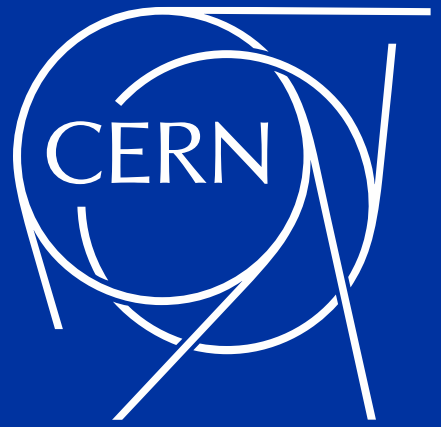


Sustainability Studies for CLIC

Benno List

CLIC Project Meeting 7.12.2022

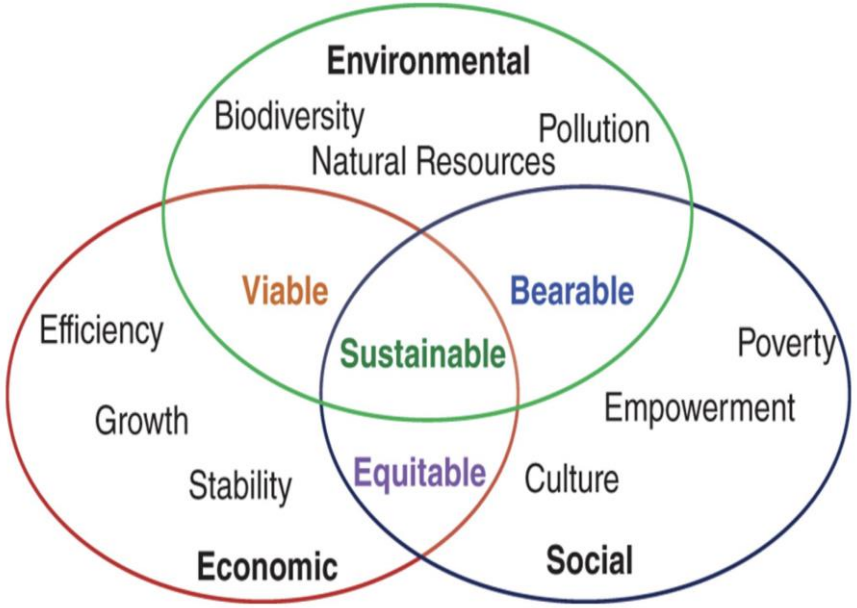
Sustainability: What It Is

Cover of the "Brundtland Report" 1987

***Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations*. (WCED, 1987)**

Gro Harlem Brundlandt at WEF 1989
© WEF, CC-BY-SA-2.0

WCED (World Commission for Environment and Development) (1987) *Our Common Future*, Oxford University Press, Oxford.



R.Y. Surampalli et al. (eds), Sustainability. Wiley 2020.

Our World in Data

The size of the wo

Demographers expect rapid population growth

Sustainability Considerations

Accelerators for High Energy Physics are at the leading edge of technology: beam energy, intensity, luminosity…

Ressource conservation is paramount:

- Tunnel length -> construction cost
- Power consumption -> operating costs

Sustainability adds new cost measures: e.g. CO_2, rare earth usage

Approaches to increase sustainability

Overall system design

- Compact (short) accelerator -> high gradient
- Energy efficient -> low losses
- Effective -> small beam sizes

Subsystem and component design, e.g.

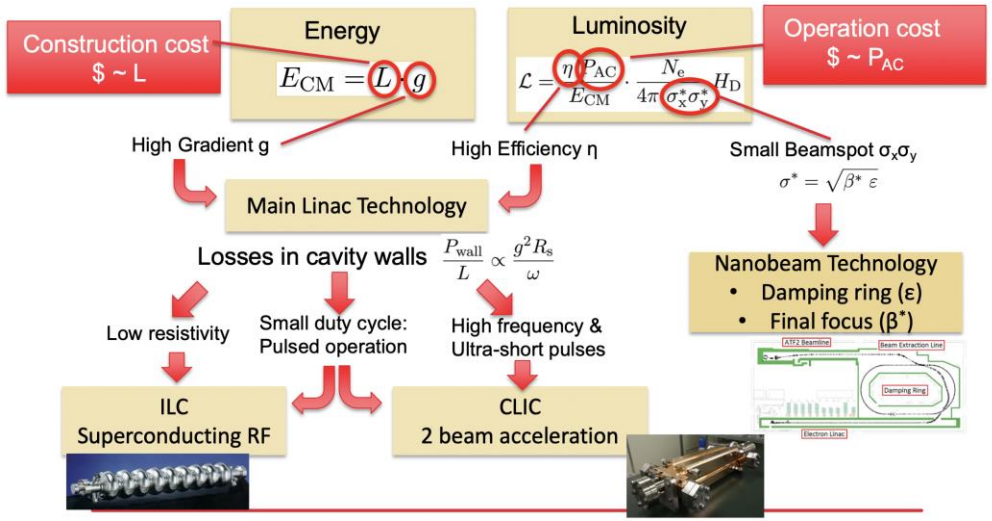
- High-efficiency cavities and klystrons
- Permanent magnets
- Heat-recovery in tunnel linings

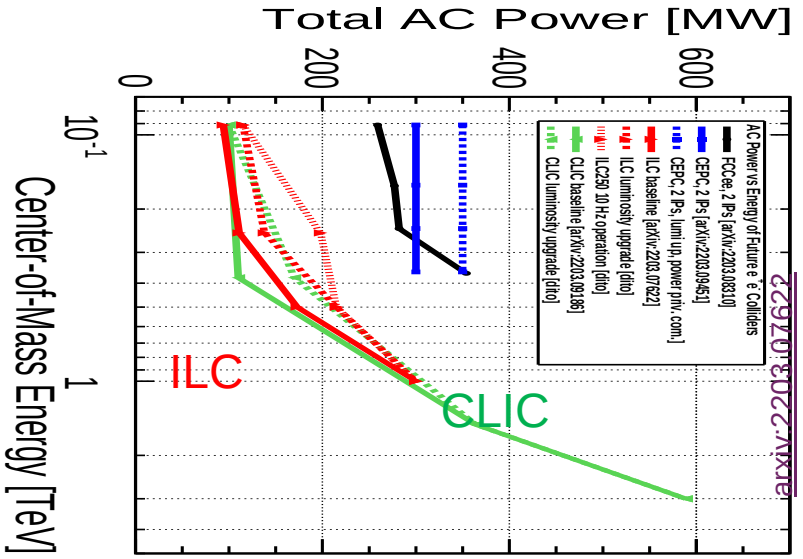
Sustainable operation concepts

- Recycle energy (heat recovery)
- Adapt to regenerative power availability
- Exploit energy buffering potential

Overall System Design

BL: https://indico.cern.ch/event/981823/contributions/4328846/





Challenge: Achieve target energy and luminosity with least possible amount of ressources

Conserve ressources for construction:

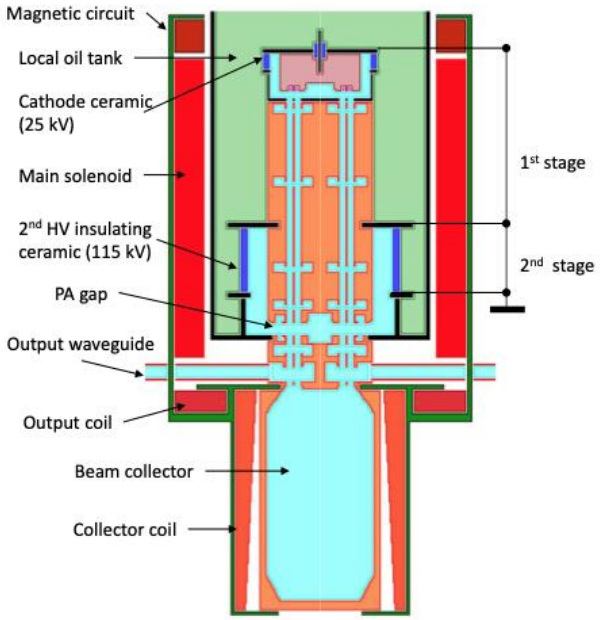
- compact -> high acceleration gradient

Conserve ressources in operation:

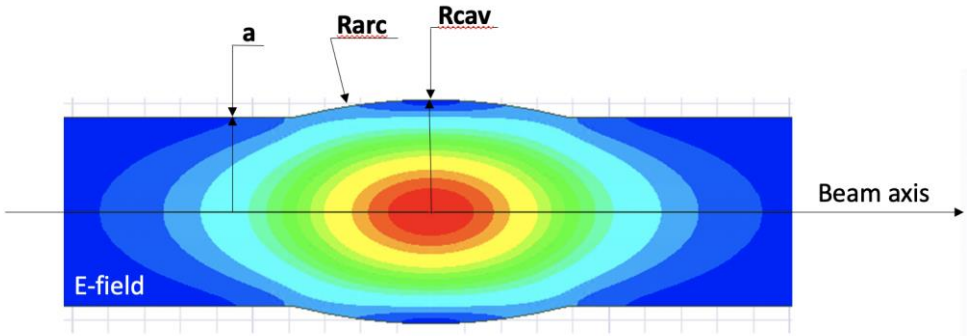
- Energy-efficiency (limit losses in cavity walls):
  superconducting RF – ILC
  high frequency & ultra-short pulses: CLIC
- Effectiveness: maximum luminosity per charge
  -> nanobeam technology

ILC and CLIC:

- different solutions to the efficiency problem
- Final power consumption similar



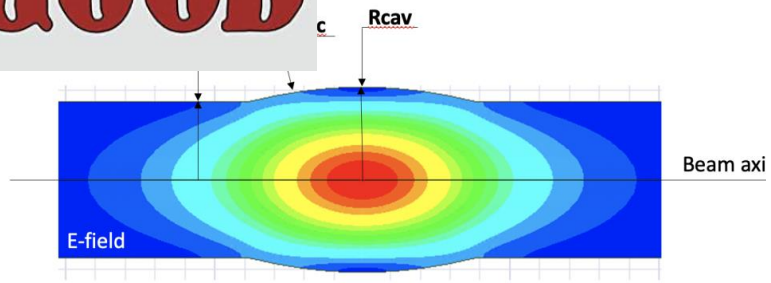
Optimization of Components and Subsystems

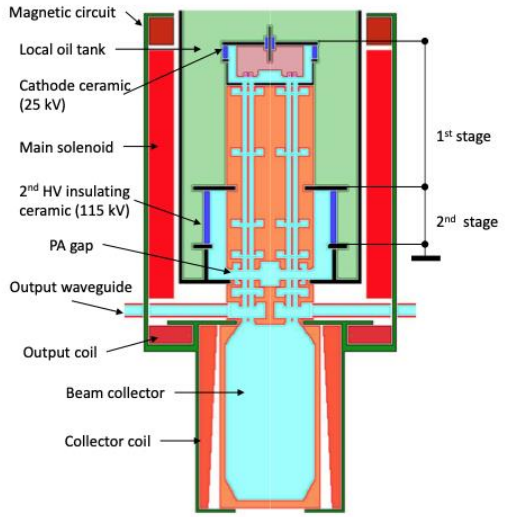


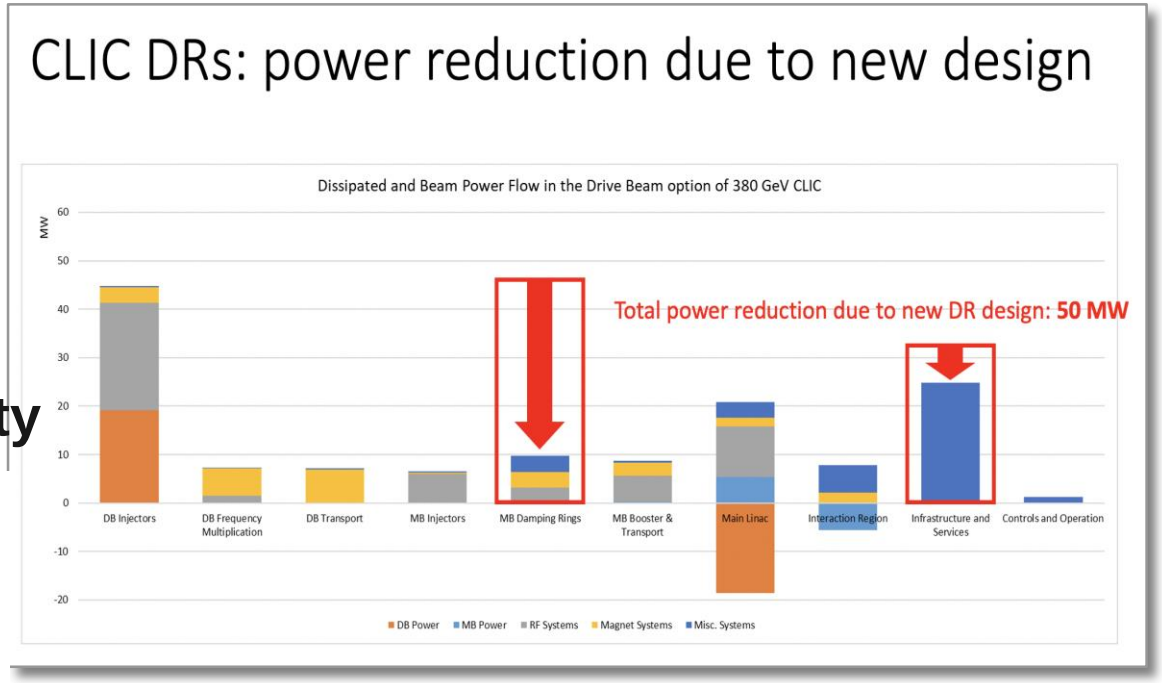
Reducing Power by Better Components

Ultra low R/Q Cavities +
High efficiency klystrons
=> Tremendous Saving!

Reduced power ->
reduced operating cost
without large investment penalty







A. Grudiev, CLIC Project Meeting 21.11.2021
https://indico.cern.ch/event/1101548/contributions/4635959

Unavoidable Embodied Emissions: Tunnel LCA Study

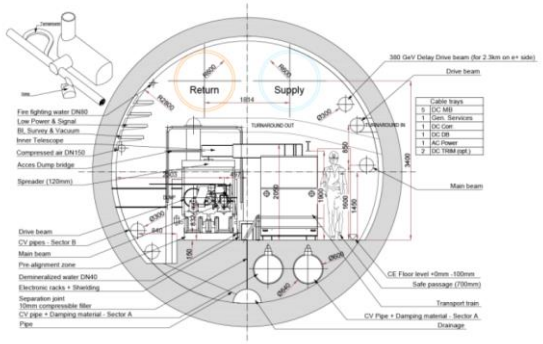
Study under preparation with ARUP by John Osborne, Liam Bromiley

Goal: Determine the embodied and construction environmental impact of tunnel, caverns and shafts
-> perform a LCA (Lifecycle Assessment) for the construction stage

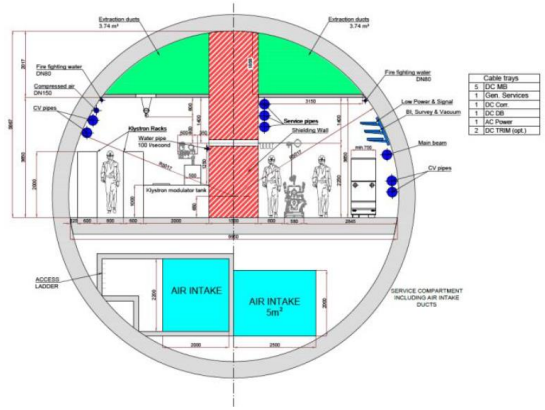
Generate solid data as basis for optimisation

Target date: LCWS at SLAC, May 2023

1. CLIC Drive Beam tunnel, 5.6m internal diameter



2. CLIC Klystron tunnel, 10m internal diameter



Trading Operation vs Invest

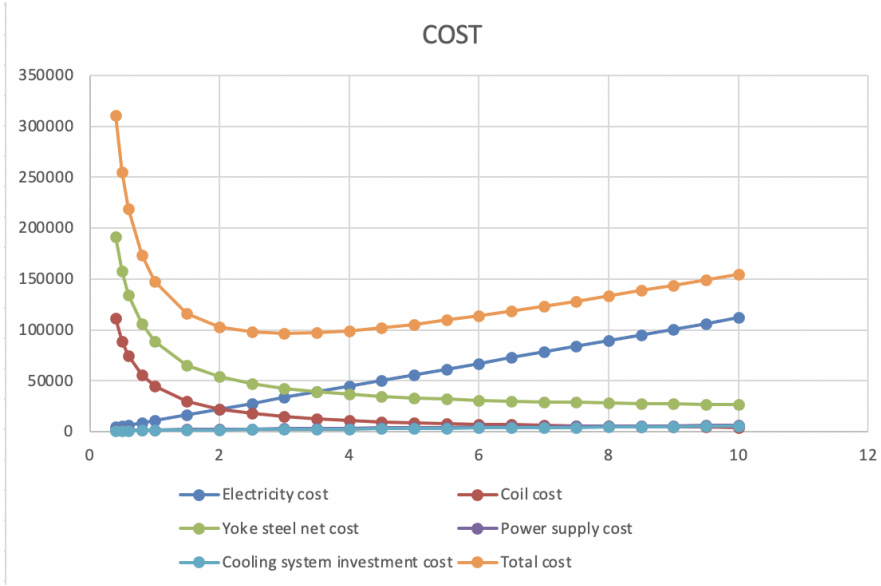
Magnets:

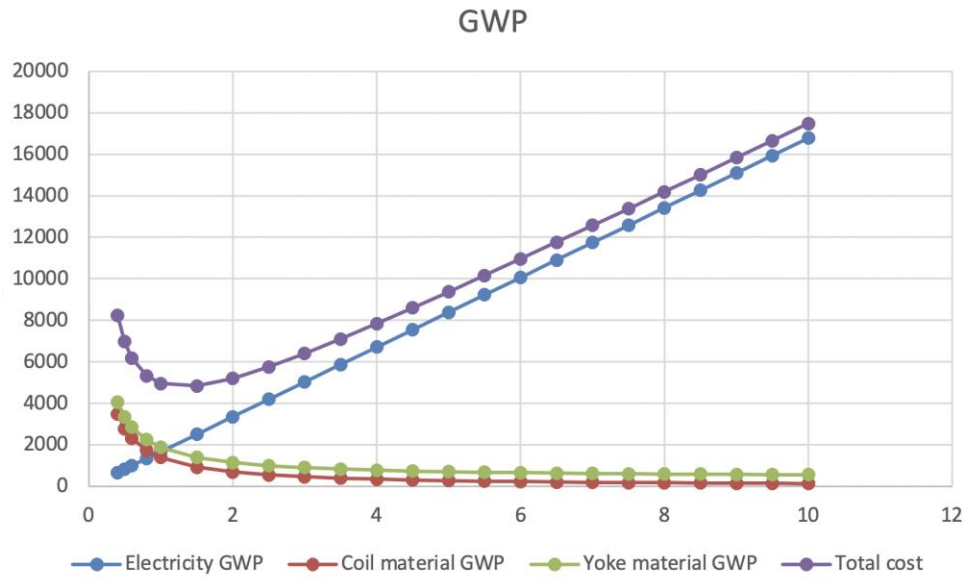
- **Consume a lot of power**
  -> dominates CO_2 footprint by far
- **Have a high invest**

Reducing power/CO2 is easy:
bigger coil cross sections
-> leads to higher embodied emissions and a higher invest

Balance

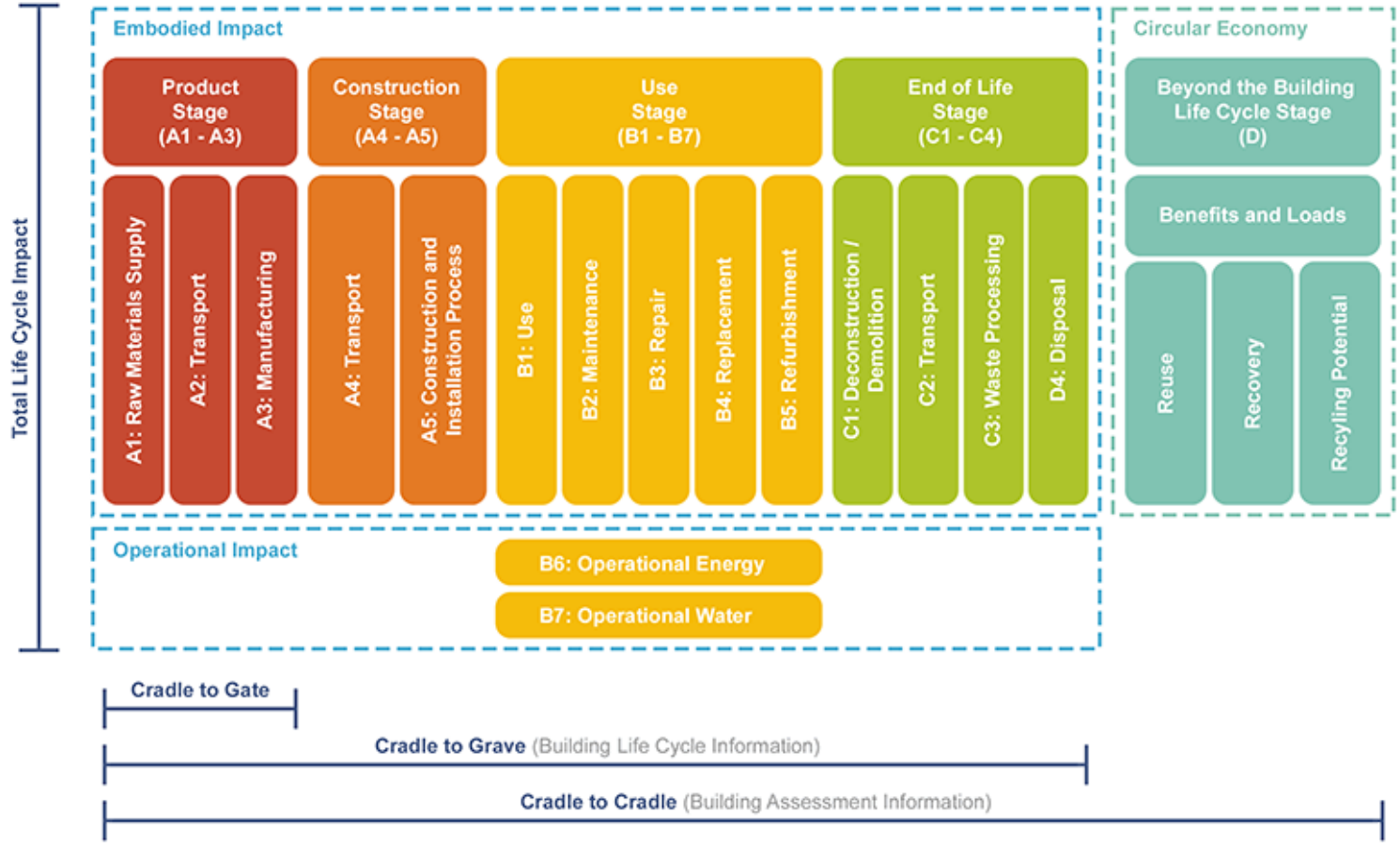
- **Operation vs invest/embodied CO_2**
- **CO_2 vs Cost**





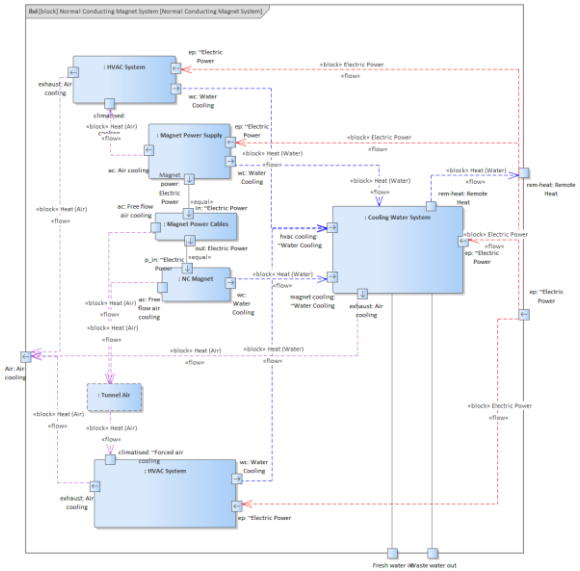
Whole Lifecycle is Important – Lifecyle Assessment LCA

https://browningday.com/news/lca-stages-matter-when-tracking-embodied-carbon/
https://www.buildingenclosureonline.com/blogs/14-the-be-blog/post/89547-lca-stages-matter-when-tracking-embodied-carbon



Lifecycle stages according to EN 15978

Defining the Right System Boundary

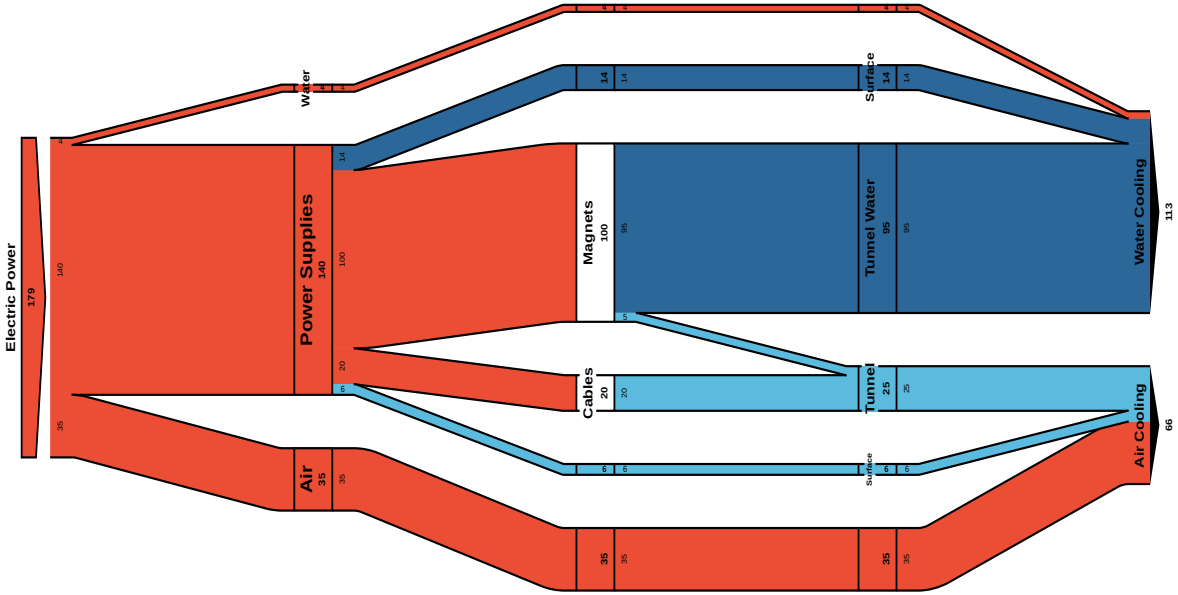


Magnet is not isolated:
requires cables, power supplies, water and air cooling

Consider the whole system to evaluate impact of changes

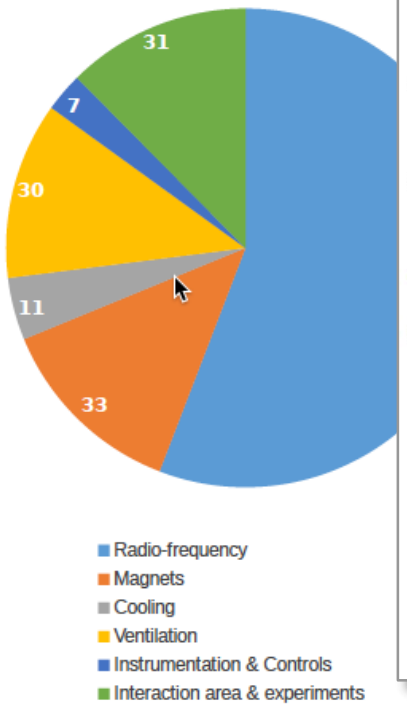
- **Invest in larger coils saves invest in power supplies and cooling**
- **Savings in operation costs are larger than for magnet alone**

Crucial when evaluating radical alternatives: permanent magnets



Magnets

1.5 TeV CLIC powe
Magnets second la



ZEPTO (Zero Power Tuneable Optics) project is a
Daresbury
witching from
agnets.

ve-beam
l tested as
nets

Bainbridge *et al*, IPAC2022

ZEPTO at Diamond Light Source

- Aim: demonstrate operation of a ZEPTO quadrupole on a working accelerator
- Use a **tunable PM quadrupole** as a drop-in replacement for an electromagnet
- Step towards **commercialisation** of ZEPTO technology
- Assembly and testing at Daresbury co
- Installed at Diamond in August

diamond

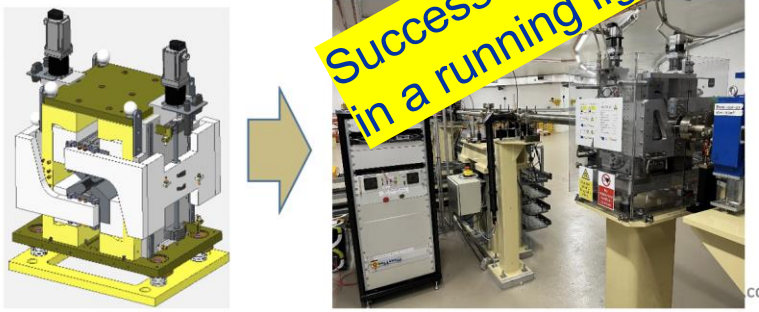
- Similar desi
  - O ing range
- C -19 T/m
- range **90 mm**
- ure diameter **32 mm**

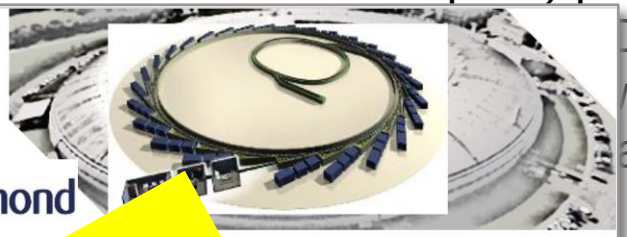
Improvements to design:

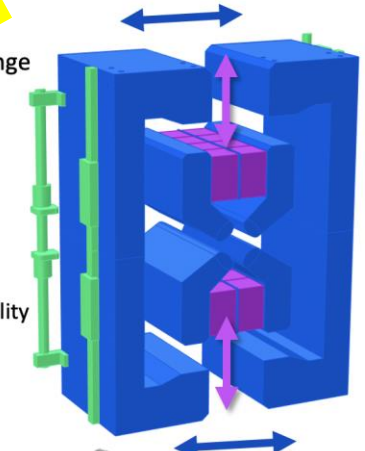
- **SmCo** blocks
  - improved temperature stability
  - better radiation resistance
- **Splittable** to allow installation around vacuum chamber
- **Two independent motors** for magnetic centre correction
- **Ice cube tray** concept for easy installation of PM blocks

ccelerators • ESSRI Workshop 2022

Successful installation and operation in a running light source!



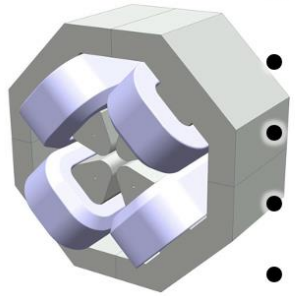


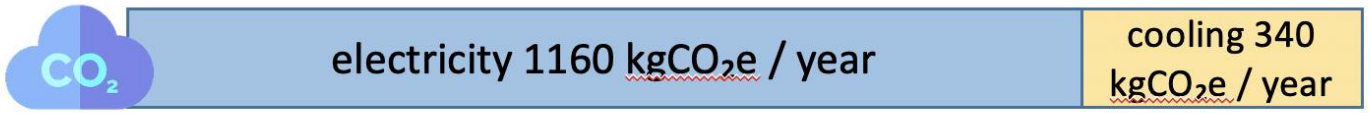


ZEPTO: comparing carbon footprints

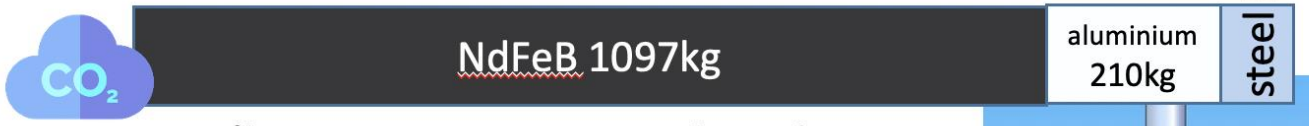
- Electromagnetic quadrupole
- Main materials: steel, copper
- Manufacture impacts

- Operation costs
  - 856W at 100% excitation
  - Another 250W for cooling
  - Assume 251 days / year operation
  - 6.7 MWh / year
  - EU avg intensity 225 gCO2e/kWh



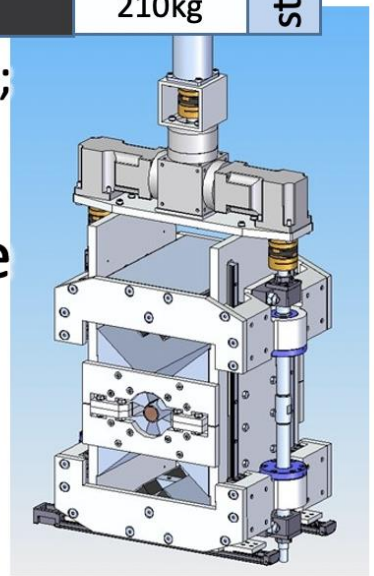


- Permanent magnet quadrupole
- Main materials: steel, NdFeB, aluminium
- Manufacture impacts ($kgCO_2e$)



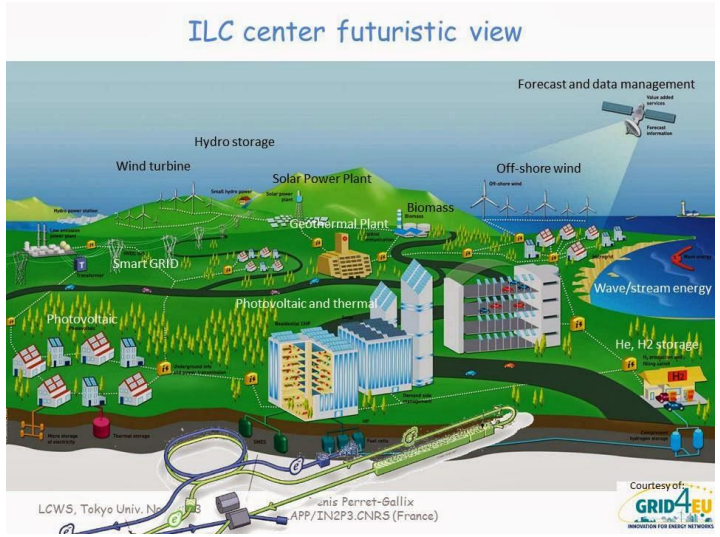
(big uncertainties in NdFeB footprint; using recycled magnets could significantly reduce it)

- Operation costs: negligible
- "Carbon payback": 1 year



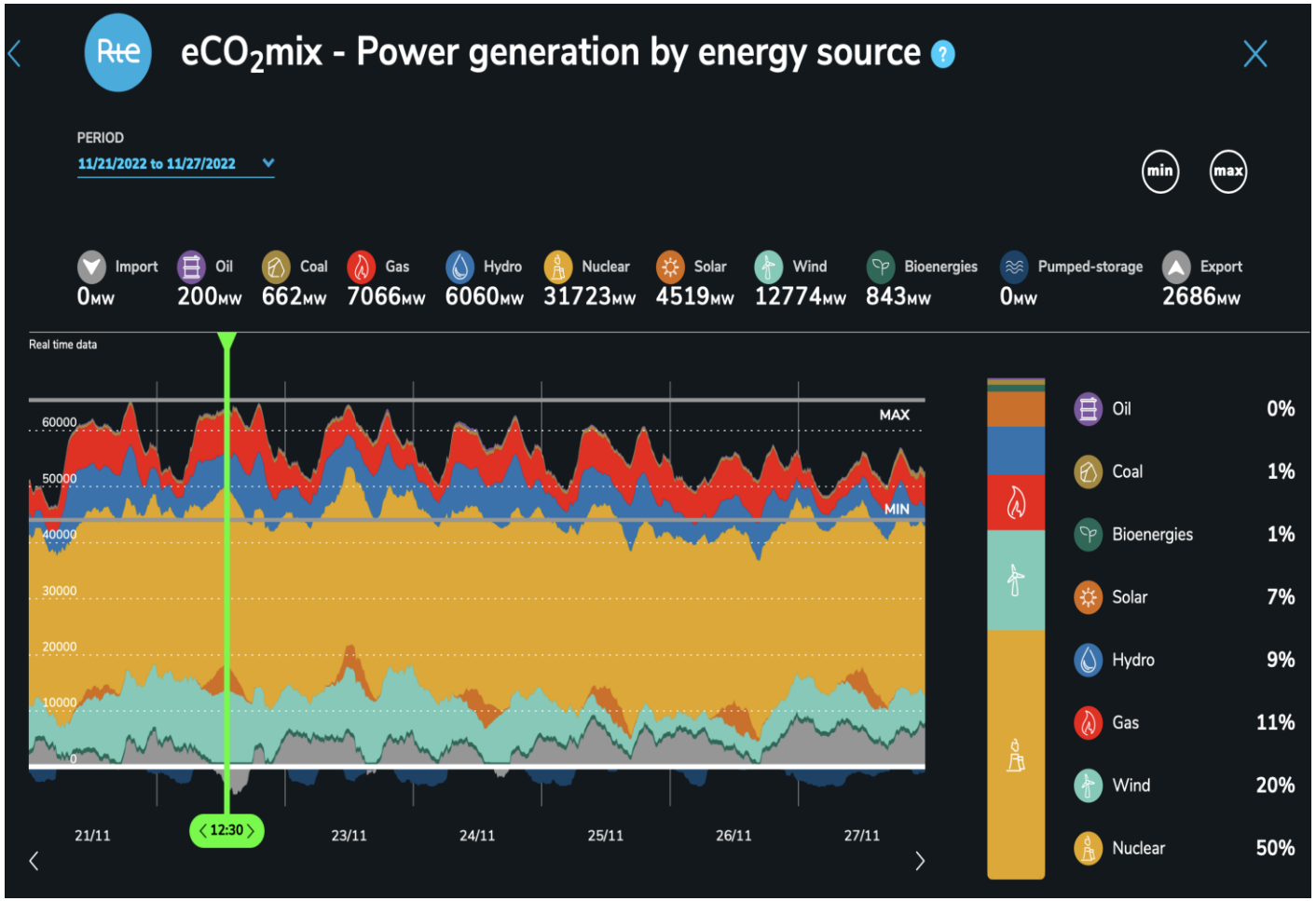
Ben Shepherd • Sustainable Accelerators • ESSRI Workshop 2022

Ben Shepherd, ESSRI Workshop 2022, https://indico.esrf.fr/event/2/contributions/108/



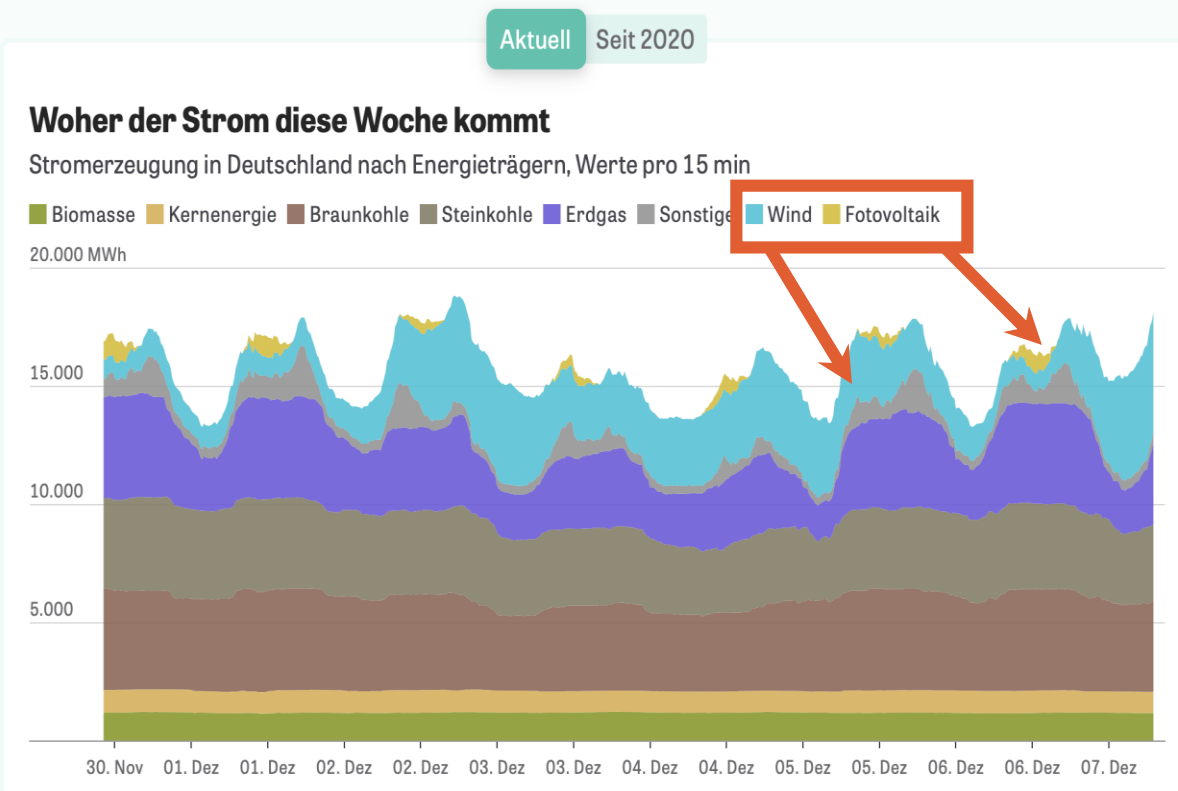
Sustainable Operation

Asurnipal CC-BY-SA-4.0



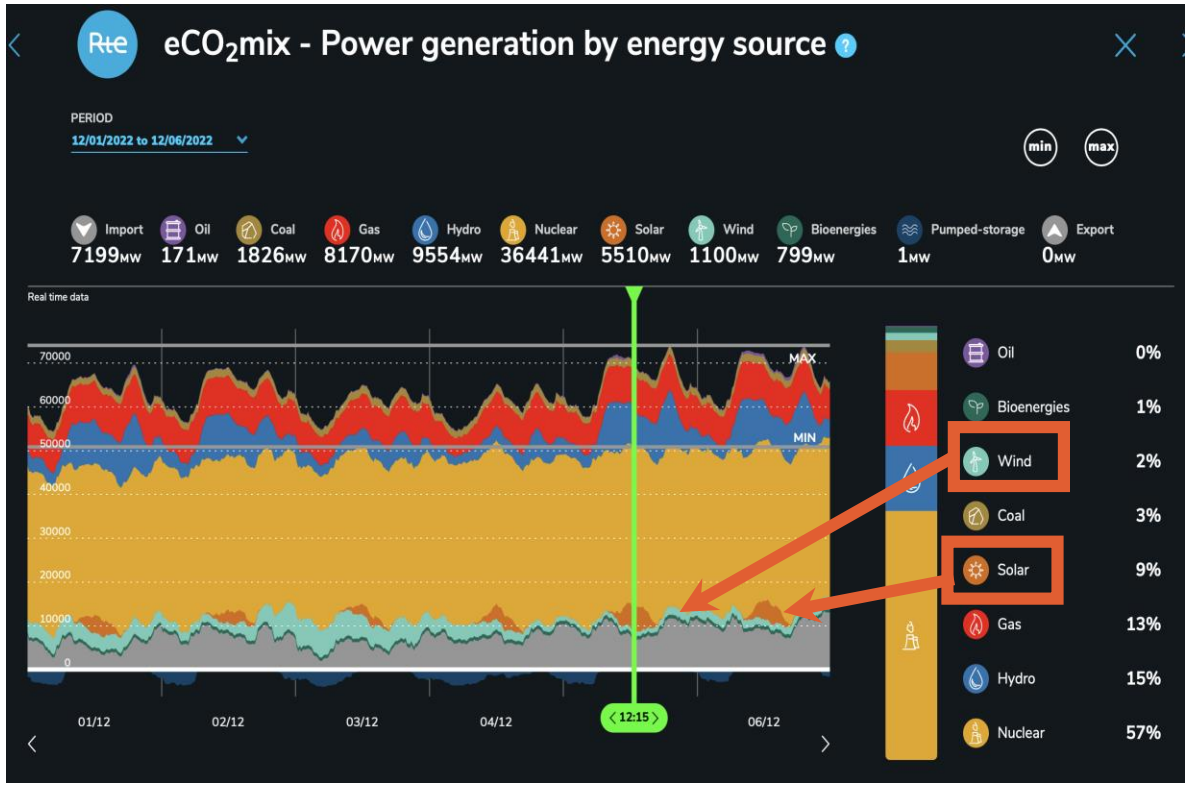
Regenerative ~~Energy~~ Power Supply Fluctuates

Germany (this week)



https://www.zeit.de/wirtschaft/energiemonitor-deutschland-gaspreis-spritpreis-energieversorgung

France (this week)

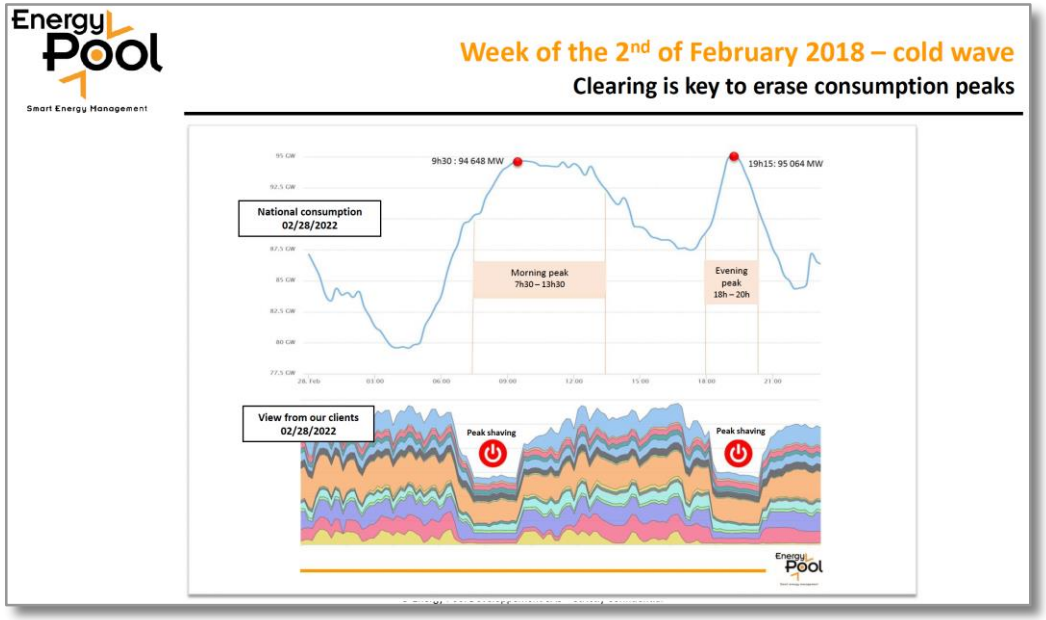


https://www.rte-france.com/en/eco2mix/power-generation-energy-source#

Collaborate: Demand Side Flexibility

(Regenerative) Power availability varies
Linear accelerators have no stored beam -> ideal for flexible operation

Study by Fraunhofer institute considered running
on renewables and participating in **demand side flexibility**



C. Gaunand, B. Remenyi: *Introduction to Demand Side Flexibility*
ESSRI Workshop 2022 https://indico.esrf.fr/event/2/contributions/94/

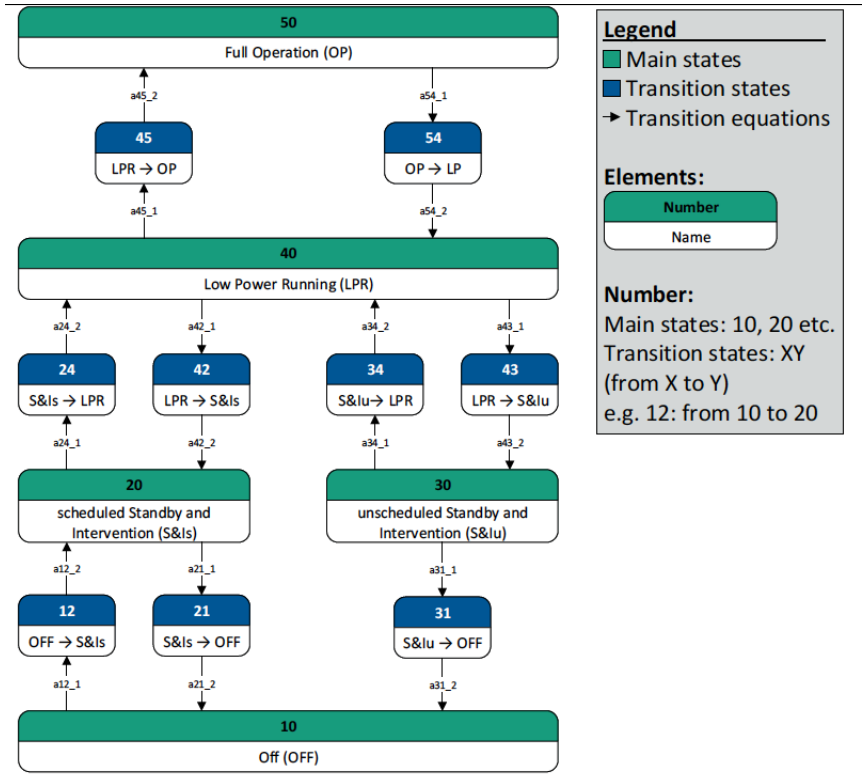
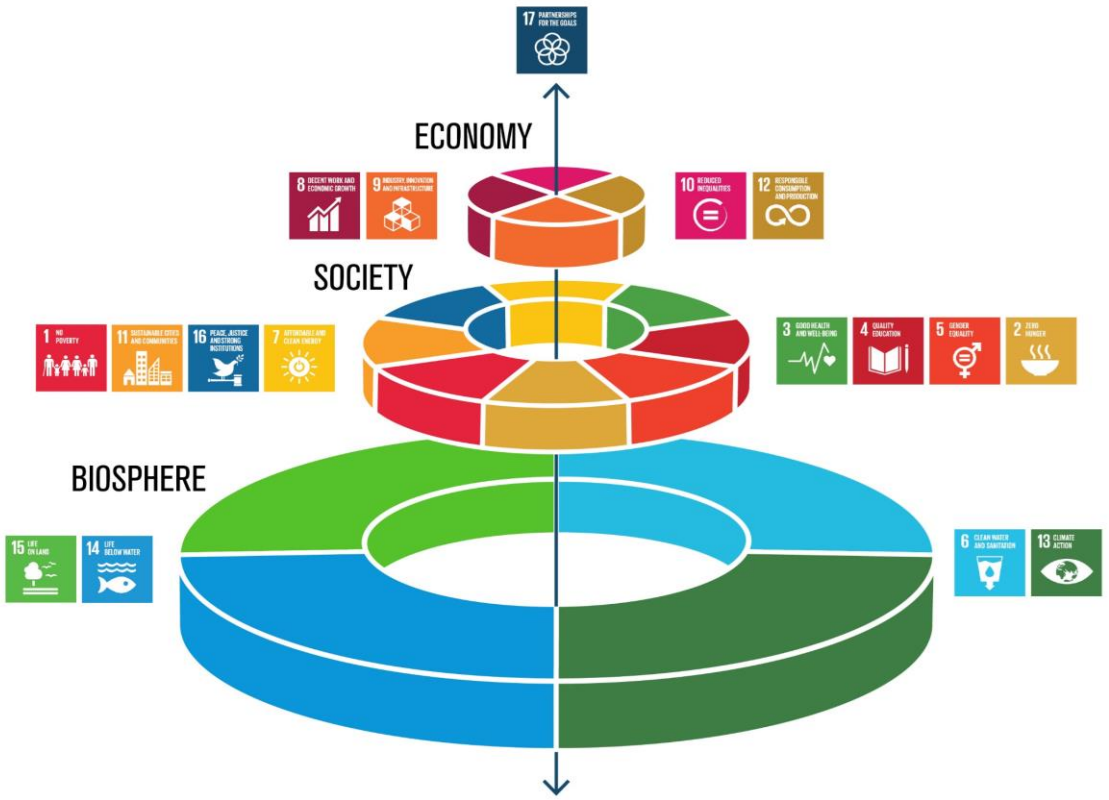


Figure 1-1: Schematic representation of the finite state machine

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

Relating to the UN Sustainable Development Goals

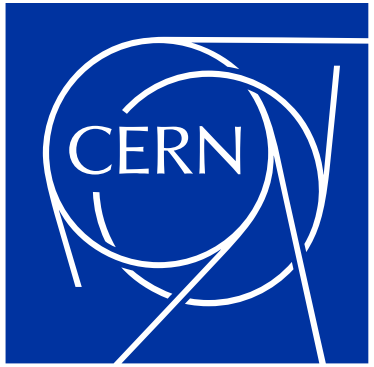


2015: “2030 Agenda for Sustainable Development” adopted by UN

17 Sustainable Development Goals

Accelerator Projects and Laboratories contribute to many of these goals:

- **Preservation of environment**
- **Society: Education, Peace&Understanding**
- **Economy: Spin Offs, Procurement**



home.cern