EISA

European Institute for Sciences and Their Applications


# Sustainability assessment of future accelerators
# LDG WG

C.Bloise (INFN-LNF), M.Titov (CEA-Saclay)

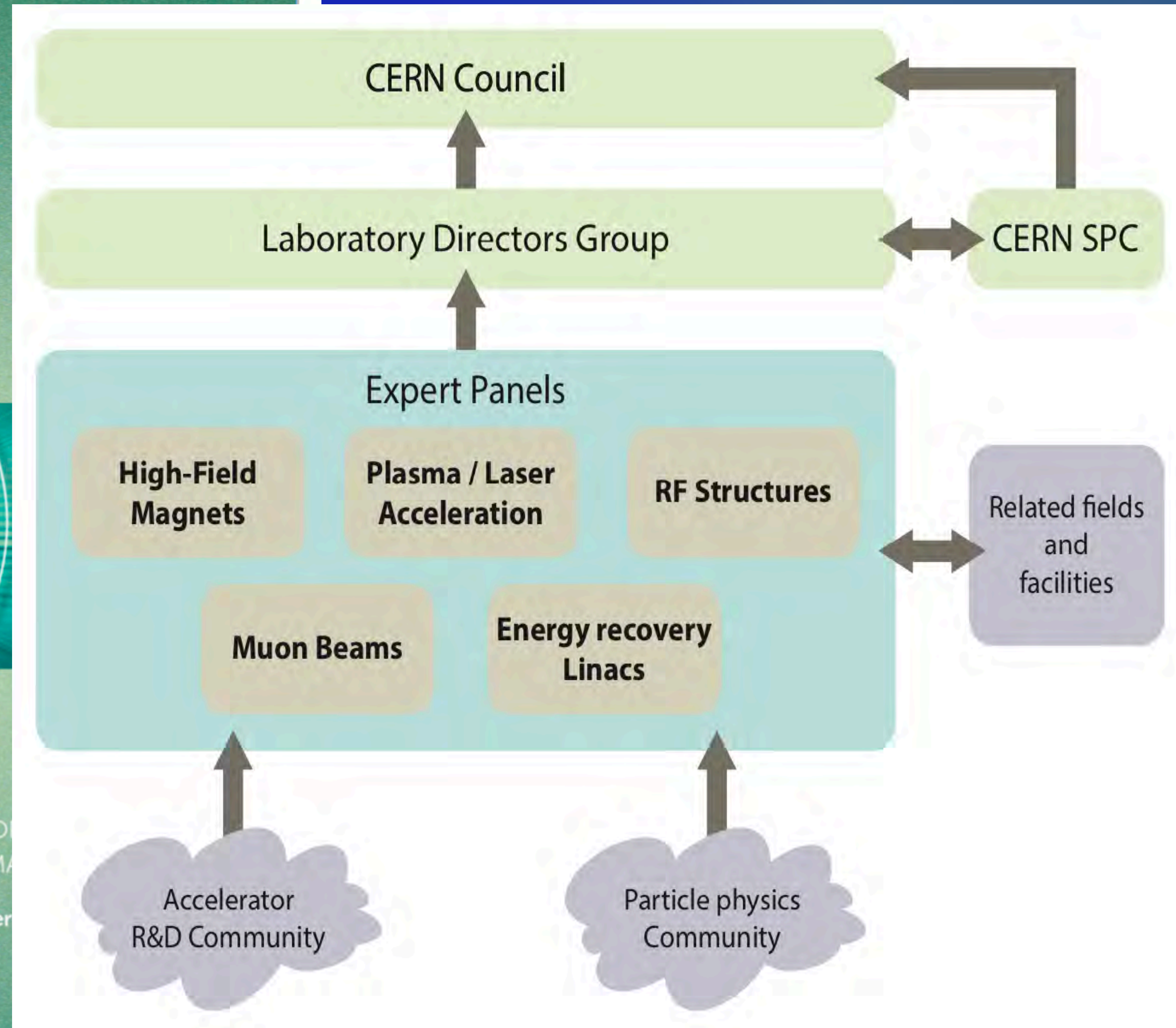
Workshop on Future Accelerators   Corfu 22 May 2024

# Sustainability assessment of future accelerators

The Laboratory Directors Group is the Advisory Committees set up by the CERN management to supervise the development of the roadmap for the accelerator R&D

In November 2023 the LDG took the decision to establish a working group for the assessment of the sustainability of future accelerators

The WG mandate is the development of guidelines and a minimum set of key indicators pertaining to methodology and scope of reports on sustainability in future HEP projects https://cds.cern.ch/record/2800190/files/146-138-PB.pdf


**Sustainability Working Group (added to 5 LDG Expert Panels) since January 2024**

# Working Group's Mandate

- Definition of key indicators to be reported, such as peak luminosity or integrated luminosity per year, lifetime - and performance specific energy consumption, lifetime- and specific Global Warming Potential including the contribution of construction. These figures should be supplemented by margins of uncertainty and possibly an assessment of the potential for improvement

- Definition of methodology and assumptions to be applied for transparent determination of the key figures across proposals. The maturity of a  proposal should be determined, for example adopting a classification scheme such as Early Concept Phase, CDR, TDR or TRL levels

- Identification of other high level environmental impacts that could be relevant for all or specific collider proposals

# Further Suggestions

Best practices determining the GWP for large infrastructure would be considered

The working group may comment on other aspects if deemed appropriate, for example:

- Treatment of future carbon intensity of electricity and materials: what scenarios should be assumed?
- Assessing the potential for dynamic operation of the various facilities, i.e. the ability to adapt to a fluctuating energy supply in a grid fed by renewables. This may include standby mode power consumption, recovery time to full luminosity and fraction of integrated luminosity per year preserved in a dynamic operation scenario.
- Treatment of regional vs global parameters: How to treat differences e.g. in carbon intensity between different host countries?
- Carbon intensity / lifecycle inventory (LCI) studies of materials specific to the accelerator projects: high-purity niobium, permanent magnet alloys etc.
- How to interface with open-source LCI databases and LCA tools to potentially ease/automate the assessment for future research infrastructures
- How the recommendations for colliders can be extended to other scientific endeavours related to HEP
- How HEP labs represented in the LDG can share/build up expertise jointly

# Update of Particle Physics Strategy in Europe

A draft of the recommendations from the WG is expected by end 2024

On time for an input document to the ESPPU due by March 2025

Subjects focused on for the ESPPU inputs incrementally enlarged

Dear Colleagues,

On 21 March 2024, the CERN Council decided to launch the process for updating the European Strategy for Particle Physics.

I am pleased to announce that the deadline for submitting written input has been set for 31 March 2025, with a view to concluding the European Strategy update process in June 2026.

The process will be managed by the Strategy Secretariat, which the Council will establish in June 2024, and more information, together with the call for input, will be issued by the Secretariat in due course.

In the meantime, the input that was submitted for the 2020 Strategy update can be consulted at the following link:
https://indico.cern.ch/event/765096/contributions/.

Kind regards,

Eliezer Rabinovici
President of CERN Council

# LDG Sustainability WG Composition

LEARN, SHARE and BUILD-UP expertise with other HEP initiatives

WG composition endorsed by LDG in March 2024

15 people involved, from

Horizon programs on accelerators

panels established at CERN, DESY, ESS, NIKHEF, STFC

ICFA panel

projects for future accelerators

External contributions planned

- Walib Kaabi - iSAS, PERLE
- Mats Lindroos - ESS - he died on 2 May 2024
- Roberto Losito - CERN Sustainability Panel
- Ben Shepherd - STFC Sustainability Task Force
- Andrea Klumpp - iSAS, DESY Sustainability Panel
- Hannah Wakeling - ISIS-II Neutron & Muon Source
- Patrick Koppenburg - NIKHEF Sustainability Panel

- Johannes Gutleber - FCC
- Yuhui Li - CePC
- Benno List - ILC
- Emilio Nanni - ICFA and CCC
- Vladimir Shiltsev - LHeC/FCC-eh
- Steinar Stapnes - CLIC/muon collider

- Caterina Bloise - Co-Chair
- Maxim Titov - Co-Chair

# Work organization

1) Inputs from the Initiatives on Sustainability and from the projects for future accelerators

2) Topics to focus on

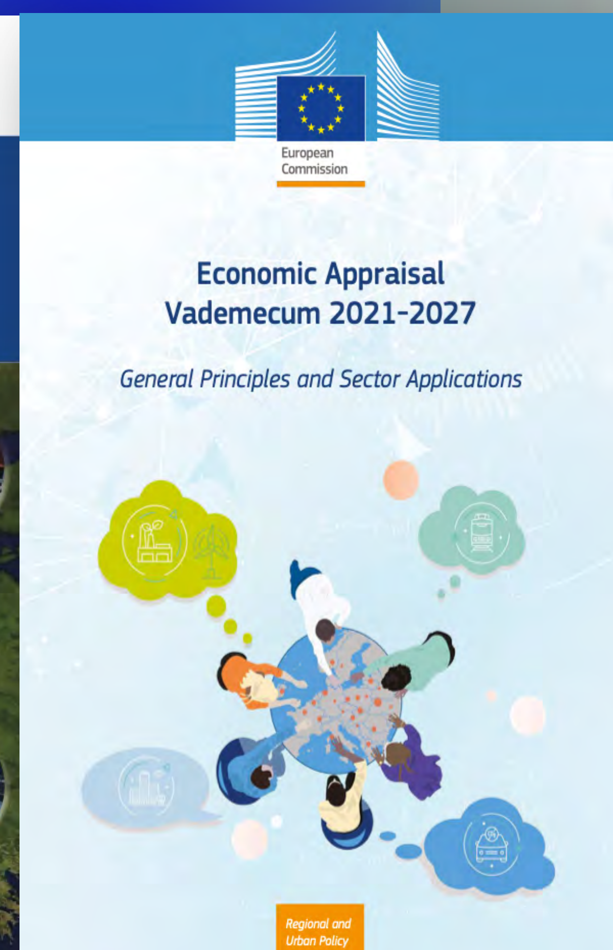
3) Discussion and Report Elaboration

# Sustainability of Research Infrastructures


https://www.esfri.eu/sites/default/files/ESFRI_SCRIPTA_SINGLE_PAGE_19102017_0.pdf


https://data.europa.eu/doi/10.2777/76269

**Reference for the integrated model FCC:**

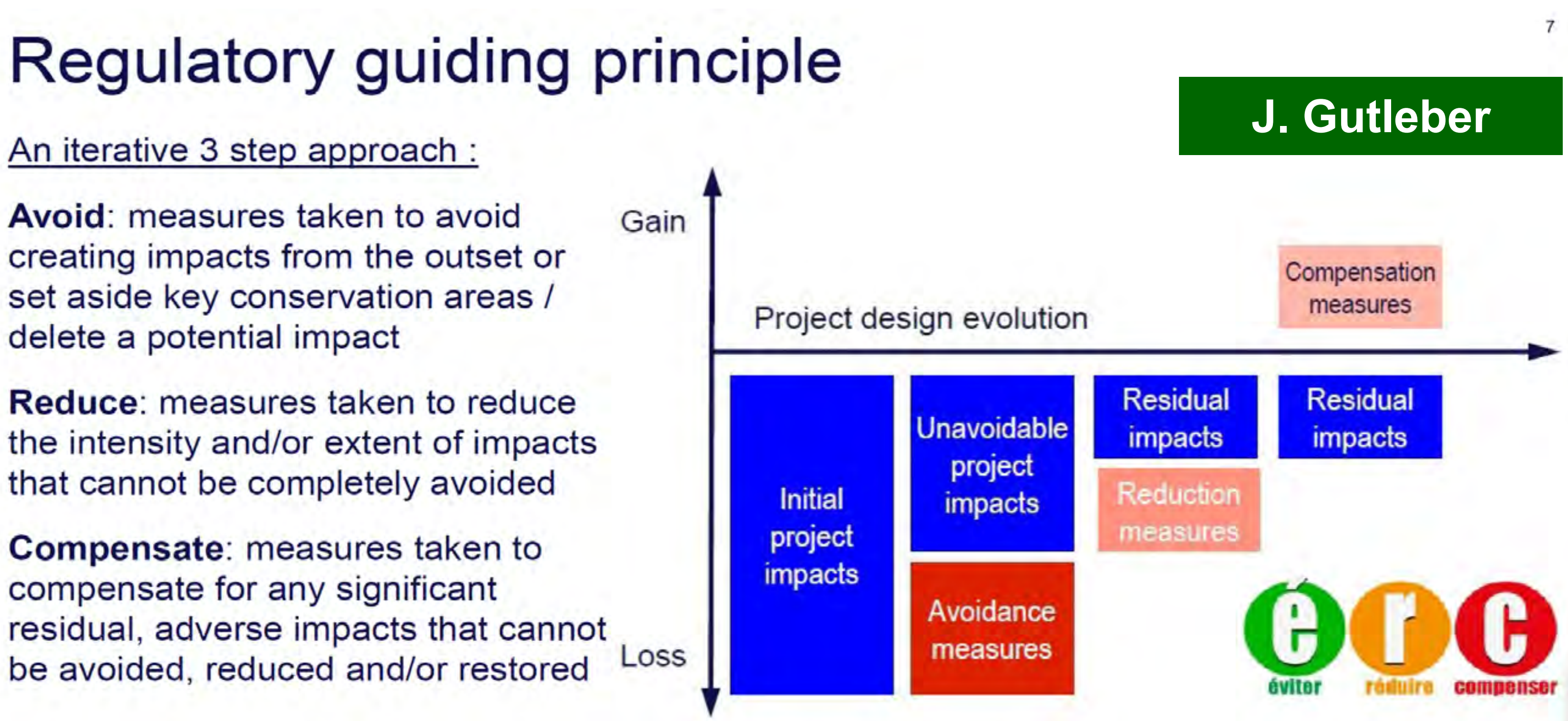




https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf

# Sustainability Assessment

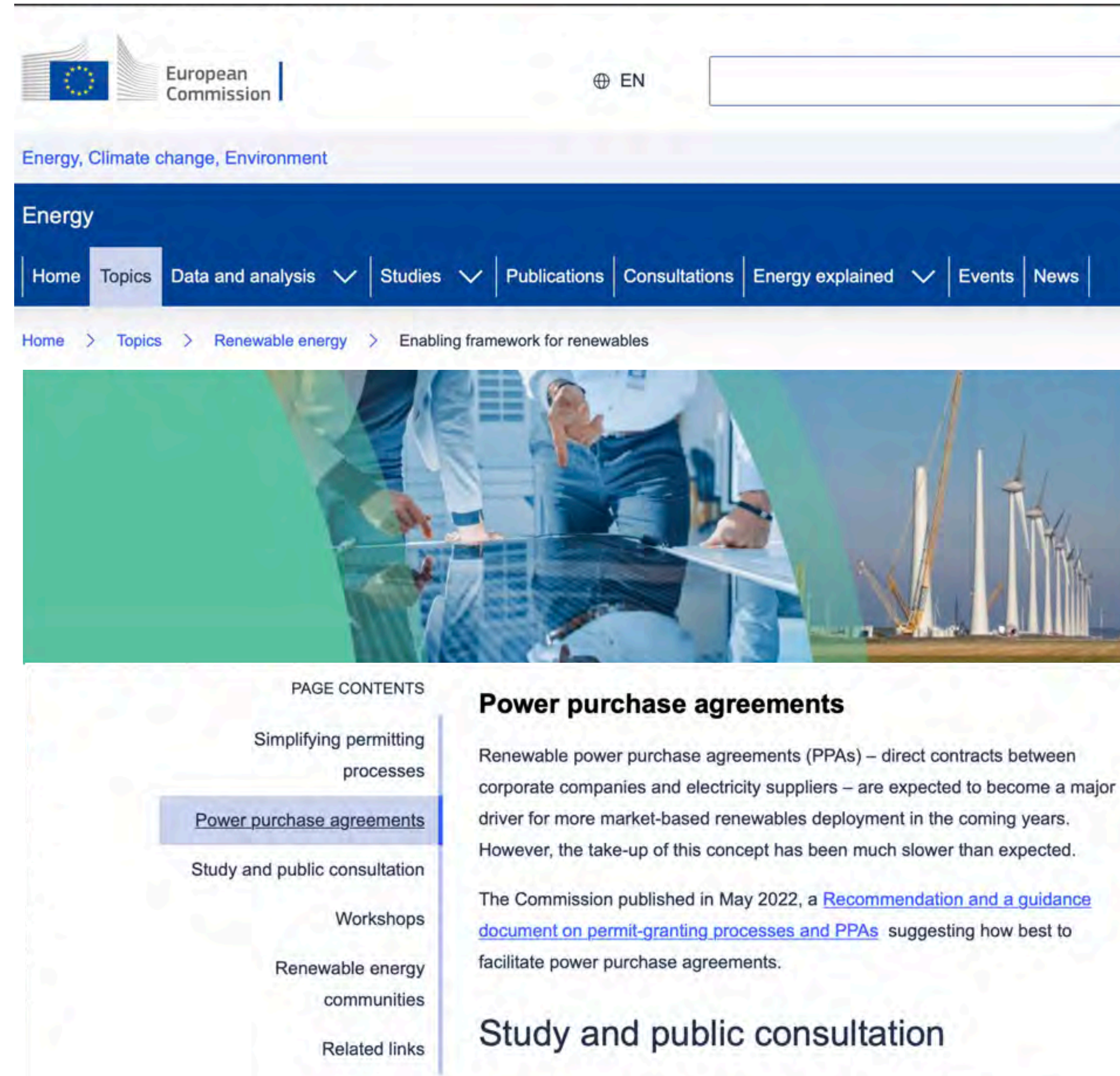
Sustainability matters are in relation with Environment, Society and Governance

WG focus is on the assessment of sustainability of the infrastructures for Environment and Climate Change




# Carbon Footprint and Green House Gas emissions

https://energy.ec.europa.eu/topics/renewable-energy/enabling-framework-




## Energy

- Reduction of energy consumption
  - Optimized designs for energy saving
  - Novel technologies
- Increase of renewables share

## Civil Engineering

- Concrete

## Specific Materials

- Manufacturing
- Re-use

# Europe-Horizon Sustainability - Supporting Programs

- ✓ *Innovation Fostering in Accelerator Science and Technology (I.FAST): https://ifast-project.eu*
- ✓ *Europe-America-Japan Accelerator Development Exchange Programme (EAJADE): https://www.eajade.eu/*
- ✓ *Innovate for Sustainable Accelerating Systems (iSAS): https://indico.ijclab.in2p3.fr/event/9521/*

**https://indico.cern.ch/event/1326603/timetable/#20240215.detailed**

## WP11 Overview

**task 1: Sustainable Concepts for RIs**: networking, workshops on selected topics
deliverable: report
1) System Efficiency of Accelerator Concepts (N.Catalan Lasheras, CERN)
2) Key Technologies and Components for High Efficiency (A.Sunesson [C.Martins], ESS)
3) Cross Linking Accelerator R&D with Industrial Approaches (P.Spiller, GSI)
4) Ecological Concepts (D. Voelker, DESY)

**task 2: High Efficiency Klystron** (O.Brunner CERN, THALES, ULANC)
- deliverable: industrial prototype
- replacing klystrons in LHC

iFAST

**task 3: Permanent Combined Function Magnets for Light Sources** (B.Shepherd, UKRI, DLS, KYMA, DESY)
- deliverable: magnet prototype, applicable for Diamond upgrade
- several advantages of permanent magnets, not just power consumption

## iSAS Objectives – *Technology Areas*

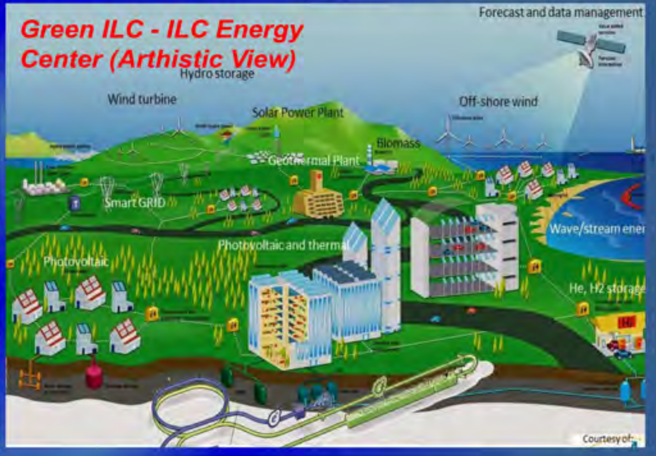
- **TA#1: energy-savings from RF power** – *While great strides are being made in the energy efficiency of various RF power generators, the objective of iSAS is to ensure additional impactful energy savings through coherent integration of the RF power source with smart digital control systems and with novel tuners that compensate rapidly cavity detuning from mechanical vibrations, resulting in a further reduction of power demands by up to a factor of 3.*
- **TA#2: energy-savings from cryogenics** – *While major progress is being made in reusing the heat produced in cryogenics systems, the objective of iSAS is to develop superconducting cavities that operate with high performance at 4.2 K (i.e., up to 4.5 K depending on the cryogenic overpressure) instead of 2 K, thereby reducing the grid-power to operate the cryogenic system by a factor of 3 and requiring less capital investment to build the cryogenic plant.*
- **TA#3: energy-savings from the beam** – *Significant progress has been achieved in maintaining the brightness of recirculating beams to provide high-intensity collisions to experiments, but most of the particles lose their power through radiation or in the beam dump system. The objective of iSAS is to develop dedicated power couplers for damping the so-called Higher-Order Modes (HOMs) excited by the passage of high-current beams in the superconducting cavities, enabling efficient recovery of the energy of recirculating beams back into the cavities before it is dumped, resulting in energy reduction for operating, high-energy, high-intensity accelerators by a factor ten.*

**https://indico.cern.ch/event/1326603/timetable/#20240215.detailed**

ESS also participates in iFAST (addition of solar panels to power modulators) and FlexRICAN (studying flexibiility in power supply)

**EAJADE Workshop on Sustainability on Future Accelerators (WSFA2023)**

**MORIOKA, JAPAN, SEPTEMBER 25-27, 2023**
**Aiina Center, the same venue as LCWS2016, hosted by Iwate University**


https://wsfa2023.huhep.org/ ; https://indico.desy.de/event/39980/

***Four blocks (not limited to future Higgs Factores and to Linear Colliders):***
- ***I. Large-Scale Research Facilities & Sustainability / Life Cycle Assessment(LCA)***
- ***II. Sustainable Accelerator Technologies***
- ***III. Europe-Horizon and National Sustainability-Supporting Programmes***
- ***IV. Green ILC and Local Industries***

**https://wsfa2023.huhep.org/**

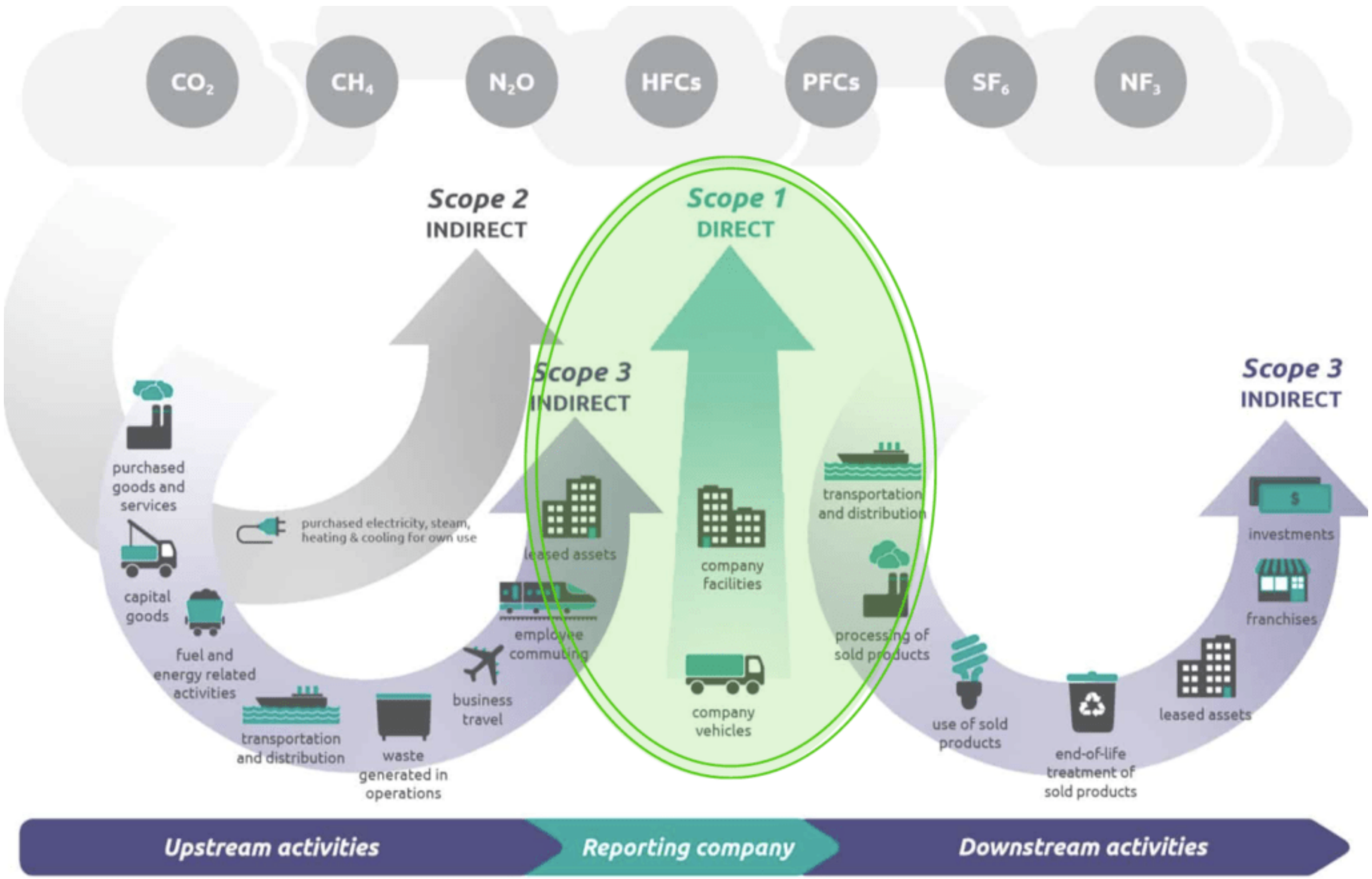
# Approaches to Increase Sustainability

- Overall system design
  - Compact accelerator -> high gradients, high field magnets
  - Energy efficient -> low losses
  - Effective -> small beam sizes to maximize luminosities
  - Energy recovery concepts
  - Civil engineering including landscaping and “community” integration
- Subsystem and component design
  - High-efficiency cavities and klystrons
  - Permanent magnets, HTS magnets
  - Heat-recovery. e.g. in tunnel linings, possibly other components
  - Responsible sourcing and material choices for all parts
- Sustainable operation concepts
  - Renewables
  - Adapt to power availability
  - Exploit energy buffering potential
  - Recover energy

# Green House Gases Emissions

According to the 2015 Paris Agreement carbon emissions have to be halved by 2030.

Emissions are categorised into scope 1, 2, and 3




https://ecochain.com/blog/scope-1-emissions-explained/

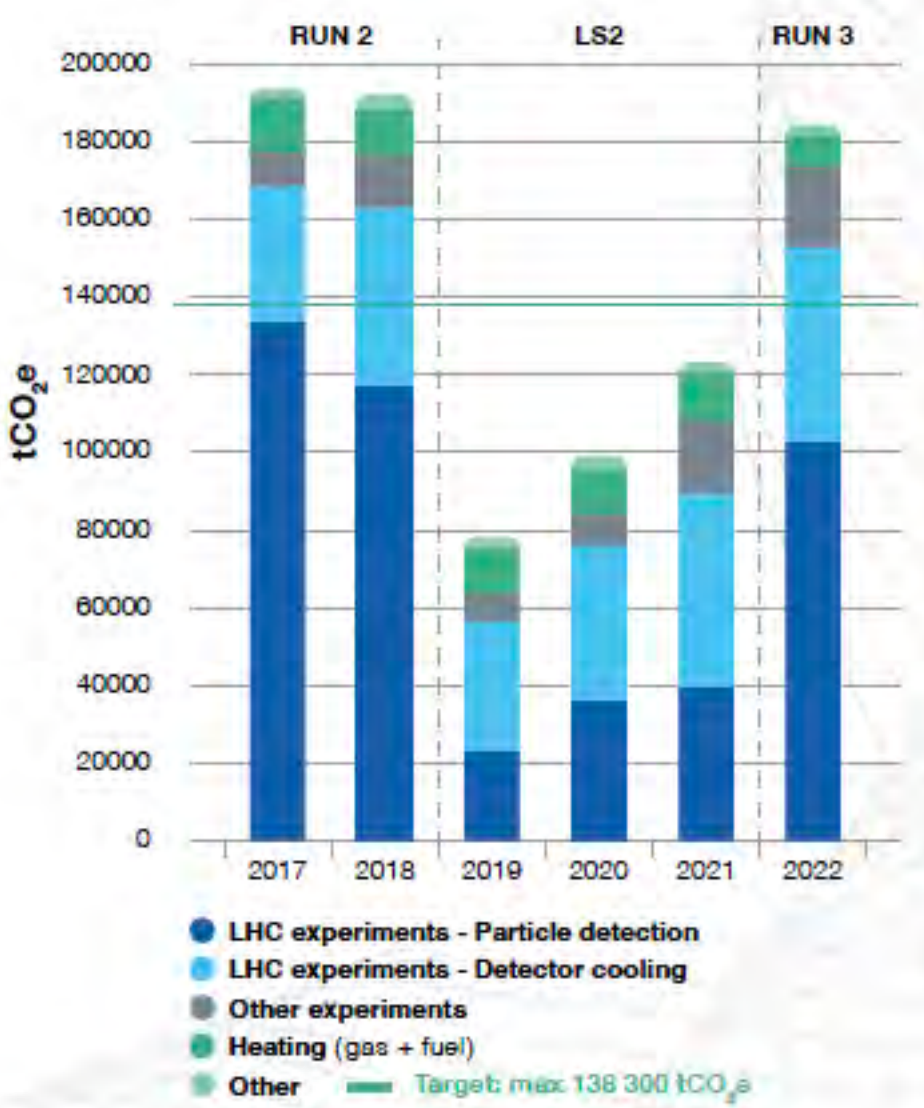
# Decarbonisation and Large HEP RI

CERN publishes environmental reports following standards of Global Reporting Initiative since 2017

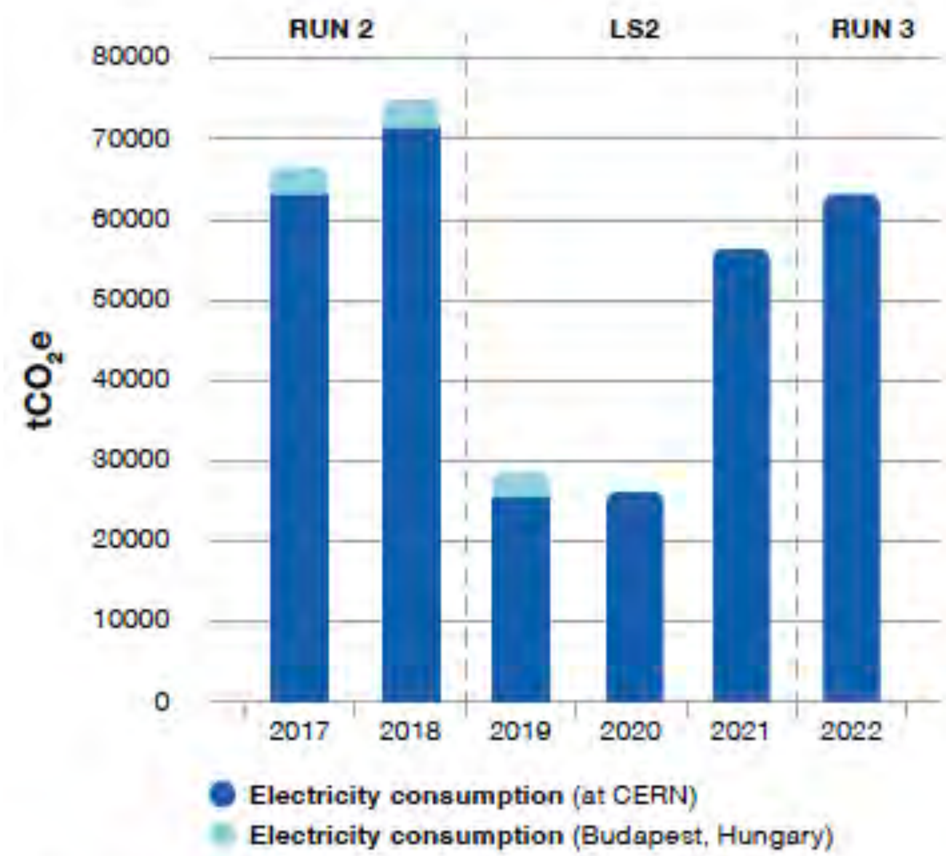
CERN has developed a strategy for energy sourcing and monitoring obtaining the ISO50001 certification for energy management

Scope 1 Direct Emissions: @LHC are dominated by gas mixtures used by particle detectors and detector cooling

Scope 2 Emissions (Energy Consumption): location-based methodology provides emission factors depending on energy sources in use




**CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY**
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.




**CERN SCOPE 2 EMISSIONS FOR 2017–2022**
Emission calculations for electricity follow a location-based methodology, with average yearly emission factors taken from ADEME Base Empreinte©. From 2017 to 2019, CERN operated a data centre at the Wigner Centre in Budapest, Hungary, for which the emissions are also shown. The location-based emission factors used for Hungary were taken from Bilan Carbone® V8.4.

**Reference: CERN Environment Report 2021-22**

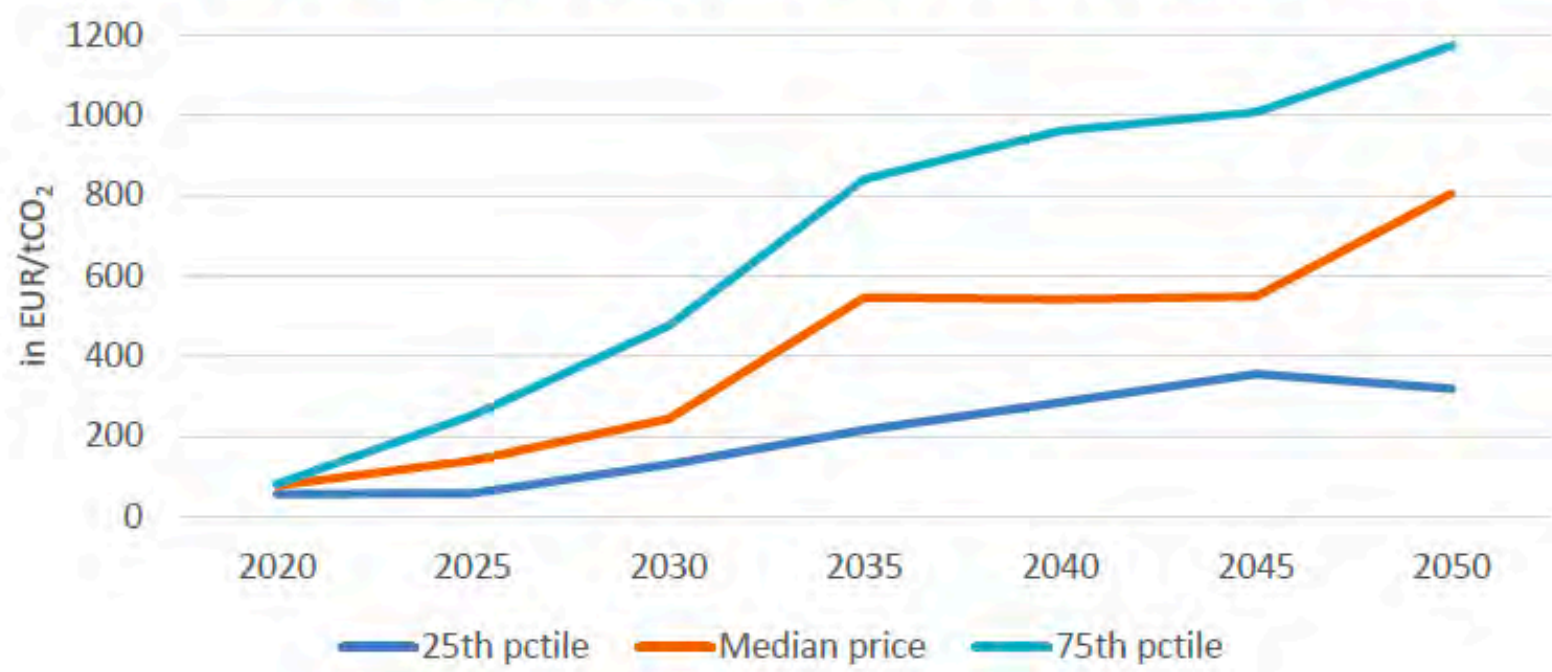
# Decarbonisation

Evaluation of shadow carbon price

Various measures to abate carbon emissions are considered and their cost evaluated

Uncertainty from the evaluation methodology that considers different scenarios

*Figure A10 – Results from review of IAMC database. All values are in €$_{2016}$/t$CO_2$e.*



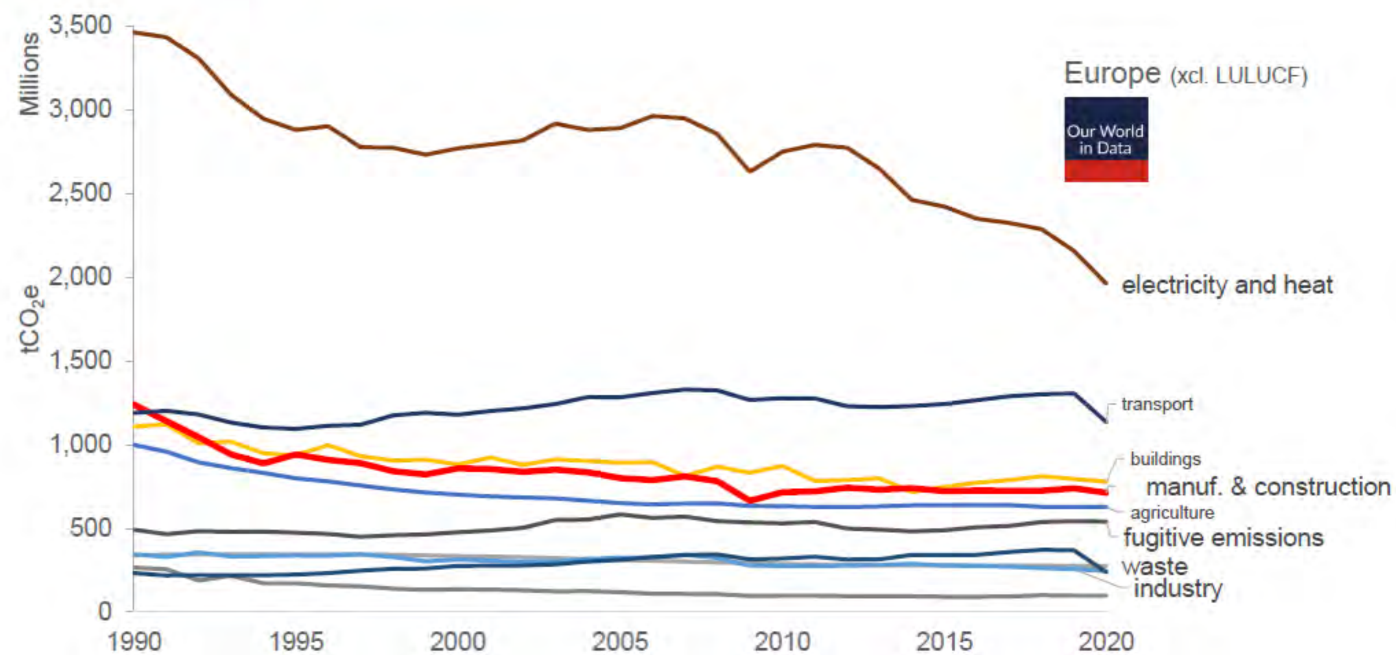

EIB Group Climate Bank Roadmap 2021-2025

https://www.eib.org/en/publications/the-eib-group-climate-bank-roadmap

# Decarbonisation & Large Research Infrastructures

## Europe's decarbonisation progress – by sector

**Which sectors does Large Research impact on?**





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


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

## Context, progress and future needs

ARUP

**H. Pantelidou**

**Transition risks for Large Research and potential financial impacts**

**Net zero laggard** | Fees to mitigate exposure to penalties, compliance costs and insurance premiums, asset impairment

**Slow grid decarbonisation – not enough for all** | Cost to deploy new agreements, capex to secure electricity supply, increased energy costs

**Shift in market and research priorities** | Reduced funding, changes in grant decisions, large research infrastructure maybe deemed a stranded asset

**Organisational reputation** | Stakeholder pressure, workforce management, employee attraction/retention, research restructuring

TCFD | TASK FORCE ON CLIMATE-RELATED FINANCIAL DISCLOSURES

**TCFD in a nutshell**

Framework to disclose risks, opportunities and financial impacts associated with climate change

Physical / Transition → Risks, Opportunities → Financial Impact → Governance | Strategy | Risk management | Metrics and Targets

TCFD recommendations and recommended disclosures

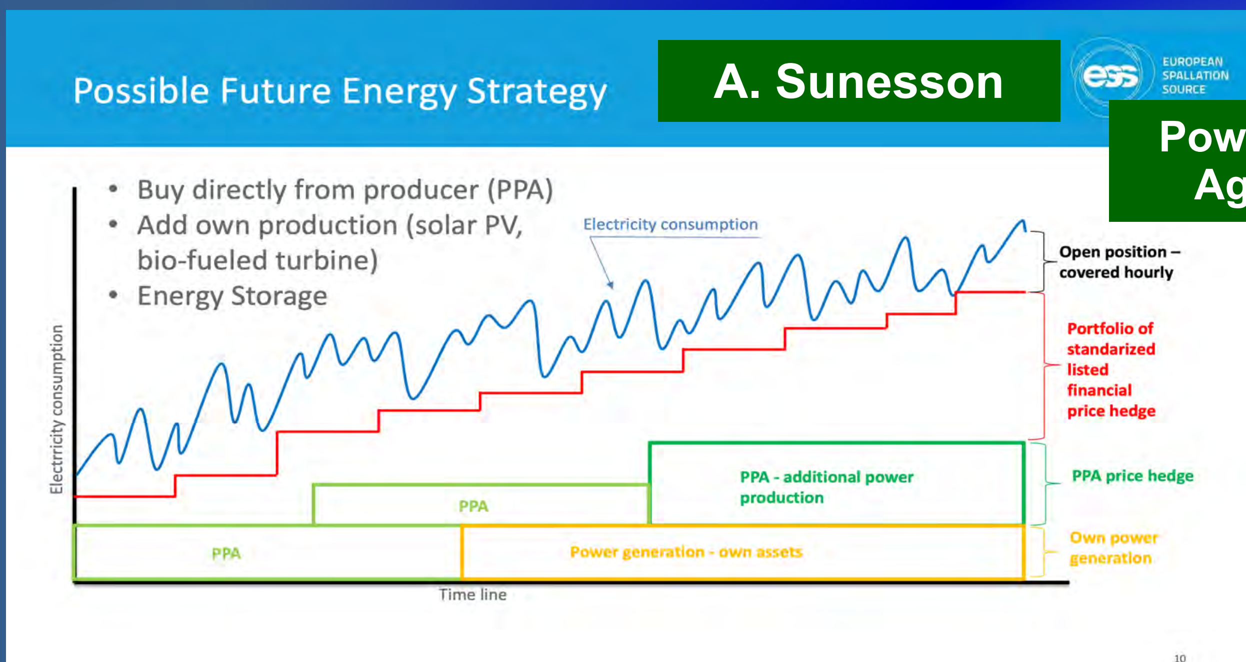
- Funding and financing landscapes are changing rapidly in Europe and beyond, which will require addressing carbon explicitly in the business case for large research infrastructure

- Identifying relevant decarbonisation initiatives: prioritising nature-based interventions, integration in local environment (e.g. CERN generally, Green ILC concept) as part of the asset management – potential to contribute towards carbon removal through environmental enhancement.

# Power Purchase Agreement - Running on Renewables

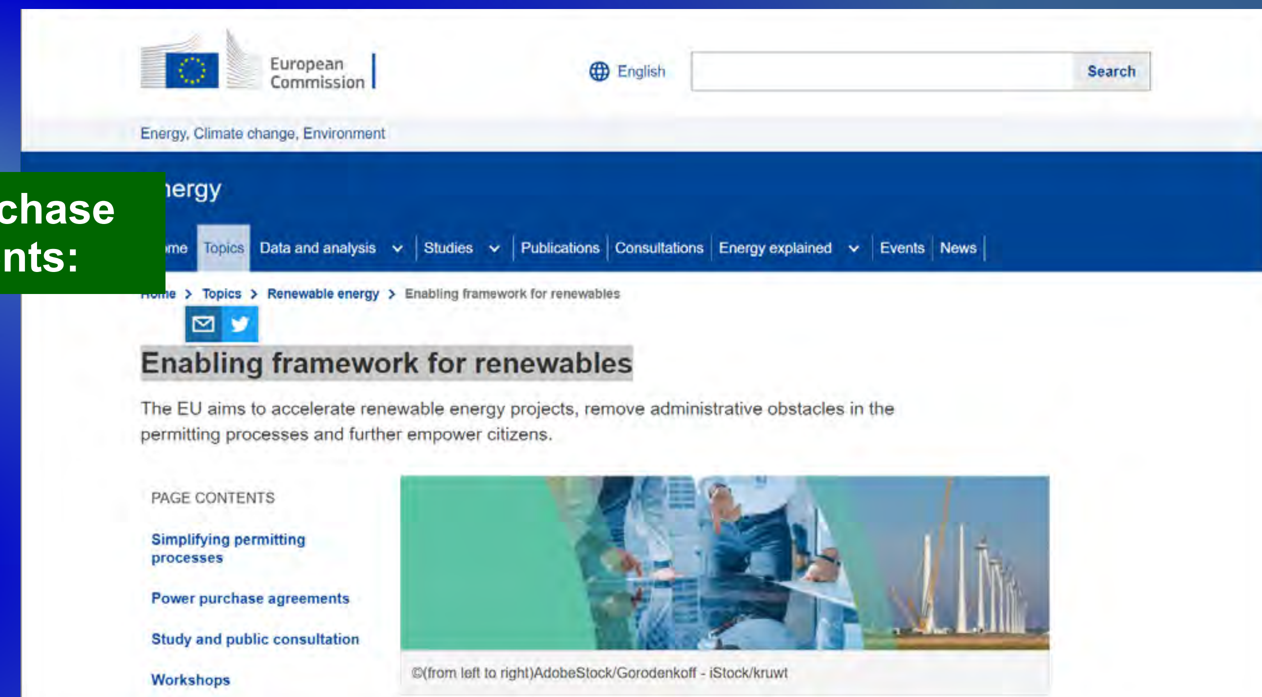
*Approaches to reduce power consumption:*
- *Reduce power (by higher efficiency)*
- *Re-use waste energy (heat)*
- *Modulate power according to availability (price)*
- *Use regenerative power*

*Enabling framework for renewables - physical power purchase agreement (PPA) is a long-term contract* for the supply of electricity for a defined period (generally 20 years. Largely configurable



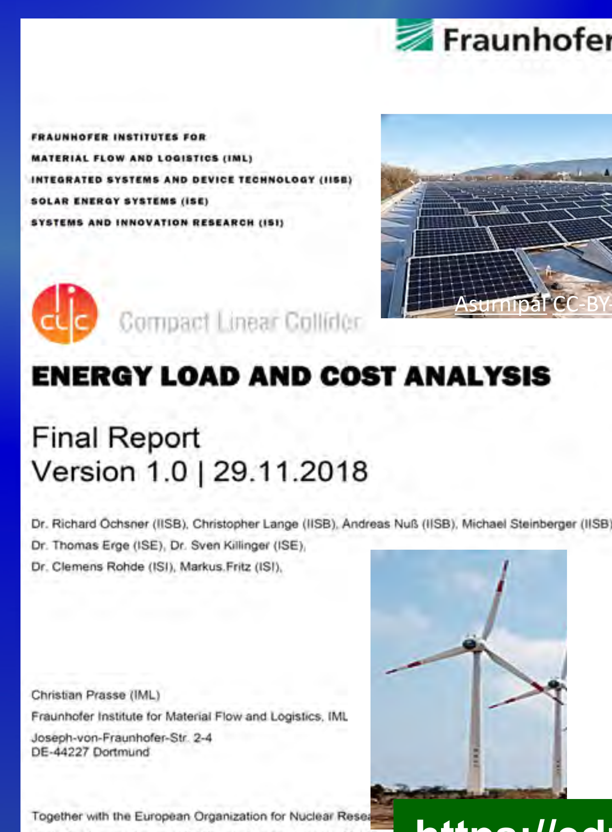

**A. Sunesson**

**Power Purchase Agreements:**




Study by Fraunhofer Institute (2018) considered running CLIC (380 GeV) for a total power of 200 MW (in reality only 110 MW needed) on renewables and participating in ***demand side flexibility:***

- *CLIC's total energy consumption could be generated from renewables (using local solar plant of 330 MWp a local wind farm of 220 MWp)*, but still needs public grid for continuity
- Flexible operating modes were investigated


Fraunhofer

FRAUNHOFER INSTITUTES FOR
MATERIAL FLOW AND LOGISTICS (IML)
INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY (IISB)
SOLAR ENERGY SYSTEMS (ISE)
SYSTEMS AND INNOVATION RESEARCH (ISI)

Compact Linear Collider

Asurnipal CC-BY-SA-4.0

**ENERGY LOAD AND COST ANALYSIS**

Final Report
Version 1.0 | 29.11.2018

Dr. Richard Öchsner (IISB), Christopher Lange (IISB), Andreas Nuß (IISB), Michael Steinberger (IISB)
Dr. Thomas Erge (ISE), Dr. Sven Killinger (ISE),
Dr. Clemens Rohde (ISI), Markus Fritz (ISI),

Christian Prasse (IML)
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Joseph-von-Fraunhofer-Str. 2-4
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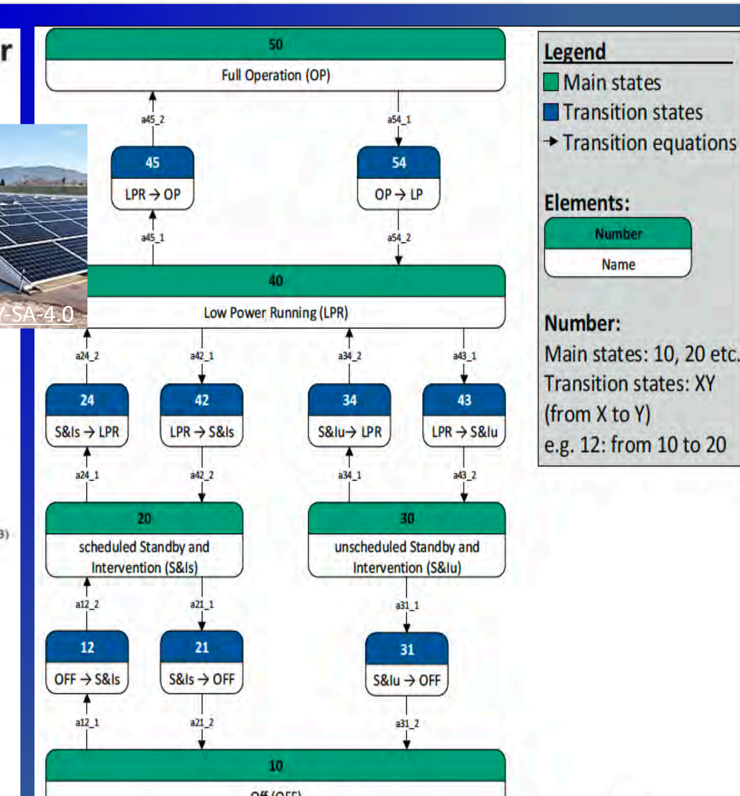
Together with the European Organization for Nuclear Rese...
Prof. Dr. Steinar Stapnes (CERN), Dr. Walter Wünsch (CERN)




**https://edms.cern.ch/document/2065162/1**

# Power Purchase Agreement - Running on Renewables

***Align to future energy markets, using green and more renewable energy (power purchase agreements), remain flexible customer and deal with grid stability/quality***

## *Requirements for future colliders: Energy*

**R. Losito**

- **CERN policy on renewables:**
  - Increase share of renewables through purchase of long term PPAs (15 to 20 years commitment towards solar plants or wind farms), within the boundaries of present energy contract with EDF (and future ones)
  - Limited by the flexibility required on the total share
  - Would require massive curtailment, not necessarily technically feasible and socially acceptable.


FCC-ee future: has warm magnets but a large SRF system with stable power required for cryogenics:
- Large oscillations among operational modes makes it difficult to manage the excess energy with the legal framework of today.
- Energy required in stand-by ~25% of energy during beam operation.

- *Two factors provide uncertainty today in a scenario fully based on renewables:*

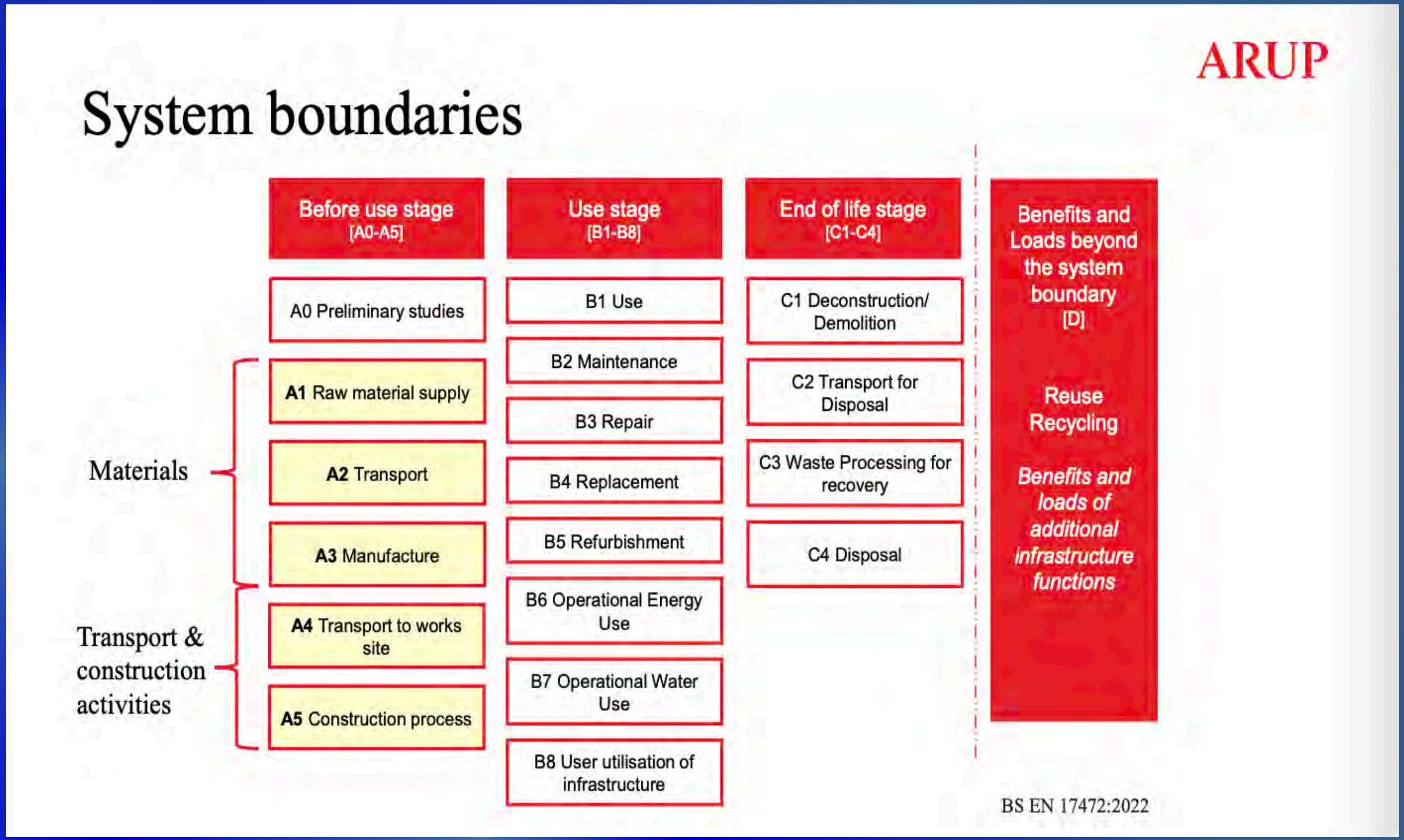
✓ Lack of one or more efficient technology to store energy in order to provide a sufficiently stable baseload → adapt to fluctuating power supply will remain a concern

✓ Lack of capacity and of the possibility to reserve capacity to move energy across borders.

# Sustainable Construction: Life-Cycle Assessment (LCA)

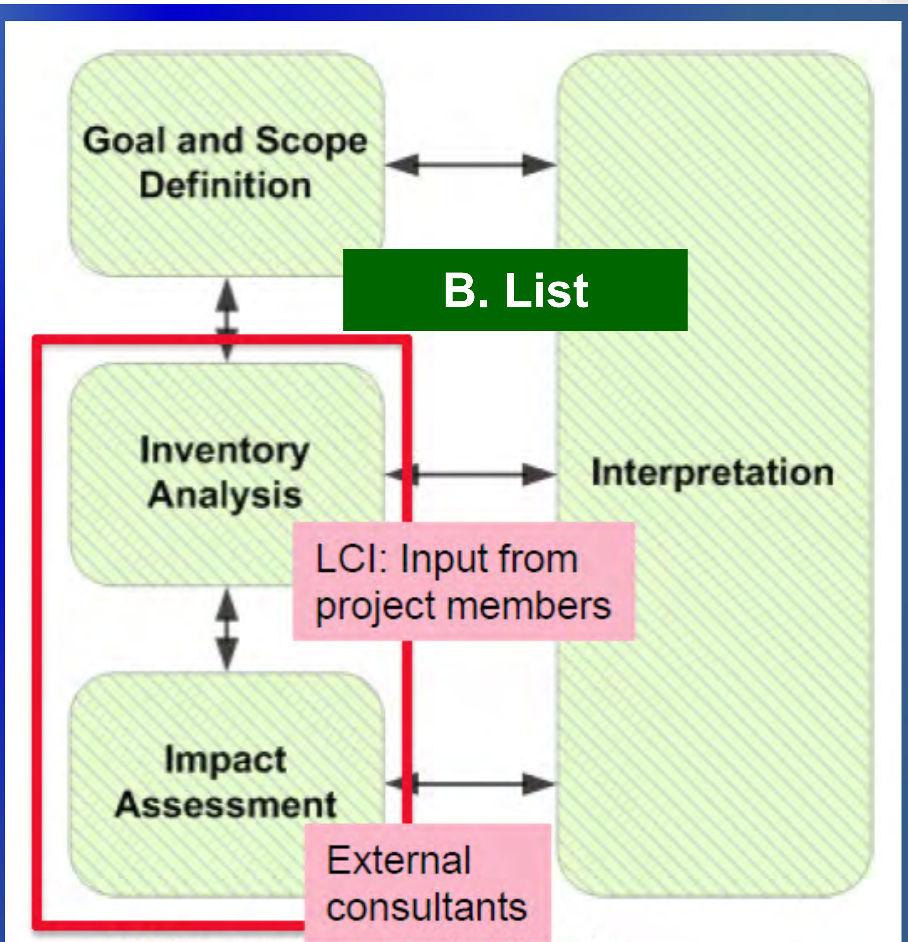
Accepted way to quantify the sustainability of a project is to assess the impacts across the whole lifecycle. International standard ISO 14040/4 define the LCA

- Covering all project stages: design, **construction, operation**, decommissioning/ disposal
- Covering all parts: accelerator, detector, civil construction, infrastructure, computing
- Covering the full scope, including raw material extraction and **electricity generation**




Inventory Analysis:
Materials, Energy, waste, production process
-> domain specific
-> input from accelerator, detector and CFS experts
- tunnel/cavern/shaft dimensions & type
- component types and numbers
- production of components

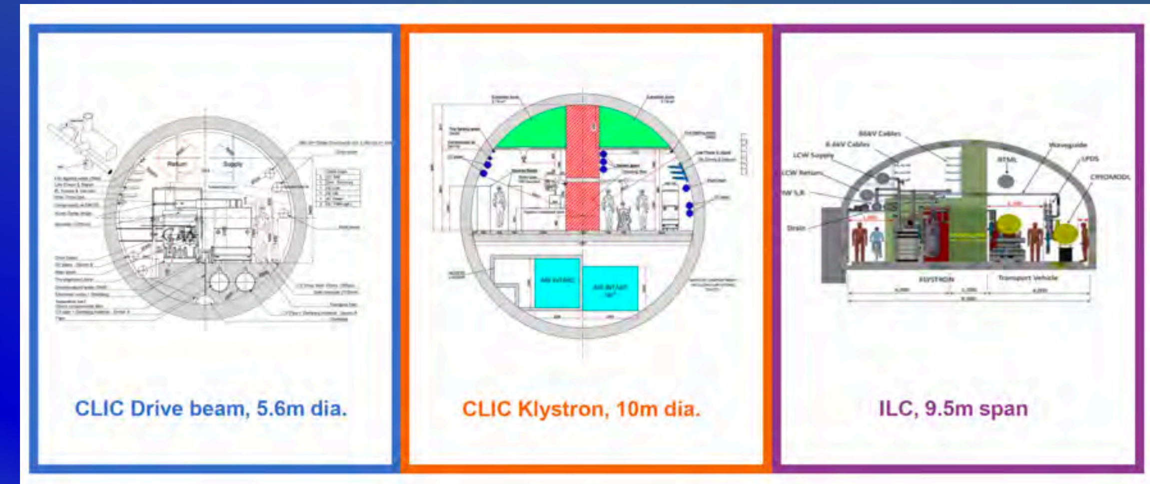
Impact Assessment
Impact of materials on environment
-> methodology
-> based on specific software (e.g. OpanLCA, Simapro) and databases (e.g. ecoinvent)
-> external consultants (e.g. ARUP) can be quite helpful




LCA Framework according to ISO 10040
Public Domain, https://commons.wikimedia.org/w/index.php?curid=40862556

# Example: ILC & CLIC LCA Studies

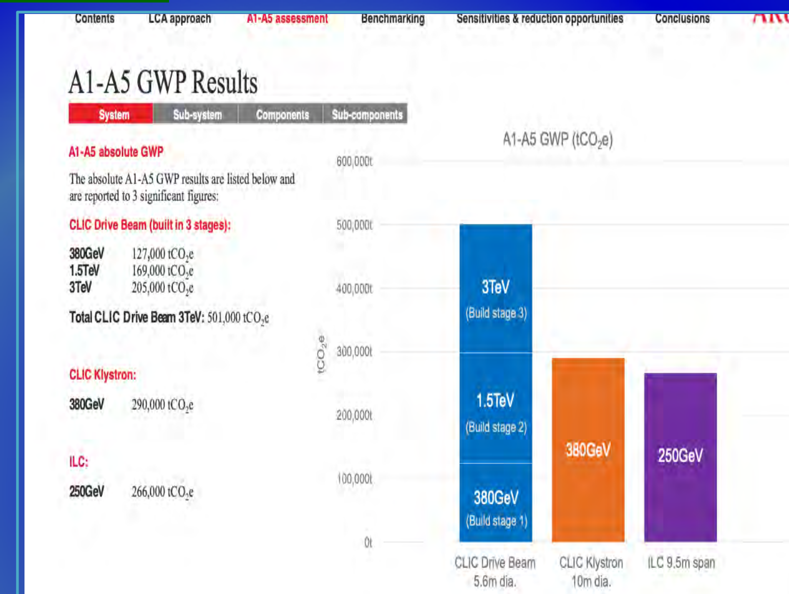
***CERN commissioned a study with ARUP to perform a Lifecycle Assessment for the CLIC and ILC civil infrastructure (tunnels, shafts, caverns)***

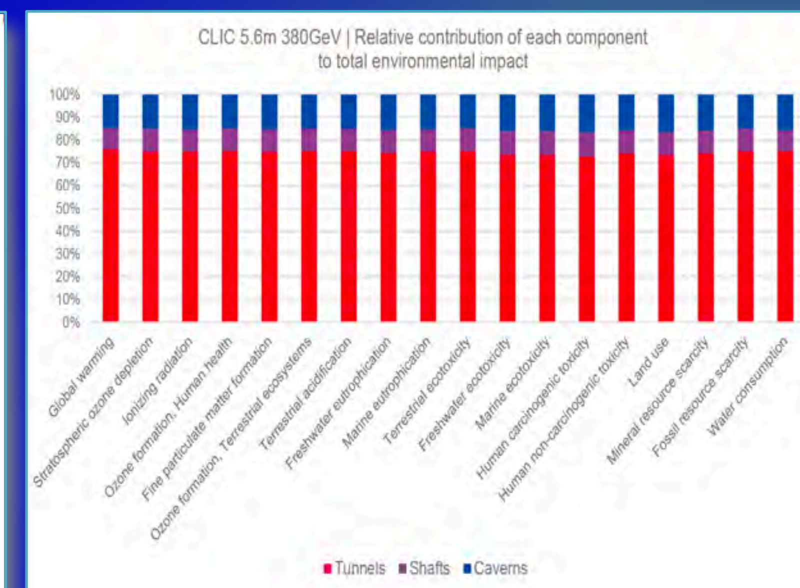



**Full ARUP report:**
**https://edms.cern.ch/document/2917948/1**

*Study provided results on:*

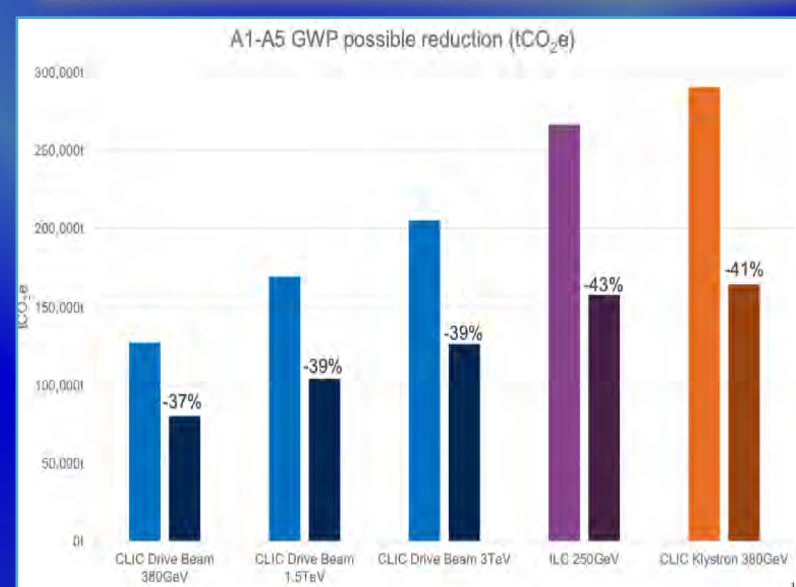
- Greenhouse gas emissions from construction
- **Full set of ReCiPe 2016 impact categories**
- Reduction potential (40%) from optimized design and use of lower carbon material




New LCA study with external company (ARUP) to start soon to provide LCA data for ILC and CLIC accelerator and detector

Goal: quantify lifecycle impact of the full project
-> results will be available by end of 2024



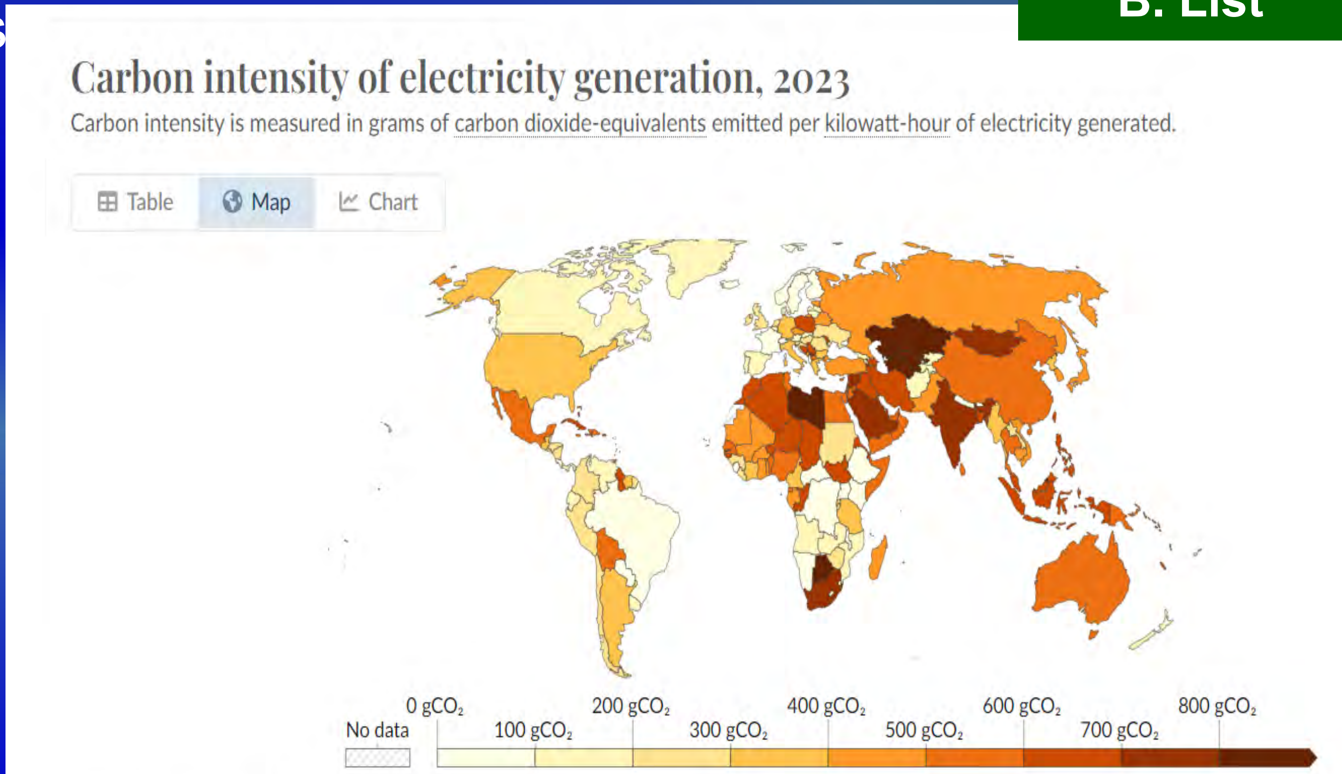

Reduction potential: 40% reduction through use of low-CO2 materials (steel, concrete) and reduction of tunnel wall thickness)


CO2-eq from underground civil engineering
and electricity for operation

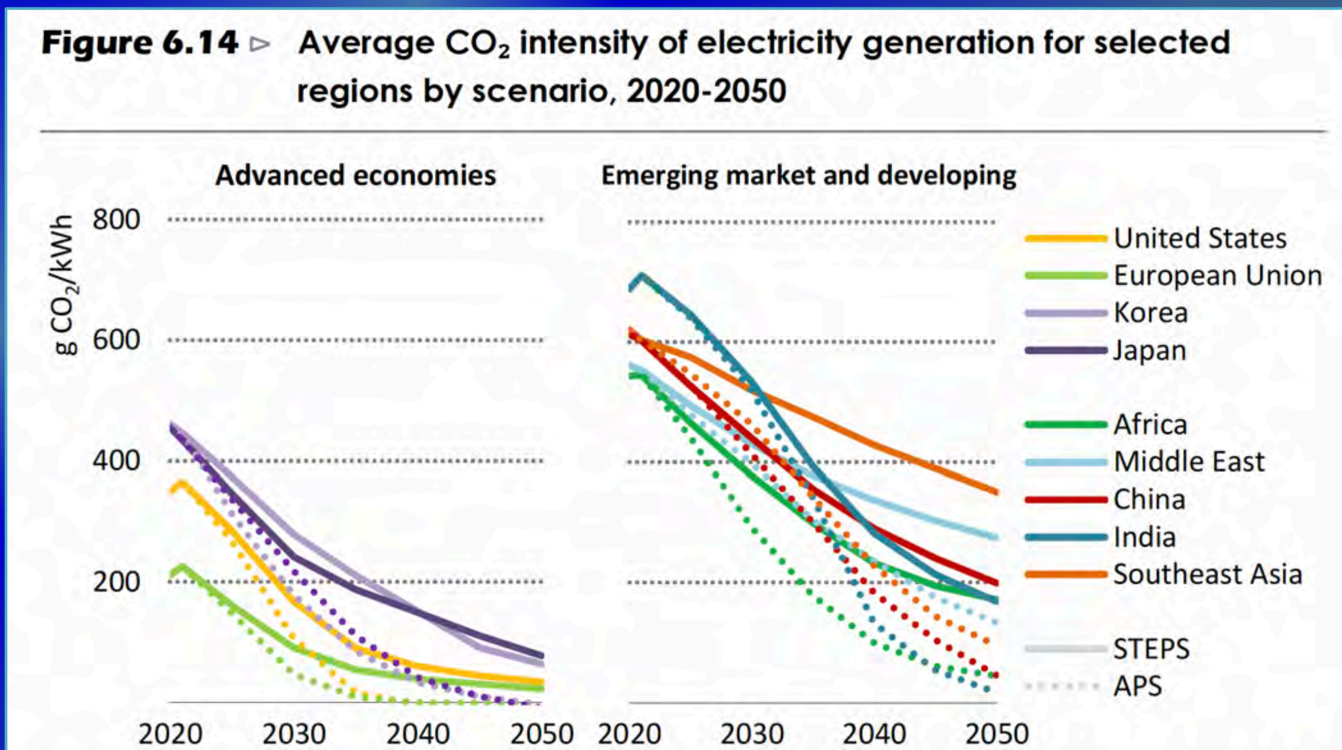
# Open Questions: Regional versus Globally Averaged Impacts

- Carbon intensity of electricity production varies enormously across regions / countries
- Carbon intensity of materials also varies
  - Different local standards
  - Different geology, primary minerals, concentrations
  - Different carbon intensity for local energy, esp. electricity (-> copper, niobium)
- Civil construction: steel and cement mostly from local sources, adhere to local codes
- Result of LCA depends heavily on
  - Source of used materials
  - Construction and operation site
  - Method of LCA: use local values or global averages
- *Should one evaluate impacts using **site-specific or globally averaged impact** values?*
  *-> or provide both?*
- Distinguish impact of intrinsic accelerator design and site specific impact
- Can we give reference values for assumed CO2 intensity of electricity for relevant regions / labs?

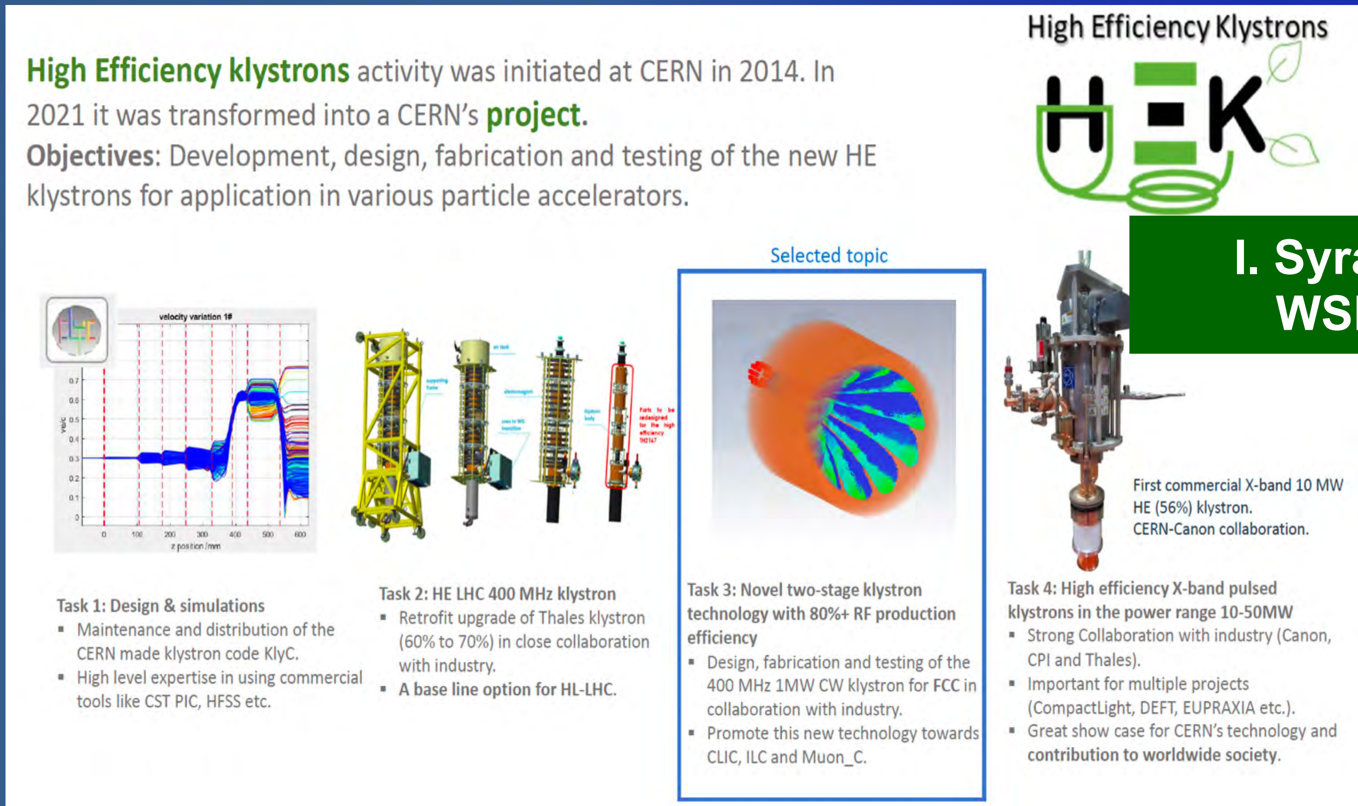
**B. List**



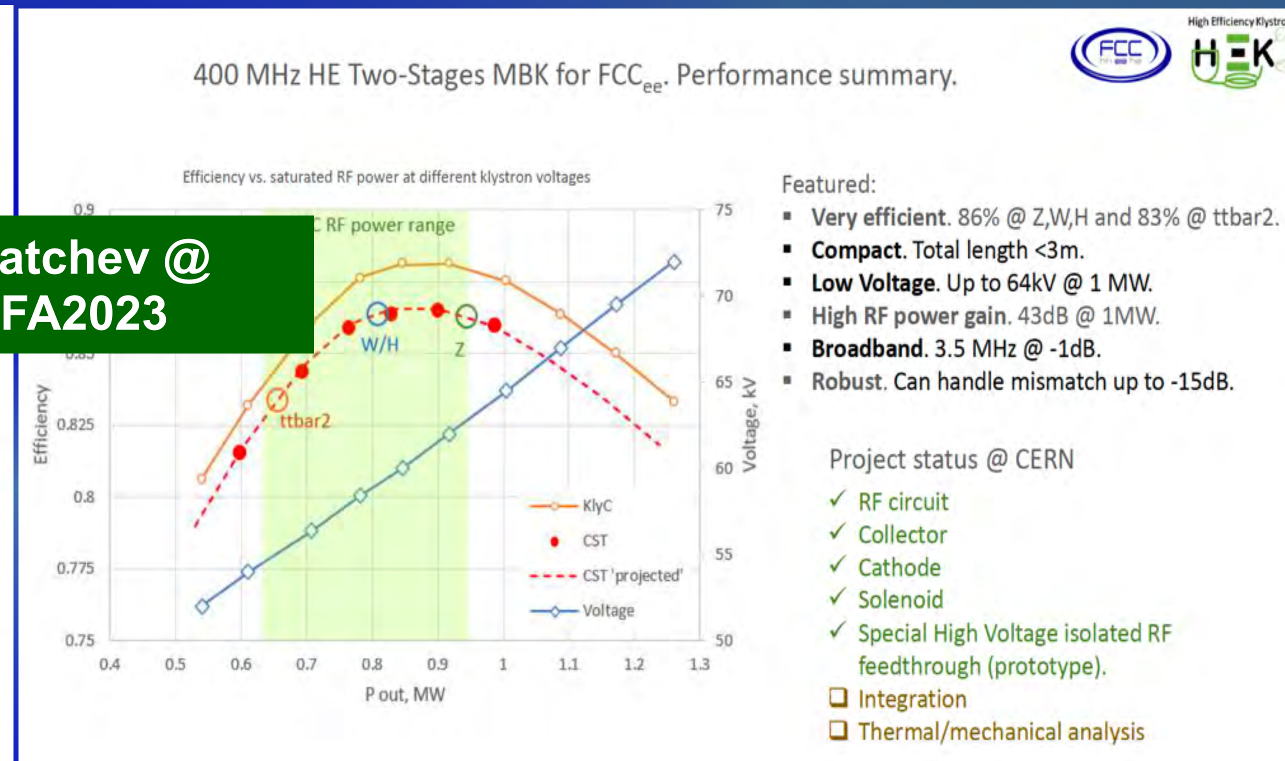

https://ourworldindata.org/grapher/carbon-intensity-electricity



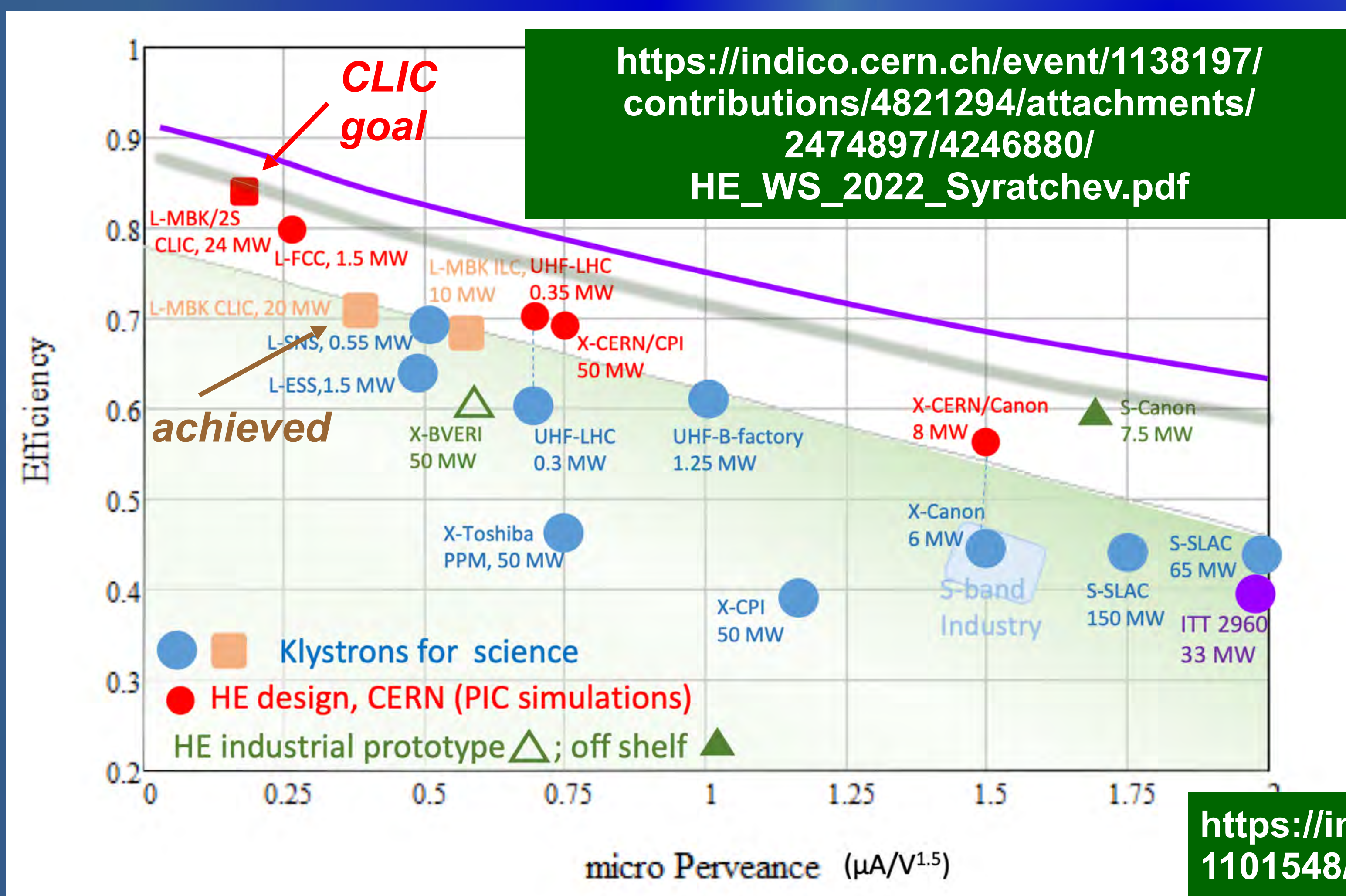
# High Efficiency Klystron Project at CERN



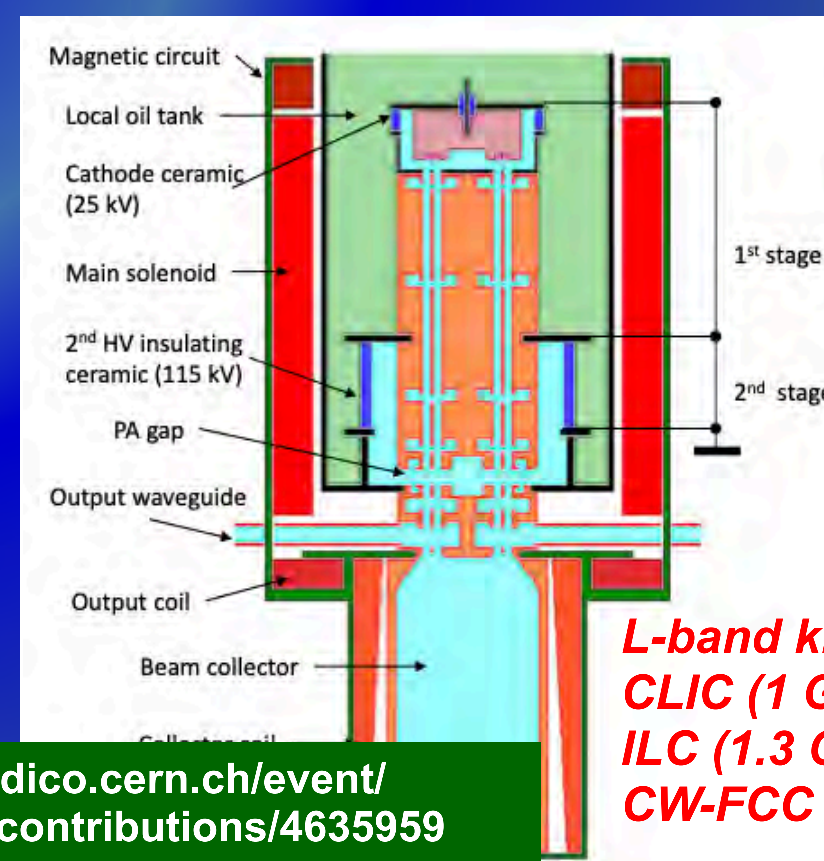

**I. Syratchev @ WSFA2023**




Drive beam klystron: The klystron efficiency (circles) and the peak RF power (squares) simulated for the CLIC TS MBK (solid lines) and measured for the Canon MBK E37503 (dashed lines) vs beam power.




**https://indico.cern.ch/event/1138197/contributions/4821294/attachments/2474897/4246880/HE_WS_2022_Syratchev.pdf**



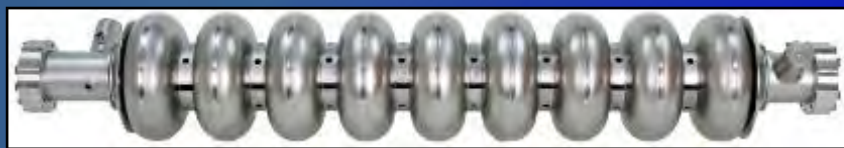

**High efficiency: 24MW, CLIC TS MBK**

**https://indico.cern.ch/event/1101548/contributions/4635959**

***L-band klystron CLIC (1 GHz), ILC (1.3 GHz) CW-FCC (600 MHz)***

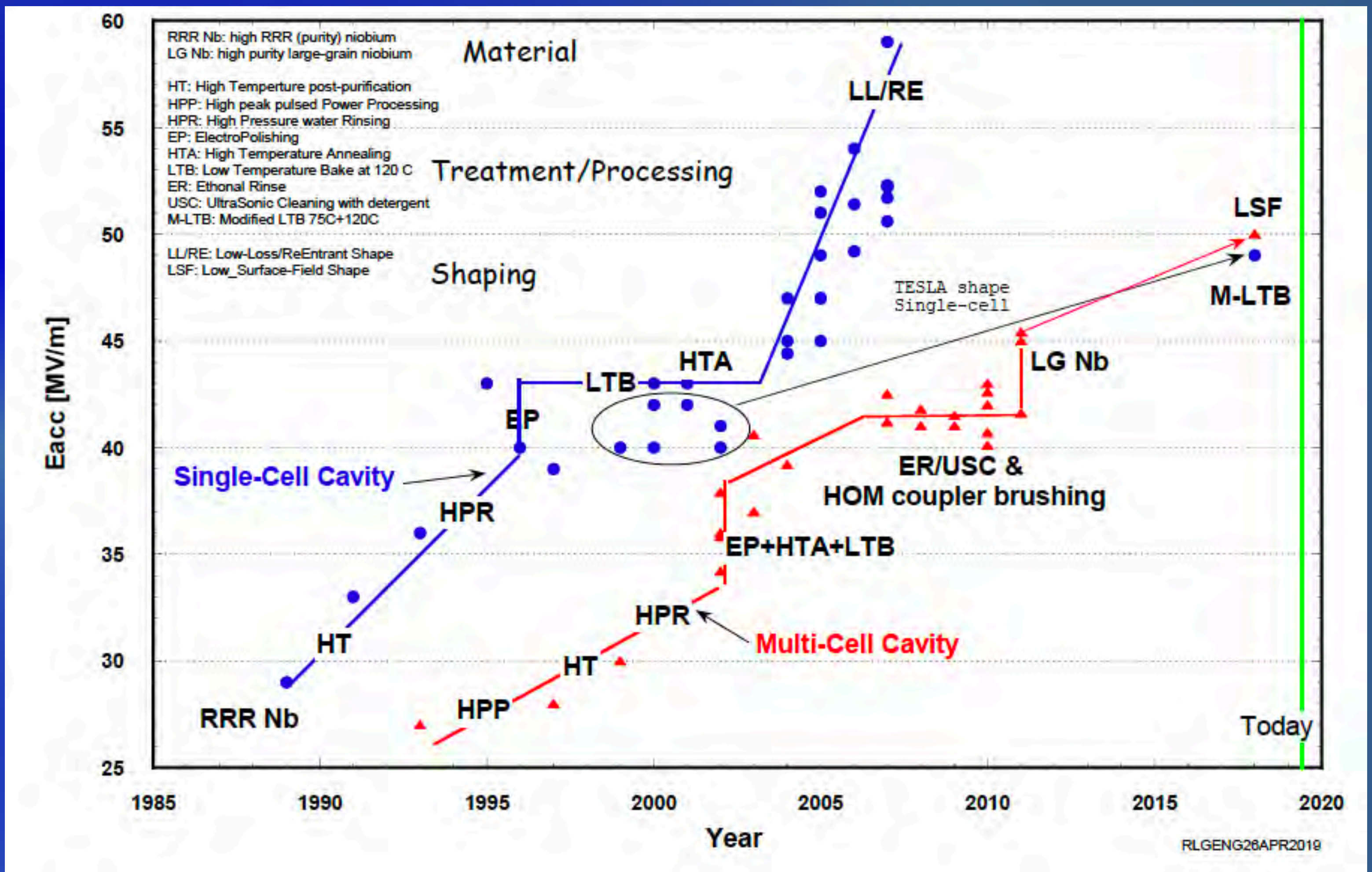
# R&D for Improved SRF Performance & Sustainability

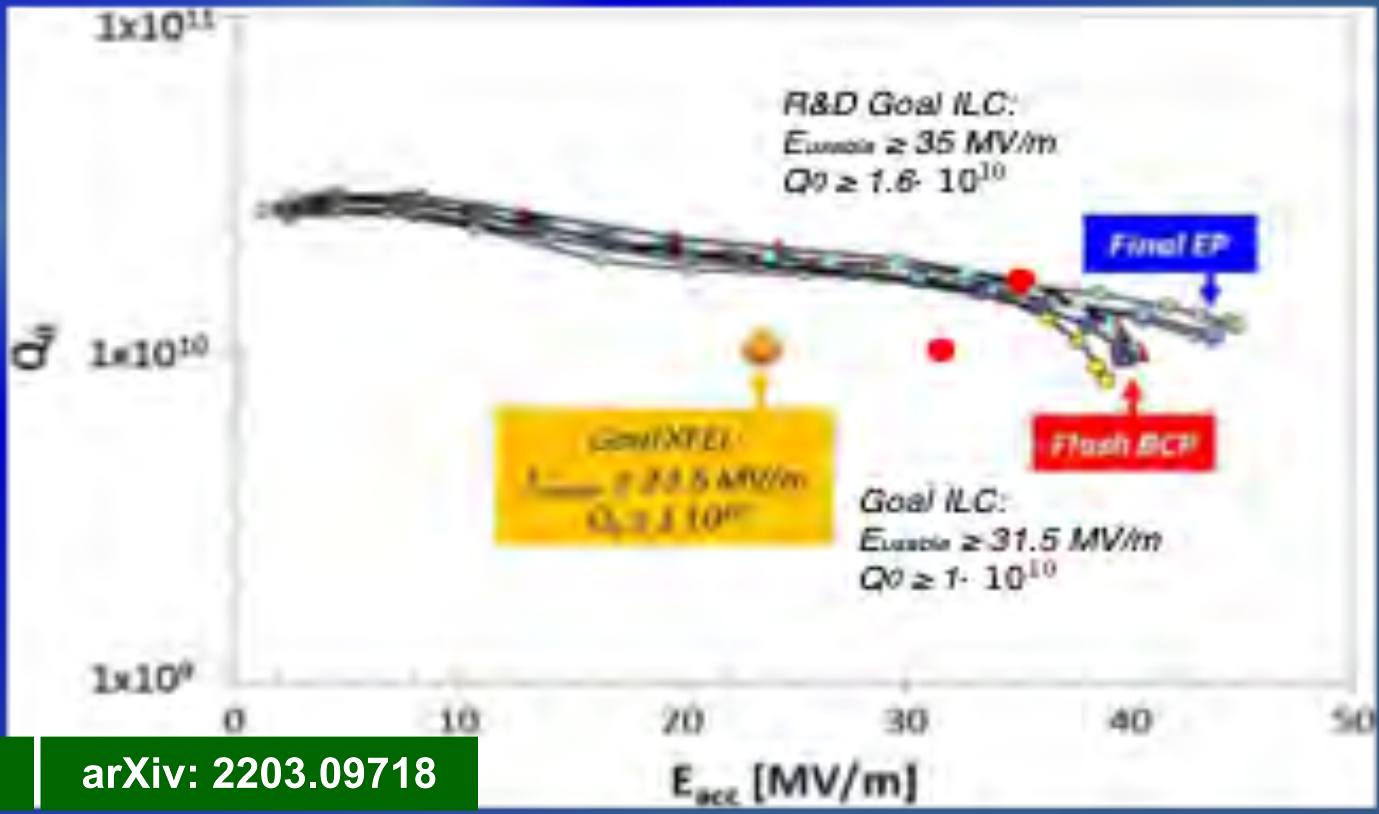
***Major progress during past 10 years:***



- *bulk niobium (1.3 GHz as ILC & FEL linacs), improvements in gradient, processing steps; surface treatment, cavity shapes; power efficiency ($Q_0$) always an integrated part of studies*

  - *Raise Gradient:*
    Short term goal: 31.5MV/m -> 35MV/m
    Medium term goal: 45MV/m
    Lab record: 59MV/m
  - *Improve $Q_0$: reduce cryogenic losses*
    (1W @ 2K requires ~750W AC power!)
    Short term goal: 1E10 -> 2E10



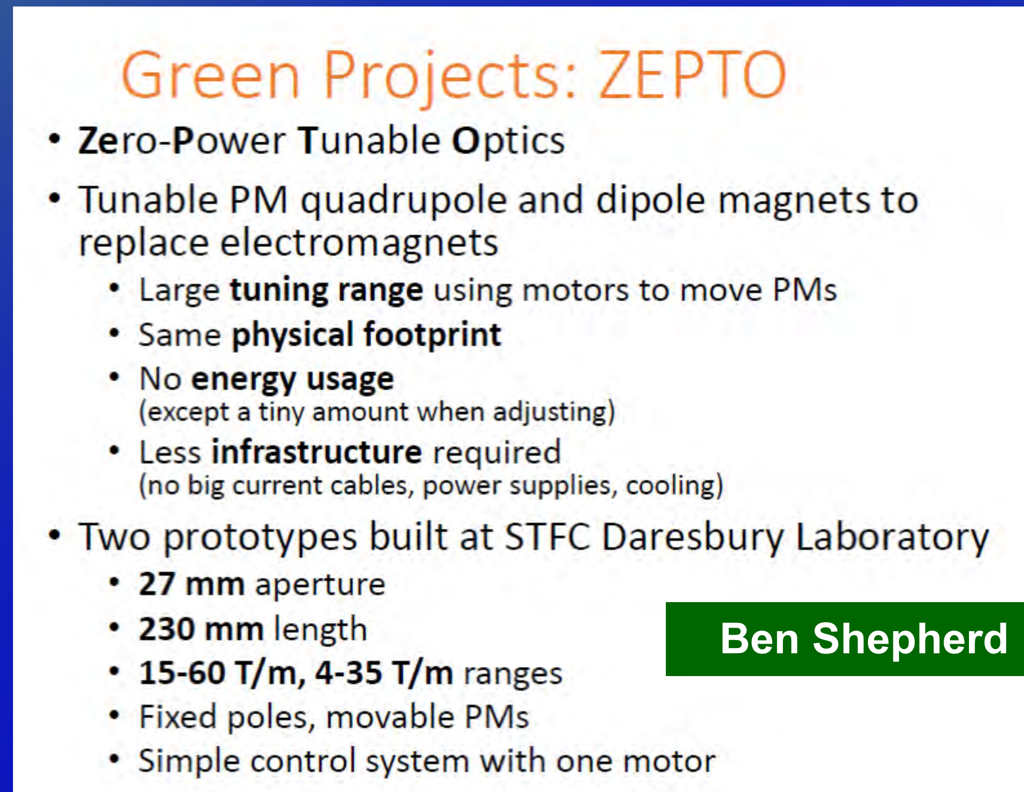

- *State-of-the-art surface treatment of bulk Nb: baking/annealing/doping, plasma processing (possibly reducing aggressive chemicals, required for electropolishing)*

- *R&D into replacement of bulk niobium cavities with Nb or Nb3Sn coated copper (beyond bulk Nb – thin-film SRF): reduce Nb consumption, increase performance*

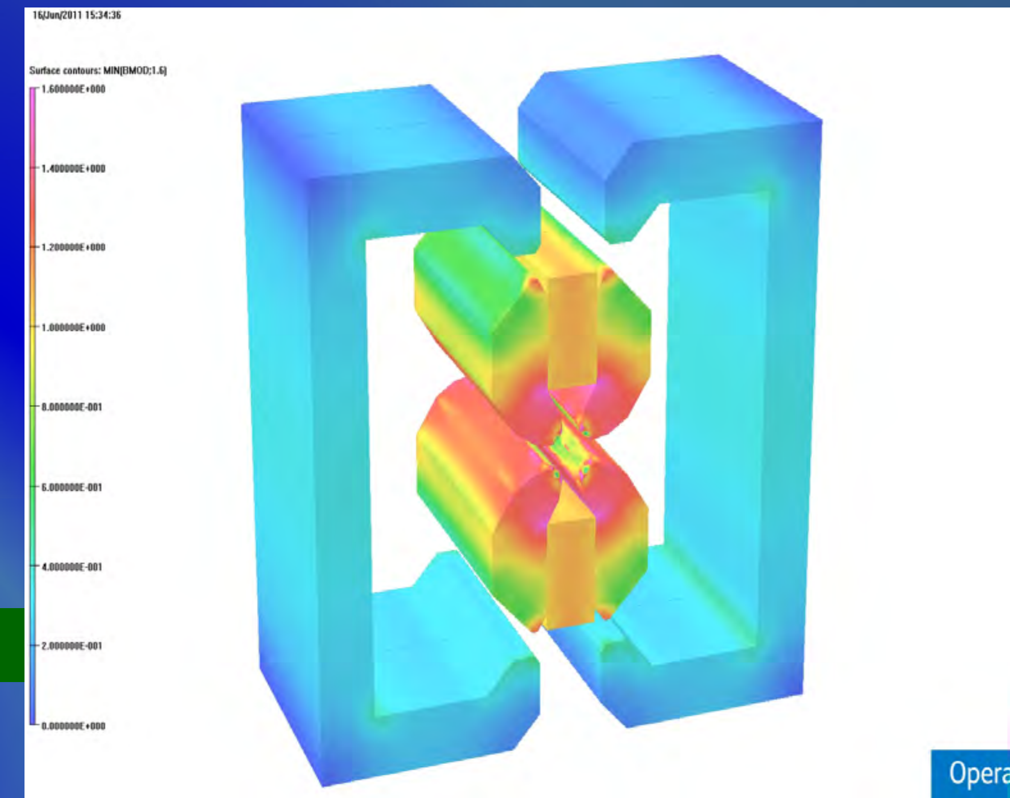
**C. Antoine talk @IPAC2023** | **arXiv: 2203.09718**

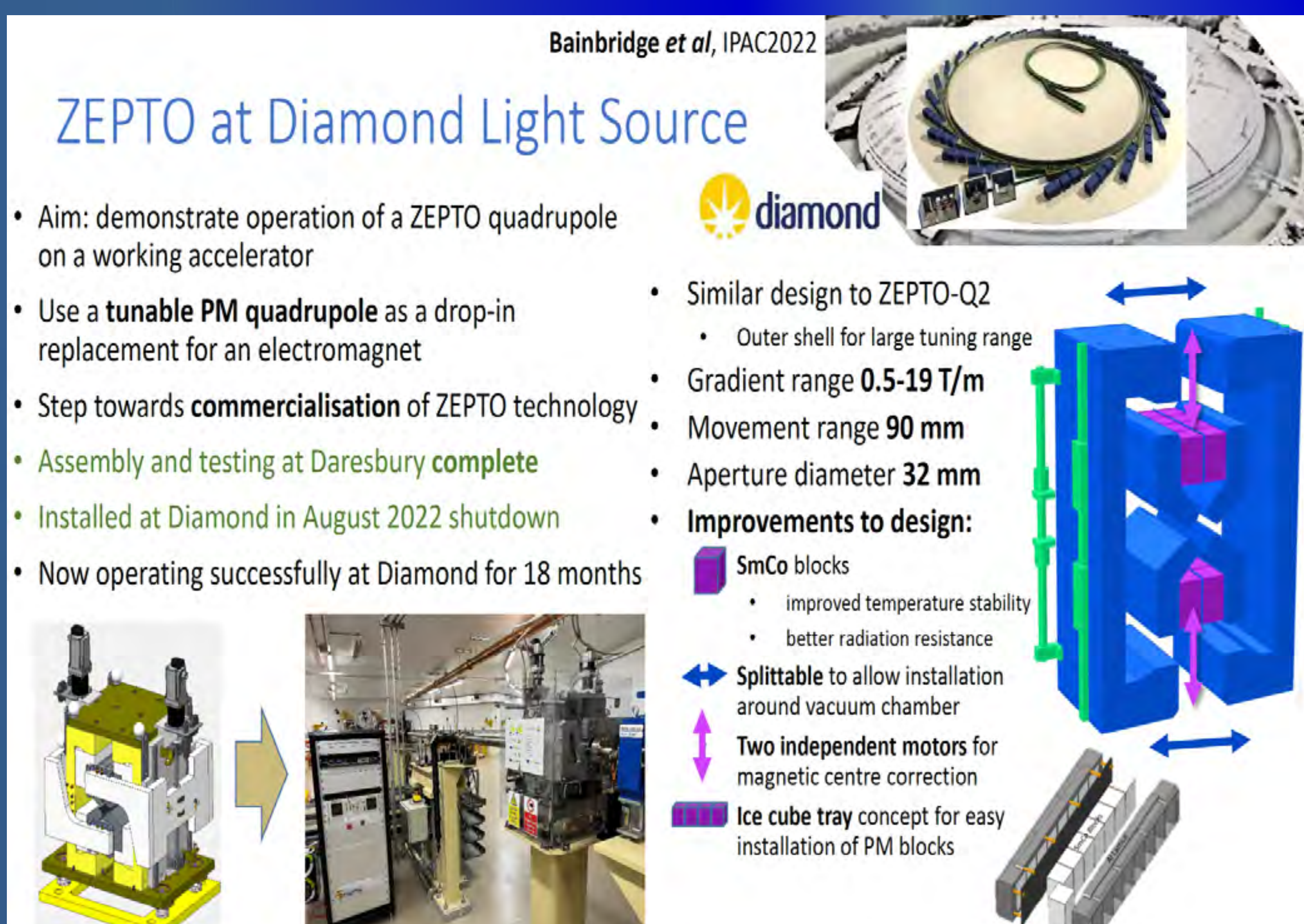
# R&D for Permanent Magnets

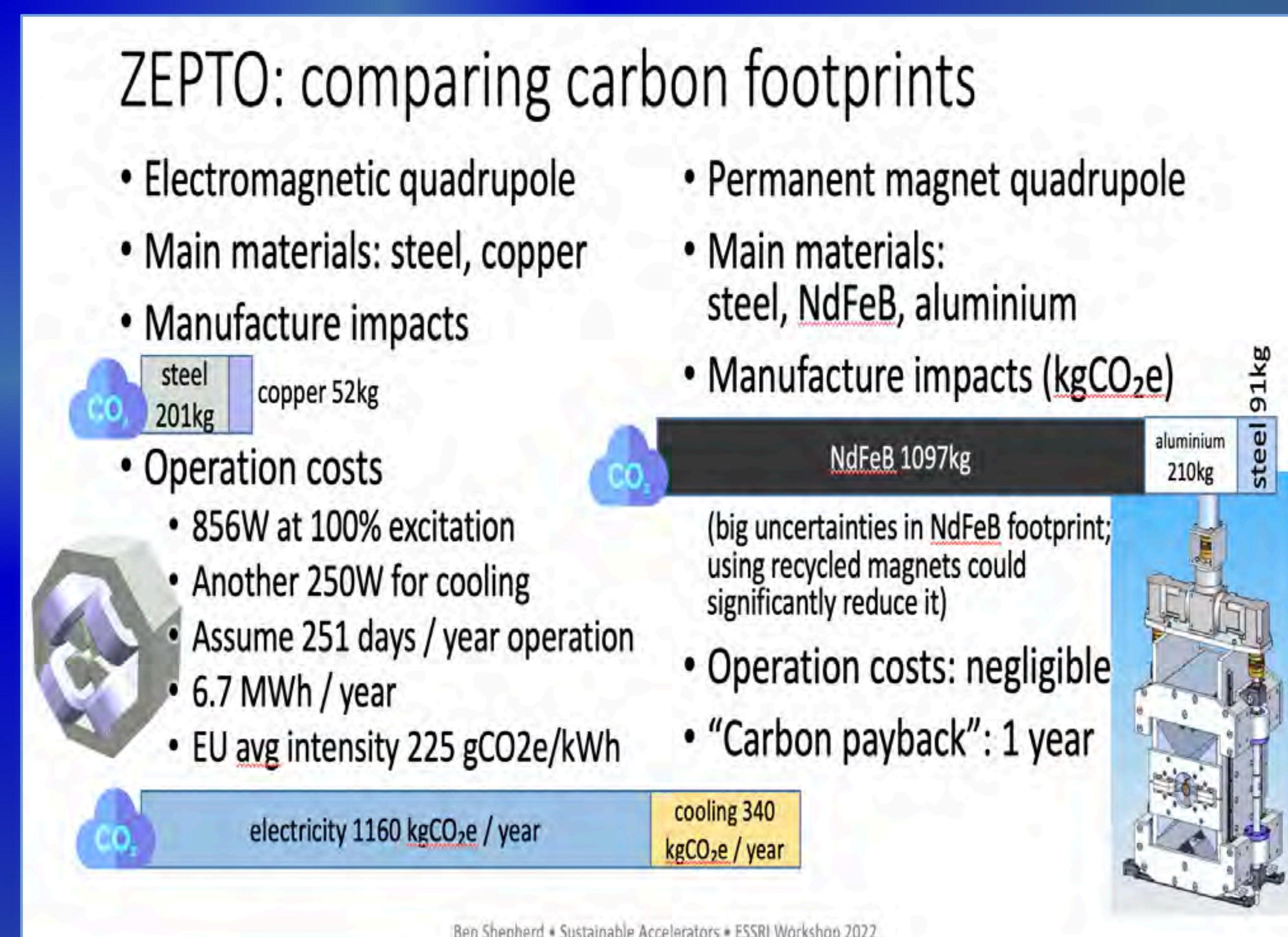
ZEPTO (Zero Power Tuneable Optics) project is a collaboration between CERN and STFC Daresbury Laboratory to save power and costs by switching from resistive electromagnets to permanent magnets




**Ben Shepherd**



# Conclusions

Goal of the WG is to propose a motivated list of key parameters for the sustainability assessment of future accelerators

Inputs from different kinds of sustainability panels related to medium and large RI for fundamental physics are being considered

Environmental sustainability is the focus

The evaluation is quite complex:

assessment criteria deserve to be

- properly tuned to the maturity of the project and
- differently developed for Researchers (our community), Management, and Society

The WG aims to elaborate a proposal for the LDG on time to be submitted to the ESPPU in March 2025