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Linear Colliders | CLIC & ILC LCA

Machine Componentry LCA Workshop with CERN and KEK

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9th April 2024

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Workshop objectives

By the end of the session, we want to:

- Identify machine componentry and granularity to be included in LCA
- Establish approach for data collection and inventory analysis
- Agree system boundaries and functional unit for assessment
- Agree LCIA methodology and tooling
- Establish outputs required

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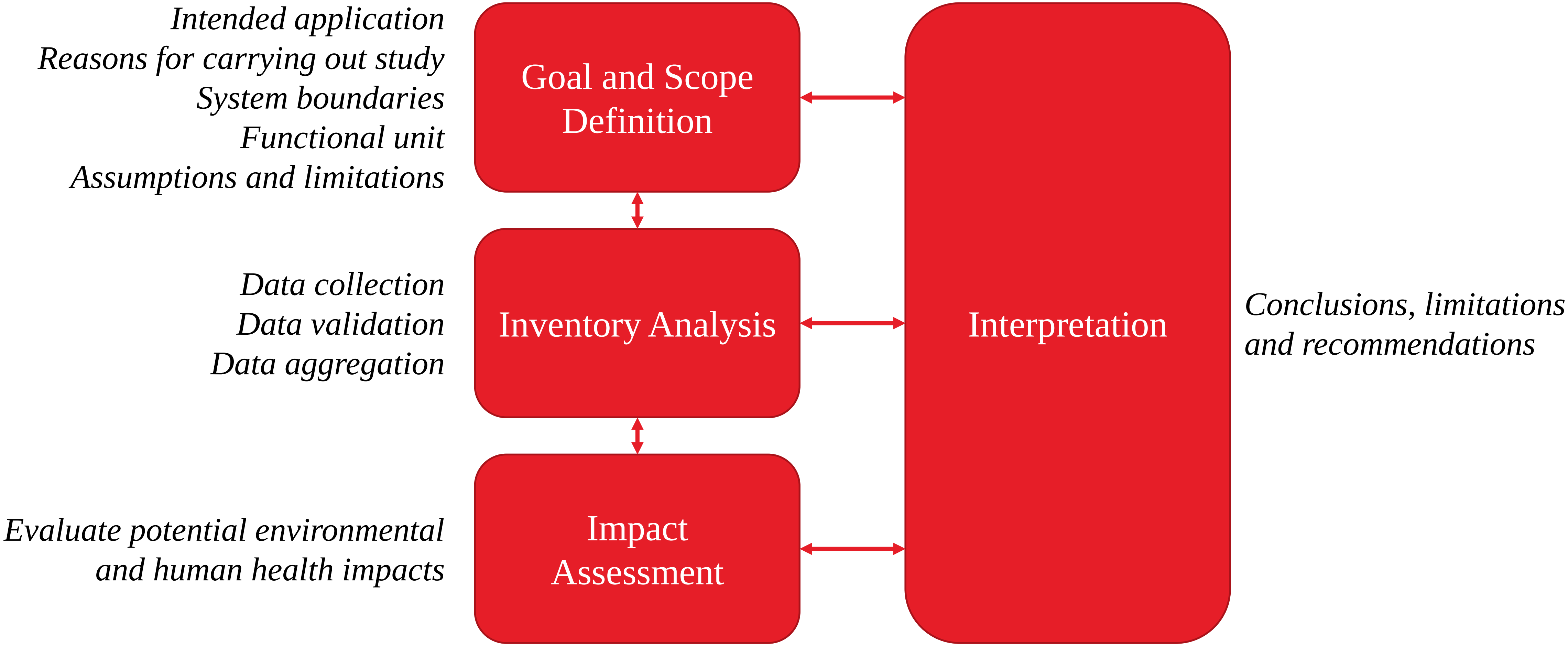
Workshop agenda

Section	Length	Time	Format
1. Introductions	10	14:00 – 14:10	
2. Machine componentry overview	30	14:10 – 14:40	CERN presentation
3. Presentation from Benno List on LCA work	10	14:40 – 14:50	CERN presentation
4. Phase 2 scope of work	10	14:50 – 15:00	Arup presentation
5. Summary of Phase 1 LCA and lessons learnt	15	15:00 – 15:15	Arup presentation
6. Approach for inventory analysis	15	15:15 – 15:30	Arup presentation
BREAK	15	15:30 – 15:45	
7. Data collection key questions	50	15:45 – 16:35	Discussion and activity
8. Impact assessment and results analysis	15	16:35 – 16:50	Arup presentation and discussion
9. Wrap-up and next steps	10	16:50 – 17:00	

Introductions

Phase 2 scope of work

Life Cycle Assessment Framework



ISO 14040:2006

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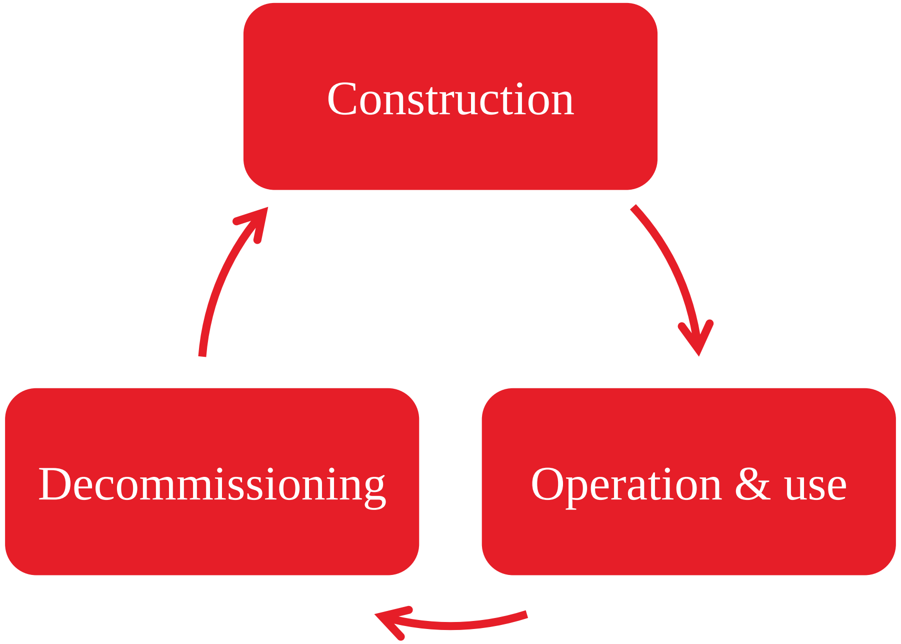
LCA Scope

Phase 2

- Whole life cycle assessment of the machine componentry for CLIC & ILC (Construction, operation & use, decommissioning)

- Embodied life cycle assessment of CLIC injector complex and CLIC & ILC tunnel services systems (Construction)



Programme

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__Note:__ Regular progress meetings are expected, especially during inventory analysis stage.

Receivable 1: Tunnel service systems information

Receivable 2: Detector high-level material quantities

Receivable 3: Draft machine componentry data collection

Receivable 4: Final machine componentry data collection

March | May | July | September | November

Goal and scope definition

- Pre-workshop preparation
- **Workshop at CERN**
- **Post-workshop creation of data collection template for agreement and dissemination**
- **Define LCIA methodology, database and tool**

Machine componentry Inventory analysis

- **Collation of data collection template responses**
- Refinement of assumptions, data requirements, outcome expectations and system boundaries
- **Creation of inventory list of machine componentry**

CLIC injector complex LCA

- **LCA of CLIC injector complex**
- Benchmarking and sensitivities

CLIC & ILC tunnel service systems LCA

- **LCA of tunnel service systems**
- Benchmarking and sensitivities

Impact assessment

- **Undertake impact assessment and analyse**

Interpretation

- **WLCA reporting, including Phase 1 LCA**
- Benchmarking and comparison
- **Environmental impact hotspots and reduction opportunities using PAS2080:2023**
- **Sensitivities analysis**
- Gap analysis for future assumptions refinement

Legend:

- **Machine component LCA**
- **CLIC injector complex and CLIC & ILC tunnel service systems LCA**

Deliverable 1: Draft data collection template for feedback

Deliverable 2: Final data collection template

Deliverable 3: LCWS2024 presentation

Deliverable 4: Summary slide deck CLIC injector complex and CLIC & ILC tunnel service systems LCA

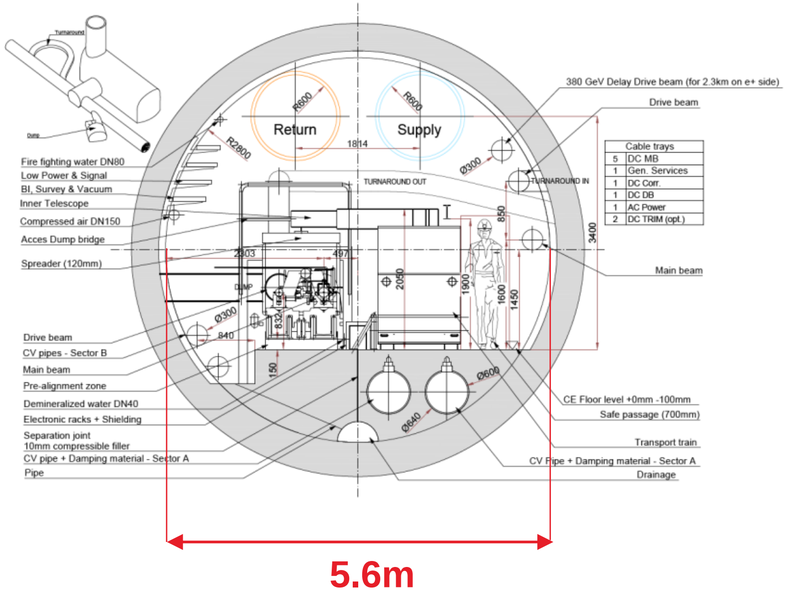
Deliverable 5: Comprehensive WLCA report

Phase 1 summary and lessons learnt

Linear collider options

CLIC Drive Beam

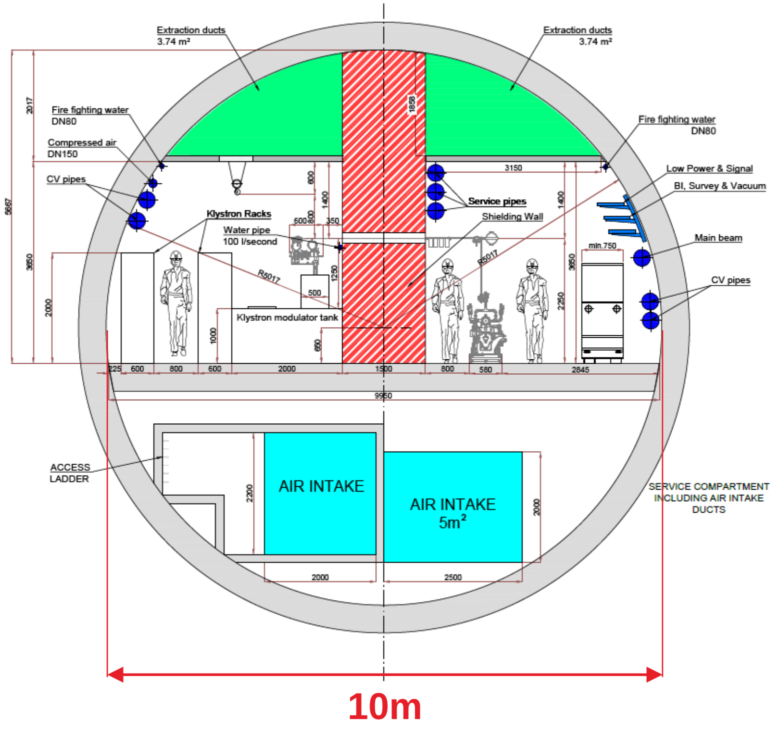
5.6m internal dia. Geneva.
(380GeV, 1.5TeV, 3TeV)



Reference: CLIC Drive Beam tunnel cross section, 2018

CLIC Klystron

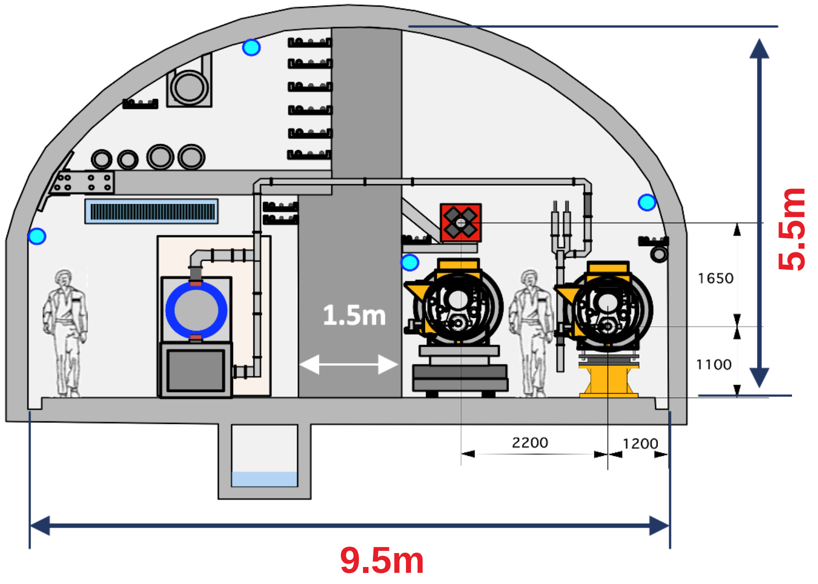
10m internal dia. Geneva.
(380GeV)



Reference: CLIC Klystron tunnel cross section, 2018

ILC

Arched 9.5m span. Tohoku region, Japan.
(250GeV)



Reference: Tohoku ILC Civil Engineering Plan, 2020

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Goal and Scope

- **Goal:** Evaluate the material and construction environmental impacts of the CLIC Drive Beam, CLIC Klystron and ILC, identifying hotspots and potential reduction opportunities.
- **Scope:** CLIC & ILC options (tunnels, caverns & access shafts).
- **Functional unit:** per km length
- **Methodology:** ReCiPe 2016 Midpoint (H) Method. Evaluates 18 environmental impact categories, including Global Warming Potential (GWP), using LCA tool is Simapro with Ecoinvent database.

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System boundaries

Before use stage [A0-A5]

- A0 Preliminary studies

Materials:
- **A1** Raw material supply
- **A2** Transport
- **A3** Manufacture

Transport & construction activities:
- **A4** Transport to works site
- **A5** Construction process

Use stage [B1-B8]

- B1 Use
- B2 Maintenance
- B3 Repair
- B4 Replacement
- B5 Refurbishment
- B6 Operational Energy Use
- B7 Operational Water Use
- B8 User utilisation of infrastructure

End of life stage [C1-C4]

- C1 Deconstruction/ Demolition
- C2 Transport for Disposal
- C3 Waste Processing for recovery
- C4 Disposal

Benefits and Loads beyond the system boundary [D]

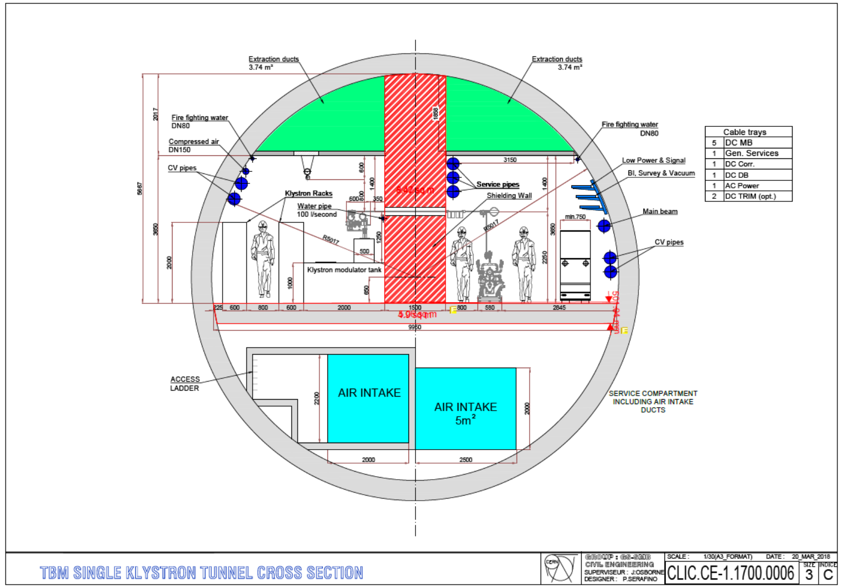
Reuse
Recycling

Benefits and loads of additional infrastructure functions

BS EN 17472:2022

Inventory analysis

- Data collected through design reports and drawings
- Assumptions provided by CERN and KEK in absence of information



Specification	5.6m TBM tunnel	10m TBM tunnel	3m beam turnaround	Caverns	Drive beam dump caverns	9m shafts	18 m shafts	12 m shafts
Precast concrete thickness, mm	300	450	-	-	-	-	-	-
Precast concrete compressive strength, MPa	50	50	-	-	-	-	-	-
Grout lining thickness, mm	100	150						
Steel fibre density per vol. concrete, kg/m^3	35	35	-	-	-	-	-	-
Rebar density, kg/m^3	80	80	-	-	-	-	-	-
Shotcrete thickness, mm	-	-	200	400	200	300	500	400
Shotcrete compressive strength, MPa	-	-	30	30	30	30	30	30
Shotcrete rebar density per vol. concrete, kg/m^3	-	-	60	55	55	20	50	50
Rock bolting length (grid layout), m	-	-	2.5m (3 x 3 m)	10m (3 x 3 m)	10m (3 x 3 m)	7m (3 x 3 m)	7m (3 x 3 m)	7m (3 x 3 m)
In-situ concrete lining thickness, mm	-	-	200	110	45	300	600	500
In-situ compressive strength, MPa	-	-	40	40	40	40	40	40
In-situ rebar density per vol. concrete, kg/m^3	-	-	100	120	120	60	130	110

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Data Hierarchy

System	Sub-system	Components	Sub-components
CLIC Drive Beam 380GeV			
	Tunnels		
		Main accelerator tunnel	
			Primary Lining Permanent Lining Invert
		Turnarounds	
			Primary Lining Permanent Lining Invert
	Shafts		
		9-18m dia.	
			Primary Lining Permanent Lining
	Caverns		
		BDS, UTRC, UTRA, BC2, DBD, service cavern, IR cavern, detector and service hall	
			Primary Lining Permanent Lining

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2030 Baseline assumptions

<table>
<tr><th colspan="2">Construction LCA</th><th>CLIC Drive Beam</th><th>CLIC Klystron</th><th>ILC</th></tr>
<tr><td colspan="2">Materials</td><td colspan="3">Concrete (CEMI) & Steel (80% recycled)</td></tr>
<tr><td colspan="2">Transport of materials to site</td><td colspan="2">Concrete: Local by road (50km)
Steel: European by road (1500km)</td><td>Concrete: Local by road (50km)
Steel: National by road (300km)</td></tr>
<tr><td rowspan="4">Construction activities</td><td>Material wasted in construction</td><td colspan="3">Concrete insitu: 5%
Precast concrete: 1%
Steel reinforcement: 5%</td></tr>
<tr><td>Transport of disposal materials off site</td><td colspan="3">Concrete and steel recycling: 30km by road
Concrete and steel landfill: 30km by road
Spoil: 20km by road
Assumed that 90% of EoL construction materials are recycled or repurposed and 10% is in landfill.</td></tr>
<tr><td>Construction process</td><td colspan="2">Tunnel Boring Machine (TBM)</td><td>Drill & Blast* *Explosives excluded due to lack of data</td></tr>
<tr><td>Electricity mix 2021/2022</td><td colspan="2">Fossil: 12%
Non-fossil: 88%</td><td>Fossil: 71%
Non-fossil: 29%</td></tr>
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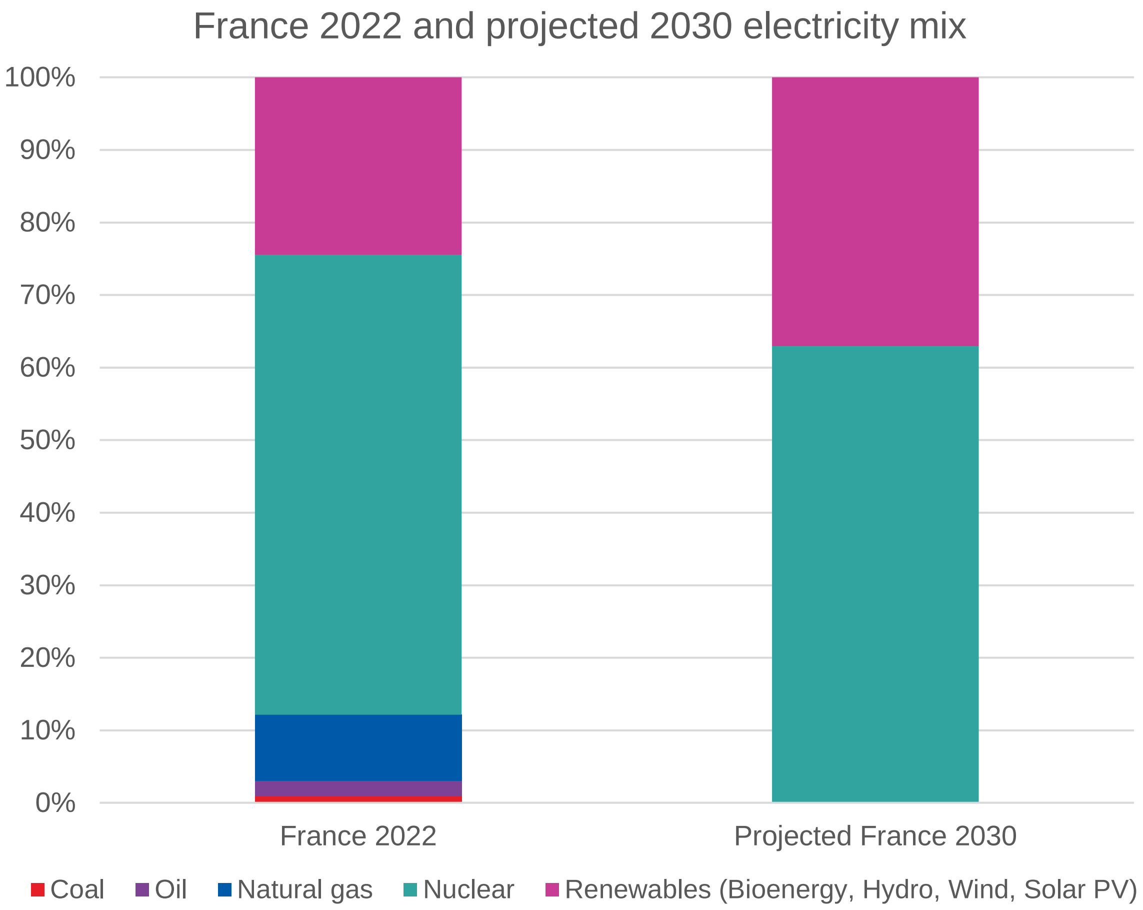
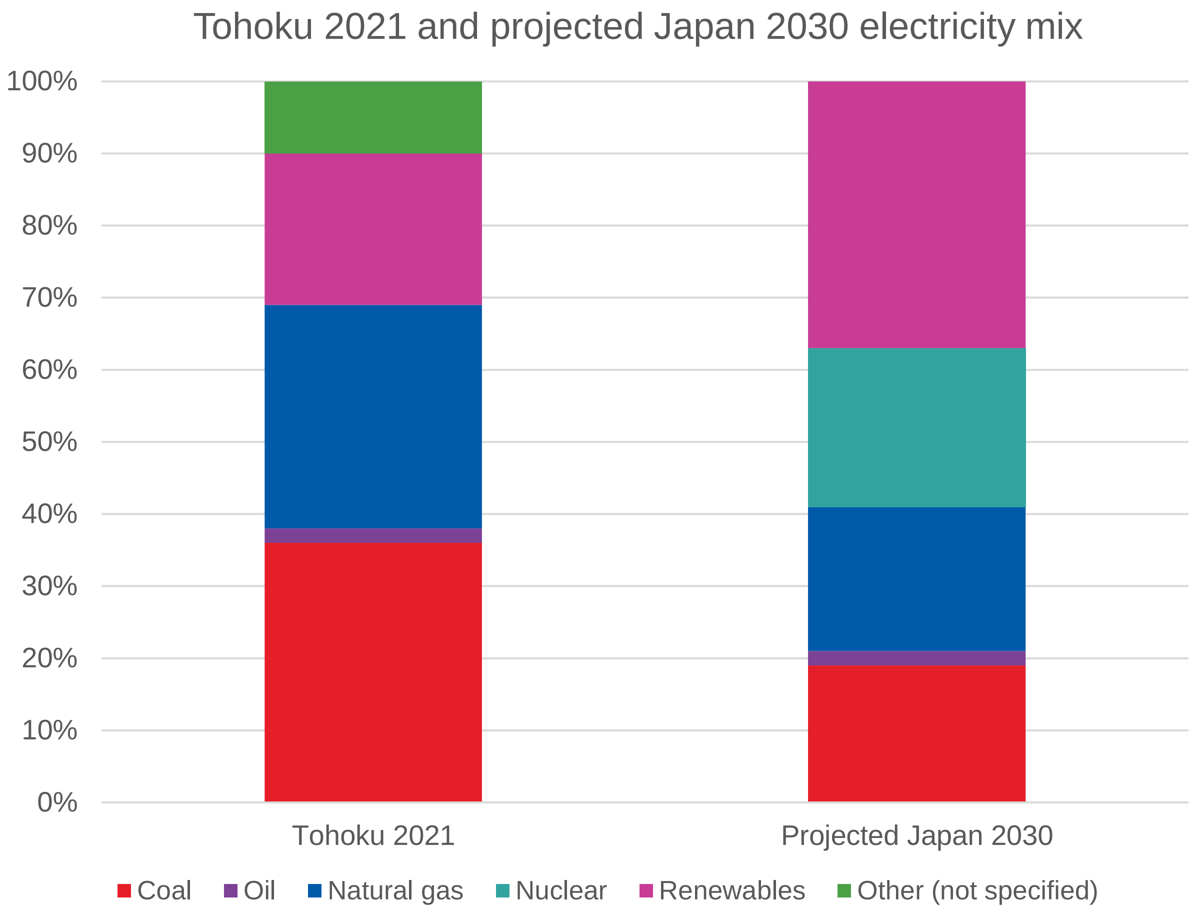
Baseline and projected electricity mix

CLIC & ILC





Reference: Our World in Data, France 2022

Reference: Energy pathways 2050 key results, RTE 2021

Reference: Tohoku Electric Power Supply, 2021

Reference: 6th Strategy Energy Plan, METI 2021

Lessons learnt

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- Determine key differences in material, transport and construction methodologies for CLIC & ILC supply chain and geographies
- Agree assumptions for both CLIC & ILC at the start so that immediate feedback can be given if there are discrepancies between them
- Use same LCIA methodology for CLIC & ILC options to enable fair comparison
- Evaluate results with a functional unit (for tunnels this is per km length)
- Granular hot spotting to identify carbon reduction opportunities
- Compare magnitude of results against other metrics (e.g. operational)

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Approach for inventory analysis

Inventory analysis approach

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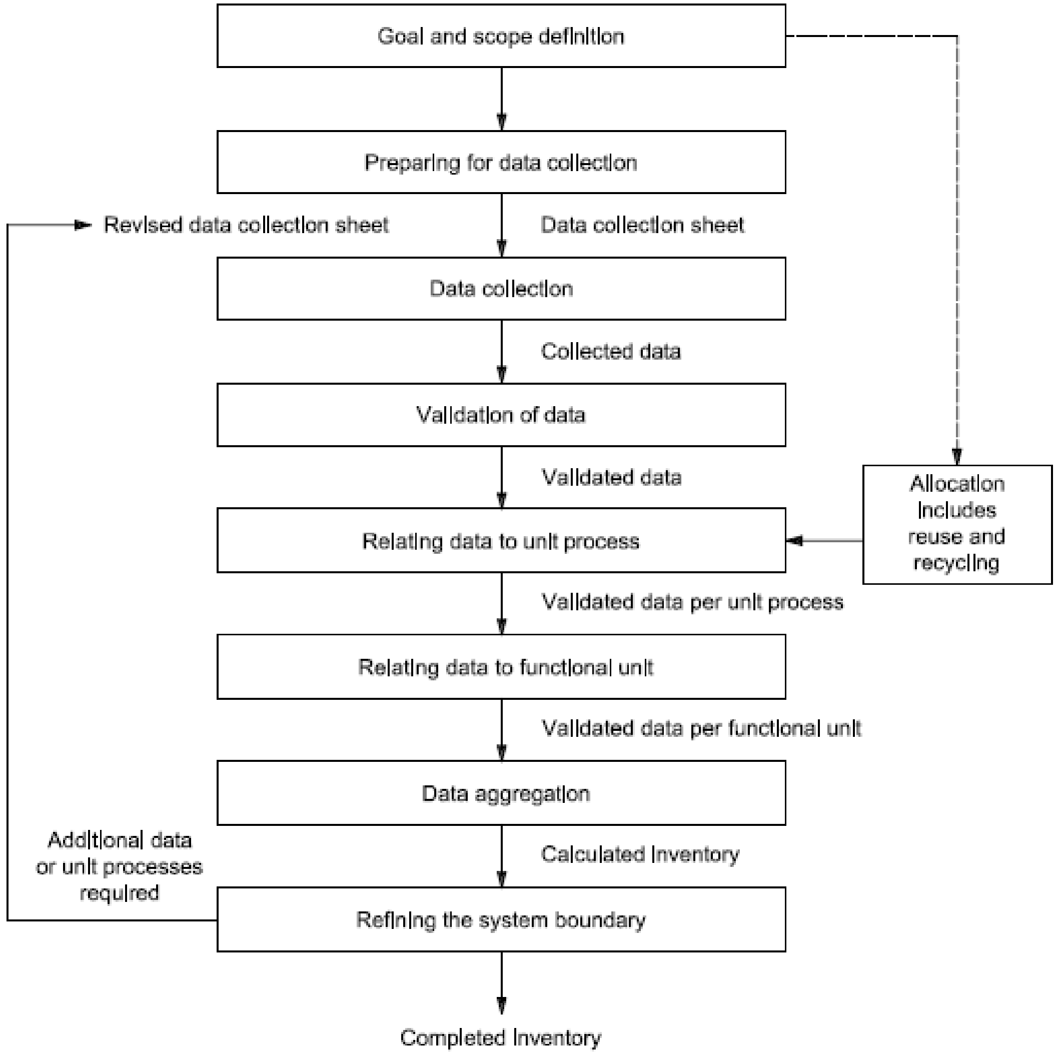

Procedure for inventory analysis
(ISO 14044:2006)

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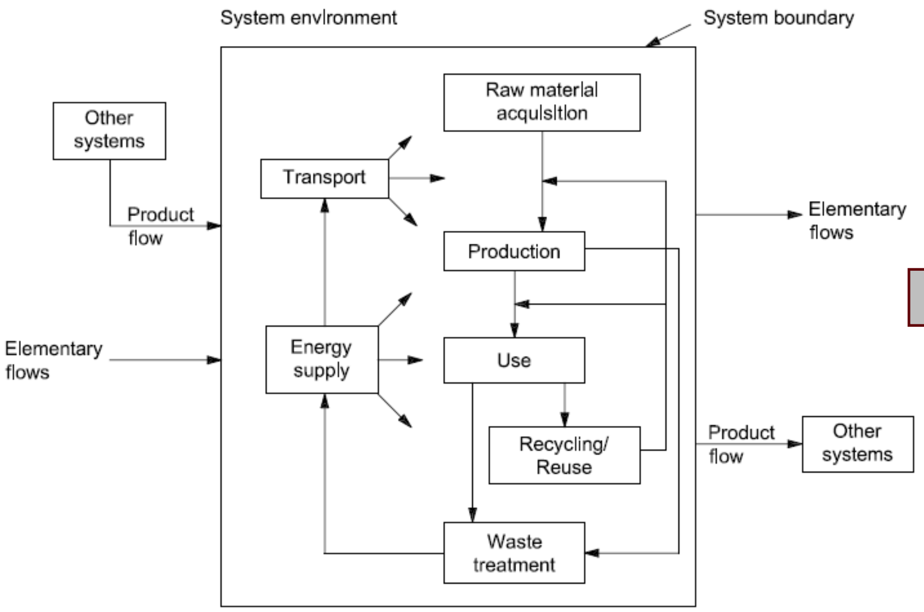
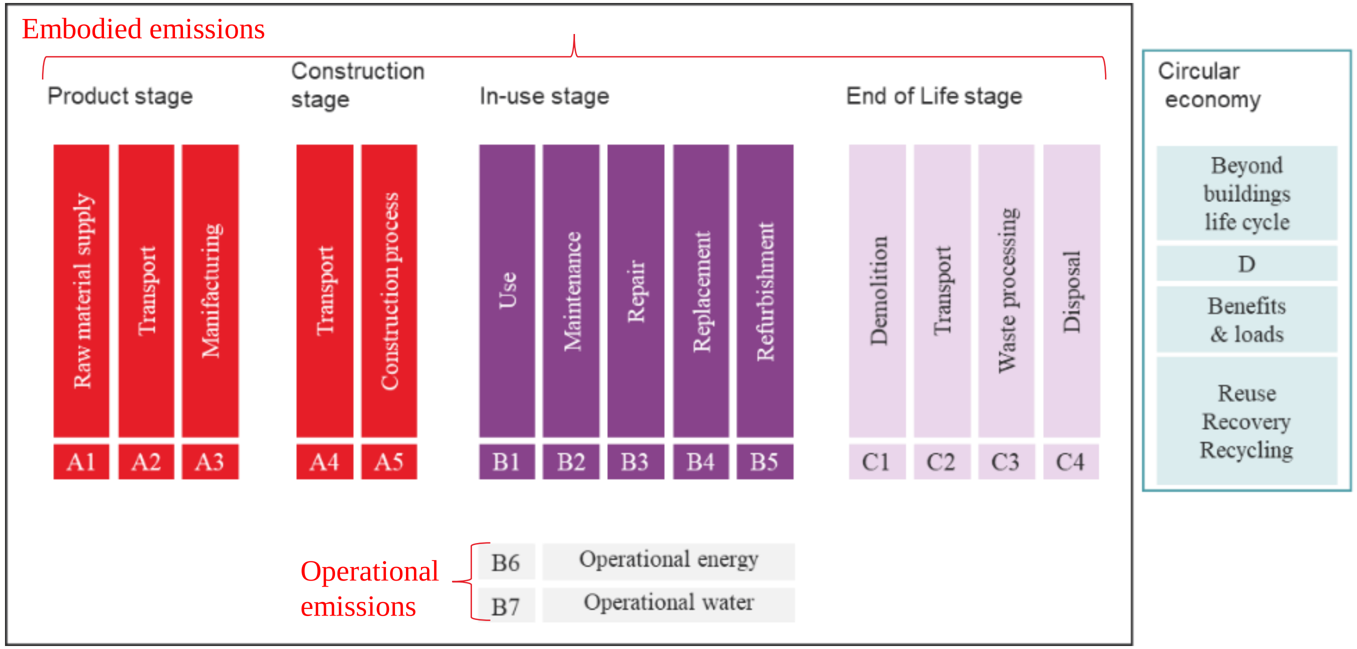
Product LCA system



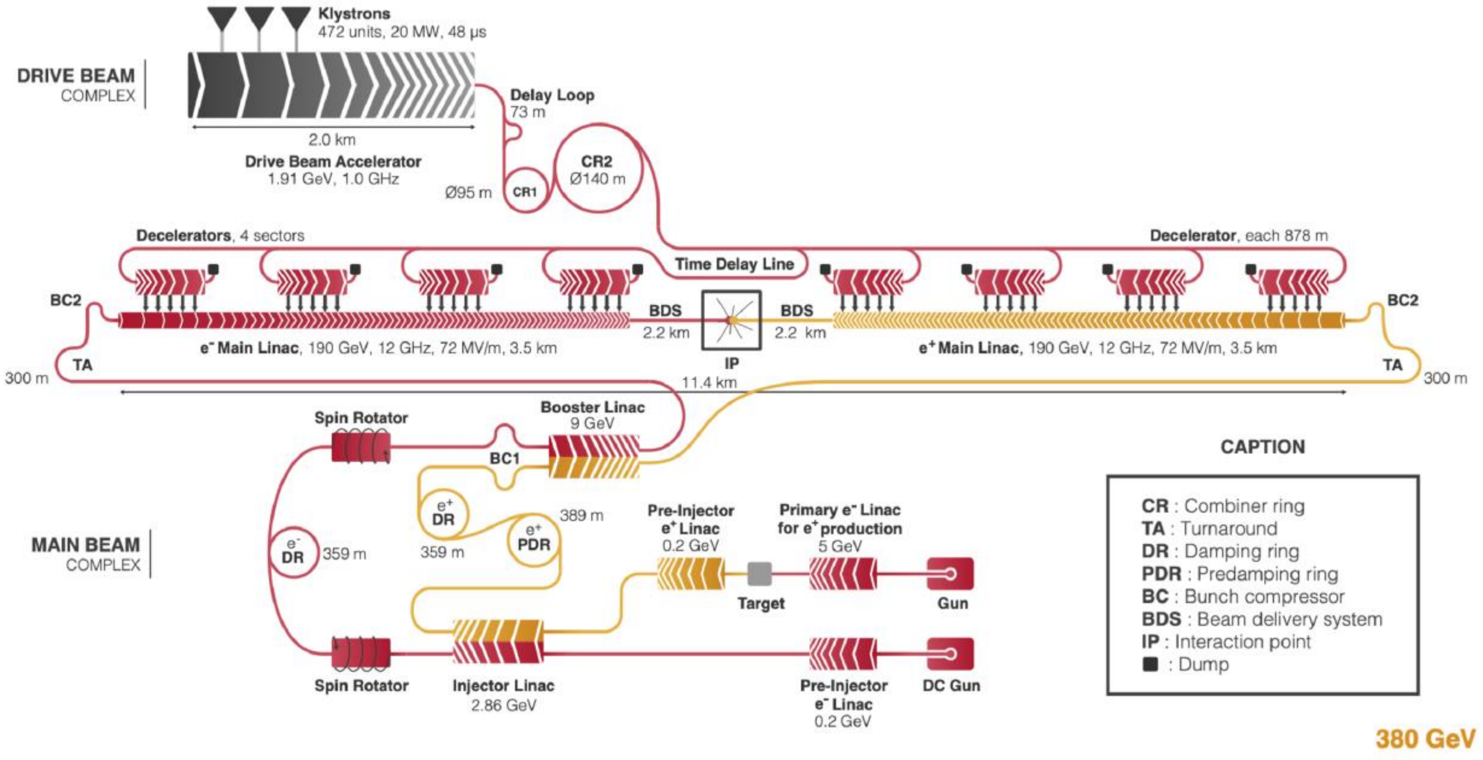
Example of product system for LCA (ISO 14040:2006)



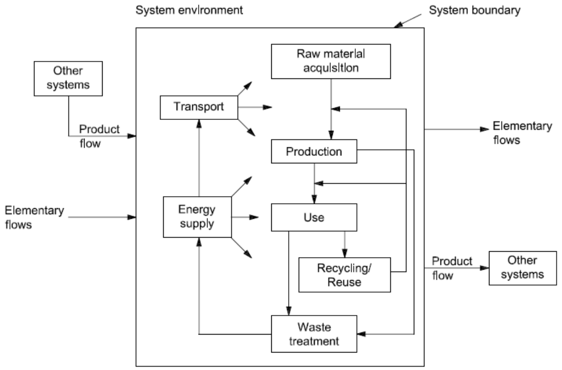
EN 15804:2012+A2:2019

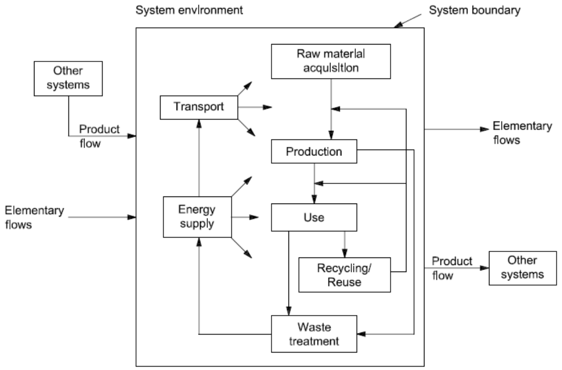
Inventory analysis

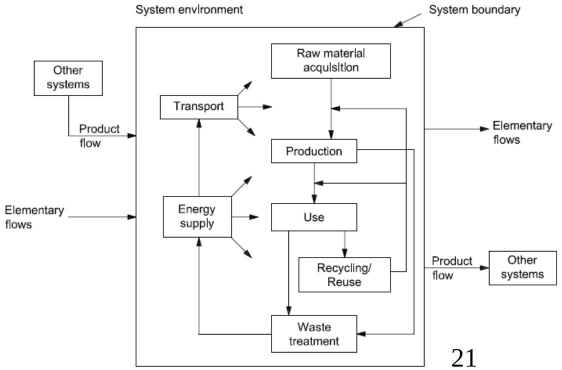
Identification of products (components)



Schematic layout of the CLIC complex at 380 GeV. The CLIC project. Brunner et al. 2022







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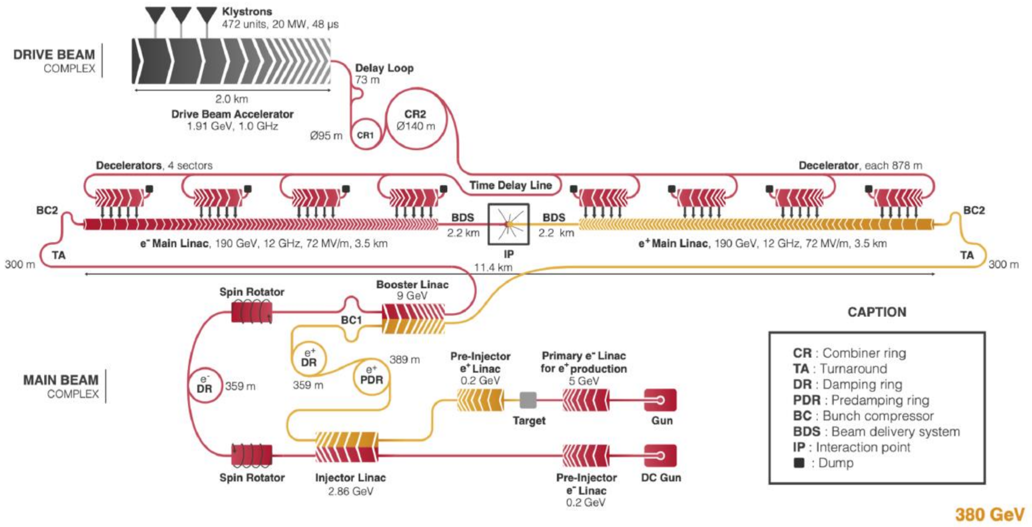
Inventory analysis

Identification of products (components) – finding a suitable categorisation



Domain	Sub-Domain	Cost [MCHF] Drive-beam	Cost [MCHF] Klystron
Main-Beam Production	Injectors	175	175
	Damping Rings	309	309
	Beam Transport	409	409
Drive-Beam Production	Injectors	584	—
	Frequency Multiplication	379	—
	Beam Transport	76	—
Main Linac Modules	Main Linac Modules	1329	895
	Post decelerators	37	—
Main Linac RF	Main Linac Xband RF	—	2788
Beam Delivery and Post Collision Lines	Beam Delivery Systems	52	52
	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
Civil Engineering	Civil Engineering	1300	1479
Infrastructure and Services	Electrical distribution	243	243
	Survey and Alignment	194	147
	Cooling and ventilation	443	410
	Transport / installation	38	36
Machine Control, Protection and Safety systems	Safety systems	72	114
	Machine Control Infrastructure	146	131
	Machine Protection	14	8
	Access Safety & Control System	23	23
Total (rounded)		**5890**	**7290**

Schematic layout of the CLIC complex at 380 GeV. The CLIC project. Brunner et al. 2022

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Data collection

Requirements

Where applicable (depending on life cycle stage and component):

- Energy inputs
- Raw material inputs and resources
- Products
- Waste
- Emissions to air and discharges to water and soil

Data collection inputs (ISO 14040:2006)

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Data collection

Level of detail, inclusions/exclusions

Cut-off criteria can be defined based on:

- Mass
- Energy
- Environmental significance

Example from construction works/products (EN 15804+A2:2019): 1% cut-off criteria based on mass/energy per process or 5% per life cycle module

Data collection template

Format of data collection

Component /assembly name	Drive beam complex
Date of completion	
Contact person	
Telephone	
E-Mail	
Quantitative reference and unit	1 item, technical characteristics? Physical characteristics (weight)?

Production stage	DESCRIPTION: The drive beam complex includes injectors abd components for frequency multiplication				
Inputs	**Amount**	**Unit**	**Origin (Country)**	**Data source**	**Notes**
Energy					
Electricity	1	kWh	Switzerland	Measurement	Electricity for production of component X
Natural gas	1	MJ	Switzerland	Expert judgement	Total gas consumption for drive beam complex production
Electricity	1	kWh	Asia	Supplier	Electricity for production of component X
Materials					
Steel	1	kg	France	Expert judgement	
Copper	1	kg	France	Measurement	
Aluminium	1	kg	China	Measurement	
Tin	5% overall weight	kg		Expert judgement	
Plastics	1	kg	Europe	Measurement	
Resources					
Water	1	l	Switzerland		
Packaging					
Plastics					
Wood pallets					
Outputs	**Amount**	**Unit**	**Source of emissions**	**Data source**	**Notes**
Emissions to air					
Carbon dioxide					
Emissions to water					
Emissions to soil					

- Data collection template structure to be agreed with CERN, e.g. one data sheet for each key component component
- Data for (sub-)components can be aggregated/disaggregated depending on data availability and desired analysis/visualisation of results

Break (15 mins)

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Data collection key questions

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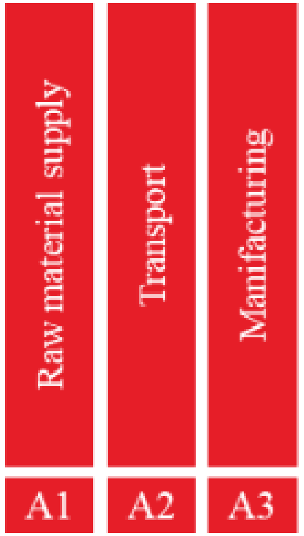
Data hierarchy – Machine componentry

System	Sub-system	Components	Sub-components
CLIC Drive Beam 380GeV / ILC 250GeV			
	Tunnels		
		Main linac modules	
			Main linac modules Post decelerators ? ? ?
	Shafts		
	Caverns		

Data collection

Production stage



Key questions:

- Where are the machine components manufactured?
- Are you able to identify the materials of the different components (by weight or % on total weight)?
- Will you be able to collect data on energy used and/or production steps to manufacture the components?
- Will you have any information on packaging and waste during manufacturing?

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Data collection

Construction stage

Key questions:

- How are the machine components transported?
- Does installation of the components require energy or ancillary materials?

Data collection

Use and maintenance

Key questions:

- Are there any emissions occurring during the use of the machines (e.g. refrigerant leakage)?
- What are the main activities to maintain the machines? How often do they occur?
- What is the assumed service life of CLIC and ILC?
- What is the service life of the machine components? Are there parts replaced on a yearly basis?

Data collection

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Operational energy and water

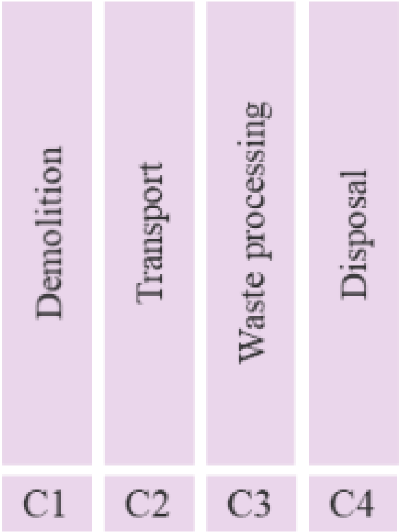
B6	Operational energy
B7	Operational water

Key questions:

- What are the sources of energy needed for the machines? What % is renewables?
- What is the first year of operation and assumption for future energy mix?
- What is the operational period per annum?
- Is energy consumption available for the whole machine operation? Is it meaningful to split the energy consumption per component or operation phase?
- Is any water input required for the functioning the machine?

Data collection

End of life



Key questions:

- Can the machine components be selectively dismantled?
- Disposal of hazardous or radioactive waste?
- Would you expect that machine components can be reused? If so, to what extent?
- Would you be able to make assumption on end of life pathways of machine components (incineration, recycling, landfilling)?
- Can we assume that the components will be disposed of/treated in Geneva/Northern Japan?

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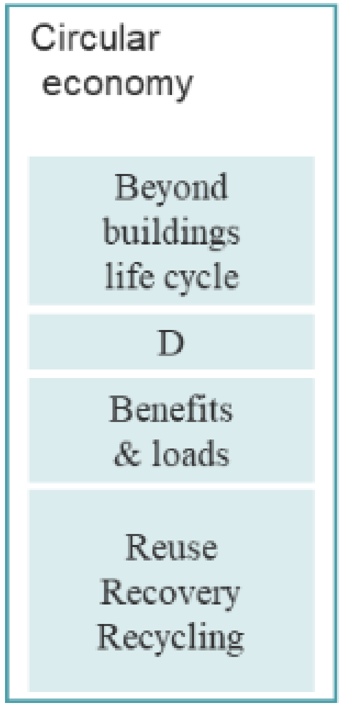
Data collection

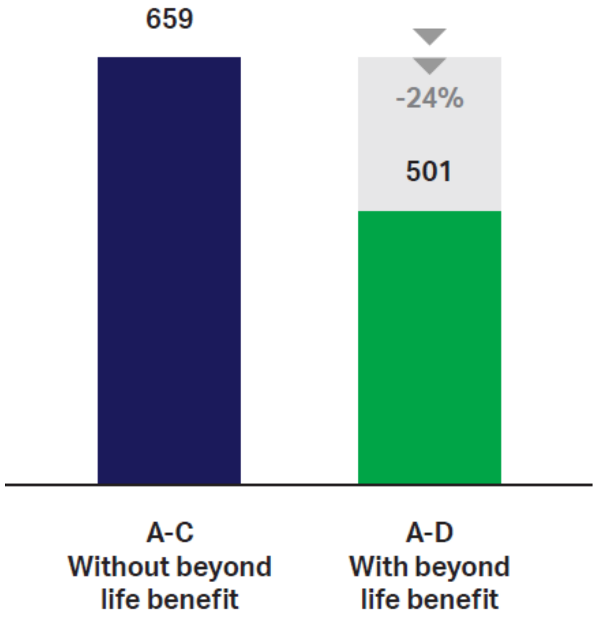
Benefits and loads beyond the system boundaries – Module D



Key aspects:

- Benefits for avoiding production of virgin raw materials/products thanks to reuse and recycling
- Benefits for avoiding production of energy (e.g. electricity, heat) thanks to thermal valorisation of waste (e.g. wood waste)

Whole life carbon example with and without module D [kg CO2e/m²]



Arup, WBCSD. Net-zero buildings. Where do we stand? (2021)

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Machine componentry system boundaries

Before use stage [A0-A5]	Use stage [B1-B8]	End of life stage [C1-C4]	Benefits and Loads beyond the system boundary [D]
A1 Raw material supply	B1 Use	C1 Deconstruction/ Demolition	Reuse Recycling
A2 Transport	B2 Maintenance	C2 Transport for Disposal	*Benefits and loads of additional infrastructure functions*
A3 Manufacture	B3 Repair	C3 Waste Processing for recovery	
A4 Transport to works site	B4 Replacement	C4 Disposal	
A5 Construction process	B5 Refurbishment		
	B6 Operational Energy Use		
	B7 Operational Water Use		

EN 15804:2012+A2:2019

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Functional unit

- What functional unit is most useful for comparison between CLIC and ILC machine components? E.g.
  - CO_2e/m
  - CO_2e/year operation

- What is a suitable reference period for the calculation of impacts (linked to service life of machines)?

Wrap-up and next steps

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