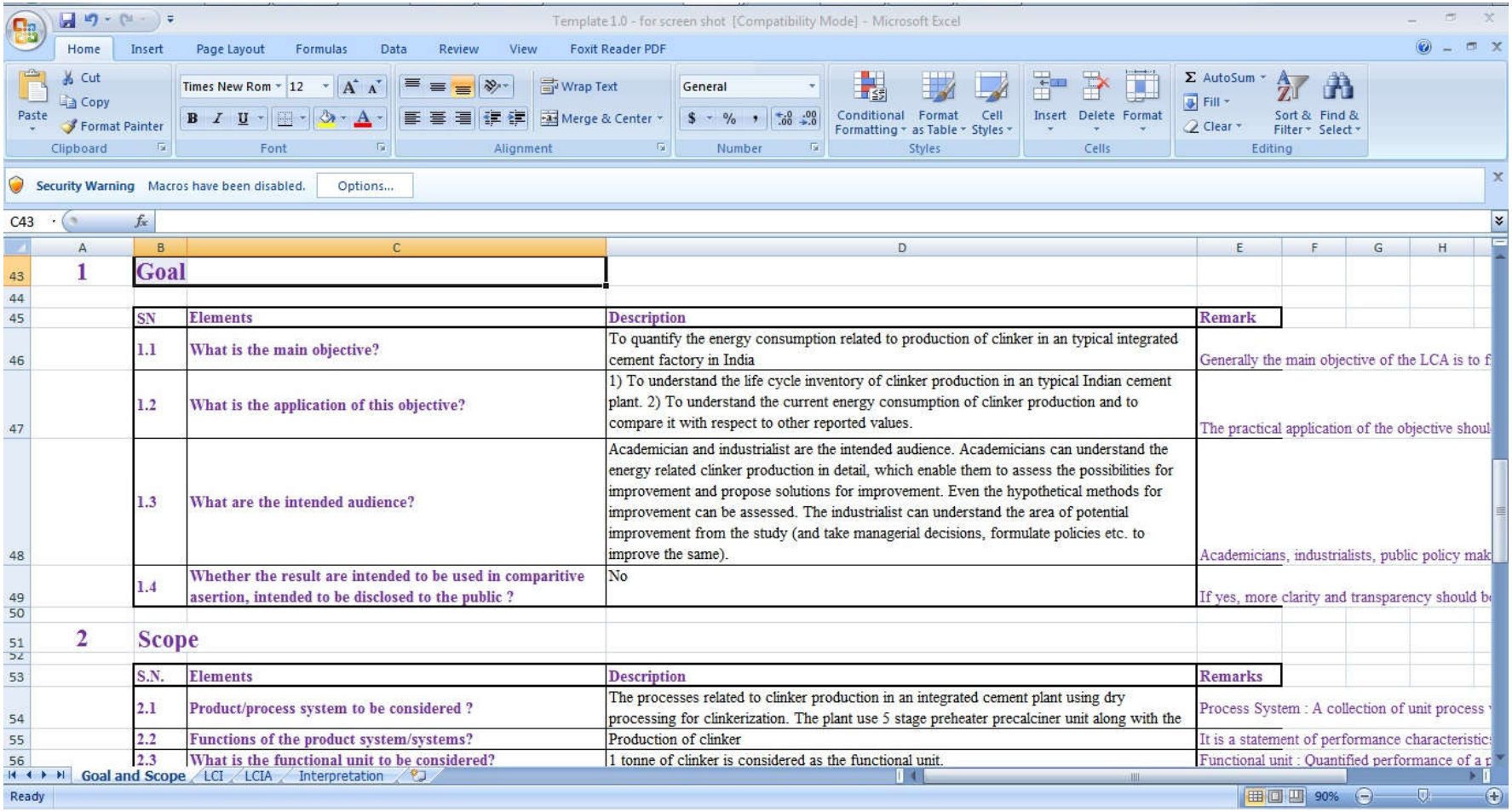
Sample Case study :LCA of clinker (an ingredient of cement)

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



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43	1	**Goal**		
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 comparitive asertion, intended to be disclosed to the public ?	No	If yes, more clarity and transparency should b
50					
51	2	**Scope**		
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 characteristic
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-continous 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

Goal and Scope

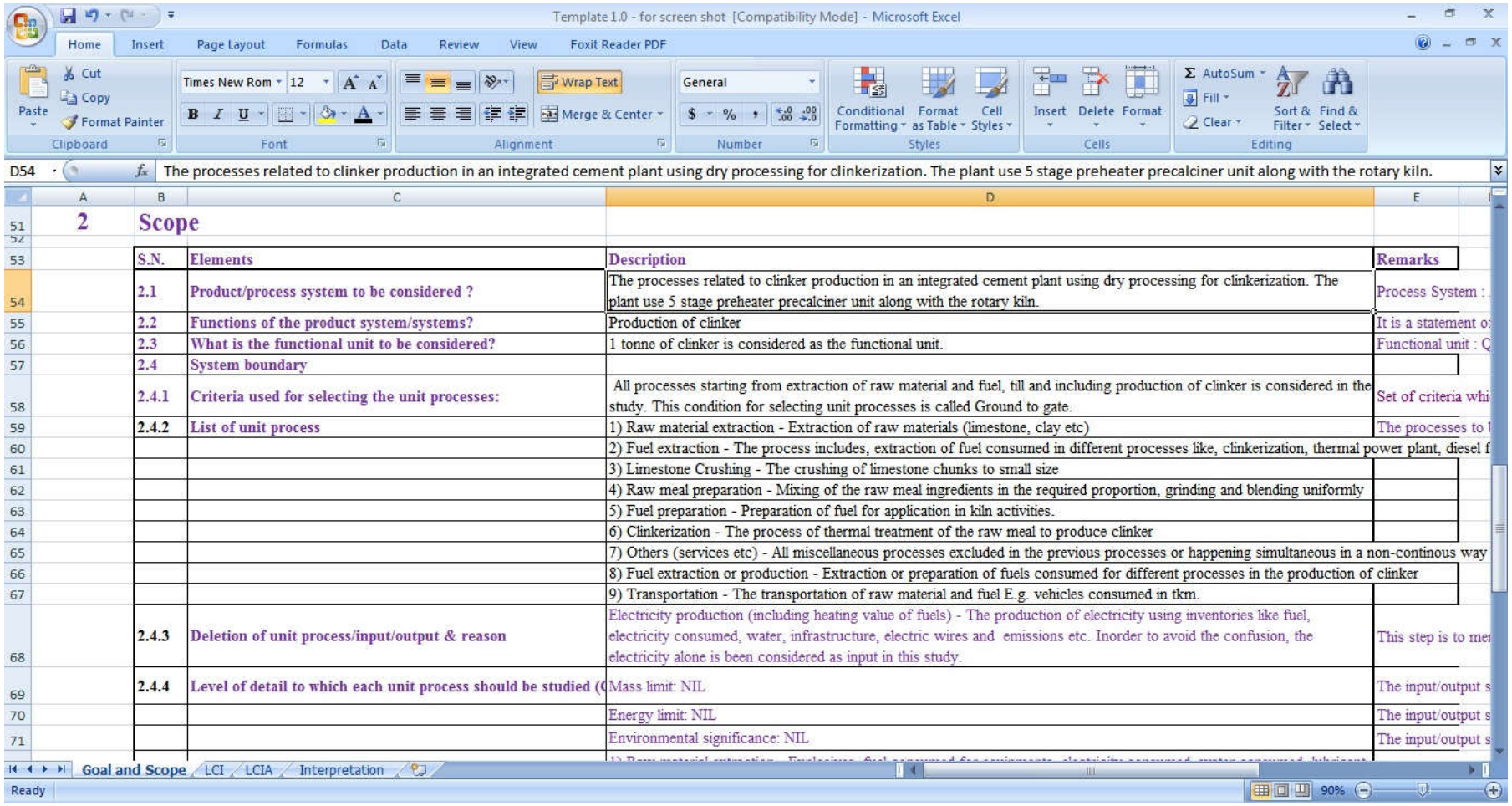
- Scope *(continued)*
  - Data requirement : All the inputs and outputs related the processes in Gate to gate
    - Raw material extraction – Explosives, water consumed, fuel consumed for equipment, electricity consumed, lubricant consumed for equipment, equipment consumables, equipment, the limestone 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, CO2, NOx, SOx, 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



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D54: 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	E
51	2	Scope			
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 rotary kiln.	Process System :
55		2.2	Functions of the product system/systems?	Production of clinker	It is a statement o
56		2.3	What is the functional unit to be considered?	1 tonne of clinker is considered as the functional unit.	Functional unit : Q
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.	Set of criteria whi
59		2.4.2	List of unit process	1) Raw material extraction - Extraction of raw materials (limestone, clay etc)	The processes to
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-continous 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.	This step is to me
69		2.4.4	Level of detail to which each unit process should be studied (	Mass limit: NIL	The input/output s
70				Energy limit: NIL	The input/output s
71				Environmental significance: NIL	The input/output s

Goal and Scope | LCI | LCIA | Interpretation

Ready 90%

Life Cycle Inventory (LCI)

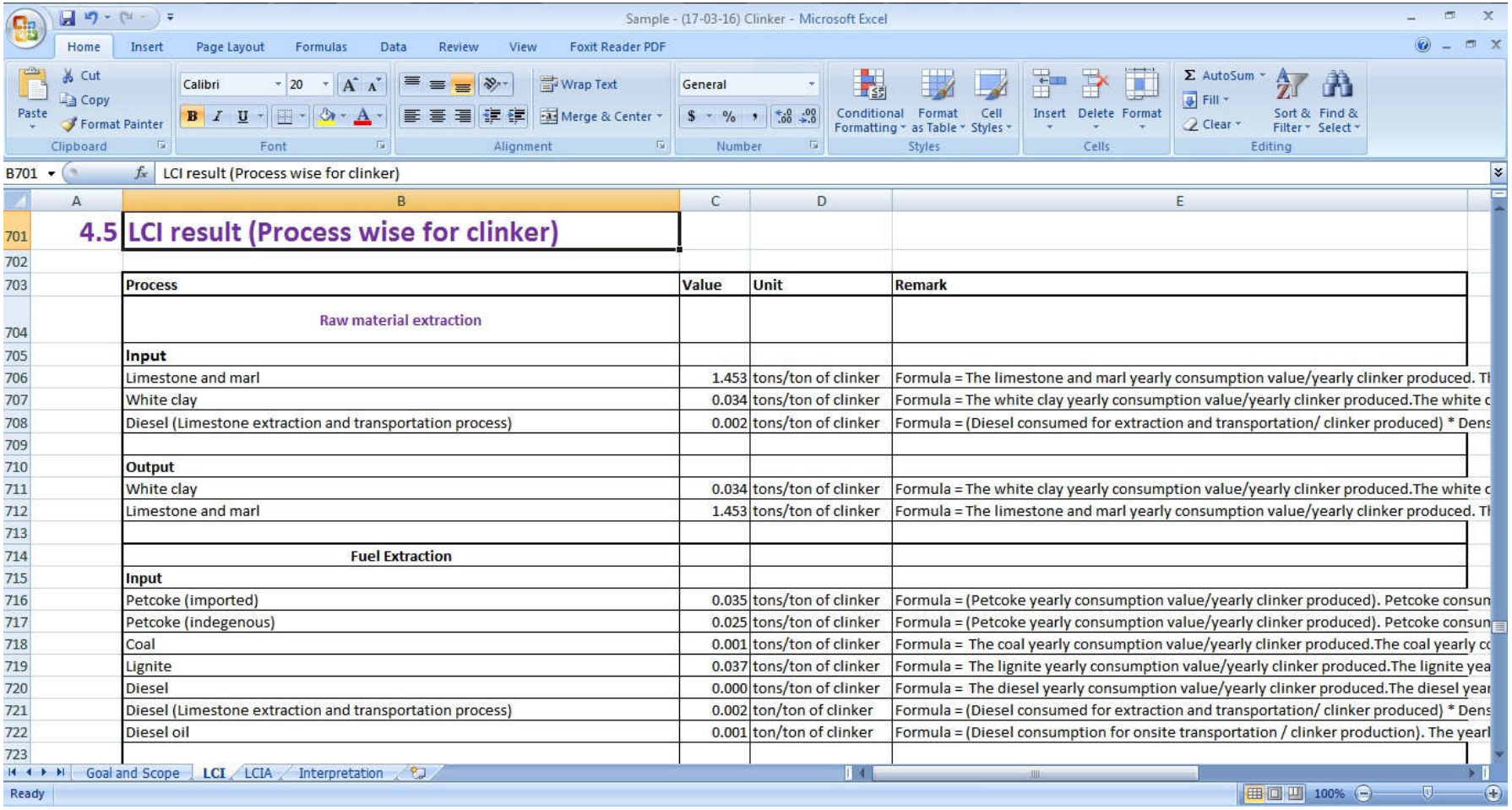
- Planning of data collection
  - A process flow chart is developed, with unit processes and data flow
  - Data is planned to collect through case study
- Data collection, formatting, and compilation
  - 2 visits were conducted to the cement plant,
  - The process map developed is modified to a realistic 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



4.5 LCI result (Process wise for clinker)

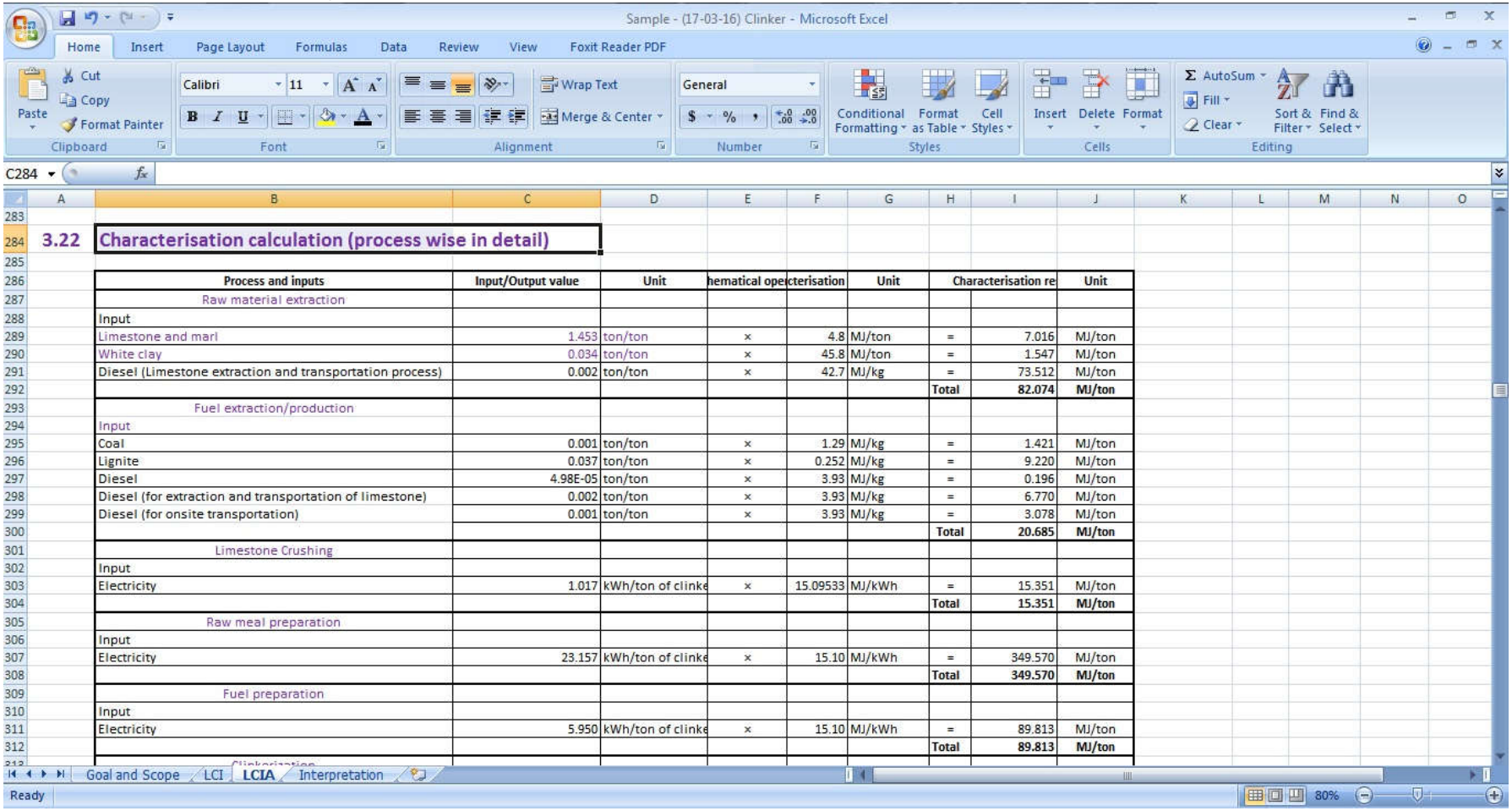
Process	Value	Unit	Remark
Raw material extraction			
Input			
Limestone and marl	1.453	tons/ton of clinker	Formula = The limestone and marl yearly consumption value/yearly clinker produced. Th
White clay	0.034	tons/ton of clinker	Formula = The white clay yearly consumption value/yearly clinker produced.The white c
Diesel (Limestone extraction and transportation process)	0.002	tons/ton of clinker	Formula = (Diesel consumed for extraction and transportation/ clinker produced) * Dens
Output			
White clay	0.034	tons/ton of clinker	Formula = The white clay yearly consumption value/yearly clinker produced.The white c
Limestone and marl	1.453	tons/ton of clinker	Formula = The limestone and marl yearly consumption value/yearly clinker produced. Th
Fuel Extraction			
Input			
Petcoke (imported)	0.035	tons/ton of clinker	Formula = (Petcoke yearly consumption value/yearly clinker produced). Petcoke consun
Petcoke (indegenous)	0.025	tons/ton of clinker	Formula = (Petcoke yearly consumption value/yearly clinker produced). Petcoke consun
Coal	0.001	tons/ton of clinker	Formula = The coal yearly consumption value/yearly clinker produced.The coal yearly co
Lignite	0.037	tons/ton of clinker	Formula = The lignite yearly consumption value/yearly clinker produced.The lignite yea
Diesel	0.000	tons/ton of clinker	Formula = The diesel yearly consumption value/yearly clinker produced.The diesel year
Diesel (Limestone extraction and transportation process)	0.002	ton/ton of clinker	Formula = (Diesel consumed for extraction and transportation/ clinker produced) * Dens
Diesel oil	0.001	ton/ton of clinker	Formula = (Diesel consumption for onsite transportation / clinker production). The yearl

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

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C284

3.22 Characterisation calculation (process wise in detail)

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

Goal and Scope | LCI | LCIA | Interpretation

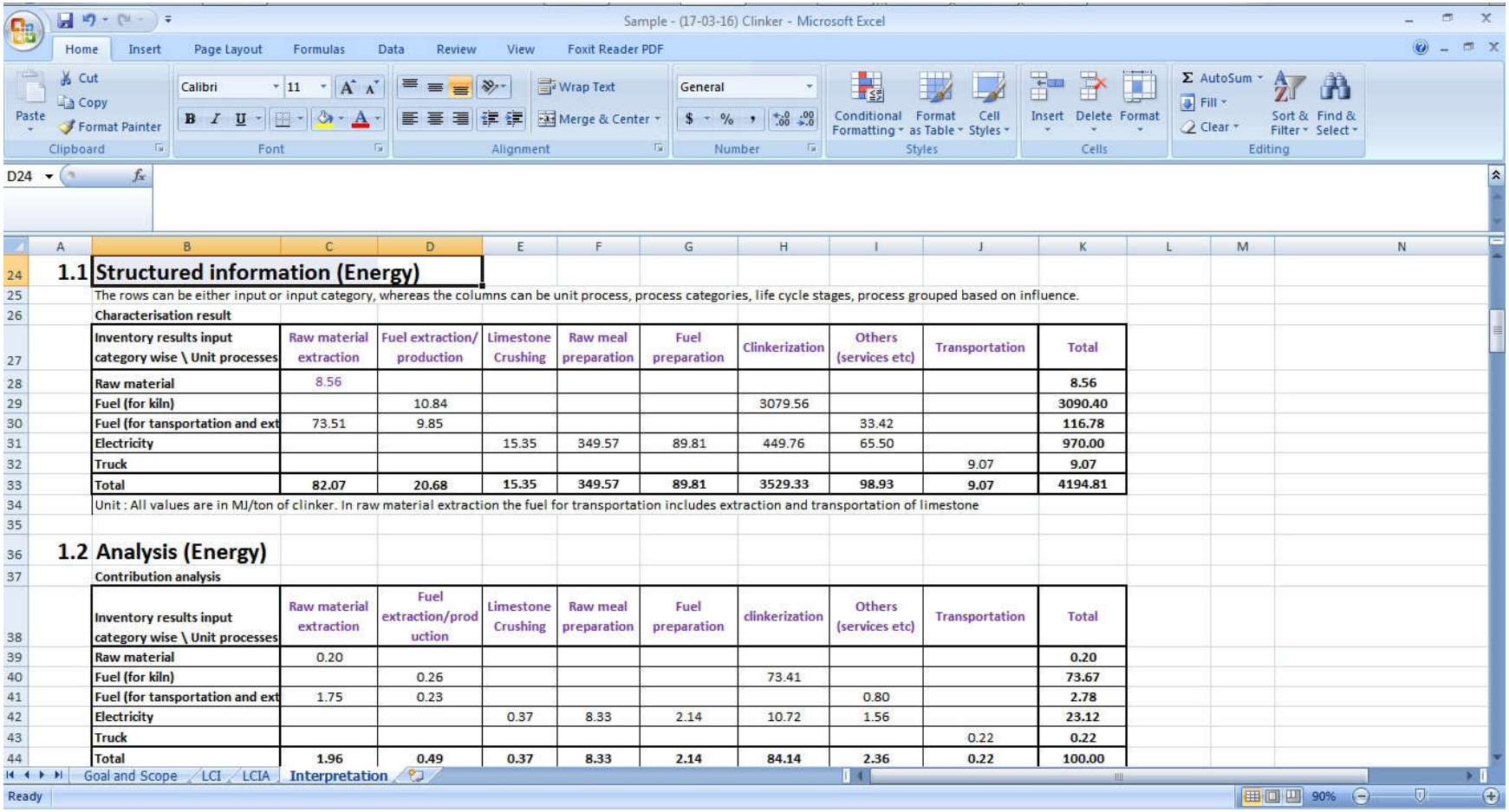
Ready

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



1.1 Structured information (Energy)

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.

Characterisation result

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
Raw material	8.56								8.56
Fuel (for kiln)		10.84				3079.56			3090.40
Fuel (for tansportation and ext	73.51	9.85					33.42		116.78
Electricity			15.35	349.57	89.81	449.76	65.50		970.00
Truck								9.07	9.07
Total	82.07	20.68	15.35	349.57	89.81	3529.33	98.93	9.07	4194.81

Unit : All values are in MJ/ton of clinker. In raw material extraction the fuel for transportation includes extraction and transportation of limestone

1.2 Analysis (Energy)

Contribution analysis

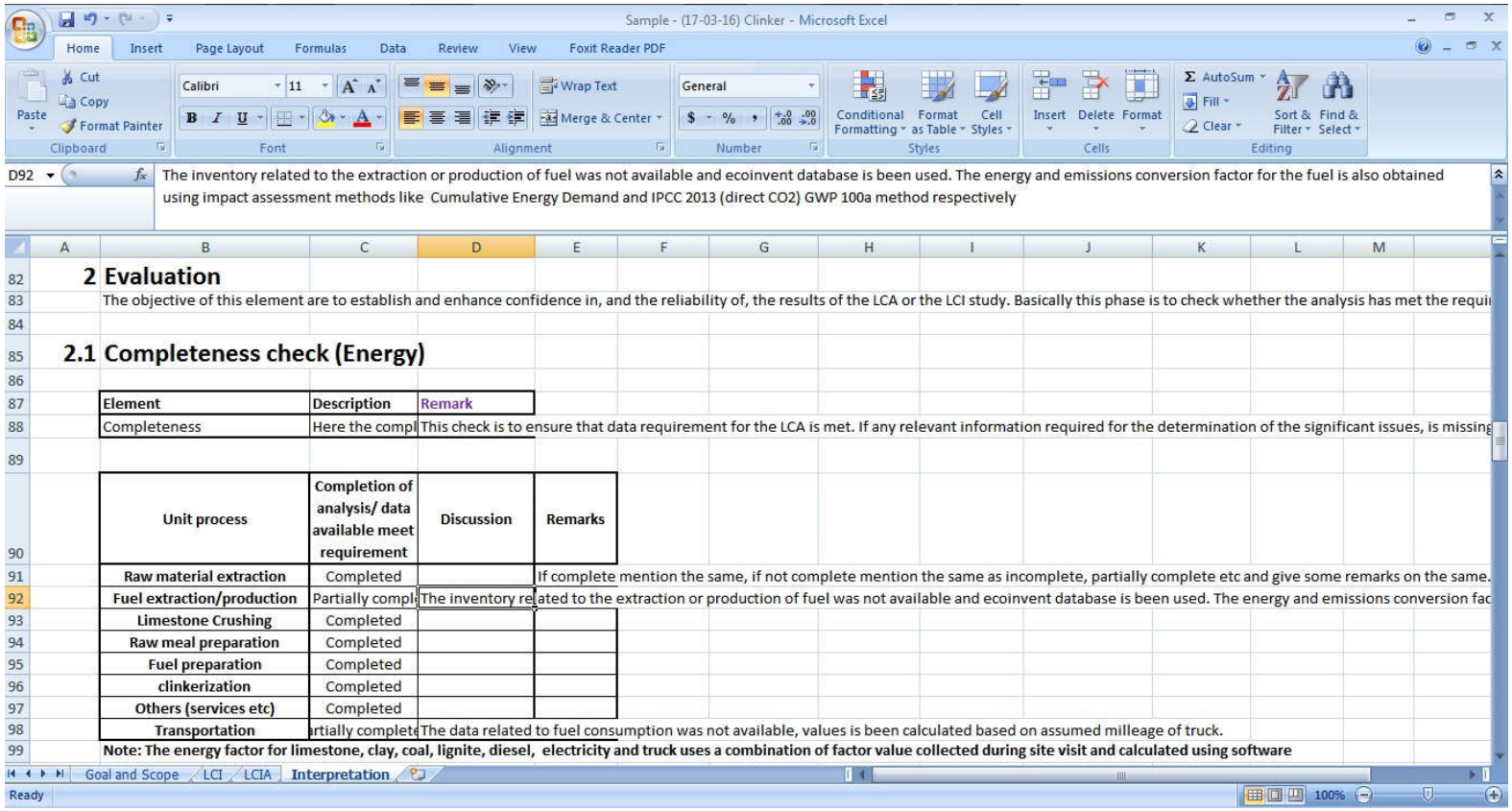
Inventory results input category wise \ Unit processes	Raw material extraction	Fuel extraction/production	Limestone Crushing	Raw meal preparation	Fuel preparation	clinkerization	Others (services etc)	Transportation	Total
Raw material	0.20								0.20
Fuel (for kiln)		0.26				73.41			73.67
Fuel (for tansportation and ext	1.75	0.23					0.80		2.78
Electricity			0.37	8.33	2.14	10.72	1.56		23.12
Truck								0.22	0.22
Total	1.96	0.49	0.37	8.33	2.14	84.14	2.36	0.22	100.00

Interpretation, *(Continued)*

- Structured embodied energy result
  - The embodied energy of clinker is calculated with in 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 shows that 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

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D92: 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

2 Evaluation

The objective of this element are 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 requi

2.1 Completeness check (Energy)

Element	Description	Remark
Completeness	Here the compl	This 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

Unit process	Completion of analysis/ data available meet requirement	Discussion	Remarks
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.
Fuel extraction/production	Partially compl	The inventory related to the extraction or production of fuel was not available and ecoinvent database is been used. The energy and emissions conversion fac	
Limestone Crushing	Completed		
Raw meal preparation	Completed		
Fuel preparation	Completed		
clinkerization	Completed		
Others (services etc)	Completed		
Transportation	artially complete	The data related to fuel consumption was not available, values is been calculated based on assumed milleage of truck.	

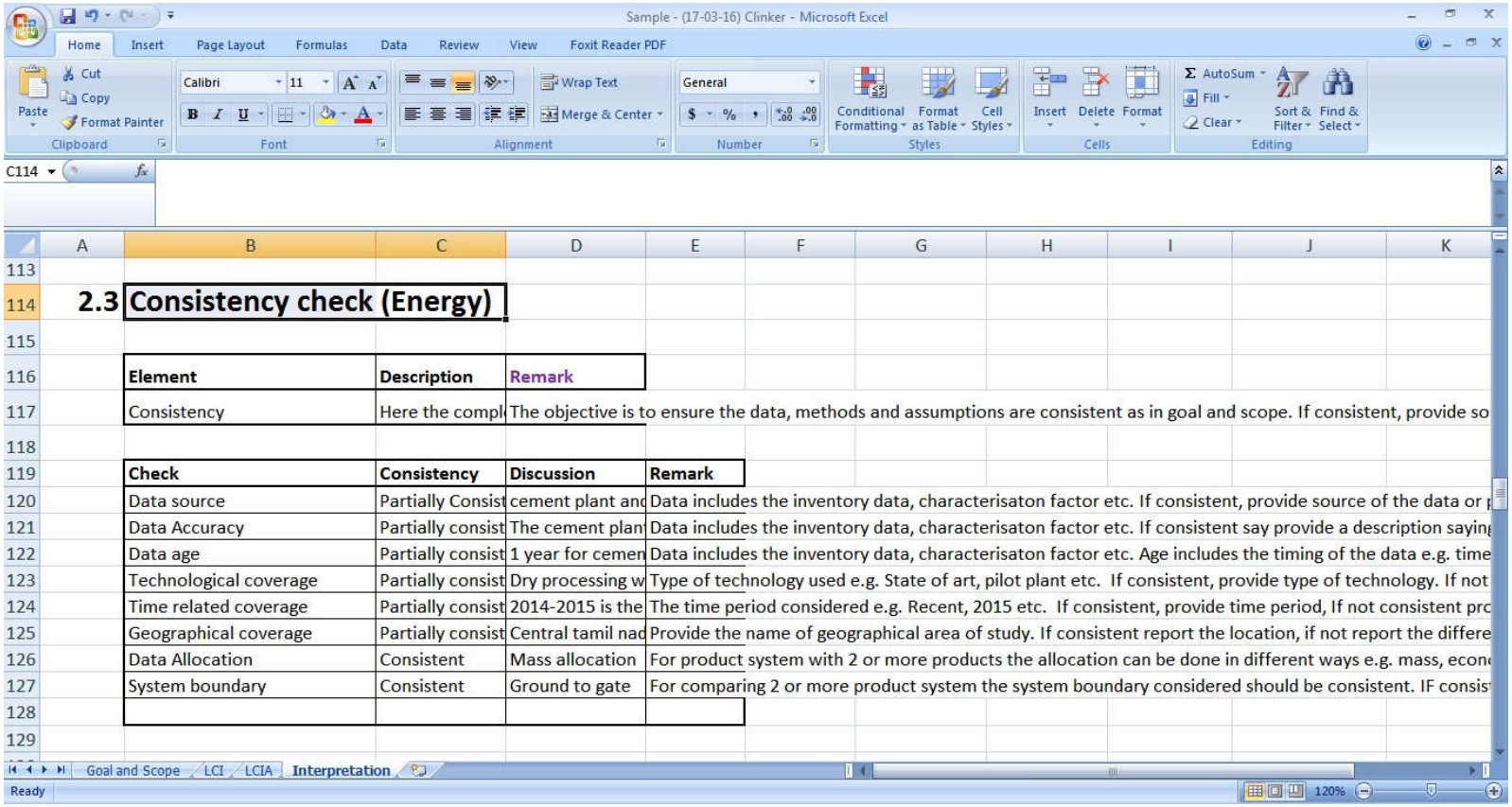
Note: The energy factor for limestone, clay, coal, lignite, diesel, electricity and truck uses a combination of factor value collected during site visit and calculated using software

Goal and Scope | LCI | LCIA | Interpretation

Ready

Interpretation, *(Continued)*

- Evaluation
  - Completeness :
  - Consistency:

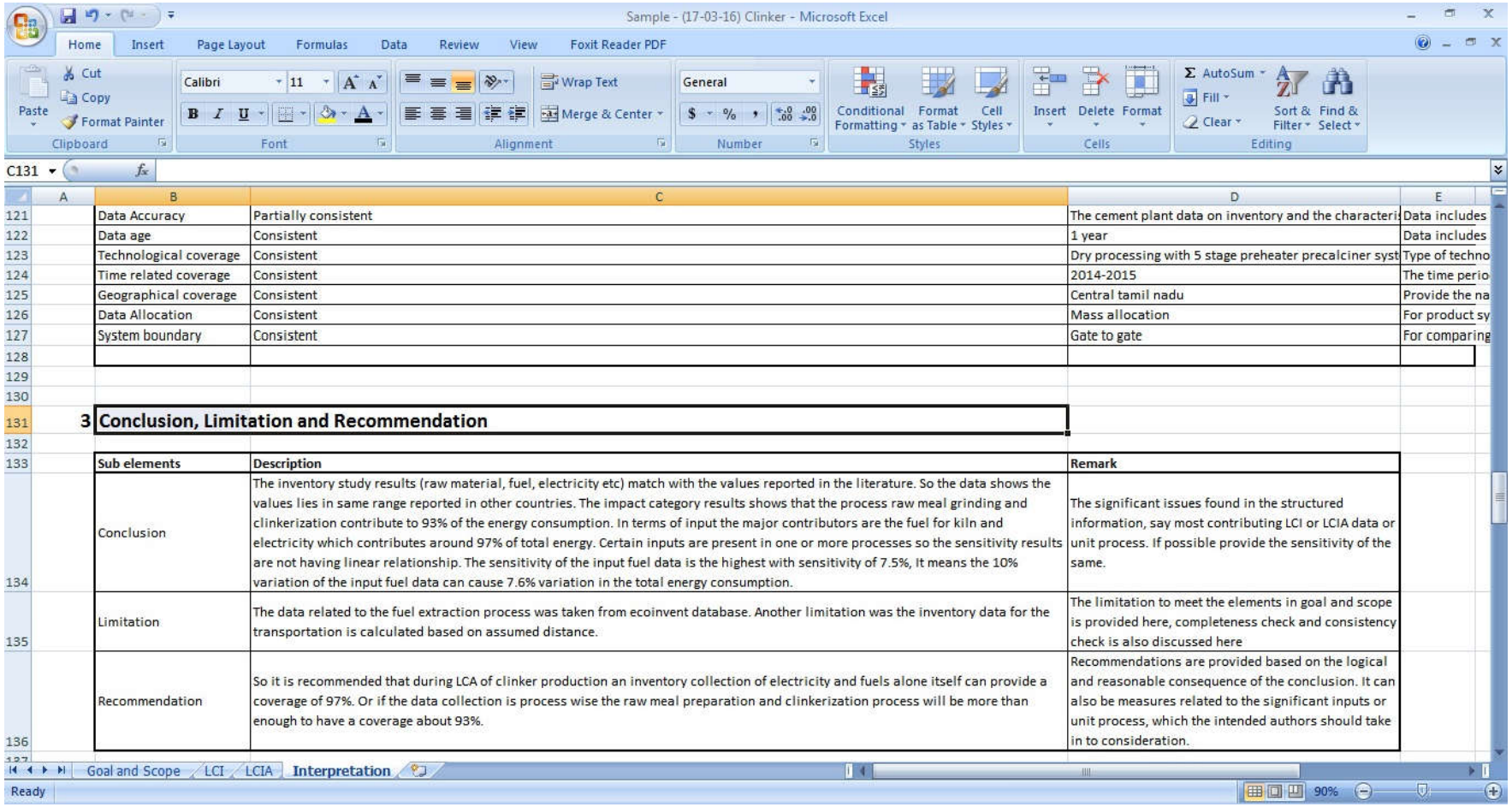


Interpretation, *(Continued)*

- 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

121	Data Accuracy	Partially consistent	The cement plant data on inventory and the characteris	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				

3 Conclusion, Limitation and Recommendation

Sub elements	Description	Remark
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.
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
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.

Interpretation

- 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 [1]. 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)

Interpretation

- Recommendation
  - It can be used in the estimation of embodied energy of different types of cement
  - If the required accuracy of the result is ±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