The 2026 International Workshop on the High Energy Circular Electron Positron Collider

21–26 Oct 2026
Sheraton Shanghai Jiading Hotel
Asia/Shanghai timezone

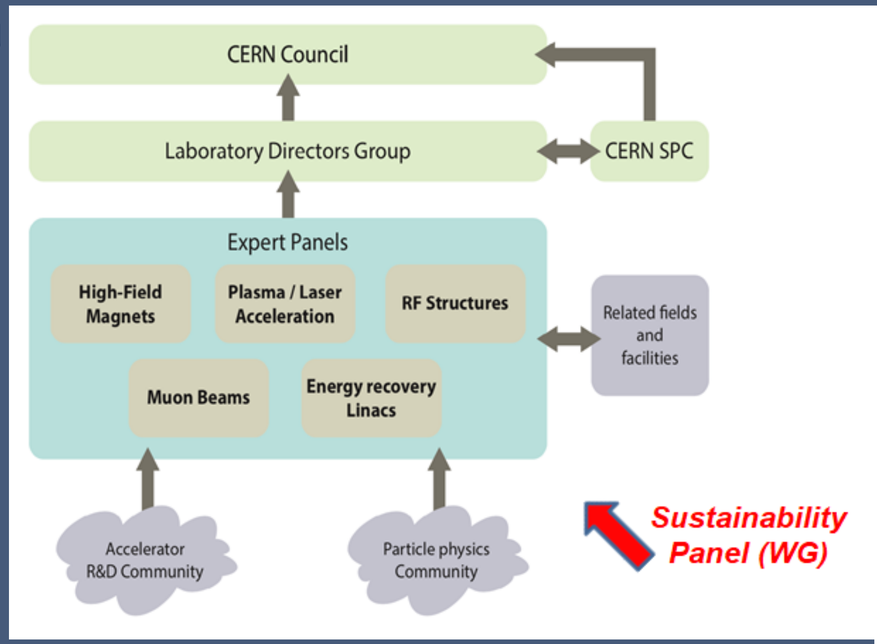
THE LDG SUSTAINABILITY PANEL : ENVIRONMENTAL IMPACT AND CONSIDERATIONS FOR LARGE ACCELERATOR FACILITIES

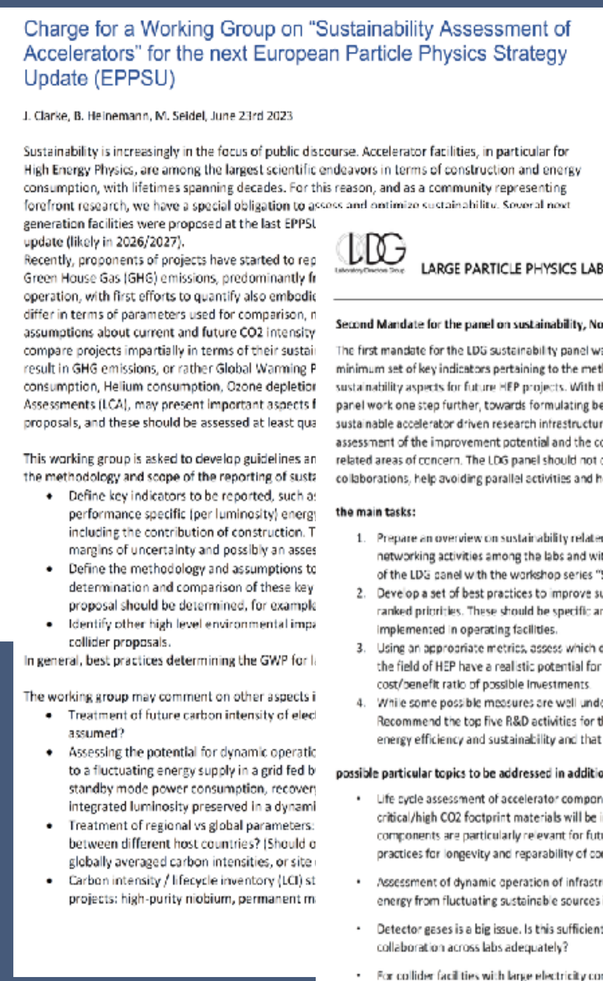
C. BLOISE (INFN-FRASCATI), M. TITOV (CEA-SACLAY)

THE LDG SUSTAINABILITY PANEL

The LDG provides a forum for coordinating the strategic programmes of European particle physics laboratories for the implementation of large-scale accelerator projects

LDG established in 2024 a panel on the Sustainability Assessment of Future Accelerators, complementing the five Expert Panels of the Accelerator R&D Roadmap





Charge for a Working Group on "Sustainability Assessment of Accelerators" for the next European Particle Physics Strategy Update (EPPSU)

J. Clarke, B. Heinemann, M. Seidel, June 23rd 2023

Sustainability is increasingly in the focus of public discourse. Accelerator facilities, in particular for High Energy Physics, are among the largest scientific endeavors in terms of construction and energy consumption, with lifetimes spanning decades. For this reason, and as a community representing forefront research, we have a special obligation to assess and optimize sustainability. Several next generation facilities were proposed at the last EPPSU update (likely in 2026/2027).

Recently, proponents of projects have started to rep Green House Gas (GHG) emissions, predominantly fr operation, with first efforts to quantify also embodie differ in terms of parameters used for comparison, n assumptions about current and future CO2 intensity compare projects impartially in terms of their sustai result in GHG emissions, or rather Global Warming P consumption, Helium consumption, Ozone depletion Assessments (LCA), may present important aspects f proposals, and these should be assessed at least qua

This working group is asked to develop guidelines an the methodology and scope of the reporting of susta

- Define key indicators to be reported, such a performance specific (per luminosity) energy including the contribution of construction. T margins of uncertainty and possibly an asses
- Define the methodology and assumptions to determination and comparison of these key proposal should be determined, for example
- Identify other high level environmental impa collider proposals.

In general, best practices determining the GWP for l

The working group may comment on other aspects i

- Treatment of future carbon intensity of elec assumed?
- Assessing the potential for dynamic operatio to a fluctuating energy supply in a grid fed b standby mode power consumption, recover integrated luminosity preserved in a dynami
- Treatment of regional vs global parameters: between different host countries? (Should o globally averaged carbon intensities, or site
- Carbon intensity / Lifecycle inventory (LCI) st projects: high-purity niobium, permanent m

LDG LARGE PARTICLE PHYSICS LABORATORY DIRECTORS GROUP

Second Mandate for the panel on sustainability, November 2025

The first mandate for the LDG sustainability panel was focused on developing guidelines and a minimum set of key indicators pertaining to the methodology and scope of the reporting of sustainability aspects for future HEP projects. With the renewed mandate the aim is to take the panel work one step further, towards formulating best practices for constructing and operating sustainable accelerator driven research infrastructures. The suggestions should be based on an assessment of the improvement potential and the cost-benefit ratio for the various sustainability related areas of concern. The LDG panel should not do its own research, but can trigger collaborations, help avoiding parallel activities and help to focus efforts.

the main tasks:

1. Prepare an overview on sustainability related expertise in the LDG laboratories and suggest networking activities among the labs and with CERN. Explore ways to synchronize the efforts of the LDG panel with the workshop series "Sustainability of HEP".
2. Develop a set of best practices to improve sustainability for accelerator driver RIs with ranked priorities. These should be specific and, if possible, substantiated by instances implemented in operating facilities.
3. Using an appropriate metrics, assess which of the aspects critical for sustainability of RIs in the field of HEP have a realistic potential for improvement. Take into account the cost/benefit ratio of possible investments.
4. While some possible measures are well understood, R&D may be required in other areas. Recommend the top five R&D activities for those aspects that show promise in terms of energy efficiency and sustainability and that should be prioritised.

possible particular topics to be addressed in addition:

- Life cycle assessment of accelerator components needed in large numbers or containing critical/high CO2 footprint materials will be important in the future. Assess which types of components are particularly relevant for future colliders. Contribute to establishing best practices for longevity and reparability of components.
- Assessment of dynamic operation of infrastructures, i.e. preferred operation when excess energy from fluctuating sustainable sources is available on the grid.
- Detector gases is a big issue. Is this sufficiently addressed in DRD panels, and do we use collaboration across labs adequately?
- For collider facilities with large electricity consumption, the option of installing co-generation power plants, such as gas turbines or possible Small Modular Reactors (SMR) can be assessed. Expertise of the technical groups of large labs should be utilized.
- Full sustainability assessment gets quickly very complex, for example if delivery chains of materials are fully analysed. The panel may develop guidelines up to which degree of detail such studies should be made for RIs in the HEP sector.

The panel provides input for the renewal of the LDG accelerator roadmap at the end of 2026 by suggesting few top ranked sustainability related R&D topics. The panel's work should conclude in February 2028 with a concise report on its findings and results (10..20 pages suggested). Depending on those results and on developments in the accelerator roadmap, the mandate may be renewed.

Initial mandate: *Development of guidelines and a minimum set of key Indicators for the sustainability assessment of future accelerators*

The WG prepared a document as Input to the European Strategy process *[arXiv:2504.01235]*
A detailed report was released in September [arXiv:2509.11705]

Renewed mandate (2026): identify, assess, and promote best practices for sustainable accelerator-based research infrastructures, including analyses of their improvement potential and cost–benefit aspects.

LDG SUSTAINABILITY PANEL – FIRST MANDATE (2024-2025)

Development of guidelines and a minimum set of key Indicators for the sustainability assessment of future accelerators

Panel consisting of 15 members with technical expertise in evaluation of accelerator sustainability

Broad community representation in sustainability:

- Sustainability Lab. Panels established at CERN, DESY, ESS, NIKHEF, STFC
- ICFA Sustainability Panel
- EU-Horizon Programs
- Future accelerator projects: FCC, ILC, CEPC, CLIC/Muon, LHeC, C3
- Invited experts on specific topics

• Walib Kaabi	IJClab
• Andrea Klumpp	DESY Sust. Panel
• Patrick Koppenburg	NIKHEF Sust. Panel
• Yuhui Li	IHEP and CEPC
• Mats Lindroos	ESS (deceased May 2, 2024)
• Roberto Losito	CERN Acc. Sust. Panel
• Emilio Nanni	ICFA Sust. Panel & C3
• Ben Shepherd	STFC Sust. Task Force
• Johannes Gutleber	FCC
• Benno List	ILC
• Vladimir Shiltsev	LHeC
• Steinar Stapnes	CLIC/MC
• Enrico Cennini	Sustainable Procurement
• Beatrice Mandelli	Gas Detector
• Niko Neufeld	HEP Data Centers
• Thomas Schoerner	ICFA, Sustainability
• Luisa Ulrici	Decommissioning
• Hannah Wakeling	Lifecycle assessment
• Caterina Bloise	Co-Chair
• Maxim Titov	Co-Chair

LDG SUSTAINABILITY WORKING GROUP REPORT

The LDG Sustainability WG report outlines the reference framework of best practices & standards for assessing and guiding sustainable development of large-scale facilities for future accelerators

Targets *future accelerators & particle physics projects, relevant for other research infrastructures*
Promotes *transparent, open discussions within research communities, to adequately convey the information to a broader range of stakeholders*

Main topics:

- ✓ ***Landscape of comprehensive sustainability assessment approaches***
- ✓ ***Basis of LCA - Status & recommendations for developing analysis of accelerator infrastructures, components and systems***
- ✓ ***Environmental impact of large RI's during construction, operation & decommissioning phases***
- ✓ ***Mitigation and Compensation Measures***



Sustainability Assessment of Future Accelerators

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[d] DESY, Hamburg, Germany [e] NIKHEF, Amsterdam, The Netherlands
[f] IHEP, Beijing, China [g] SLAC, Menlo Park, CA, USA
[h] ASTeC, Daresbury Laboratory, STFC, UK [i] Northern Illinois University, DeKalb, IL, USA
[j] IRFU, CEA-Saclay, Gif-sur-Yvette, France
[k] John Adams Institute, University of Oxford, Oxford, UK

arXiv:2509.11705v1 [physics.acc-ph] 15 Sep 2025

Abstract

The Large Particle Physics Laboratory Directors Group (LDG) established the Working Group (WG) on the Sustainability Assessment of Future Accelerators in 2024 with the mandate to develop guidelines and a list of key parameters for the assessment of the sustainability of future accelerators in particle physics. While focused on accelerator projects, much of the work will also be relevant to other present and upcoming research infrastructures. The development and continuous update of such a framework aim to enable a coherent communication amongst scientists and adequately convey the information to a broader set of stakeholders. This document outlines the key findings and recommendations of the LDG Sustainability WG and provides a summary of current best practices aimed at enabling sustainable accelerator-based research infrastructures. Not all sustainability topics are addressed at the same level. The assessment process is complex, largely under development and a homogeneous evaluation of all the aspects requires a strategy to be developed and implemented over time.

Released in Sep. 2025:
http://arxiv.org/abs/2509.11705

EXECUTIVE SUMMARY:

COMPREHENSIVE SUSTAINABILITY ASSESSMENT

- *Several examples exist of comprehensive impact assessments conducted by large research infrastructures using different approaches & methodologies - some more quantitative, like Cost-Benefit Analysis (CBA), carried out at CERN to assess the HL-LHC and the FCC project, and others more qualitative, such as narratives and case studies*

- *A comprehensive Cost-Benefit Analysis of HEP projects is recommended. It integrates both tangible and intangible contributions across the UN SDGs and is required by several countries for public investment, including science projects.*

LIFE CYCLE ASSESSMENT (LCA)

- *LCAs quantify environmental impacts, help comparing design alternatives and identifying reduction potential*

- *LCA objectives (and target audiences) range from identifying the most critical contributions optimising designs (for researchers), to providing input for informed decisions and for recommending improvements (for decision takers), to communicating global performance (for general public)*

- *Future accelerator projects are encouraged to perform LCAs at every project stage (e.g. proposal, CDR, TDR)*

- *Coordinated efforts among accelerator-based laboratories to create a shared database of accelerator materials and components, and to develop open-source, cost-free LCA tools (e.g., an accelerator-specific extension to ecoinvent), are necessary to improving the accuracy and reliability of environmental assessments.*

EXECUTIVE SUMMARY:

ENVIRONMENTAL IMPACT OF LARGE RIS

- ***Since LCAs are relatively new for accelerator components and particle detectors, progress in this area is especially important for improving quality and reliability of the evaluations***
- ***Impacts from civil engineering works rely on full LCAs carried out by external firms for CERN (FCC-ee, CLIC, LCF), ILC in Japan and have been also estimated for LHeC, C3 in USA and CEPC in China***
- ***LCAs of accelerator components and detectors have been added to the CLIC/ILC/LCF project***
- ***Assessments might differ substantially when data from generic, current productions are replaced by information from specific EPDs or from projections based on decarbonization pathways outlined by industrial consortia.***
- ***The use of data referring to specific materials or manufacturing processes – whether region-specific or technology-specific – should be supported by a realistic expectation that their production can meet the required quantities at reasonable costs.***

MITIGATION AND COMPENSATION MEASURES

- ***The assessment of mitigation and compensation measures – particularly those enabled by innovative technologies specific to accelerator-based infrastructures – is essential to sustainable future accelerators***
- ***Several pathways have potential to substantially reduce environmental impacts:***
  - opportunities to reduce CE environmental impacts by 40-50% have been identified through the use of low-carbon concrete and through tunnel designs at the current stage of the projects,
  - adoption of responsible procurement policies
  - implementation of advanced energy management plans
  - waste-heat recovery solutions,
  - investments in innovative technologies
  - Nature-based interventions and circular economy principles are recognized as complementary strategies to offset residual impacts

COMMON FORMAT FOR SUSTAINABILITY REPORTING

- ***The Sustainability WG has agreed on a common format for sustainability reporting tailored to the current project stage and based on a small set of figures of merit for GHG emissions in the construction and operation phases of future colliders.***
- ***The report presents up-to-date preliminary evaluations of these key parameters, together with the assumptions and simplifications applied by future accelerators projects at CERN (CLIC, FCC-ee, LCF, LHeC), ILC in Japan, CEPC in China, and C3 in the USA.***

Synthesis of data on GHG emissions of FCC-ee

Table 7: Data on GHG emissions for the FCC-ee project

FCC Mode	Z	W	ZH	tt
CoM energy [GeV]	91.2	160	240	365
Luminosity/IP [$10^{34}cm^{-2}s^{-1}$]	140	20	7.5	1.4
Number of IPs	4			
Operation time for physics/yr [10^7s/yr]	1.2[1]			
Integrated luminosity/ yr [1/fb/ yr]	68 000	9 600	3 600	670
Host countries	France and Switzerland			
GHG emissions from construction, stage A1-A5				
Subsurface tunnels, caverns, shafts [kt CO_2e]	480 (according to EN ISO 15804+A2) ~1000 (with generic LCA data)			
Surface sites and constructions [kt CO_2e]	50 (according to EN ISO 15804+A2) ~184 (with generic LCA data)			
All constructions [kt CO_2e]	530 (according to EN ISO 15804+A2) ~1 184 (with generic LCA data)			
Accelerator (coll.) [kt CO_2e]	Not estimated: subject to equipment design & procurement			
Accelerator (inj.) [kt CO_2e]	Not estimated: subject to equipment design & procurement			
Detectors (A1 - A3, scaled from linear colliders) [kt CO_2e]	142 - 186			
Total [kt CO_2e]	Not estimated			
Collider tunnel length [km]	90.658			
Collider tunnel diameter [m]	5.5			
Concrete GWP used for LCA [kg CO_2e/m^3]	220 (C12/15), 340 - 422 (C35/45), 400 - 540 (C40/50)			
Low-carbon concrete GWP (for comparison) [kg CO_2e/m^3]	150 (C12/15), 170 (C35/45), 175 (C40/50)			
Accelerator GWP / m [t CO_2e/ m]	Not estimated: subject to equipment design & procurement			
GHG emissions from operation				
Maximum power in operation [MW]	222	247	273	357
Average power in operation [MW]	122	138	152	202
Electricity consumption / yr [TWh/ yr]	1.2	1.3	1.4	1.9
Years of operation	4	2	3	5
Carbon intensity of electricity [g CO_2e/ kWh]	14 - 18, conservative assumption based on actual data: 12.625[2] in France and 15.7[3] in Switzerland			
GHG emissions/year of physics operation [kt CO_2e/yr]	18 - 26	20 - 29	22 - 31	29 - 40

[1] 185 operation days per year (1.6e7) with an efficiency of 75% for physics.
[2] Switzerland, Umweltbilanz Strommixe Schweiz, BAFU/OFEV, 2018, https://www.bafu.admin.ch/bafu/de/home/themen/klima/fragen-antworten.html
[3] France, Base empreinte, ADEME, 2023: 75% off shore wind and 25% nuclear, https://base-empreinte.ademe.fr

FCC-ee: https://arxiv.org/pdf/2505.00273

Synthesis of data on GHG emissions of ILC/LCF and CLIC

Table 11: Data on GHG emissions for the ILC project in Japan and the Linear Collider Facility (LCF) proposal for CERN [202]. These are baseline numbers, before application of possible CO_2 reduction measures. The optimisation potential for tunnels, caverns and shafts is estimated to be 50 %, for accelerators, services and detectors it is assumed to be 25 %.

	ILC 250	ILC 500	LCF 250 LP/FP	LCF 550 LP/FP
CoM energy [GeV]	250	500	250	550
Luminosity/IP [$10^{34}cm^{-2}s^{-1}$]	1.35 / 2.7	3.6	1.35 / 2.7	1.9 / 3.85
Number of IPs	1		2	
Operation time for physics/yr [10^7s/yr]	1.6		1.2	
Integrated luminosity/ yr [1/fb/ yr]	215 / 430	580	325 / 650	460 / 920
Host countries	Japan		France and Switzerland	
GHG emissions from construction, stage A1-A5				
Subsurface tunnels, caverns, shafts [kt CO_2e]	266	372	380	
Surface sites and constructions [kt CO_2e]	Not estimated		Not estimated	
Accelerator (coll.) [kt CO_2e]	150	270	165	310
Accelerator (inj.) [kt CO_2e]	59 / 82	83	60 / 84	
Services [kt CO_2e]	32	46	46	
Detectors [kt CO_2e]	94		94	
Total [kt CO_2e]	601 / 624	865	745 / 769	890 / 914
Collider tunnel length [km]	20.5	33.5	33.5	
Collider tunnel diameter [m]	9.5		5.6	
Collider tunnel GHG / m [t CO_2e/ m]	8.6		8.5	
Concrete GHG [kg CO_2e/ kg] / [kg CO_2e/m^3] (type)	0.16 / 400 (C25/30)		0.16 / 400 (C25/30)	
Main Linac accelerator GHG / m [t CO_2e/ m]	5.3		5.3	
GHG emissions from operation				
Maximum power in operation [MW]	111 / 138	164	143 / 182	250 / 322
Electricity consumption / yr [TWh/ yr]	0.7 / 0.9	1.1	0.8 / 1.0	1.4 / 1.8
Reference year of operation	2040		2050	
Carbon intensity of electricity [g CO_2e/ kWh]	81		16	
Average Scope 2 GHG emissions / yr [kt CO_2e]	59 / 74	87	13 / 15	23 / 28

ILC/LCF: arXiv:2503.24049

Table 10: Data on GHG emissions for the CLIC project. Data in parenthesis are for two IPs

CLIC	Stage 1	Stage 2
CoM energy [GeV]	380	1500
Luminosity/IP [$10^{34}cm^{-2}s^{-1}$]	2.3 (4.5)	3.7
Number of IPs	1(2)	1
Operation time for physics/yr [10^7s/yr]	1.2	
Integrated luminosity/ yr [1/fb/ yr]	276 (524)	434
Host countries	France and Switzerland	
GHG emissions from construction, stage A1-A5		
Subsurface tunnels, caverns, shafts [kt CO_2e]	268	337
Surface sites and constructions [kt CO_2e]	118	
Accelerator (coll.) [kt CO_2e]	38	N.E.
Accelerator (inj.) [kt CO_2e]	110	N.E.
Accelerator Services [kt CO_2e]	19	N.E.
Detectors [kt CO_2e]	94	
Total [kt CO_2e]	609	
Collider tunnel length [km]	11.5	17.6
Collider tunnel diameter [m]	5.6	
Collider tunnel GWP / m [t CO_2e/ m]	8.1	
Concrete GWP [kg CO_2e/ kg]	0.16	
Accelerator GWP / m [t CO_2e/ m]	Not estimated	
GHG emissions from operation		
Maximum power in operation [MW]	107 (160)	287
Electricity consumption / yr [TWh/ yr]	0.6(..)	
Years of operation	2040	2040
Carbon intensity of electricity [g CO_2e/ kWh]	16	
Average Scope 2 GHG emissions / yr [kt CO_2e]		

CLIC: arXiv:2503.24168

Comprehensive overview of GHG emissions from construction and operation: Available for ILC in Japan and scaled/ adapted for an LCF at CERN

ENVIRONMENTAL IMPACT OF LARGE RESEARCH INFRASTRUCTURE

- ***Civil engineering's works (A1-A5):* excavation material and concrete shielding constitute core subjects of sustainability assessment for CE infrastructure (e.g. tunnels, caverns)**
  - → *civil engineering's works hold a massive footprint (demand is rapidly accelerating for low-carbon materials (at higher cost) and direct reuse and systematic recovery of inert excavation materials*

- ***Accelerator construction (A1-A5):* assessment of areas with the largest emission (beam line shielding, supporting structures, magnets, RF cavities, power supplies, …)**
  - → material manufacturing: emissions during fabrication (e.g. high-purity Ni, permanent magnet allosys)
    - → accelerator infrastructure inevitably relies on mining and mineral processing. (hard-to-abate activity)
  - → adoption of sustainable and responsible procurement policy for civil engineering & accelerator construction

- ***Accelerator operation (B1 – B7):* electricity consumption, power for operation (air conditioning, water cooling, cryogenic plants, RF and klystrons, magnets)**
  - → *currently assessment of accelerator operation concentrate mostly on the electricity consumption, assuming it is the dominant source to GHG emissions (high dependency on electricity from the country of origin -> procurement policy important)*

- ***Particle detectors operation & computing (B1 – B7):* impact of gas emissions in detectors, optimization of power consumption & environmental impact of computing**
  - → *assume that future RIs will overcome today's high Scope 1 emissions from detectors and cooling plants by eliminating GHG and implementing gas recirculation/recuperation systems*

- ***Decommissioning (stages C1- C4):* analysis of recycling and disposal of used components, radioactive waste, land re-use**
  - → *global approach, which takes into account the entire life-cycle of waste from design phase to disposal*
    - → *early consideration of radioactive waste disposal pathways simplifies the entire industrial disposal process*

SECOND WORKING GROUP MANDATE (2026-2028)

LDG Laboratory Directors Group — LARGE PARTICLE PHYSICS LABORATORY DIRECTORS GROUP

Second Mandate for the panel on sustainability, November 2025

The first mandate for the LDG sustainability panel was focused on developing guidelines and a minimum set of key indicators pertaining to the methodology and scope of the reporting of sustainability aspects for future HEP projects. With the renewed mandate the aim is to take the panel work one step further, towards formulating best practices for constructing and operating sustainable accelerator driven research infrastructures. The suggestions should be based on an assessment of the improvement potential and the cost-benefit ratio for the various sustainability related areas of concern. The LDG panel should not do its own research, but can trigger collaborations, help avoiding parallel activities and help to focus efforts.

the main tasks:

1. Prepare an overview on sustainability related expertise in the LDG laboratories and suggest networking activities among the labs and with CERN. Explore ways to synchronize the efforts of the LDG panel with the workshop series "Sustainability of HEP".
2. Develop a set of best practices to improve sustainability for accelerator driven RIs with ranked priorities. These should be specific and, if possible, substantiated by instances implemented in operating facilities.
3. Using an appropriate metrics, assess which of the aspects critical for sustainability of RIs in the field of HEP have a realistic potential for improvement. Take into account the cost/benefit ratio of possible investments.
4. While some possible measures are well understood, R&D may be required in other areas. Recommend the top five R&D activities for those aspects that show promise in terms of energy efficiency and sustainability and that should be prioritised.

possible particular topics to be addressed in addition:

- Life cycle assessment of accelerator components needed in large numbers or containing critical/high CO2 footprint materials will be important in the future. Assess which types of components are particularly relevant for future colliders. Contribute to establishing best practices for longevity and reparability of components.
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- Detector gases is a big issue. Is this sufficiently addressed in DRD panels, and do we use collaboration across labs adequately?
- For collicer facilities with large electricity consumption, the option of installing co-generation power plants, such as gas turbines or possible Small Modular Reactors (SMR) can be assessed. Expertise of the technical groups of large labs should be utilized.
- Full sustainability assessment gets quickly very complex, for example if delivery chains of materials are fully analysed. The panel may develop guidelines up to which degree of detail such studies should be made for RIs in the HEP sector.

The panel provides input for the renewal of the LDG accelerator roadmap at the end of 2026 by suggesting few top ranked sustainability related R&D topics. The panel's work should conclude in February 2028 with a concise report on its findings and results (10. 20 pages suggested). Depending on these results and on developments in the accelerator roadmap, the mandate may be renewed.

- **With the renewed mandate the aim is to take the panel work one step further, towards *formulating best practices for constructing and operating sustainable accelerator driven research infrastructures.***
- **The suggestions should be based on an *assessment of the improvement potential and the cost-benefit ratio* for the various sustainability related areas of concern.**
- ***The LDG WG should trigger collaborations and studies*, help avoiding parallel activities and help to focus efforts.**

→ **We will *analyze best practices implemented* and identify opportunities for improvements (on carbon footprint, water consumption, resource depletion) analysing feasibility and cost-benefit balance**

→ **Final summary report (Q1 2028) will capture status and perspectives**

- ***Sustainability LDG WG Web site:***
  https://ldg.web.ch/working-groups/sustainability-panel

LDG SUSTAINABILITY PANEL – SECOND MANDATE (2026-2028)

Panel membership for the second term, 2026-2028

Broad community representation in sustainability:

- Representatives of HEP Laboratories and Sustainability Panels at CERN, DESY, NIKHEF, STFC
- Representative of ICFA Sustainability Panel
- Representatives of future accelerator projects: FCC, CLIC/ILC, CEPC, C3
- Experts on specific topics: Energy management, Socio-Economic assessments, Gas detectors, Data Centers, LCA

• Nicolas Bellegarde	CERN, FCC sust. deliv.
• Walib Kaabi	IJClab
• Andrea Klumpp	DESY Sust. Panel
• Patrick Koppenburg	NIKHEF Sust. Panel
• Benno List	DESY CLIC/ILC
• Roberto Losito	CERN Acc. Sust. Panel
• Emilio Nanni	ICFA Sust. Panel & C3
• Ben Shepherd	STFC Sust. Task Force
• Zusheng Zhou	IHEP CEPC
• Giovanni De Carne	KIT -Energy management
• Massimiliano Fiorini	Univ. Ferrara -Gas Detectors
• Johannes Gutleber	CERN -Socio-economic ass.
• Beatrice Mandelli	CERN -Gas Detectors
• Niko Neufeld	CERN -HEP Data Centers
• Ozgur Sahin	CEA-IRFU -HEP Data Centers
• Thomas Schoerner	DESY -ICFA, sustainability
• Hannah Wakeling	U. Oxford -Lifecycle assess.
• Caterina Bloise	INFN-LNF Co-Chair
• Maxim Titov	CEA-IRFU Co-Chair

LDG WORKING GROUP PRIORITIES: BEST PRACTICES AND NETWORKING

***Task I:** Prepare an **overview on sustainability related expertise in the LDG laboratories** and suggest networking activities among the labs and with CERN.*

—> Identifying opportunities to foster collaborations among HEP labs is a priority

- *Energy management*
- *Reduction of direct GHG emissions*
- *Water consumption*
- *Refurbishment and renovation of working systems*
- *Waste management*
- *Study, design and implementation of novel technologies*
- *Responsible procurement*

***Task II:** Explore ways to **synchronize the efforts of the LDG panel with the workshop series** "Sustainability of HEP".*



- *Sustainability LDG Panel is actively engaged with the community contributing to the organisation and participating to conferences, workshops, discussions*
  - *Sustainability@HEP2026*
  - *ICHEP2026*
  - *ET-EMR Sustainability Workshop*
  - *ESSRI2026*
  - *CEPC2026*
  - *LCWS2026*
- *It is also engaged with EU projects in the area of sustainability of large RIs (RF2.0, EAJADE, iSAS,…)*

LDG WORKING GROUP PRIORITIES: BEST PRACTICES AND IMPROVEMENTS

Task III: *Develop a set of best practices to improve sustainability for accelerator driven RIs with ranked priorities. These should be specific and, if possible, substantiated by instances implemented in operating facilities*

- *Foster awareness of total environmental impact for the construction and operation of large facilities, including detector and computing infrastructure, and formulate best practices (e.g. assessments, continuous optimization, procurement, operation, construction, decommissioning)*
- *Effective action: promote training courses that provide opportunities to exchange experiences and share the results of best practices; participation in sustianbility-related future EU calls*
- *Encourage the adoption of common sustainability assessment methodologies (suggesting, not imposing)*

Task IV: *Using an appropriate metrics, assess which of the aspects critical for sustainability of RIs in the field of HEP have a realistic potential for improvement.*
Take into account the cost/benefit ratio of possible investments.

- *Coming from actual lab experience and building on the environmental reports and specific initiatives of the HEP Labs*
- *Obstacles/Problems with the implementation considered as well*
- *Caveat: Costs and costs breakdown not always available*

LDG WORKING GROUP PRIORITIES: IMPROVEMENT IN ENERGY EFFICIENCY

Task V : **While some measures are well established, others require further R&D. Recommend the five most promising activities in energy efficiency and sustainability that should be prioritised.**

Improving energy efficiency and reducing energy consumption – key to minimise carbon emissions – complements the transition to low-carbon energy sources.

WG will Review R&D activities that include both Designs/Projects applicable to future accelerator systems and those useful for refurbishment/renovation of older installations

LDG WORKING GROUP PRIORITIES: BEST PRACTICES AND IMPROVEMENTS

Overview of laboratory sustainability expertise —> work has commenced on selected topics

- **Energy management -** *we had an overview from CERN, ESS in 2024 and more recently at ESSRI 2026 —> dedicated meetings, discussions are being organised*
- **Sustainable Procurement -** *dedicated meeting on 2 September with presentations from CERN, DESY and InProCap —> short report under preparation*
- **Task force on "Gaseous Detectors"** *- established on 16 September (mandate in next slides)*
- **Task force on "Computing and Machine learning"** *- established on 16 September (mandate in next slides)*
- **Energy efficiency & accelerator technologies -** *engagement with the other LDG WGs to be established (RF and RF power sources, HTS, plasma acceleration, …)*

PUBLIC INSTITUTIONS AND PROCUREMENT PROCEDURES

Alignment with the most advanced criteria of responsible procurement —> substantial improvement in RI sustainability

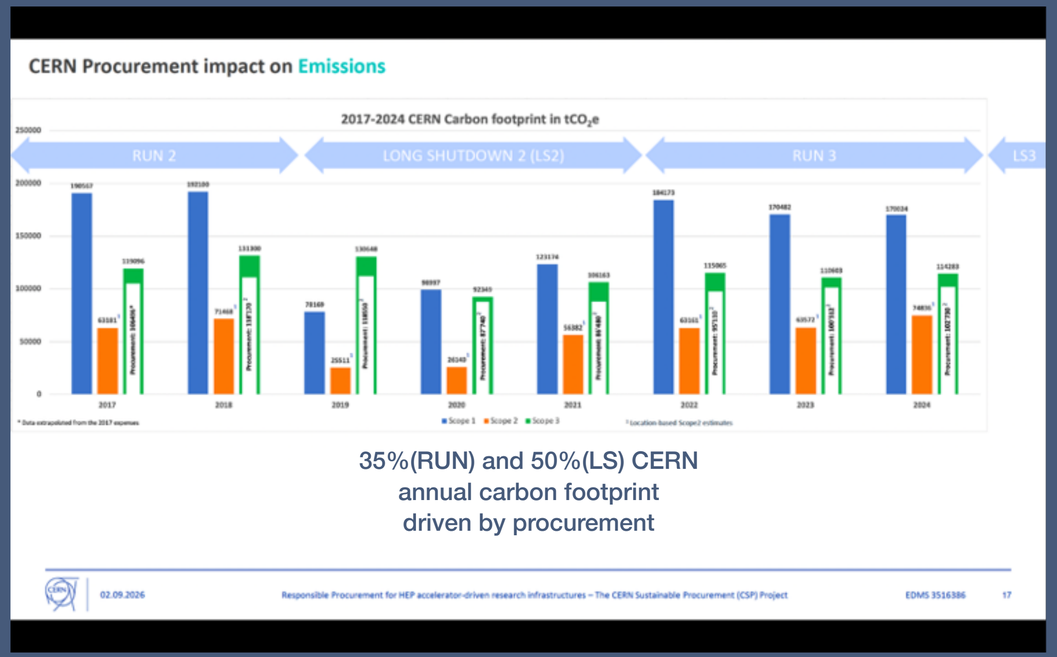
Scope 3 emissions relevant in all laboratories, during all phases (construction of new infrastructures, maintenance during operation, renovation works)

Meeting with experts from

- ***CERN*** ***E. Cennini***
- ***DESY*** ***L. Winkler***
- ***EU-project InProCap*** ***J. Kubinec***
  (Innovation Procurement Capabilities)

Status: criteria and associated KPIs under study

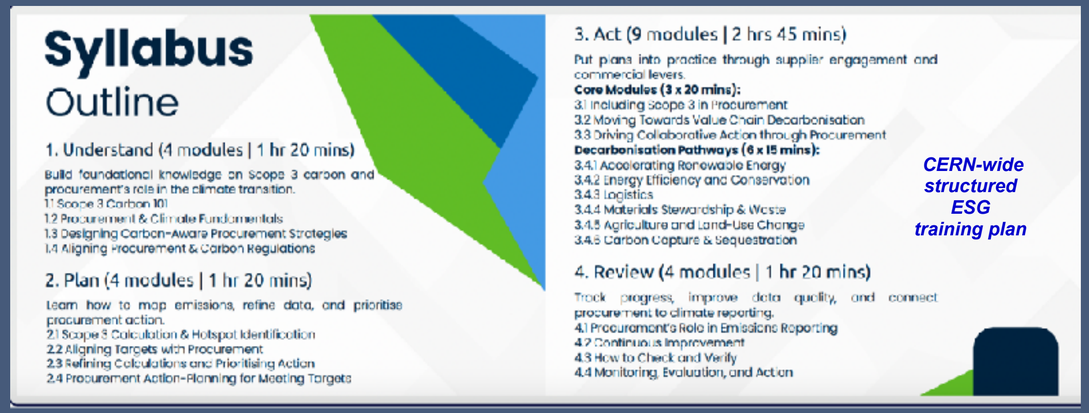
Test cases and training material exist



Benefits from sustainable procurement
besides carbon footprint reduction are expected in risks mitigation, increasing resilience and global costs reduction

RESPONSIBLE PROCUREMENT : MAIN RECOMMENDATIONS (DRAFT)

- ***Develop an adequate pre-procurement phase*** → ***the most impactful to embed sustainability***
- ***Assess impact and risks*** → ***procurement procedures should contain proportionate ESG requirements – focus the efforts on high-impact materials and supplies***
- ***Avoid to embed ESG requirements as companies exclusion criteria (rather incorporate sustainability as award criterion)***
- ***Test the procedures with real procurements and learn from suppliers and peers experience***
- ***Use early-market engagement to connect sustainability needs with available innovation***
- ***Progressively establish governance, accountability, data, and targets to move towards a systematic approach***
- ***Strengthen procurement competencies with practice-based learning***



CERN Programme for Training – Internal capacity-building (Syllabus)



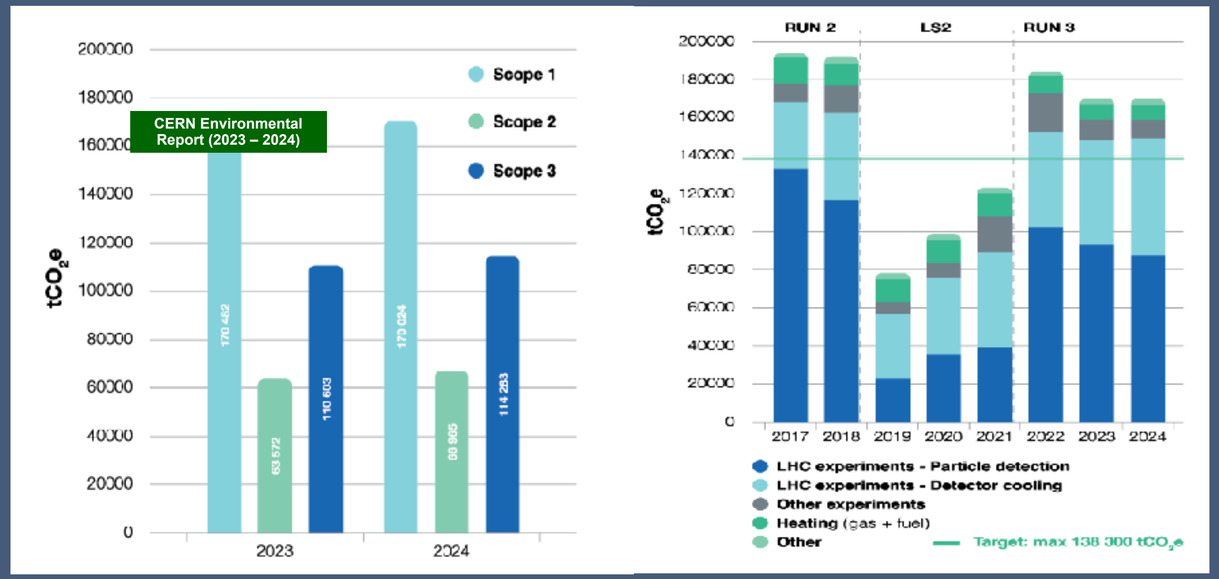
EU-INPROCAP "Innovation Procurement in Big Science: From Needs to Award"

LDG SUSTAINABILITY WORKING SUB-GROUP: GASEOUS DETECTORS

Co-Chairs: *Beatrice Mandelli (CERN & DRD1)*
Massimiliano Fiorini (Univ. Ferrara & DRD4)

Established in September, 2026

The Subgroup is mandated with creating comprehensive guidelines, evaluation frameworks, and collaborative strategies to assess, report, and improve the sustainability of GHG use in particle detectors



Addressing the ecological challenges of greenhouse gases (GHG) usage in particle physics detectors in research facilities

EU F-gas Regulation restricts and phases down the use of greenhouse gases through a progressive policy targeting a total phase-out in Europe by 2050 compared to the 2015 baseline levels.

↓

Reduced availability and **significant cost increases** for the F-gases.
A challenge for the long-term operation of experiments where large gas detector volumes are present and these gases are needed.

↓

Subgroup on the sustainability of gaseous detectors
to ensure the continued operation of gaseous detectors in alignment with EU regulations and the European Strategy for Particle Physics roadmap

WORKING GROUP ON GASEOUS DETECTORS

The Subgroup is mandated with creating comprehensive guidelines, evaluation frameworks, and collaborative strategies to assess, report, and improve the sustainability of GHG use

A collaborative framework for detector gas studies uniting CERN-DRD1 / DRD4, Sustainability LDG WG, active HEP experiments, and national laboratories

Cost/Benefit Assessments

- **Objective:** *Evaluate high-potential improvement areas via cost/benefit analysis for infrastructure upgrades.*
- **Scope:** *Target high-impact operational detector infrastructures, detector frame designs, and leak-prevention strategies.*

R&D activities on gas systems and alternatives gas mixtures:

- **Objective:** *Identify priority R&D pathways for low-GWP alternative mixtures, compatible detectors and gas systems*
- **Scope:** *Advance on gas mixture search as well as gas recirculation, purification, recovery systems, and long-term material compatibility/aging testing.*

Community Synergies :

- **Objective:** *Map ongoing activities across DRD panels and experiments to maximize global collaboration*
- **Scope:** *Promote shared infrastructure, joint facilities, and unified validation efforts to avoid duplication*

***R&D Roadmap**: Recommendations on short- and long-term gas sustainability priorities*

***Final Report**: Comprehensive report integrated into LDG Sustainability WG report in 2028*

LDG SUSTAINABILITY WORKING SUB-GROUP: COMPUTING AND ML

Co-Chairs: *Niko Neufeld (CERN)*
Ozgur Sahin (Irfu, CEA Saclay)

Established in September, 2026

A collaborative framework for Computing & Machine Learning:
rapid capacity growth of data centres and the energy requirements induced by AI processing are increasing demand for electricity and cooling water as well as for the memory, processors and the manufacturing capacity behind them

The Subgroup ia mandated to establish guidelines, evaluation frameworks, and key KPIs to assess, report & optimize the environmental and sustainability impacts of HEP computing and machine learning in HEP within the LDG Sustainability WG scope

Area	Coverage within LDG scope
Infrastructure	Data centres, distributed computing, cloud resources, storage and networks
Software and data	Simulation, reconstruction, analysis and data retention
AI/ML workflows	Data preparation, training, repeated inference and model reuse

WORKING GROUP ON COMPUTING AND MACHINE LEARNING

- ***Assessment Methods & Indicators***

Develop a minimal, transparent set of indicators:

- Report AI/ML sustainability metrics alongside performance measures such as accuracy and latency.

Level	Examples identified in the mandate
Facilities	Power and carbon usage effectiveness, with water usage effectiveness where relevant
Computing and AI/ML	Energy and high level CO^2 emission per processed event, training run or inference
Resources and use	Hardware utilisation, memory, storage, data movement, model reuse and frequency of use

- ***Practical Improvements and Opportunities***

Recommend priority R&D based on assessed improvement potential:

also considering operational impacts alongside hardware production, useful lifetime and end-of-life handling

Assessment criteria	Areas to assess
• Expected impact and realistic improvement potential	• Energy sourcing, heat recovery and hardware lifetime
• Feasibility, maturity and cost-benefit	• Software, storage and energy-aware scheduling
• Scientific suitability and evidence from operating facilities	• Resource-proportional ML architectures and model reuse

- ***Deliverables and Community-Wide Consultation***

Technical assessment, review and community consultation inform the recommendations

Deliverable	Content and review
Interim status report	Baselines and priority areas, submitted to the parent Working Group for review
Draft guidance	Provisional metrics circulated to member laboratories for community feedback
Final report	Proposed reference framework, standardised indicators and policy recommendations

***Final Report**: Comprehensive report integrated into LDG Sustainability WG report in 2028*

SUMMARY AND OUTLOOK

- ***Funding landscape are rapidly changing in Europe and beyond:***
  → ***requires a long-term vision and "culture" for all aspects of the project, including decarbonization path of RI's - which help to demonstrate the laboratory's commitment to sustainability to the governing bodies and public***

- ***The WG report already served as an input to the ESPPU2025 update (WG was in a close contact with ESG Working Group 5: Sustainability and Environmental Impact)***

- ***Within the outlined Sustainability WG reference framework, there is broad scope for effective collaboration among particle physics laboratories, centered on sharing results and coordinating efforts - for the rational use of available resources.***

- ***The Sustainability WG is looking forward to the new LDG Mandate*** to discuss best practices for sustainable accelerator driven RIs, analyzing their potential environmental benefits, technical feasibility, and cost-benefit balance