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Whole life cycle assessment approach for linear colliders

International Workshop on Future Linear Colliders 2024

Suzanne Evans
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Decarbonisation context

Annual CO_2 emissions by world region

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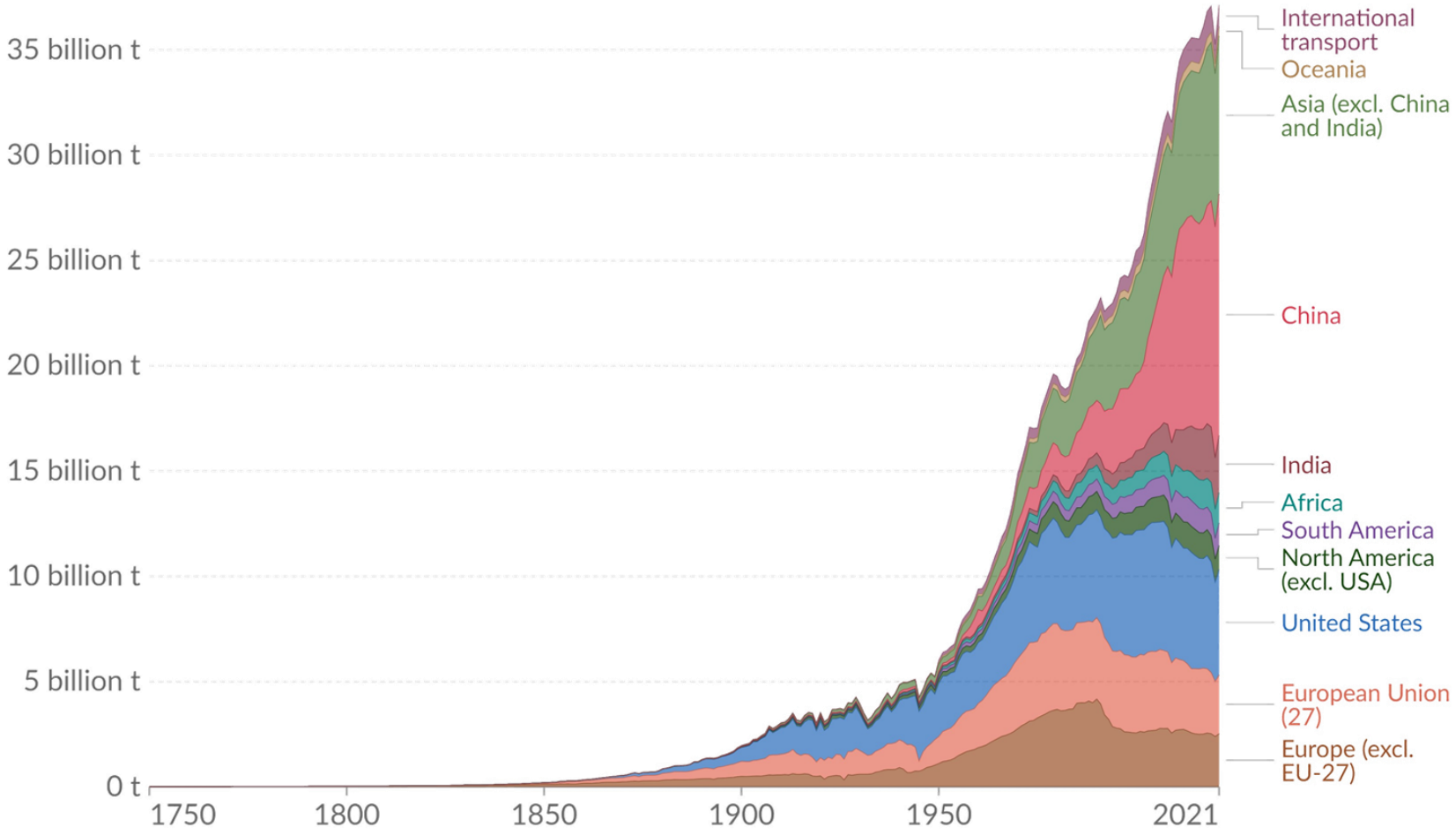
To limit global warming to 1.5°C (relative to 1900), the estimated remaining carbon budget from the beginning of 2020 is **< 300 billion t** https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

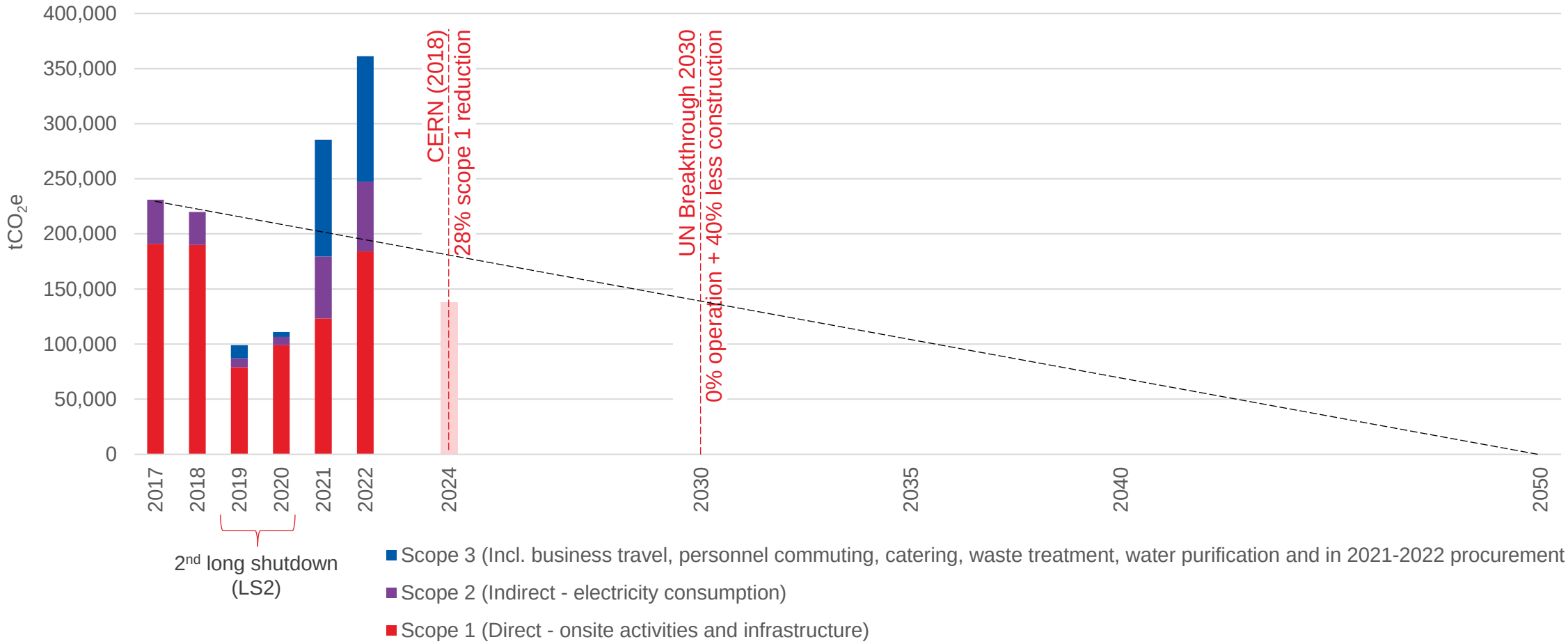


Data source: Global Carbon Budget (2022)

OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

What is required for net zero 2050?

Future decarbonisation of CERN



Reference: CERN Environment Report 2021-2022

What is required for net zero 2050?

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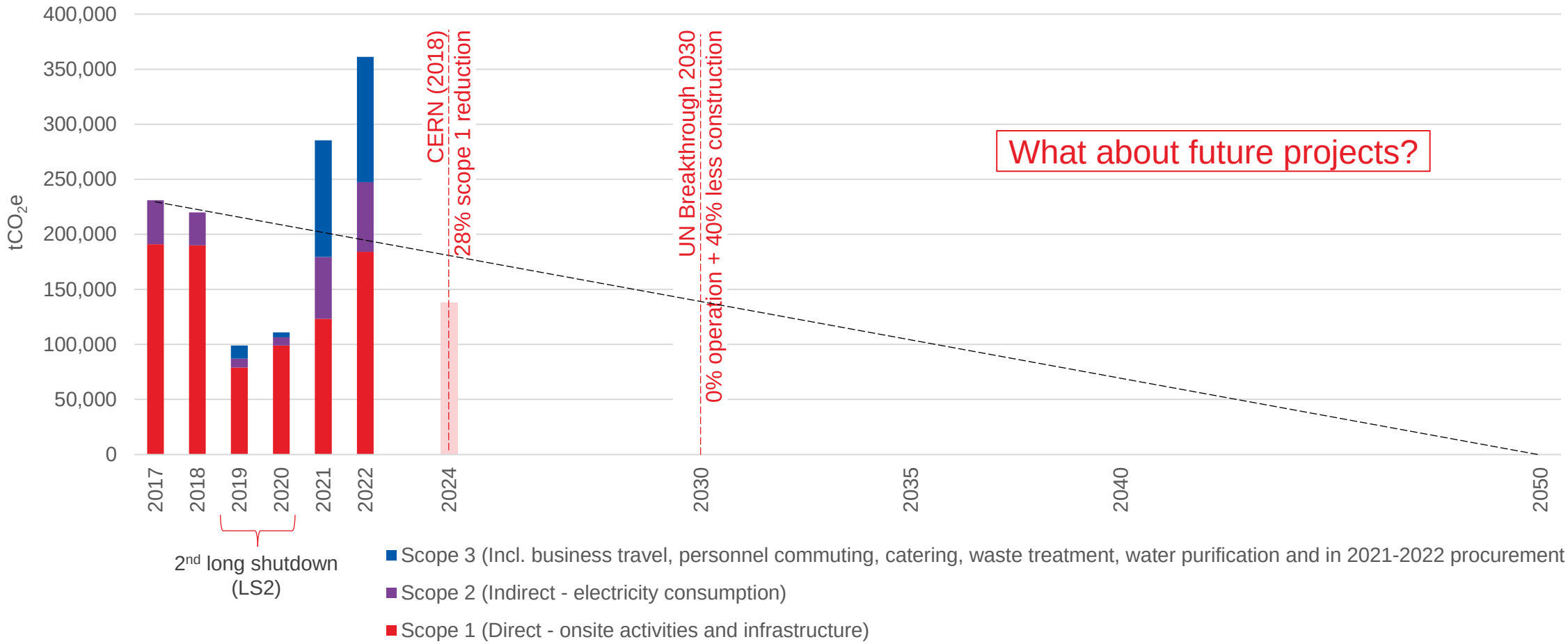
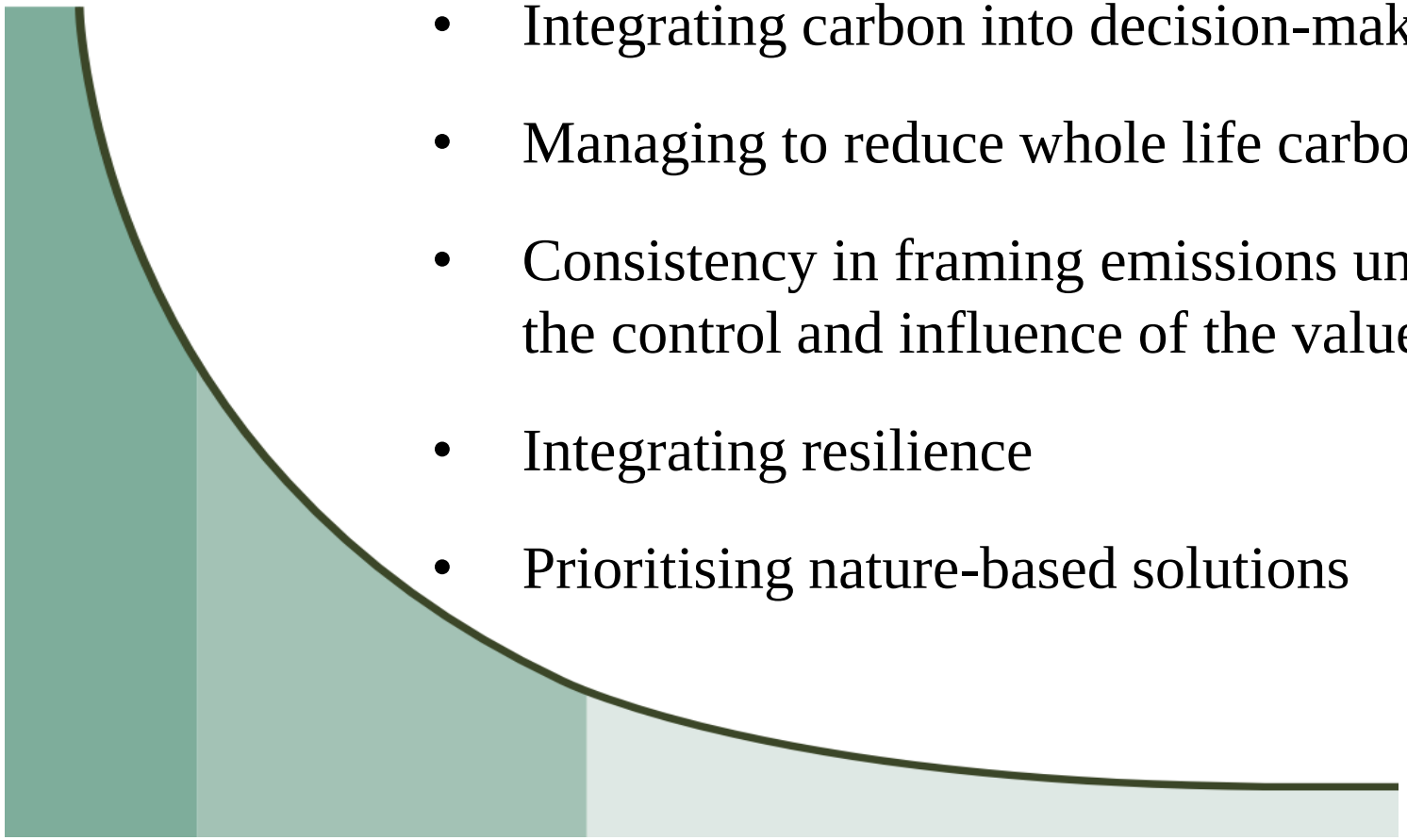


Reference: CERN Environment Report 2021-2022

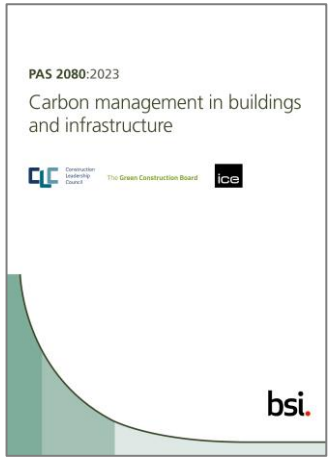
Managing to reduce whole life carbon

Accelerating decarbonisation

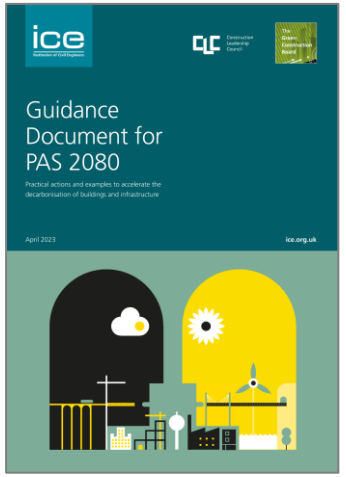
PAS2080:2023 Carbon management in buildings and infrastructure



- Integrating carbon into decision-making
- Managing to reduce whole life carbon
- Consistency in framing emissions under the control and influence of the value chain
- Integrating resilience
- Prioritising nature-based solutions



https://www.bsigroup.com/en-GB/standards/pas-2080/



https://www.ice.org.uk/engineering-resources/briefing-sheets/guidance-document-pas2080

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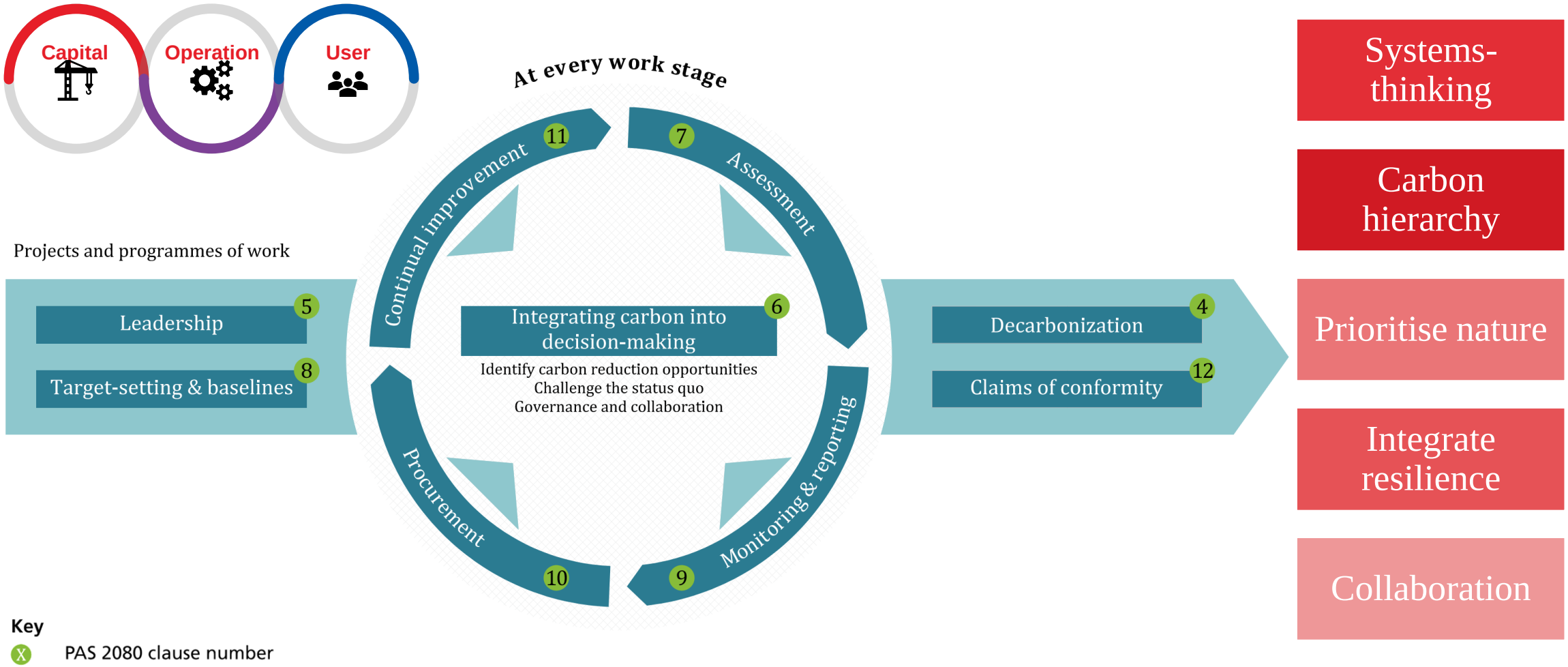
Carbon management process

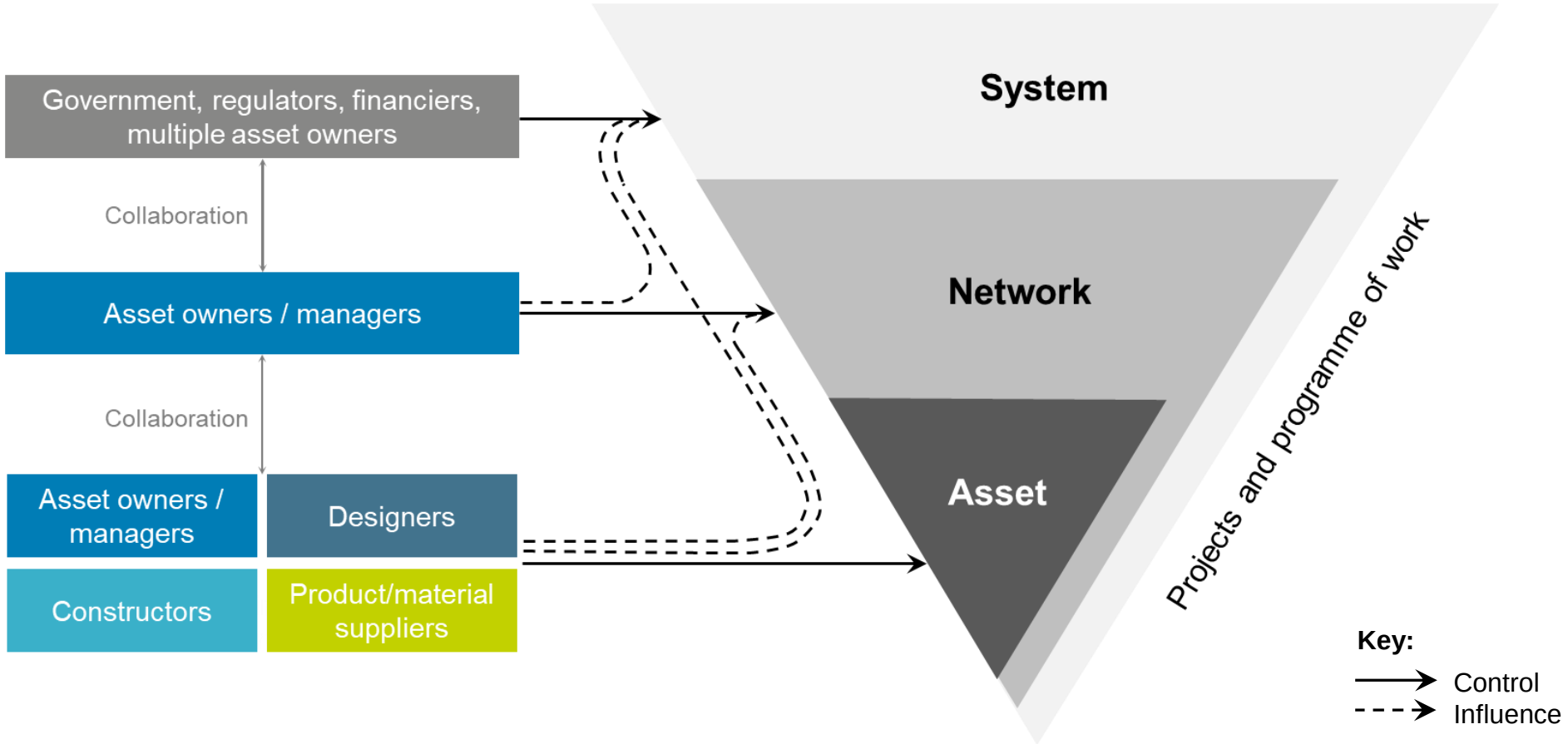
PAS2080:2023



PAS 2080: 2023 Carbon management in buildings and infrastructure: https://www.bsigroup.com/en-GB/standards/pas-2080/

Control and influence

Systems decarbonisation



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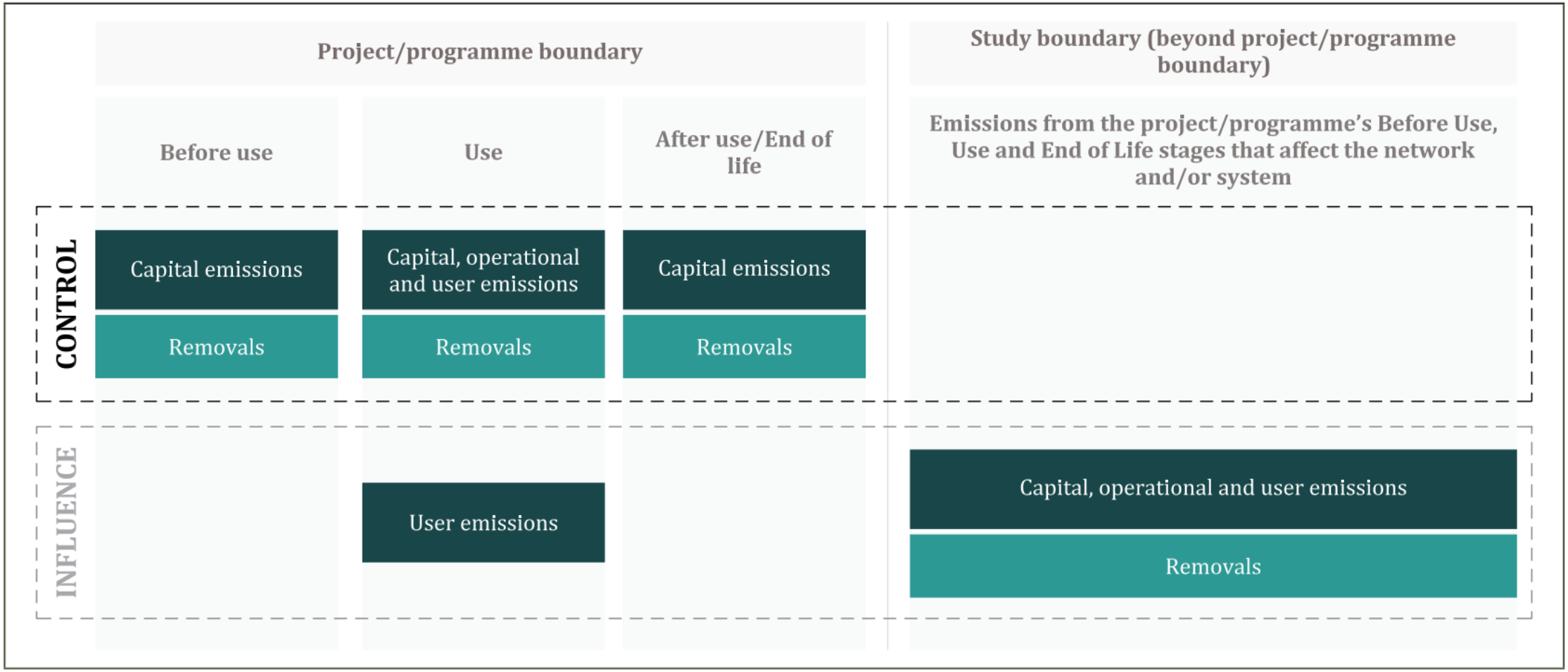
Control and influence

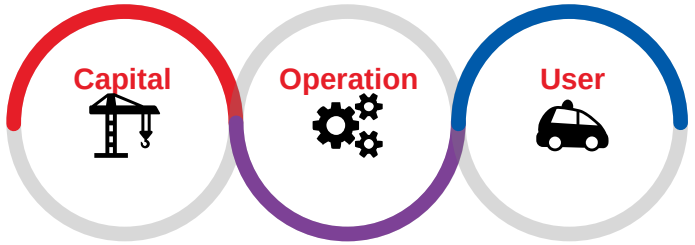
Systems decarbonisation

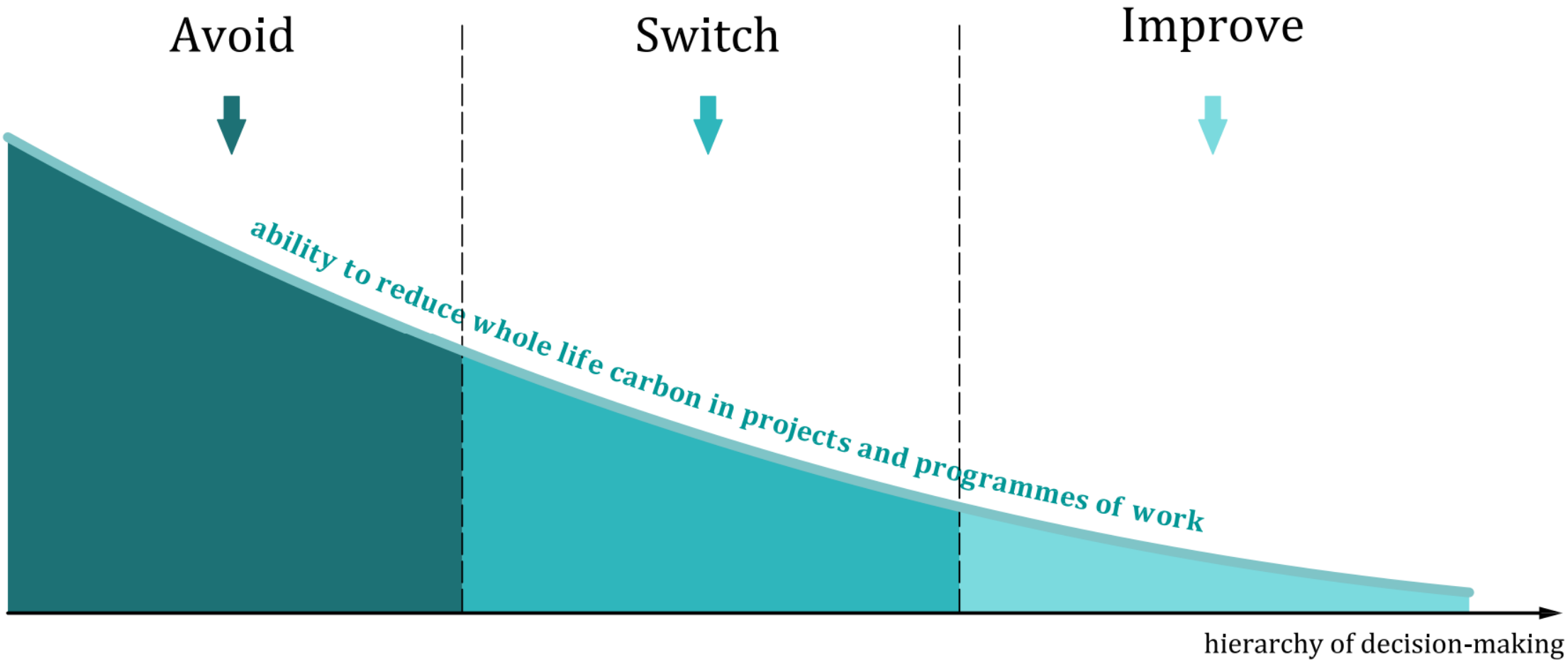


PAS 2080: 2023 Carbon management in buildings and infrastructure: https://www.bsigroup.com/en-GB/standards/pas-2080/

Carbon reduction hierarchy

Prioritise meaningful decarbonisation





PAS 2080: 2023 Carbon management in buildings and infrastructure: https://www.bsigroup.com/en-GB/standards/pas-2080/

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Life cycle assessment of CLIC and ILC

Phase 1

ARUP: Suzanne Evans, Yung Loo, Heleni Pantelidou, Ben Castle, Jin Sasaki
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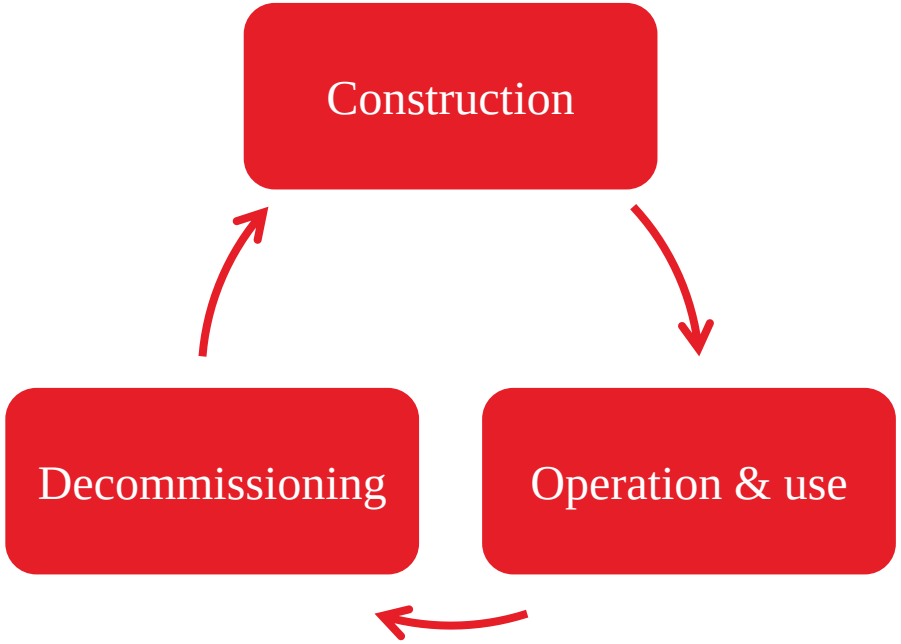
KEK: Nobuhiro Terunuma, Akira Yamamoto, Tomoyuki Sanuki

Life cycle assessment

A life cycle assessment systematically assesses the environmental impact of a product or asset throughout its life cycle



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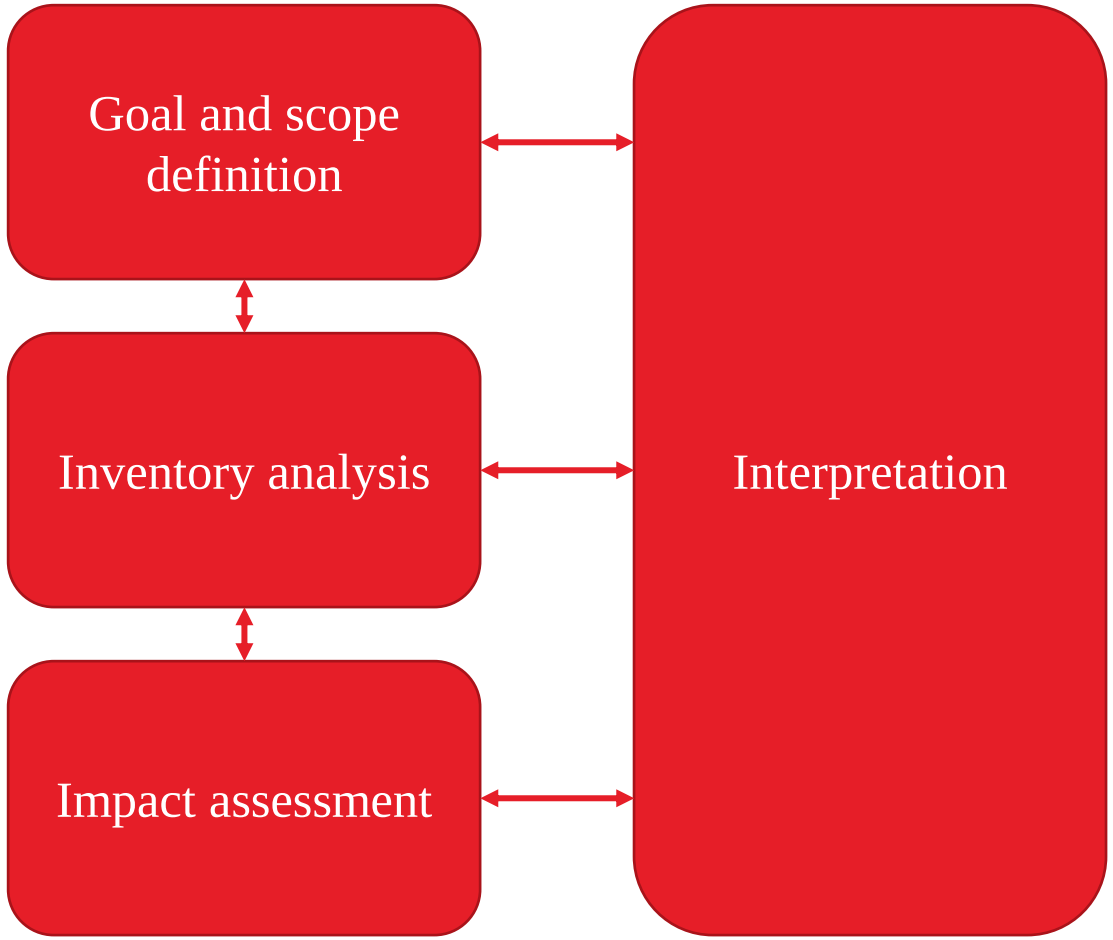
Life cycle assessment

Intended application
Reasons for carrying out study
System boundaries
Assumptions and limitations

Data collection
Data validation
Data aggregation

Evaluate potential environmental and human health impacts



Conclusions, limitations and recommendations

ISO 14040:2006

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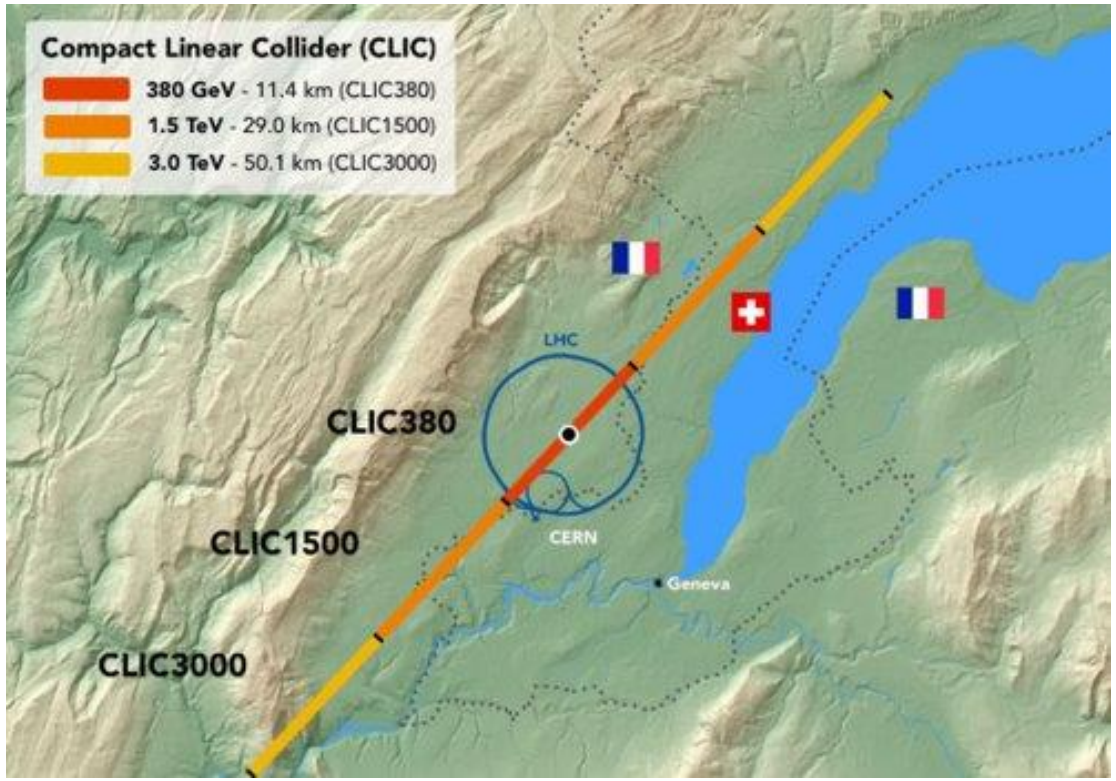
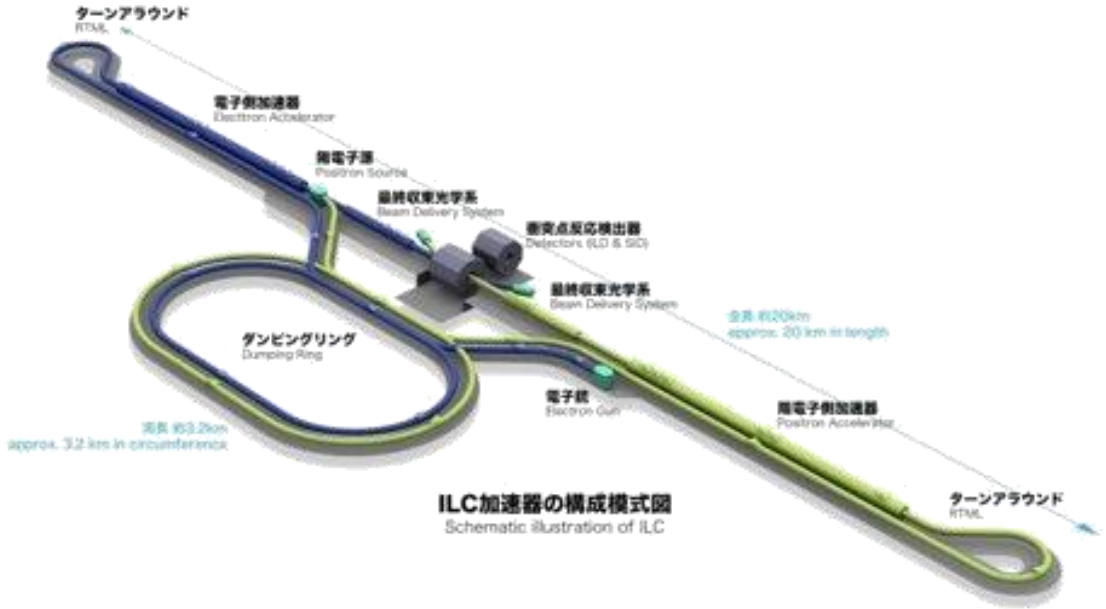
Linear collider options

Compact Linear Collider (CLIC)

a) Drive Beam b) Klystron



International Linear Collider (ILC)

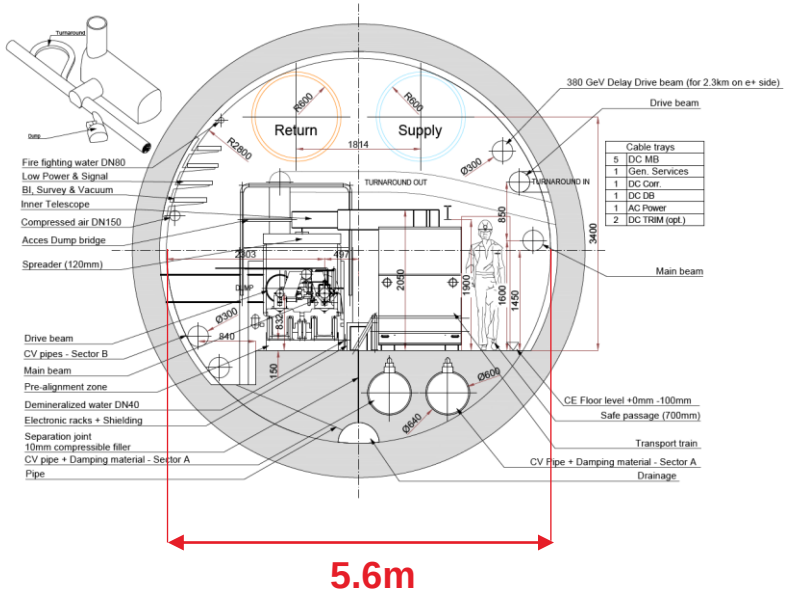


Proposed construction 2030

Linear collider options

CLIC Drive Beam

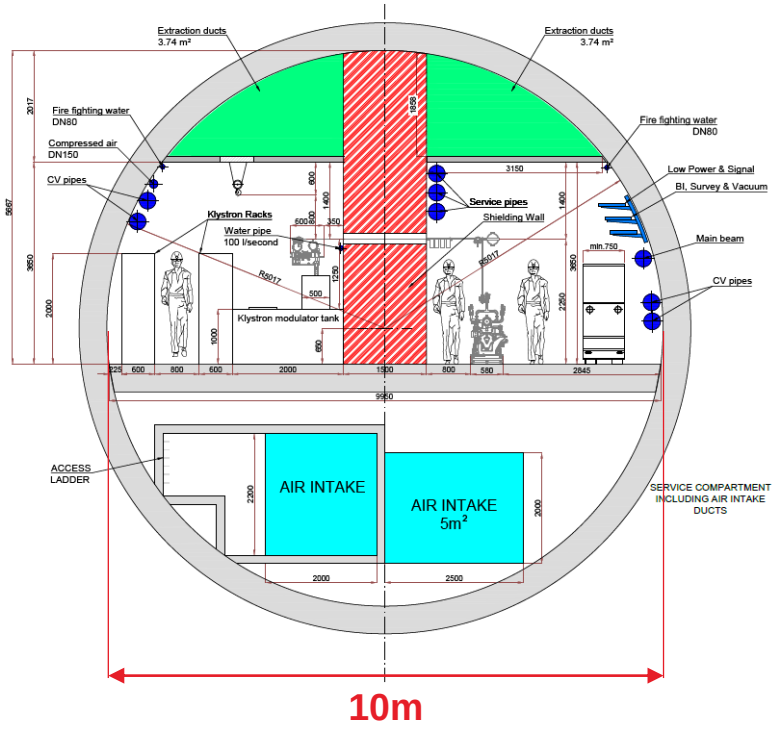
5.6m internal dia. Geneva.
(380GeV, 1.5TeV, 3TeV)



Reference: CLIC Drive Beam tunnel cross section, 2018

CLIC Klystron

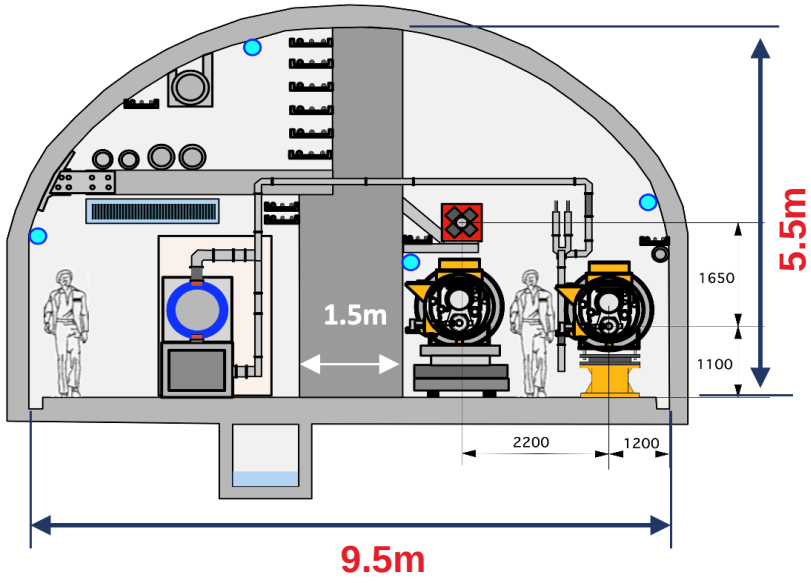
10m internal dia. Geneva.
(380GeV)



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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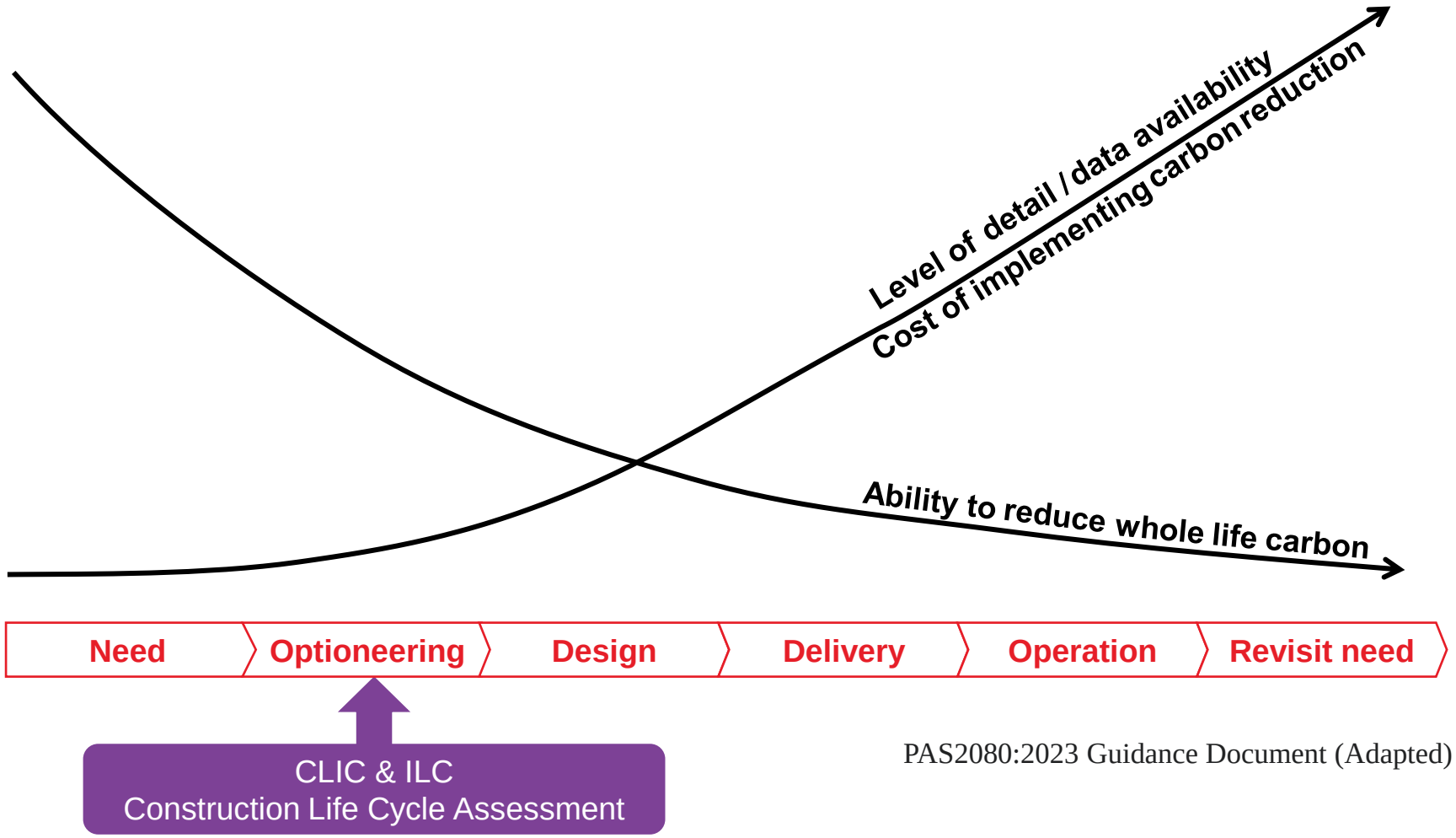
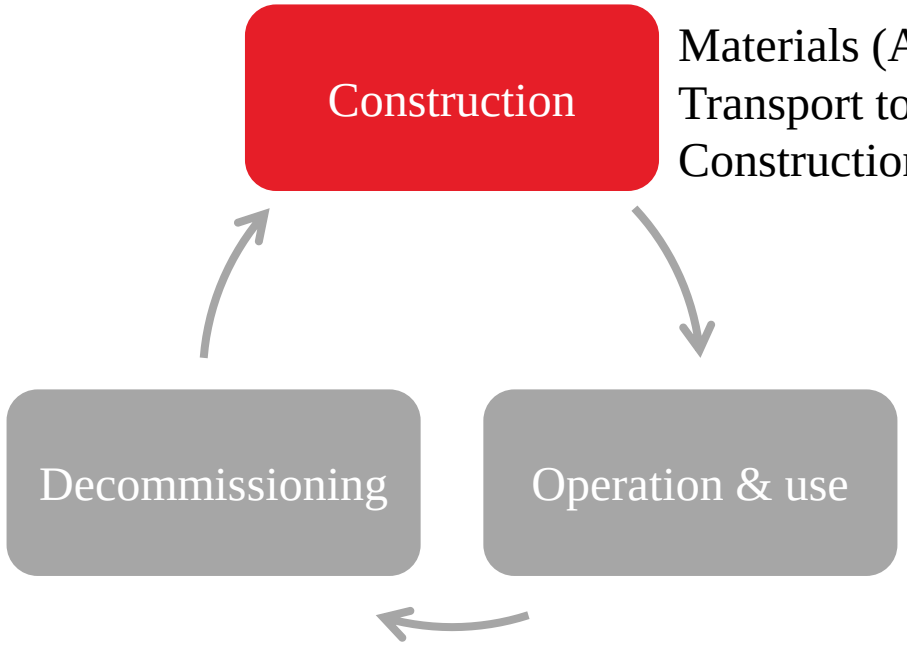
Early stage Influence



PAS2080:2023 Guidance Document (Adapted)

Goal and scope

Evaluate the construction environmental impacts of the CLIC and ILC tunnels, shafts and caverns, identifying hotspots and potential reduction opportunities

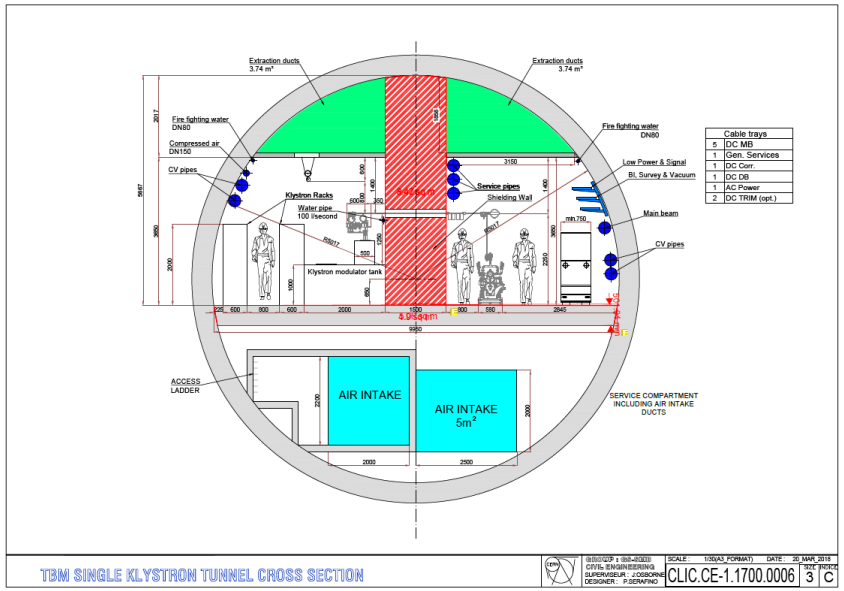


Materials (A1-A3)
Transport to site (A4)
Construction activities (A5)

18 environmental impact categories using ReCiPe 2016 Midpoint (H) Method

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

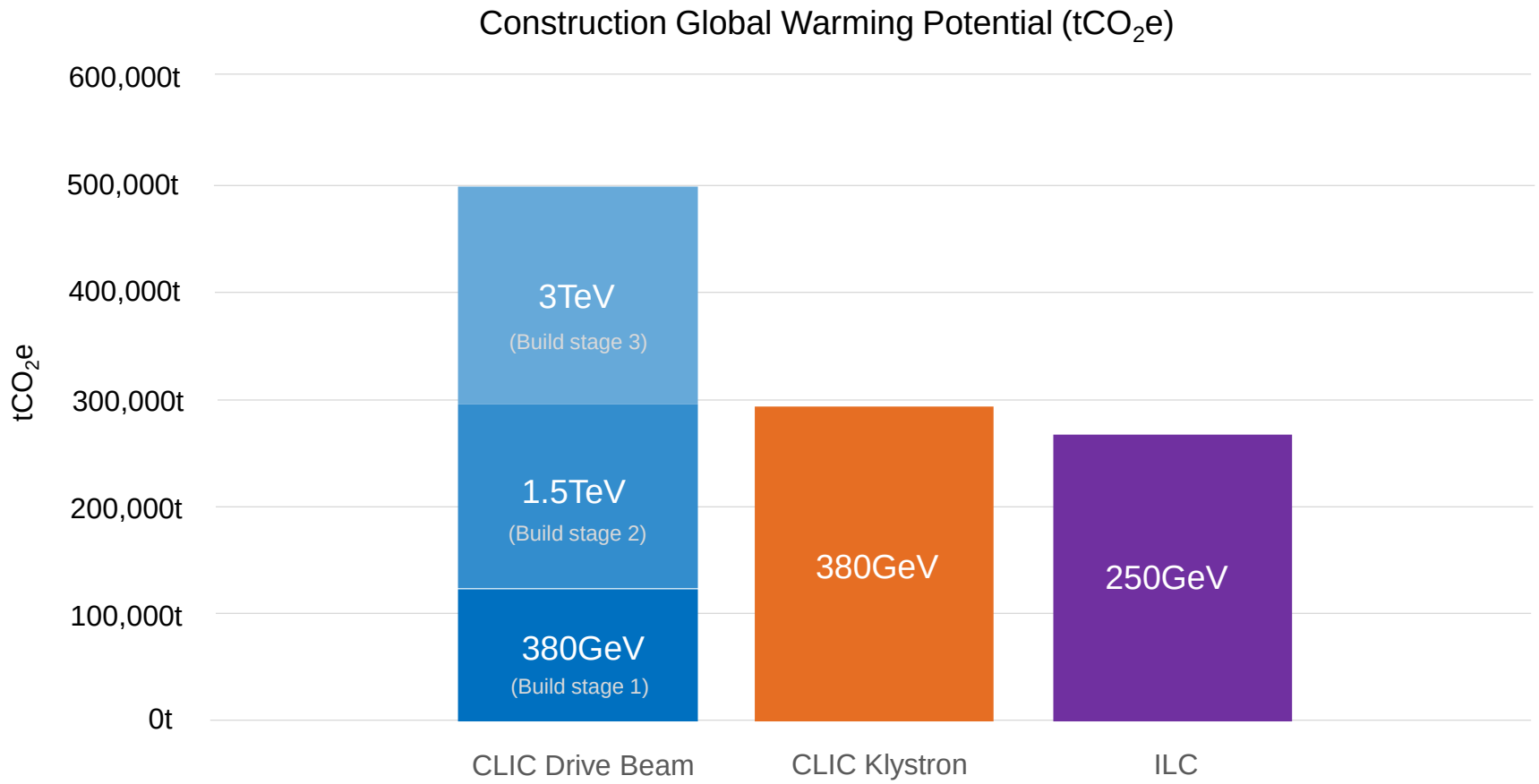
System	Sub-system	Components	Sub-components
CLIC Drive Beam 380GeV			
	Tunnels		
		Main accelerator tunnel	
			Primary Lining Permanent Lining Invert
		Turnarounds	
			Primary Lining Permanent Lining Invert
	Shafts		
		9-18m dia.	
			Primary Lining Permanent Lining
	Caverns		
		BDS, UTRC, UTRA, BC2,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

2030 Baseline assumptions

Construction LCA		CLIC Drive Beam	CLIC Klystron	ILC
Materials (A1-A3)		Concrete (CEMI) & Steel (80% recycled)		
Transport of materials to site (A4)		Concrete: Local by road (50km) Steel: European by road (1500km)		Concrete: Local by road (50km) Steel: National by road (300km)
Construction activities (A5)	Material wasted in construction	Concrete insitu: 5% Precast concrete: 1% Steel reinforcement: 5%		
	Transport of disposal materials off site	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.*		
	Construction process	Tunnel Boring Machine (TBM)		Drill & Blast* *Explosives excluded due to lack of data
	Electricity mix 2021/2022	Fossil: 12% Non-fossil: 88%		Fossil: 71% Non-fossil: 29%

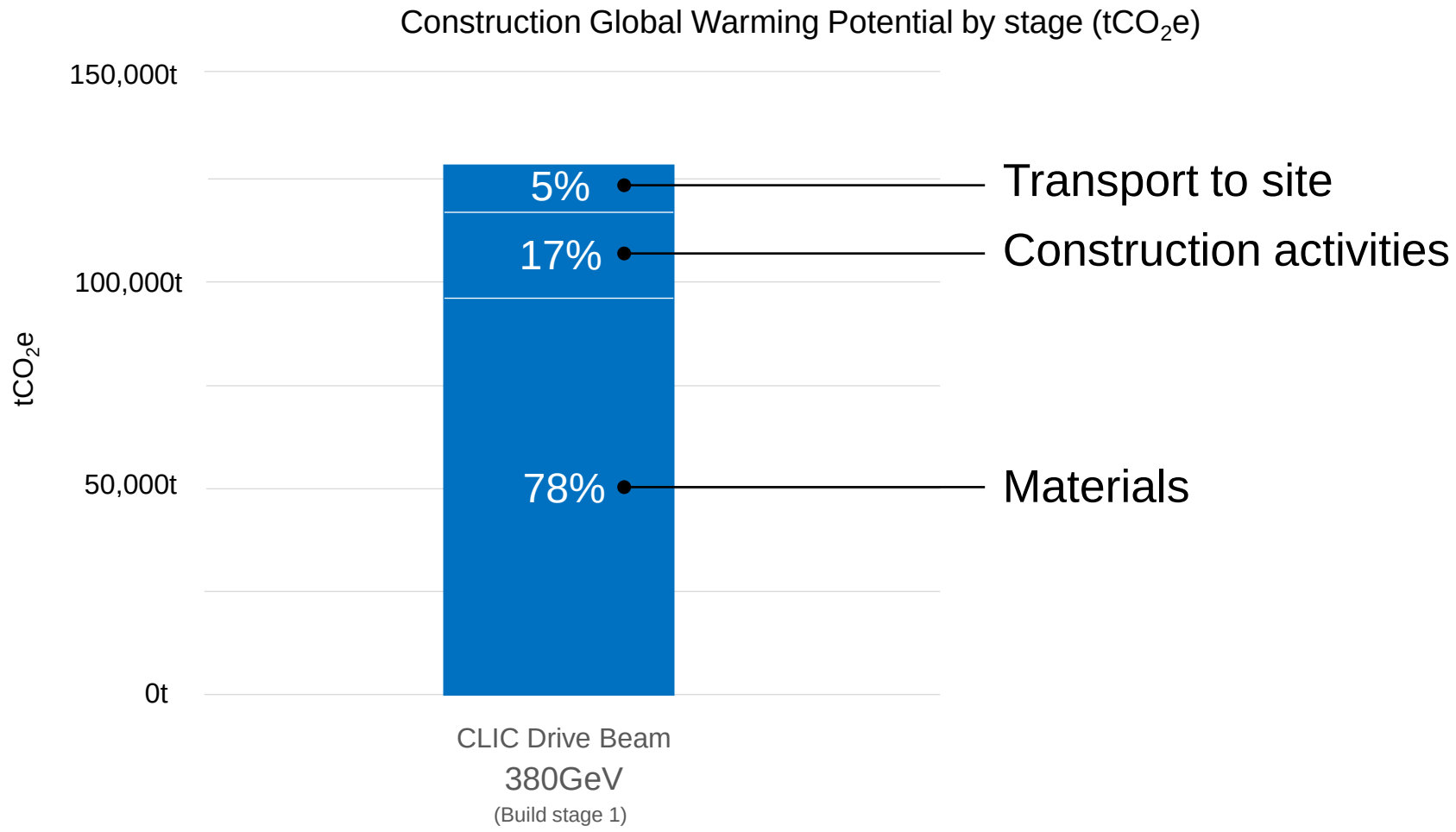
Impact assessment

CLIC & ILC



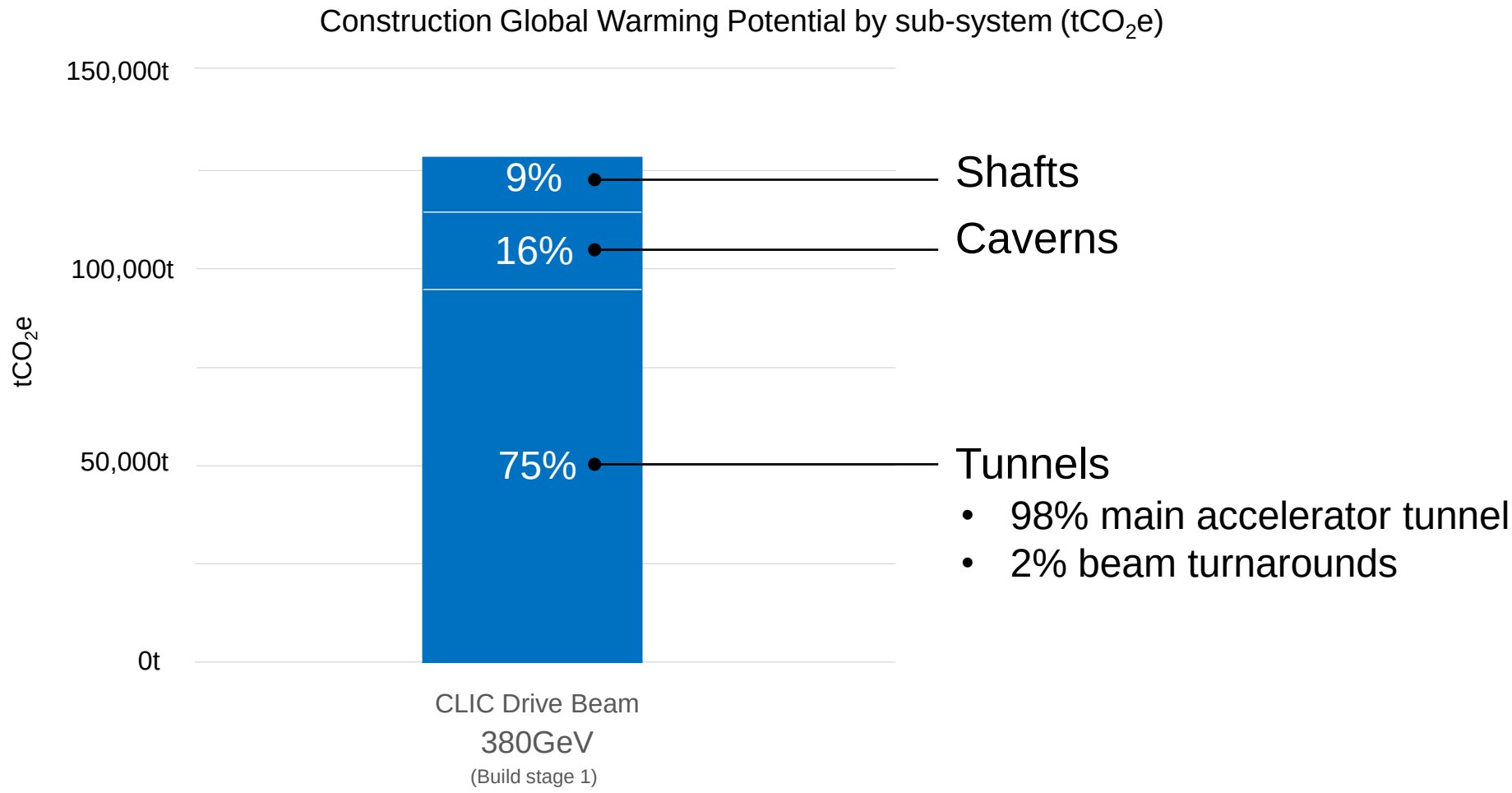
Impact assessment

CLIC Drive Beam 380GeV



Impact assessment

CLIC Drive Beam 380GeV



Hotspots

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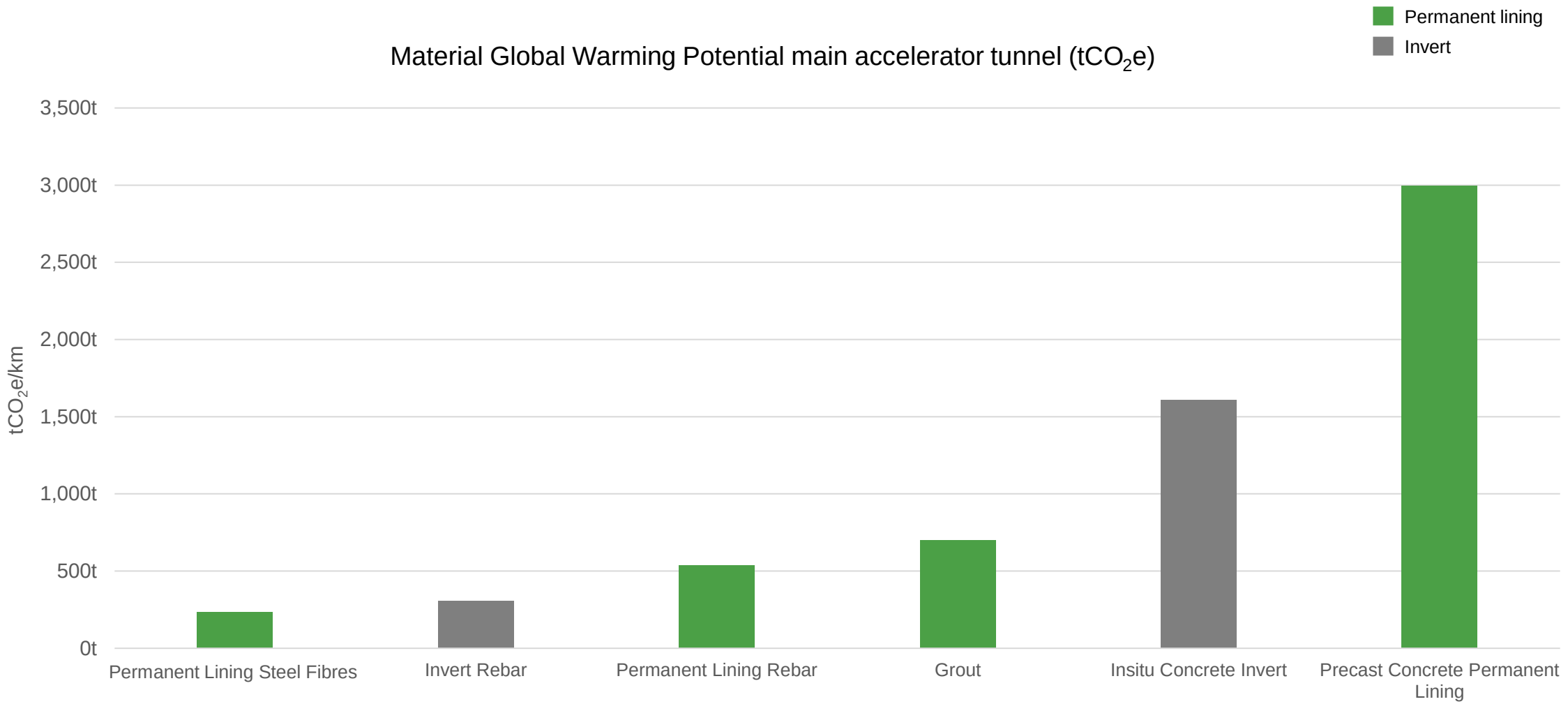
CLIC Drive Beam 380GeV main accelerator tunnel



Benchmarks

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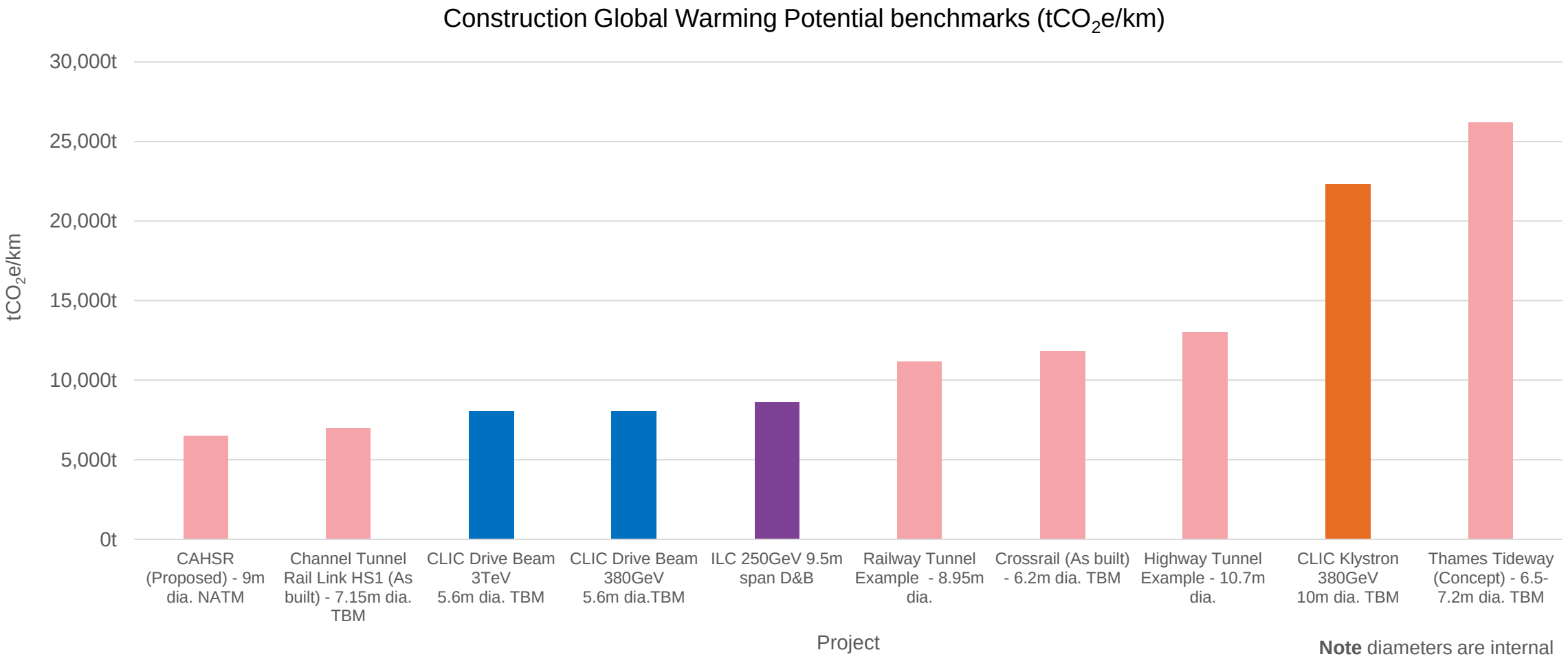
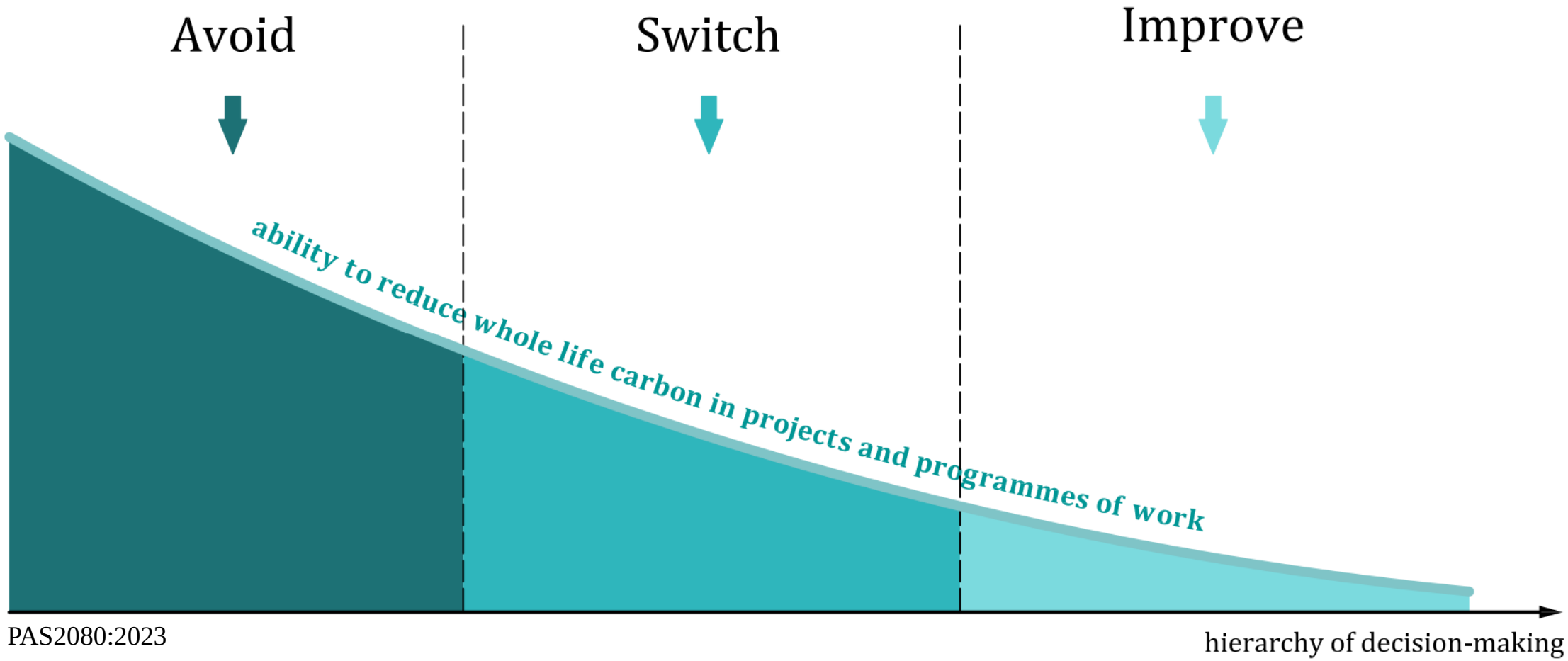
CLIC & ILC main accelerator tunnel



Note diameters are internal

Carbon reduction hierarchy

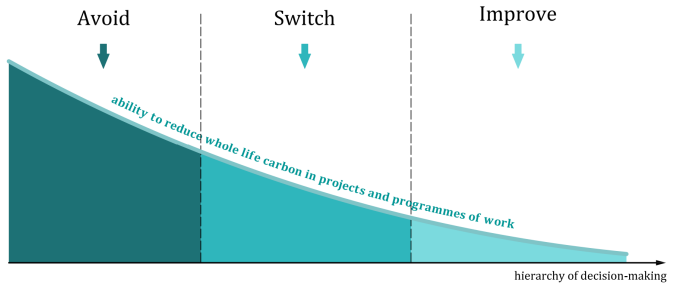
Prioritise meaningful decarbonisation



PAS2080:2023

Reduction opportunities

CLIC Drive Beam 380GeV tunnels



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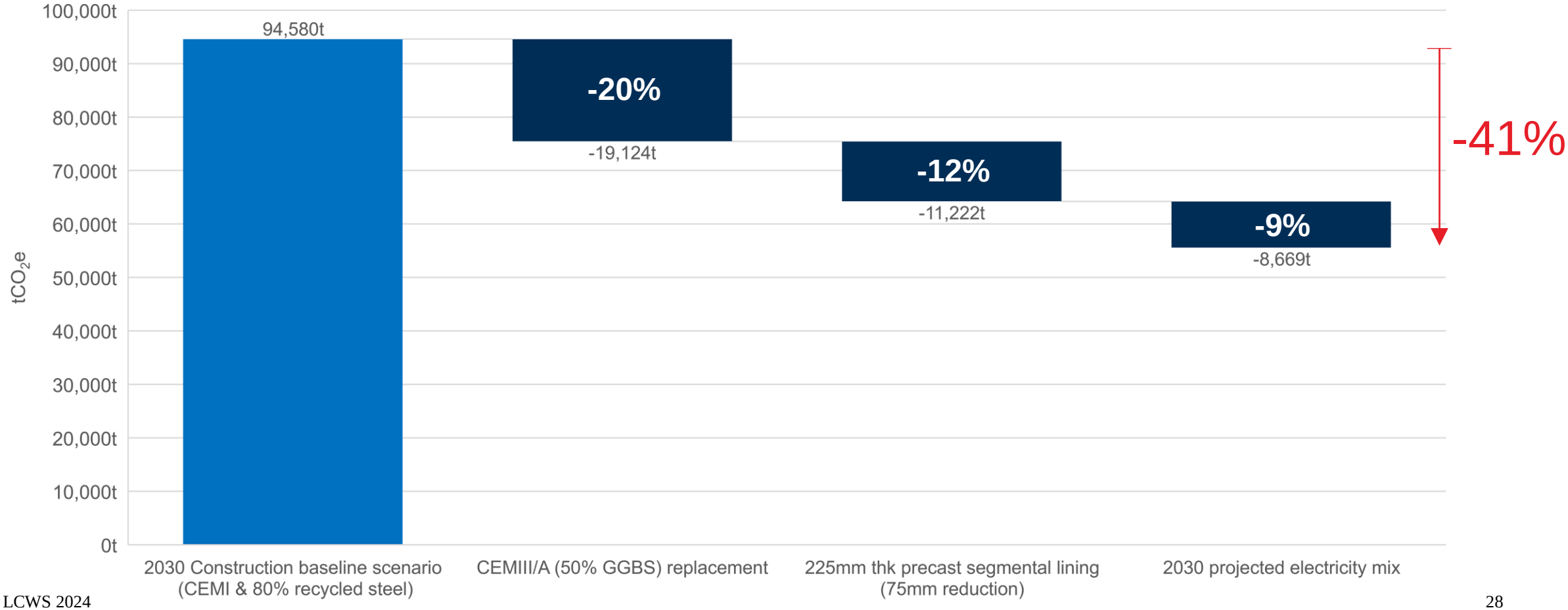
Construction GWP possible reduction opportunities (tCO_2e)



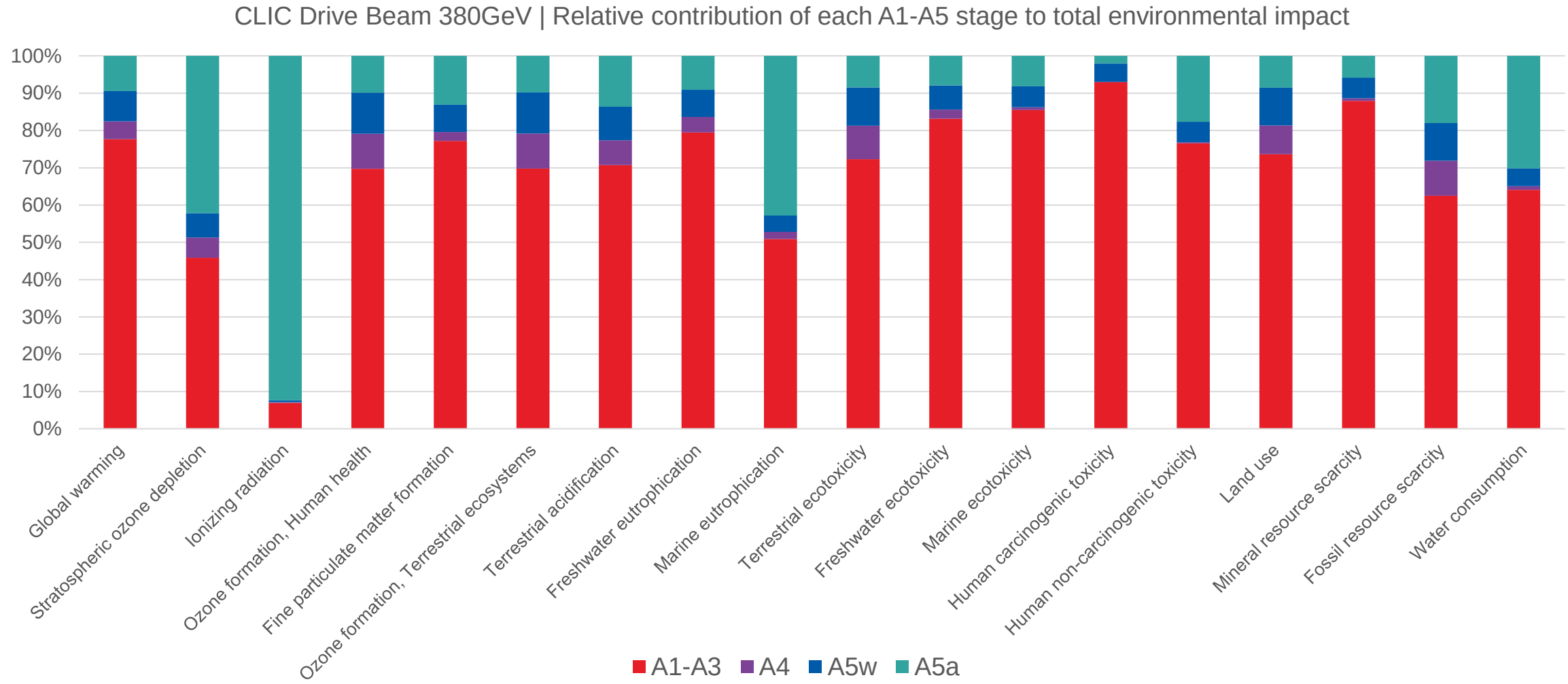
Reduction opportunities

What else?

- Partially replacing Portland cement (CEMI)
- Totally replacing Portland cement with “Portland cement-free”
- Carbon sequestering in concrete
- Plant fibres
- Rubber tyre steel fibres
- & more…

ReCiPe 2016 Midpoint (H) Impact Categories

CLIC Drive Beam 380GeV



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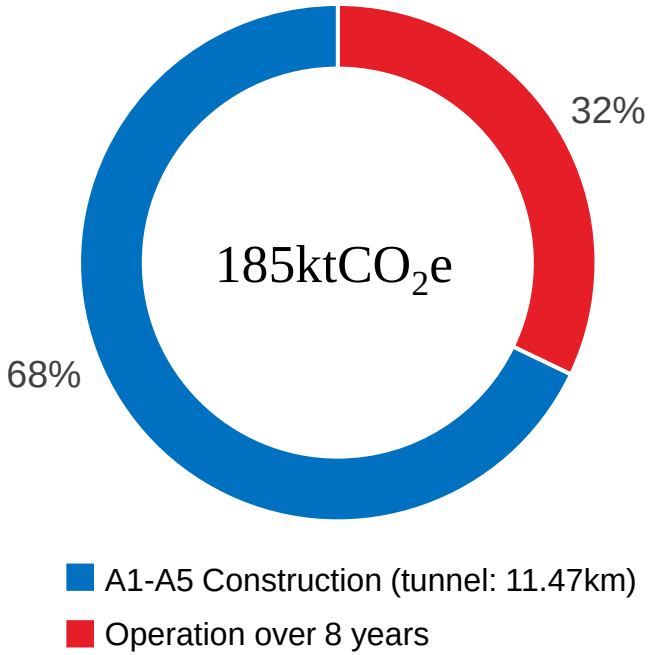
Construction and operation carbon

CLIC Drive Beam

Operational estimates provided by CERN. Based on a projected electricity mix in 2050 (50% nuclear, 50% renewables).

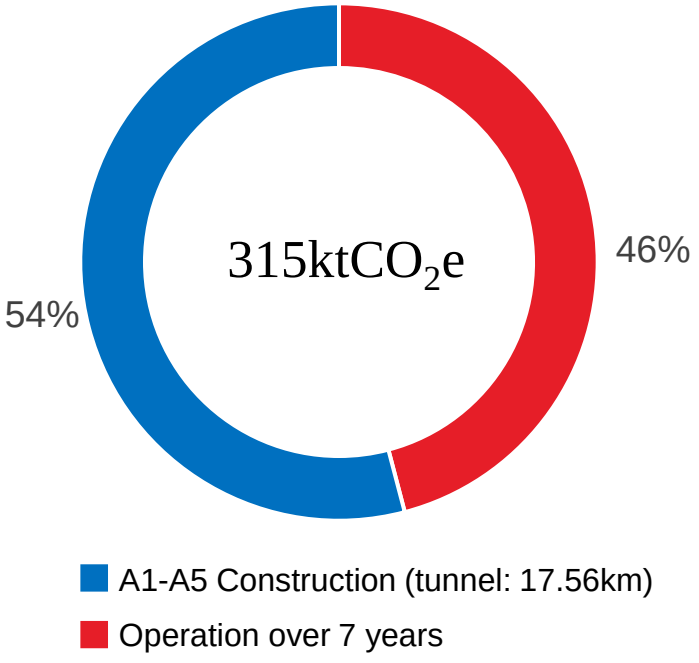
380GeV

Construction GWP is equivalent to 1.7 decades of running accelerator



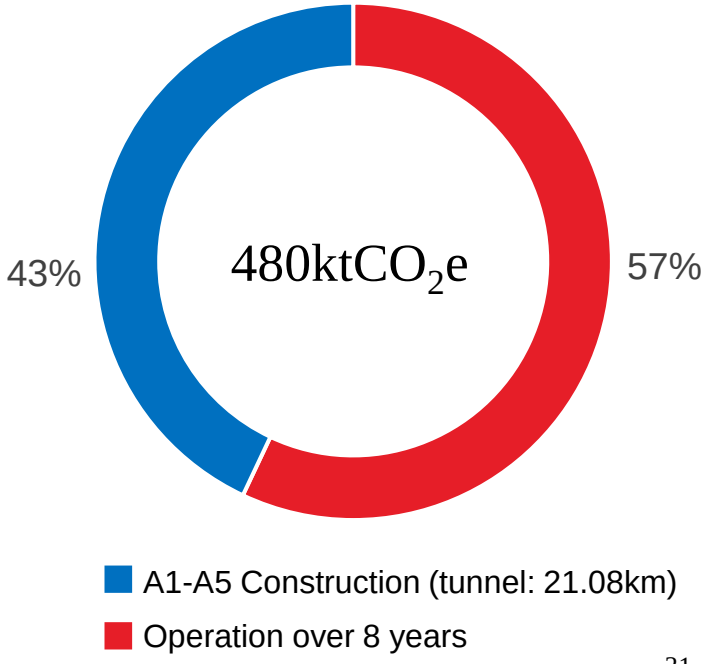
1.5TeV

Construction GWP is equivalent to 0.8 decades of running accelerator



3TeV

Construction GWP is equivalent to 0.6 decades of running accelerator



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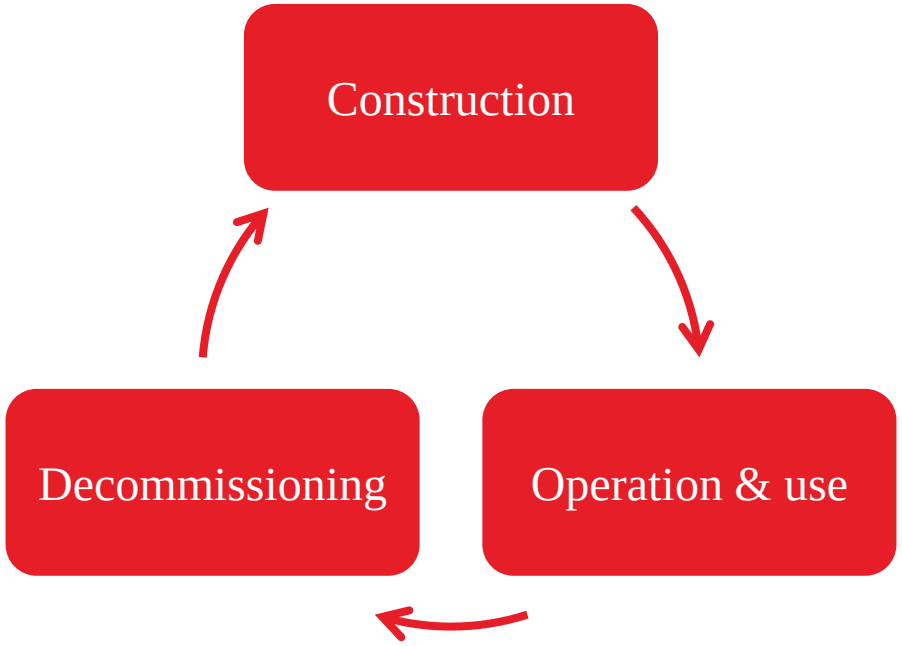
Learning points

- Establish baseline and consistent methodology for LCA
- Design changes e.g. replace the shielding wall with excavated fill in casing
- Design optimisation e.g. reduce lining thickness
- Alternative materials e.g. low carbon concrete and steel technologies
- Influencing operational / whole life carbon
- Carbon quantification integrated into project development
- Managing carbon is integral to decision making

Phase 2

Next steps

- Whole life cycle assessment of the machine componentry for CLIC & ILC (Construction, operation & use, decommissioning)
- Construction life cycle assessment of CLIC injector complex and CLIC & ILC tunnel services systems (Construction)



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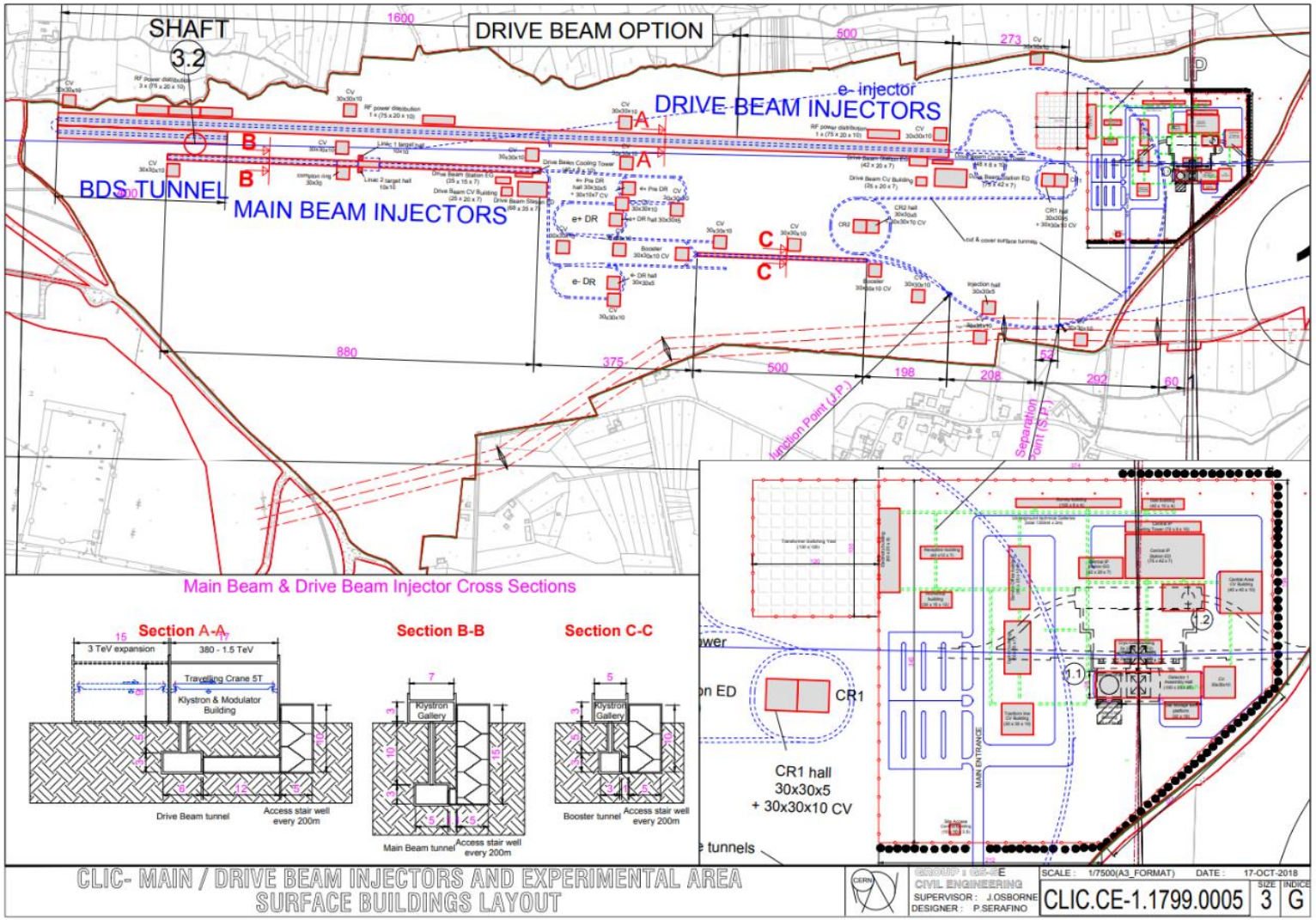
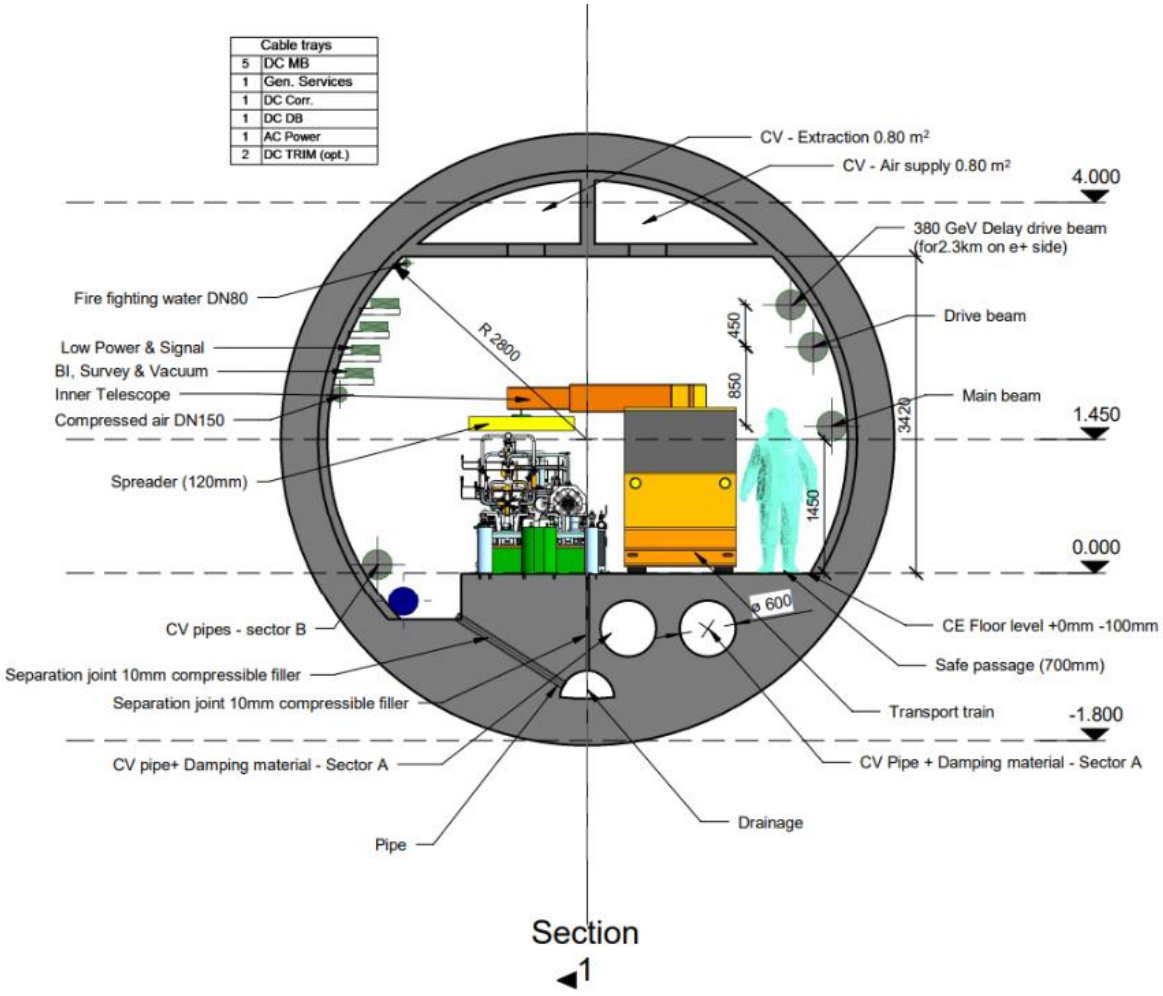
Machine componentry

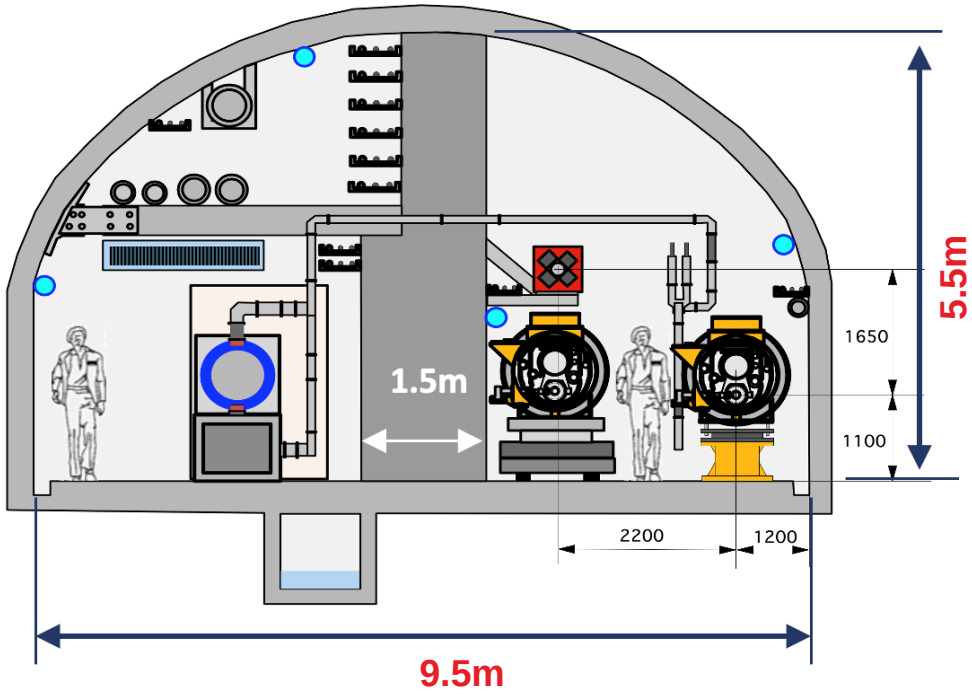
System	Sub-system	Components
CLIC Drive Beam 380GeV		
	Drive beam injector complex and transfer to ML tunnels	
		DB linac module (supports, diag, vacuum) DB linac waveguide system DB linac magnets DB linac Modulator/Klystron Delay Loop and Combiner Rings CV infrastructure
	Main beam injector complex	
		Injector module (supports, vacuum, diag, modulator, klystron, waveguides) Injector magnets Injector CV infrastructure Damping ring (DR)
	Transfer to main line, RTML, main and drive beam	
		RTML vacuum, diagnostics, support RTML magnets RTML CV infrastructure
	Main Linac (ML)	
		Main linac modules drive beam Main beam magnets Post decelerators/dumps CV infrastructure drive beam
	Beam delivery and post collision lines	
		Beam delivery system (BDS) Post collision lines/dumps CV infrastructure
	Central area	
		Detector Infrastructure

CLIC Injector complex & surface buildings



Tunnel service systems





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Thank you and questions

Contact

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