International Development Team

LC Sustainability: Shadow Costs, Publication Strategy

Benno List, DESY

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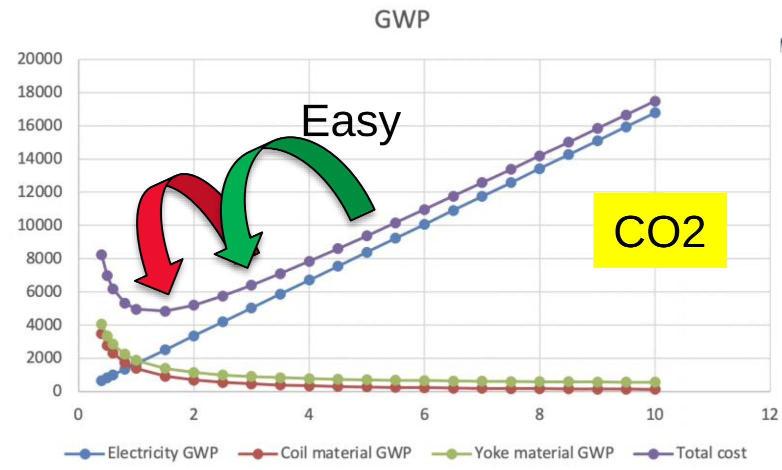
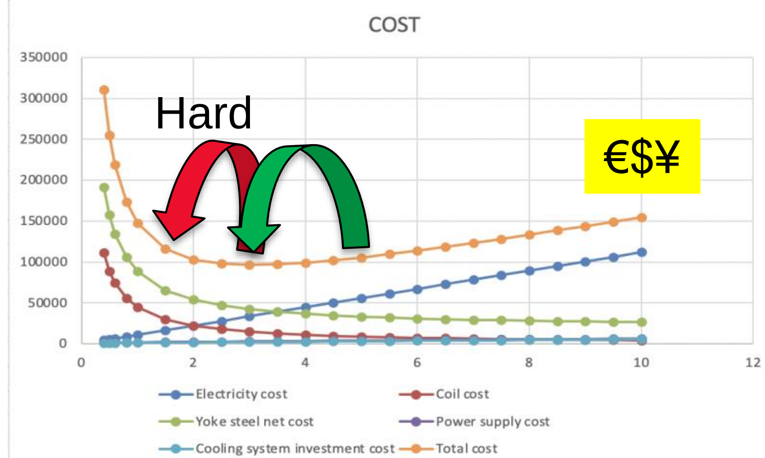
Example: Cost vs CO2 Optimisation

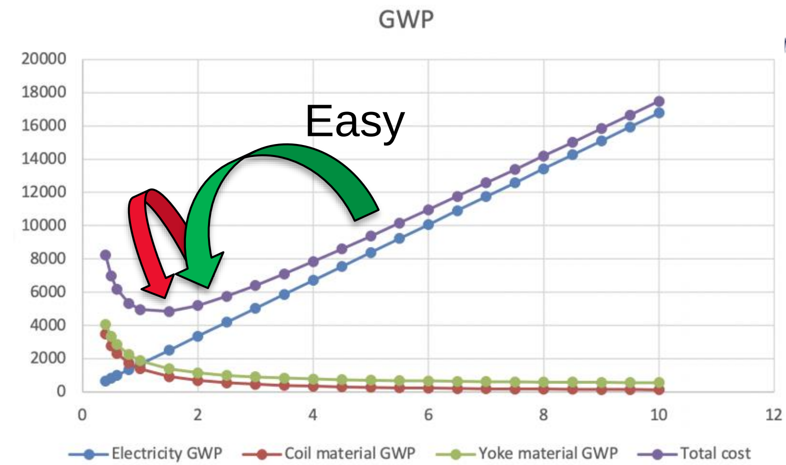
- Resistive electro magnet:
  Evaluate CO2 (GWP) and cost as a function of coil current density
- High density: less copper, but more electric losses
- Plausible claim: "*We moved from 5A/mm2 to 3, saving 3000kg of CO2 over the lifetime of the magnet*"!
- Increases investment cost by 15000$, but reduces electricity cost by 20000$
  -> saves 5000$ over the magnet lifetime
  -> just economic sense (although already a tough sell to funding agencies)
- The sustainable optimum would be at 1.5A/mm2, saving another 1500 kg CO2, but costing another 20000$ in invest, which is more than the 15000$ saving in electricity
- **Are you prepared to move away from the economic optimum towards the environmental optimum**?

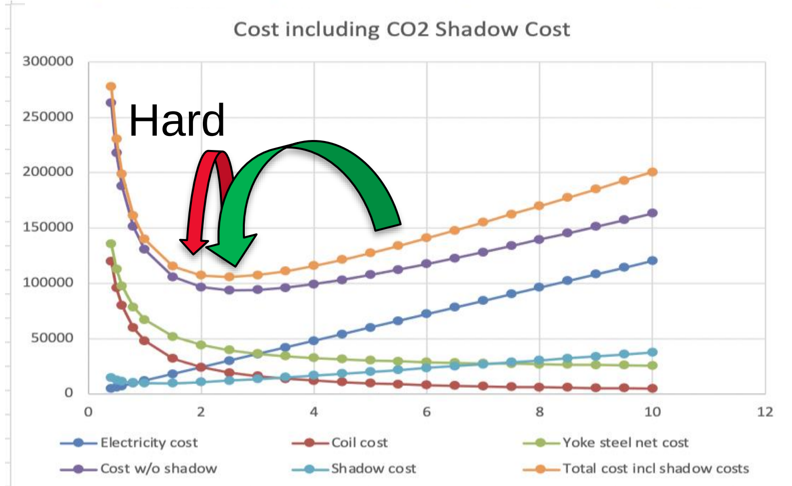




Shadow Costs

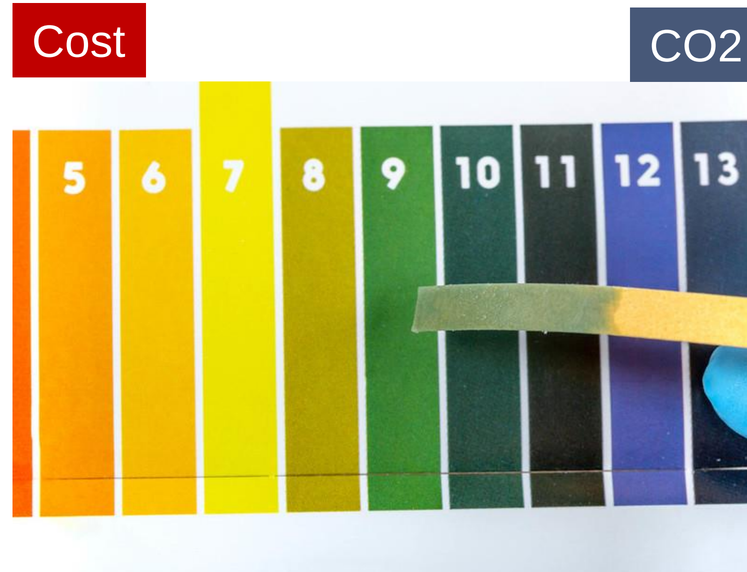
- **Are you prepared to move away from the economic optimum towards the environmental optimum**?
- Concept of shadow costs:
  Gives an economic "value" to CO2 savings:
  a ton of CO2 (savings) is worth e.g. 200€
- Including the shadow costs in the overall costs shifts the cost optimum towards lower CO2
- **Shadow costs allow to include environmental effects in a cost-benefit analysis**
- Caveats
  - Shadow costs are significantly lower than the claimed overall damage from CO2 emissions
  - Nobody pays you the "savings" in shadow costs, instead you pay a very real cost increase for lowering the shadow costs
  - Shadow costs are so small (currently, 80€/ton) that in many cases they do not motivate significant CO2 savings
    (the figure was made with a whopping 2000€/ton figure!)





Cost and Sustainability

- Improvements in resource efficiency (shorter tunnel, less power) generally reduce CO_2
  -> are often presented as “improving sustainability” (including by myself!)
- This is correct, but nothing new:
  the incentive to reduce resource use is mostly **cost reduction**.
  This has always been there
- But: in most cases,
  cost optimum ≠ sustainability optimum!
- The litmus test of a serious sustainability concept: **are you prepared to move away from the cost optimum towards an environmental (sustainability) optimum**?
- This requires evaluating cost and environmental (e.g., CO_2) impact



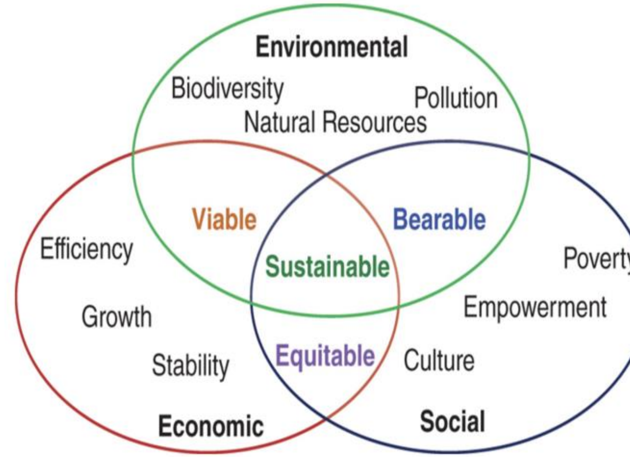
Sustainability: What It Is…

Cover of the "Brundtland Report" 1987

Gro Harlem Brundlandt at WEF 1989

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

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



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

Three aspects:

- environmental
- economical
- social

Observation:
"Economy", i.e. cost, is also part of "Sustainability"
Nevertheless: Let us talk about tension between
cost and sustainability,
although more strictly it is
environmental vs economic sustainability

Publication Strategy

- Consider 2 papers
  - ARUP study
  - More general “sustainability studies” paper
- ARUP study
  - Finished => publication ready
  - Very thorough, conforms to international standards -> needs a strong methodology part, somewhat technical
  - Authorship needs to include ARUP personnel
- Sustainability Studies
  - We have a lot of material
  - Worth publishing
  - Varying degree of thoroughness and rigor
  - Certainly not worse than C3 sustainability paper
  - Consider same journal:
    PRX Energy

PRX ENERGY **2,** 047001 (2023)

Perspective

Sustainability Strategy for the Cool Copper Collider

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The particle physics community has agreed that an electron-positron collider is the next step for continued progress in this field, giving a unique opportunity for a detailed study of the Higgs boson. Several proposals are currently under evaluation by the international community. Any large particle accelerator will be an energy consumer and so, today, we must be concerned about its impact on the environment. This paper evaluates the carbon impact of the construction and operation of one of these Higgs factory proposals, the Cool Copper Collider. It introduces several strategies to lower the carbon impact of the accelerator. It proposes a metric to compare the carbon costs of Higgs factories, balancing physics reach, energy needs, and carbon footprint for both construction and operation, and compares the various Higgs factory proposals within this framework. For the Cool Copper Collider, the compact 8 km footprint and the possibility for cut-and-cover construction greatly reduce the dominant contribution from embodied carbon.

DOI: 10.1103/PRXEnergy.2.047001

I. INTRODUCTION

An electron-positron collider gives a unique opportunity to study the Higgs boson’s properties with unprecedented precision and also provides an exceptionally clean environment to search for subtle new physics effects [1]. A number of different “Higgs factory” (HF) proposals, based on linear and circular colliders, are now under consideration. All of these provide e^+e^- collisions at center-of-mass energies ($\sqrt{s}$) in the range of 240–370 GeV, and some are also capable of reaching higher energies.

A high-energy particle collider is a large energy-consuming research facility. Therefore, it is important to balance its scientific importance against its environmental cost. The environmental impact of large accelerators has been analyzed in the recent Snowmass 2021 study [2] of the future of particle physics in the USA [3–5]. References [4,6–8] have examined the environmental cost of particular Higgs factory proposals, although often concentrating on particular elements of the total cost.

In this paper, we attempt a comprehensive evaluation of the carbon cost of the Cool Copper Collider (C^3) Higgs factory proposal [9,10] over its full lifetime, including costs from construction and from operation over the proposed timeline. This paper is structured as follows: In Sec. II, we briefly review the design of C^3. In Sec. III, we review the physics reach for C^3 and other Higgs factory proposals and introduce a metric for balancing carbon impact against the physics impact of each proposal. In Sec. IV, we analyze the power costs of operation of C^3 and describe methods for modifying the power design of the accelerator that would lead to substantial savings with little impact on the physics performance. In Sec. V, we analyze the carbon impact of the construction of C^3 and emphasize that cut-and-cover construction, as opposed to construction in a deep tunnel, has significant advantages. In Sec. VI, we discuss options for the source of electrical power for the C^3 laboratory. In Sec. VII, we bring these analyses together to estimate the total carbon footprint of C^3. Using information from available studies and design reports, we estimate the carbon impact of other Higgs factory proposals and compare these with C^3 in the framework described in Sec. III.

II. REVIEW OF THE C^3 ACCELERATOR DESIGN

C^3, which was proposed recently [9,10], is a linear facility that will first operate at 250 GeV center-of-mass collisions. Immediately afterward, without further extension of the linac, it will run at 550 GeV with an rf power upgrade.

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Journal: Physical Review X - Energy

PRX Energy Scope

PRX Energy welcomes manuscripts on all topics relevant to the multidisciplinary energy science and technology research communities spanning physics, chemistry, materials, engineering, biology, environmental studies, and policy. Research coverage in the journal comprises: fundamental and applied science; theoretical, experimental, computational, and data-intensive research, including significant advances in methods and instrumentation; and interdisciplinary and emerging areas. The full scope statement including subject areas can be found here.

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PERSPECTIVE

Sustainability Strategy for the Cool Copper Collider

In the pursuit of advancing particle physics and gaining deeper insights into the Higgs boson, proposals for electron-positron colliders are being examined. This Perspective takes a closer look at one such collider, the Cool Copper Collider, and introduces strategies aimed at minimizing its carbon footprint, while also conducting a thoughtful comparison with other Higgs factories.

Martin Breidenbach *et al.*
PRX Energy **2**, 047001 (2023)

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https://journals.aps.org/prxenergy/

New: Launched April 22, 2 volumes

Digest of C3 Paper

C3 Paper (PRX Energy **2**, 047001) adresses several aspects which should be covered in our paper. Chapter headings:

- **Power consumption and optimization**
  - Present our evaluation of power consumption (never shown in peer reviewed article)
- **Carbon impact of construction**
  - Refer to (separate) ARUP study
- **Mitigation Strategies for Operation**
  - Discusses projections for regional carbon intensity (check/refine -> Benno)
  - Describe Fraunhofer study for CLIC -> Q: **could this be updated**???
  - Discuss Japan concept for **carbon offsets**
- **Analysis of Total Carbon Footprint**
  - Sums it up
  - Provide our own plots, including Carbon Profile (work out for ILC as well)
  - Biggest issue: Estimate for accelerator construction!

To be discussed:

C3 paper has a chapter on “Comparison of Higgs Factory Physics Reach”

Tries to quantify physics benefit by weighted average of precision improvements over HL-LHC

- Pro: Defines a measurable Key Performance Indicator KPI
- Con: Approach is highly debatable

What do we do?

- Adopt?
- Argue?
- Ignore?

Outline

- Introduction
  - Introduce Life Cycle concept, importance of overall design, three pillars (system design subsystem optimization, operation)
- Accelerator Design
  - Explain general approach (energy and lumi, construction vs operation, high gradient requires pulsed op + SC or 2-beam, effectiveness: nanobeam)
  - Parameter tables
- Construction
  - LCA of civil construction
  - LCA of accelerator (sketch!)
- Operation
  - Power consumption (tables, explanations / discussion)
  - Operation modes (Fraunhofer study), mention demand side flexibility, prospects for RES
  - Mitigation (CO2 offset, Green ILC, Heat recovery)
  - Carbon intensity of el. power
- Decommissioning
  - One paragraph mentioning waste, including radioactive stuff, no quantitative analysis yet
- LCA result
  - Total carbon for specified run scenarios
  - Carbon emission profile
  - Mention need for more impact categories

To Do

- Unify approach to running time per year, machine development, downtimes etc; refine/define ILC power estimate in down times
- Make carbon emission profile for ILC
- Revisit potential for energy storage? 100MW x 10h = 1GWh possible
- **Accelerator LCA**

Cost: ~2M$ for 3MWh according to
https://www.teslarati.com/tesla-hiring-megapack-factory/