PETRA IV.
NEW DIMENSIONS

A sustainable accelerator?

Sustainability at PETRA IV.

Andrea Klumpp
16.12.2024

HELMHOLTZ

DESY.

DESY Sustainability D6 – Staff unit to the directorate

Our team

Denise Völker
Head of D6

Kathrin Schulz
Research funding
Specialist for BMBF
Civil construction
Support FLASH

Frank Merker
Technical monitoring

Andrea Klumpp
Sustainability in **PETRA IV.** project

Eva Leistner
Technical monitoring

General

What is sustainability at DESY

Broad approach with focus on energy efficiency

Science

- Science case supports sustainability goals
- High number of beamlines
- Innovation and technology transfer

Infrastructure

- Reuse of infrastructure
- Energy saving technologies
- New building concepts and materials

Supporting processes

- Key infrastructure of Science City Bahrenfeld
- Cooperation in campus security, safety, enviromental protection and mobility

Personnel

- Sustainable career development
- Keep knowledge on campus and attract best talents

Management

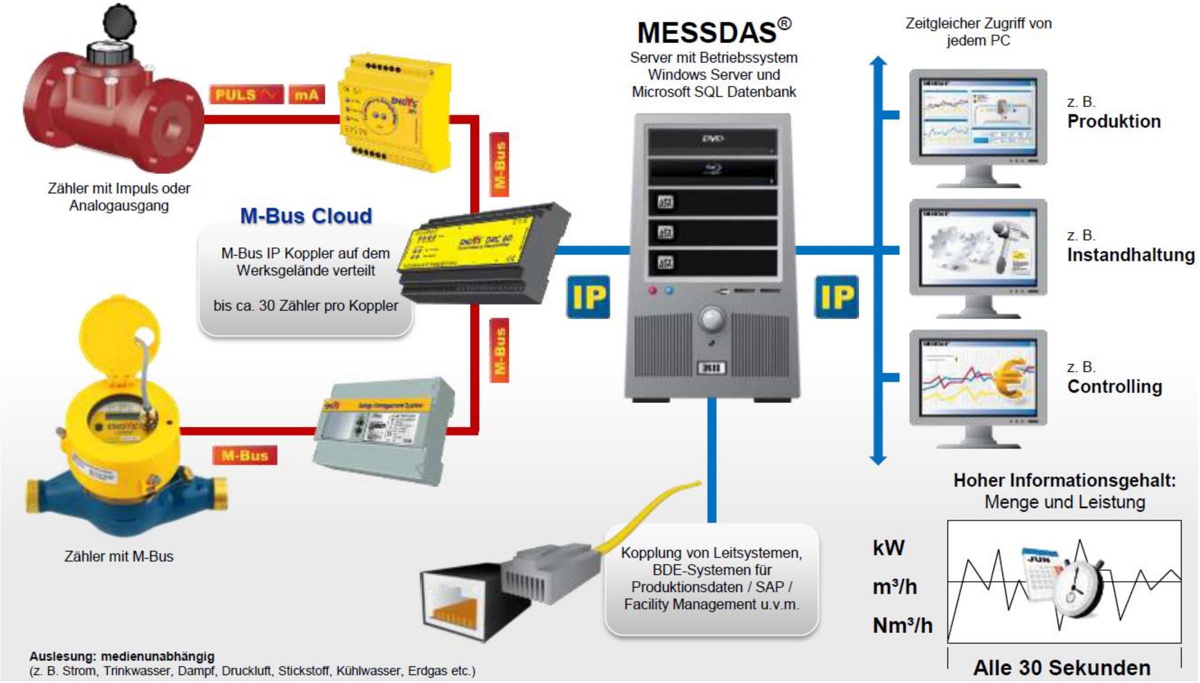
- Transperent to employees and stakeholders
- Documentation of processes and decions
- Boost socio-econimic impact (education, employment…)

Energy approach

Energy monitoring system

- Detailed, unified meter marking, centralized data collection and analysis, meters directly connected to database
- For Electricity, Water, Heat, Cooling

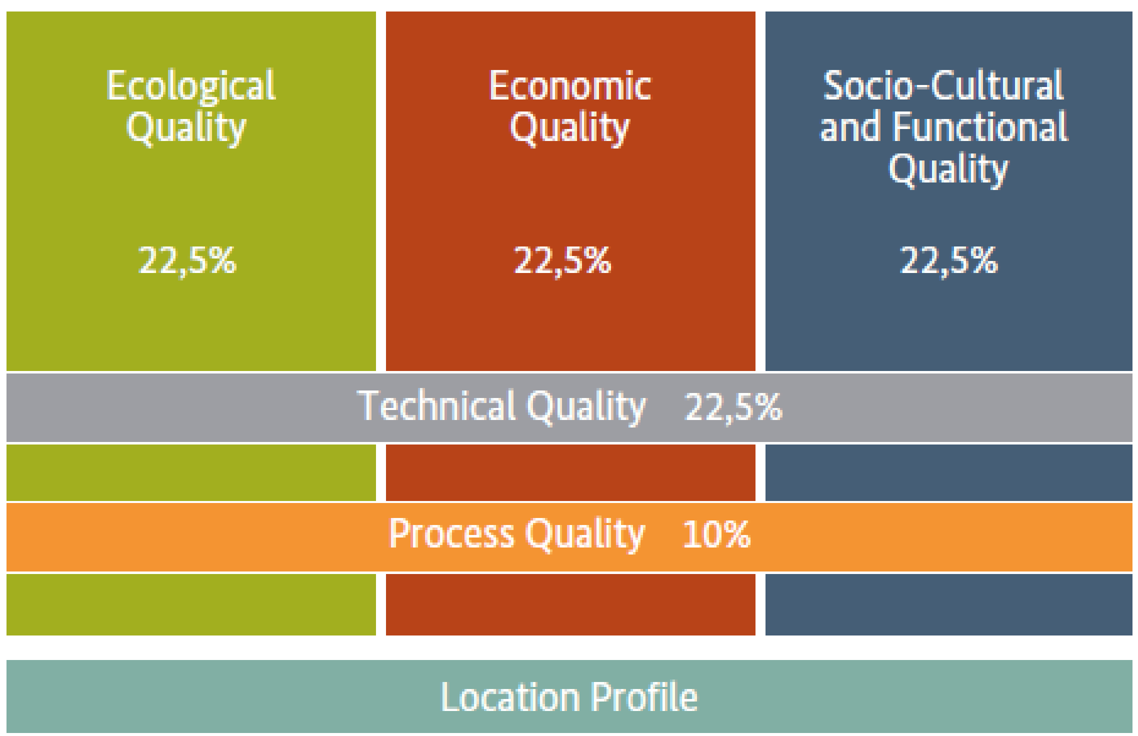
→ Enables for user-based/source-related accounting, identification of efficiency potentials and therefore more awareness



Civil construction

LCA for buildings

Main Criteria Groups of the BNB System



Source: BBSR

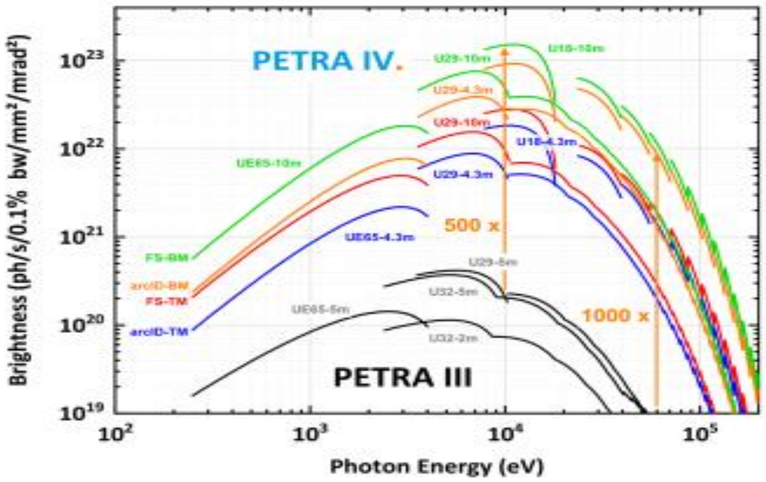
National certification system for sustainable building (BNB):

- Consideration of the whole life cycle of the building (LCA)
- Ecological, economic, socio-cultural and technical qualities are rated equally
- End of life and recycling are included
- BNB silver for all new buildings at **PETRA IV.**
- New experimental hall with equivalent criteria

PETRA IV

Upgrade PETRA III : PETRA IV.

What is the benefit of the upgrade?

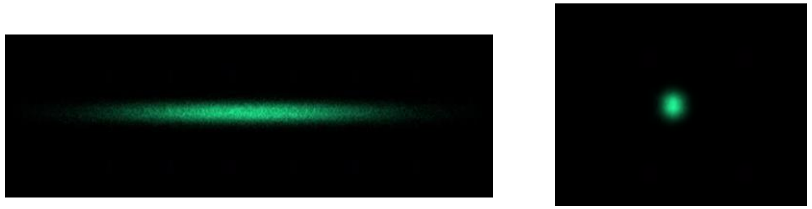


Spectral brightness of PETRA IV (H6BA lattice) compared to PETRA III [1]

Brilliance increase by
➔500 x (hard X-rays)
➔1000 x (high-energy X-rays)

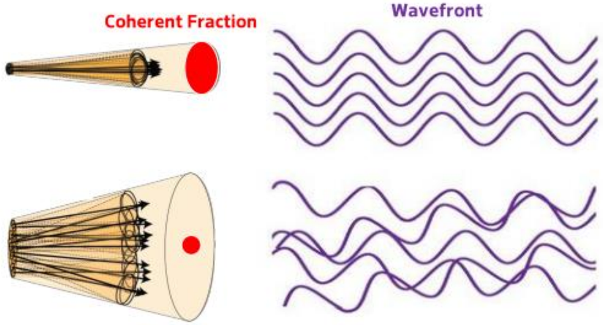
PETRA IV. brilliance at 100 keV
higher than for 10 keV at PETRA III today!!

Photon source size –ideal imaging capabilities



Comparison of the beam emittance for PETRA III (left) and PETRA IV (right)

	PETRA III	PETRA IV
Horizontal	1300 pm rad	20 pm rad
Vertical	10 pm rad	5 pm rad



Coherence of the emitted light for PETRA III (bottom) and PETRA IV. (upper figure)

[1] C.G. Schroer et all **Eur. Phys. J. Plus 137, 1312 (2022)**

Design 4 Sustainability

Design 4 sustainability? – Design for:

Manufactoring Assembly

Logistics Use (avoid rebound effect) Disassembly

Reuse Repurposing Repair Maintenance

Remanufactoring Refurbishment Recycling

Composting Circularity

Strategies for D4S

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Innovate solutions

- Rethink how to provide the benefit
- Anticipate technology change
- Optimise or integrate functions
- Integrate natural systems

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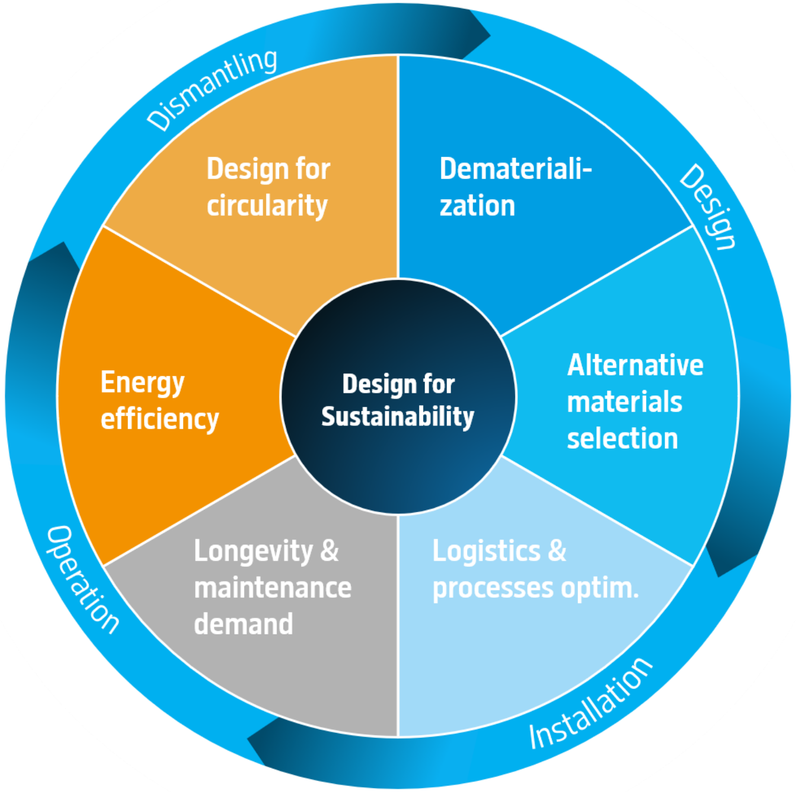

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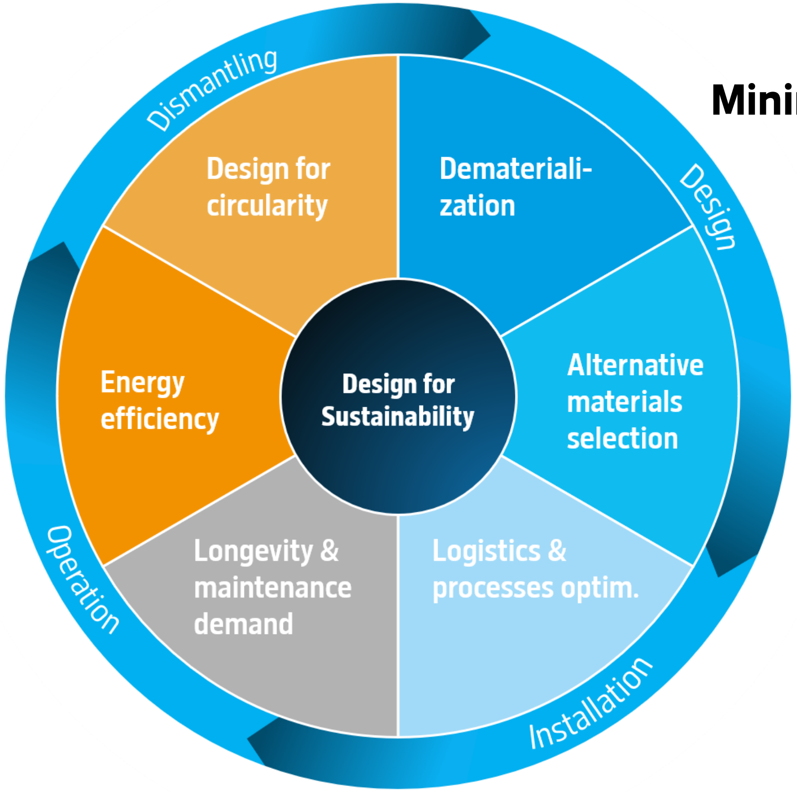

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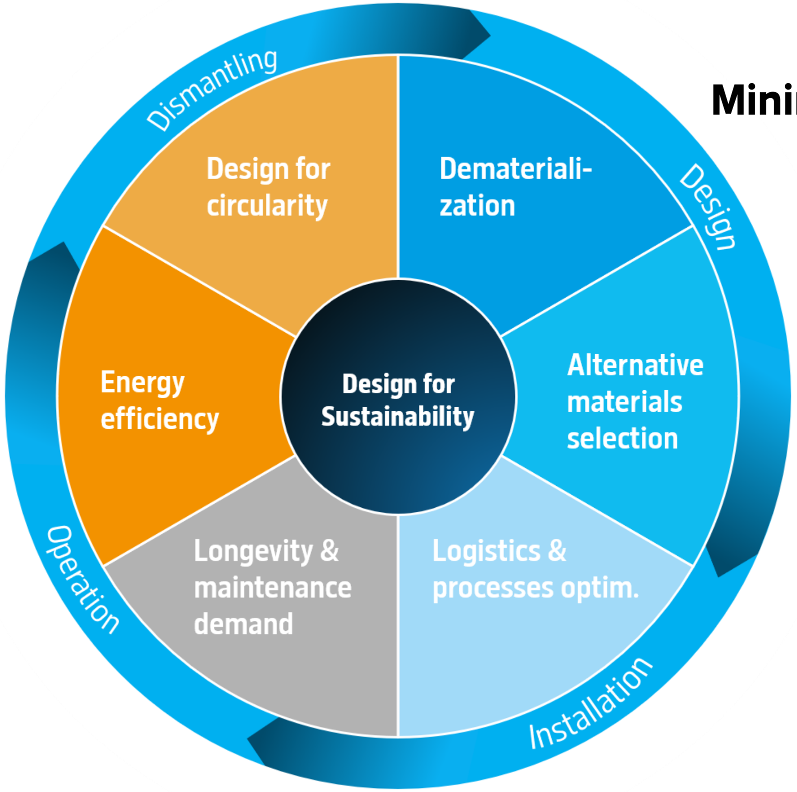

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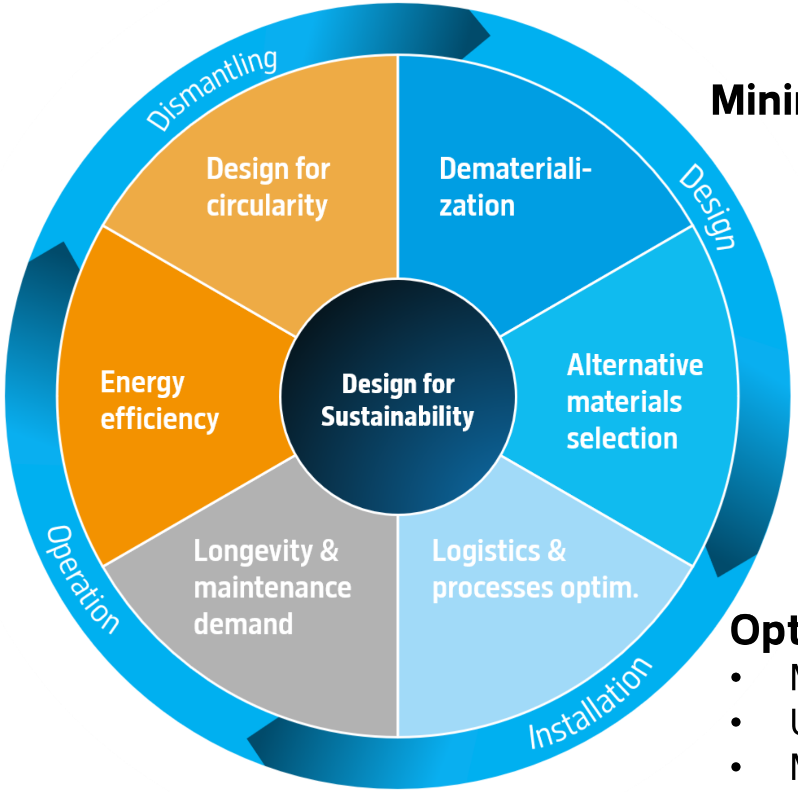

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- Use renewable and carbon-neutral energy
- Minimize number of parts, materials and steps in production
- Reduce weight and volume of product and packaging
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- Use lowest-impact transport and source locally

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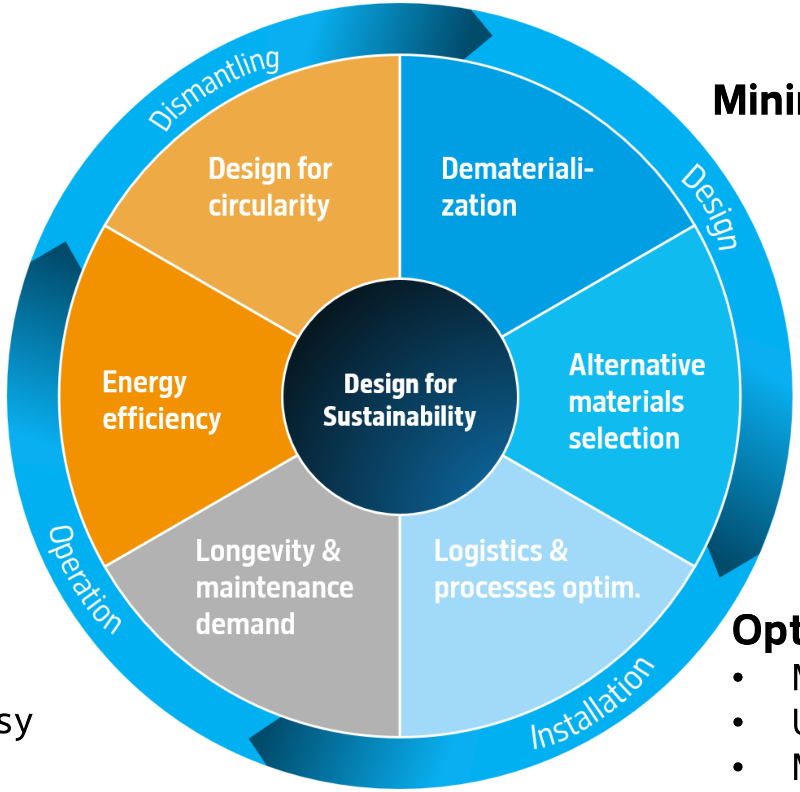

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- Design for durability
- Design for maintenance, easy repair, reuse and exchange
- Consider upgradable products and second life with different function

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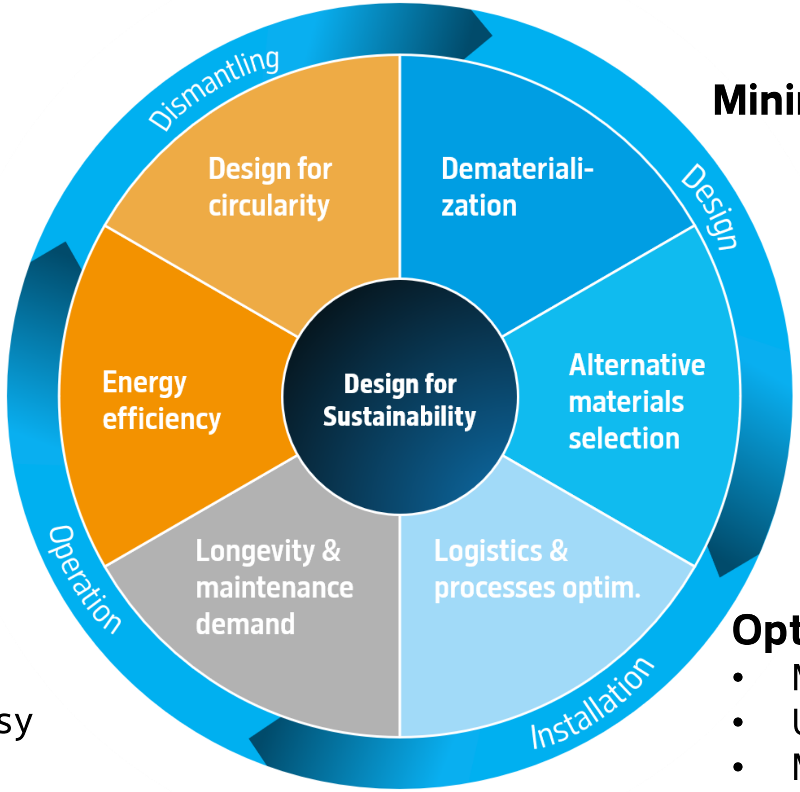

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- Reduce energy, water and material requirments during use
- Design for carbon-neutral or renewable energy

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Strategies for

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Optimize end-of-life
- Design for easy disassembly, component reuse and recycling
- Integrate with used-product collection models
- Design for safe disposal and biodegradability

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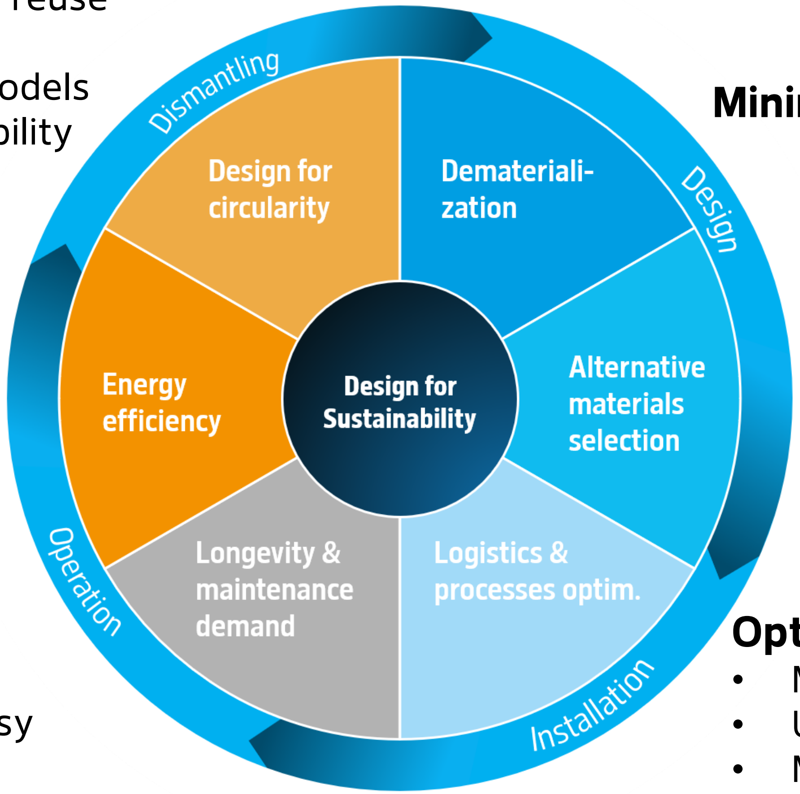

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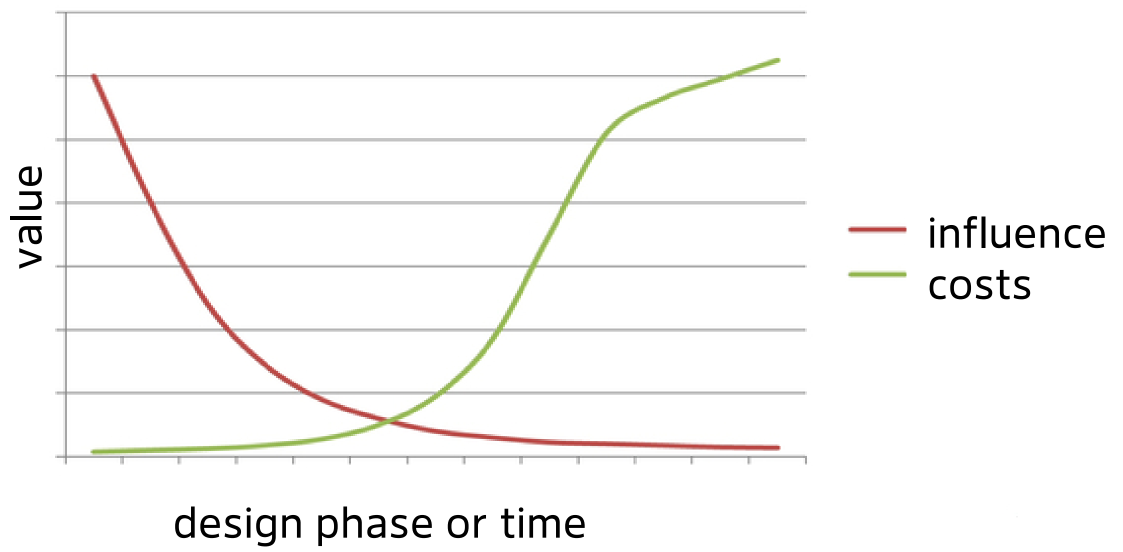
How to …

Start as early as possible

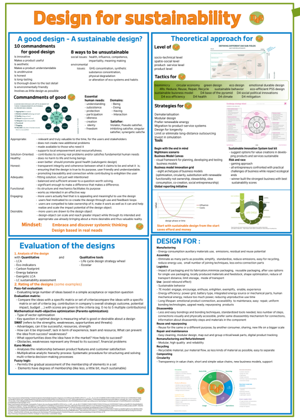


Our Roadmap

- Analyze the starting point and/or current status
  - Legal requirements (VDI, …)
  - How do others do? (eg. industry)
  - LCA (collecting information and experiences)
- Discussions with developers and technicians
  - How to include sustainability in existing processes
  - Find examples for D4S in existing projects
- Develop of strategies and ideas
  - Stakeholder, approaches, possible projects
- In cooperation with developer and technicians: developing a training programme for physicians and technicians

First steps at DESY

What is D4S



Design for sustainability

A good design - A sustainable design?

10 commandments for good design

Is innovative
Makes a product useful
Is aesthetic
Makes a product understandable
Is unobtrusive
Is honest
Is long-lasting
Is thorough down to the last detail
Is environmentally friendly
Involves as little design as possible

8 ways to be unsustainable

social issues: health, influence, competence, impartiality, meaning making
enviromental issues: GHG concentration, synthetic substance concentration, physical degradation or alteration of eco systems and habits

Commandments of good

Essential human needs:
- understanding
- subsistence
- protection
- participation
- idleness
- creation
- identy
- freedom

Domains:
- Being
- Doing
- Having
- Interaction

Satisfier:
Violator, Pseudo satisfier, inhibiting satisfier, singular satisfier, synergetic satisfie

Appropriate:
- relevant and truly valuable to the time, for the users and stakeholders
- does not create new additional problems
- made available to those who need it
- supports local empowerment and resourcefulness.

Solution-Oriented: - contributes to solving real problems and/or satisfies fundamental human needs

Healthy:
- does no harm to life and living beings
- even better: should promote good health (salutogenic design)

Honest:
- transparent integrity and coherence between what it claims to be and what it is;
- ensuring that the design is true to its purpose, user friendly and understandable.
- promoting traceability and connection while contributing to enlighten the user

Adequate:
- fitting solution, not just well intentioned
- balanced and sufficient answer to a question worth solving.
- significant enough to make a difference that makes a difference.

Functional:
- its structure and mechanics facilitates its purpose
- works as intended in an effective way

Engaging:
- more users actually feel that is is appealing and meaningful to use the design
- users feel motivated to co-create the design through use and feedback loops
- users are compelled to take ownership of it, make it work as well as it can and help realize and scale the impact potential of the design object.

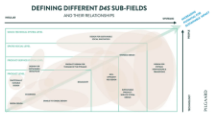
Desirable:
- more users are drawn to the design object
- design-object can scale and reach greater impact while through its intended and appropriate use already bringing about a more desirable and thus valuable reality.

Mindset: Embrace and discover systemic thinking
Design based in real needs

Theoretical approach for D4S

Level of D4S

socio-technical level
spatio-social level
product- service level
product level



Tactics for D4S

biomimicry | circular economy | green design | eco design | emotional durable design
4Rs: Reduce, Reuse, Repair, Recycle | sustainable behavior | eco-efficient PSS design
sustainable buisness model | D4 base of the pyramid | D4 social political innovations
D4 eco efficiency | D4 health | D4 climate | D4 mitigation

Strategies for D4S

Dematerialisation
Modular design
Prefer renewable energy
Migration to product-service systems
Design for longevity
Limit or eliminate long-distance outsourcing
Invest in simulation

Tools

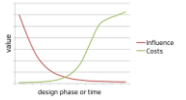
Begin with the end in mind
Nightmare scenario
Business Model Canvas
- visual framework for planning, developing and testing business models

Business model Innovation grid
- eight archetypes of business models (optimization, circularity, substitution with renewable functionality not ownership, stewardship, slow consumption, co-creation, social entrepreneurship)

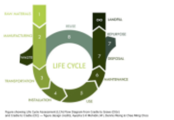
Global reporting Initiative

Sustainable Innovation System tool kit
- suggest options for value creations in developing products and services sustainable

Risk and race
- gaming approach
- all entrepreneurs confronted with practical challenges of business while respect ecological ends
- winner built the strongest business with best sustainability scores



Start with sustainable design from the start saves efford and money



Evaluation of the designs

1. Analysis of the design

with **Quantitative**
- LCA
- Eco-indicators
- Carbon footprint
- Energy balance
- Exergetic LCA
- LC sustainability assessment

and **Qualitative tools**
- Life cycle design strategy wheel
- Ecostar

2. Rating of the designs (some examples)

Pass-fail evaluation:
- Evaluating large number of ideas based in a simple acceptance or rejection question

Evaluation matrix:
- Compare the ideas with a specific matrix or set of criteriacompare the ideas with a specific matrix or set of criteria (eg. contribution in company's overall strategic outcome, potential impact, budget ....) with scores are given to the criteria (eg. 0 no to 5 multiple contributions)

Mathematical multi-objective optimization (Parento optimization):
- Type of vector optimization
- Key question in optimal design is measuring what is good or desirable about a design

SWAT (refers to the strengths, weaknesses, opportunities and threats):
- Advantages, can it be successful, resources, strength
- How can it be improved?, lack in term of experience, team and resource, What can prevent the idea from success? weaknesses?
- What opportunities does the idea have in the market? How help to succeed?
- Obstacles, weaknesses represent any thread to its success?, financial problems

Kano Model:
- Analyses the relationship between product features and customer satisfaction
- Multiplicative analytic hierachy process: Systematic procedure for structuring and solving multi-criteria decision-making processes

Fuzzy logic:
- Permits the gradual assessment of the membership of elements in a set
- Elements have degrees of membership (like less, a little bit, much sustainable)

DESIGN FOR :

Manufactoring
- Energy consumption auxiliary materials use, emissions, residual and reuse potential

Assembly
- Eliminate as many parts as possible, simplify, standardize, reduce emissions, easy for recycling, reduce energy use, small number of joining techniques, less extra connection parts

Logistics
- Impact of packaging and its fabrication,minimize packaging, reusable packaging, after use options for single use packaging, locally produced materials and feedstock, shape optimization, reduce of transport distance, limit storage, mode of transport

Use (avoid rebound effect)
- Sustainable behavior
- 7E model: engage, encourage, enthuse, enlighten, exemplify, enable, experience
- Energy efficiency: power grid, battery type, integrated energy source or mechanical parts, human mechanical energy, reduce too much power, reducing unproductive use time
- Long lifespan: emotional product connection, accessibility to maintenance, easy repair, uniform bonding technologies, upgrad ready, repurposing products

Disassembly
- Less and easy bondings and bonding techniques, standardized tools needed, less number of steps, connections visually and physically accessible, prefer same disassembly mechanism for connections, information about disassembly steps and materials in the component

Reuse and repurposing
- Reuse for the same or a different purpose, by another consumer, sharing, new life on a bigger scale

Repair and maintenance
- Easy cleaning, modular design, map out and group critical/weak parts, digital product tracking

Remanufactoring and Refurbishment
- Modular, high quality and reliability

Recycling
- Recyclable material, pur material flow, as less kinds of material as possible, easy to separate

Composting

Circularity
- Transparency in value chain, short and simple value chains, new business models, support

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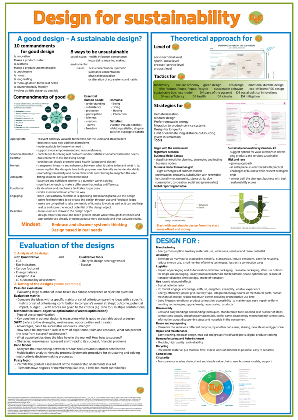
SUSTAINABLE DESY.

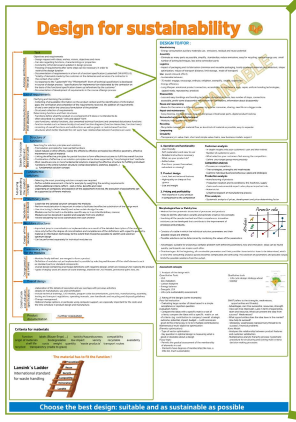
DESY.

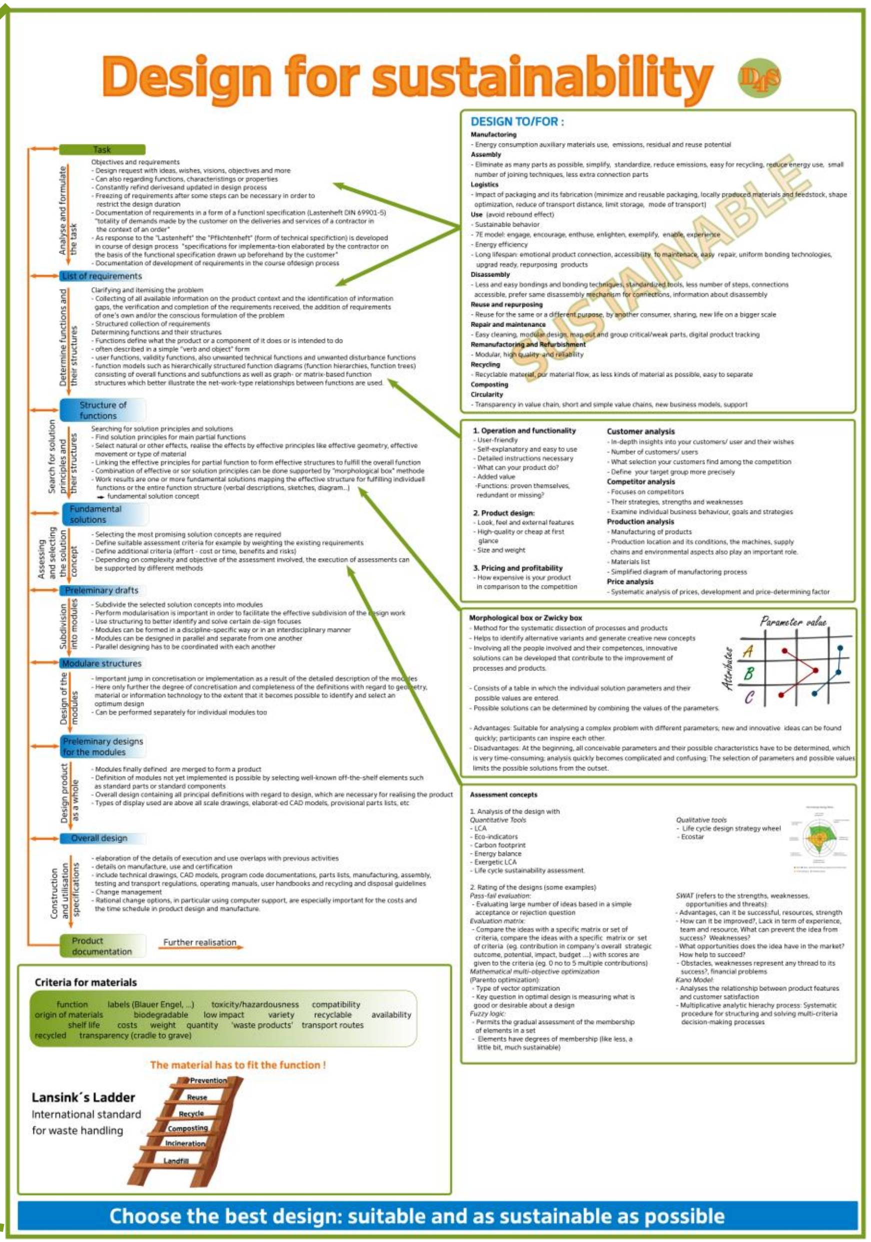
First steps at DESY

What is D4S



VDI and D4S





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First steps at DESY

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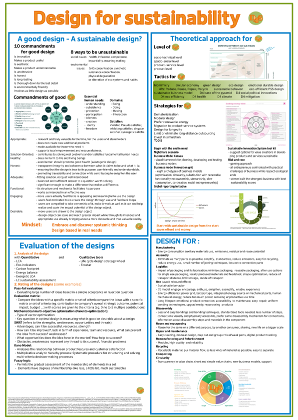

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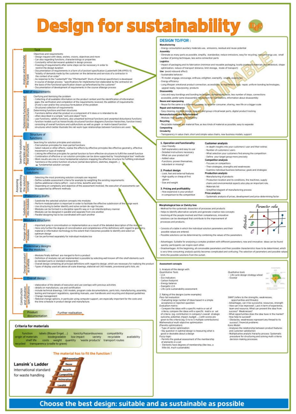


Life Cycle Assessment

Sustainability accounting for research facilities

Why we need accounting

- Groundwork for any sustainability or CSR strategy
- Comply With Regulations and laws (50001,...)
- Development of more sustainable instruments and components
- Choosing of supplier in procurement
- Strategical decision (Can we do this science or shouldn´t we do)
- Which changes has large impact which less
- Definition of start point for improvement

Methodes

LCA
- Standardised (14040:2006 and 14044:2006, DIN EN ISO 14040, 500001 ...)
- Procedure for recording and evaluating environmentally relevant processes
- Cross-media consideration: All relevant potential harmful effects on the environmental media soil, air and water must be taken into account
- all environmental impacts are considered
- for the carbon footprint and water footprint, only one environmental impact is considered in each case (calculation methods are based on the LCA method)

IOA
- Not internationally standardised
- Methods can vary greatly depending on the issue at hand, the research interest and the analysis system
- Records substance and material flows associated with specific products, processes, services or entire areas of need, such as construction and housing, mobility or nutrition
- Raw materials or resources, different types of energy, water, emissions to air, land, or water by substance

Material and energy balances differ from life cycle assessments in that they relate to a specific period (often referred to as the balance sheet year) and are not based on the causation principle (what material and energy flows has the product caused over its entire life cycle?) Due to their methodological proximity, it is not always possible to make a clear distinction between life cycle assessments and material flow analyses. Put simply, material flow analyses tend to focus on the quantities and paths of a system's substance, material and energy flows. Life cycle assessments, on the other hand, also analyse and evaluate the environmental impacts associated with these flows.

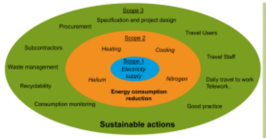
More
- ABC-analysis: multidimensional cradle-to-grave LCI for material and energy flows
- CML-methode: multidimensional cradle-to-grave impact analysis for material and energy flows (14 categories)
- CO2-accounting one dimensional cradle-to-gate impact analysis for directe and indirecte GHG emissions
- Eco-indicator 99 one-dimensionally aggregated cradle-to-grave impact analysis for material and energy flows (9 categories)
- Critical volumina: multidimensional cradle-to-grave LCI (pollution of air and water, waste, energy consumption)
- Cumulative energy expenditure: one-dimensional cradle-to-gate LCI for energy expenditure
- Cumulative energy expenditure: one-dimensional cradle-to-gate LCI for energy expenditure
- MIPS: one-dimensional aggregated cradle-to-grave LCI for material flows and service units
- Method of ecological scarcity: one-dimensional aggregated cradle-to-gate LCI for material and energy flows
- UBA impact indicators: multidimensional cradle-to-gate impact analysis for material and energy flows in different categories

How to do LCA

1. Definition of goal and scope of investigation

Goal and Recipient
- Laws
- Optimization of processes and technology
- Decision support
- Definition starting point
- Society
- Politicians......

Scope



Scopes for accelerator facilities
(talk 15.02.2024 Jean-Luc Revol)

scope 3 (Fraunhofer)
- Paper
- Cantine
- IT-equipment
- Water
- IT- and communication services
- Logistics services (mail and parcel delivery)
- Civil construction
- Fuel and energy-related emissionen
- Waste
- Travel staff
- Commuting by employees
- Miscellaneous: Events ...

Indicators

Greenhouse Gases (GHG): Carbon dioxid (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Ozone (O_3), Chloroflourocarbons (CFCs and HCFCs), Hydroflourocarbons (HFCs), Perfluorocarbons (CF_4, C_2F_6, etc.), SF_6, and NF_3

Water footprint:
Reduced LCA: which factors are important for us?
Complete LCA: including all ecological and socio-economical impacts

Models

Cradle-to-grave:
- Analyze a product's impact along the 5 product lifecycle steps
- Cradle is the inception of the product with the sourcing of the raw materials
- Grave being the disposal of the product
- Transportation is mentioned as step 3, but can, in reality, occur in between all steps

Cradle-to-gate:
- Only assesses a product until it leaves the factory gates before it is transported to the consumer
- Common in environmental product declarations (EPD)

Cradle-to-cradle:
- Circular Economy
- Variation of cradle-to-grave, exchanging the waste stage with a recycling process

Gate-to-gate:
- To reduce complexity, only one value-added process in the production chain is assessed.

2. Life cycle inventory (LCI)

- Input/Output flows
- Technical monitoring for electricity, water heat, cooling
- Questionnaires
- Use of averages
- Use of flow models in order to miss nothing
-

3. Impact assessment (LCIA)

- ***Selection of indicators and models:*** Human toxicity, Global Warming Potential, Ecotoxicity, Acidification, Eutrophication
- ***Classification:*** assigning Life Cycle Inventory to defined impact categories
- ***Impact Measurement:*** finally calculate all equivalents and sum up in overall impact category totals

4. Evaluation

- Identifying significant issues based on our LCI and LCIA phase
- Evaluating the study itself, how complete it is, if it's done sensitively and consistently
- Conclusions, limitations, and recommendations

Tools

- LCA with Simulation program: GaBi, Open LCA, SimaPro, Sphera, Ecochain,EarthShift Global, iPoint, Pré sustainability, ... and Data base: ProBas, ELCD, ÖKOBAUDAT, ...
- Literature research (LCA´s for materials like rare earth elements, for technical components like electro motors,...)
- Technical monitoring (energy, fresh water, heating, cooling...)

Laws and standards

ISO 14001: Environmental Management System: ISO 14001 defines the criteria Environmental Management Systems have to comply with. It ensures that environmental impacts are being measured and improved.
ISO 14021: Environmental Claims and Labels: ISO 14021 defines how specific environmental claims have to be and how they have to be formulated and documented.
ISO 14040:2006: Life Cycle Assessment Framework: ISO 14040:2006 defined the principles and framework of a Life Cycle Assessment. Many parts of this article are based on ISO 14040:2006.
ISO 14044: The Update: ISO 14044 replaced earlier versions of ISO 14041 with ISO 14043.
ISO 14067: Quantifying carbon footprint: ISO 14067 defines how the carbon footprint of products is quantified during a Life Cycle Assessment.
ISO 50001: Efficient Energy Management: ISO 50001 defines Energy Management Systems

Normalization

- employees for Campus
- user, publications or measure time for research infrastructure (machine, tunnel...)

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Life Cycle Assessment

Life Cycle

It starts with the design

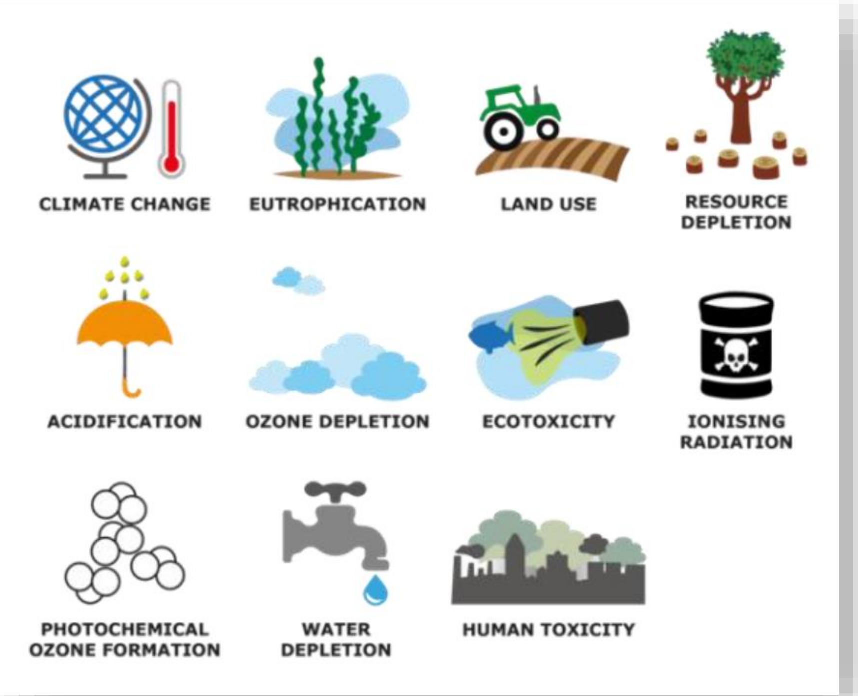
"LCA is a tool for the analysis of the **environmental** burden of **products** at all stages in their **life cycle**"

+ Social

+ Governance

What is being considered:

Not only Greenhouse Gases

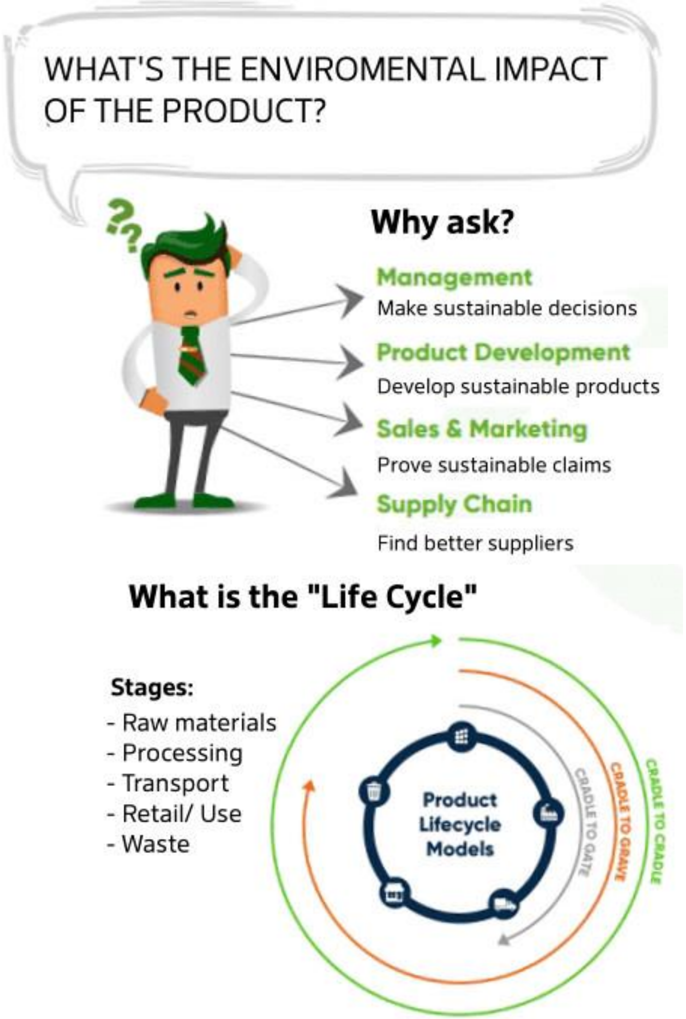


I Source: European Commission, Joint Research Centre, Cristobal-Garcia, J., Pant, R., Reale, F., et al., *Life cycle assessment for the impact assessment of policies*, Publications Office, 2017, https://data.europa.eu/doi/10.2788/318544

First GWP calculations for magnets have been done. Now a complete LCA for a power supply is ready!

Life Cycle Assessment

Basics



1 Goal and Scope

What do we want to measure

Why do we do the LCA
For whom (audience)

Define the product to measure
Which parts of the life cycle?
Which impact category (CO2, water,...)

What do we exclude?

2 Life Cycle Inventory

Collect and structure our data

Collect all the inputs and processes that we want to measure.

Raw materials and bill of materials
Energy we use and buy

Supplier data
- Everything that goes into and flows out of the system

3 Impact Assessment

Translate our data to impacts

Who does the LCA
Which programme we used and which Databases

Process to manage the data input in the programme

4 Interpretation

What does all of this mean?

How high are our emissions?

Can we improve them?

Can we improve our processes?

What are the biggest levers for us?

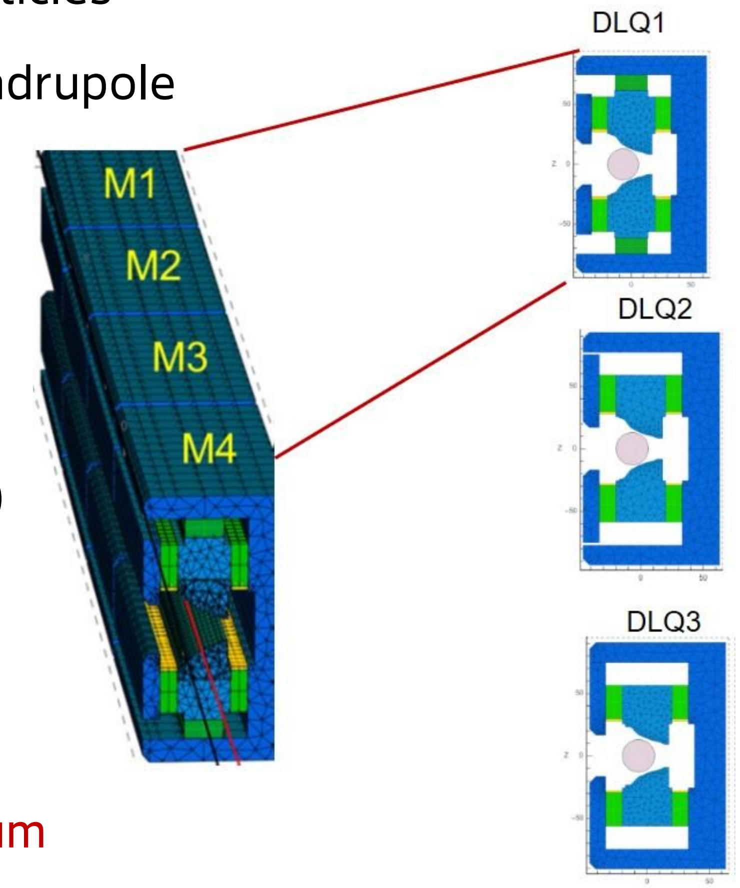
Ökobilanz (LCA) - Vollständiger Leitfaden für Einsteiger - Ecochain - DE

Examples

Bending magnets for PETRA IV.

Permanent magnet-based dipoles with transverse and longitudinal gradient

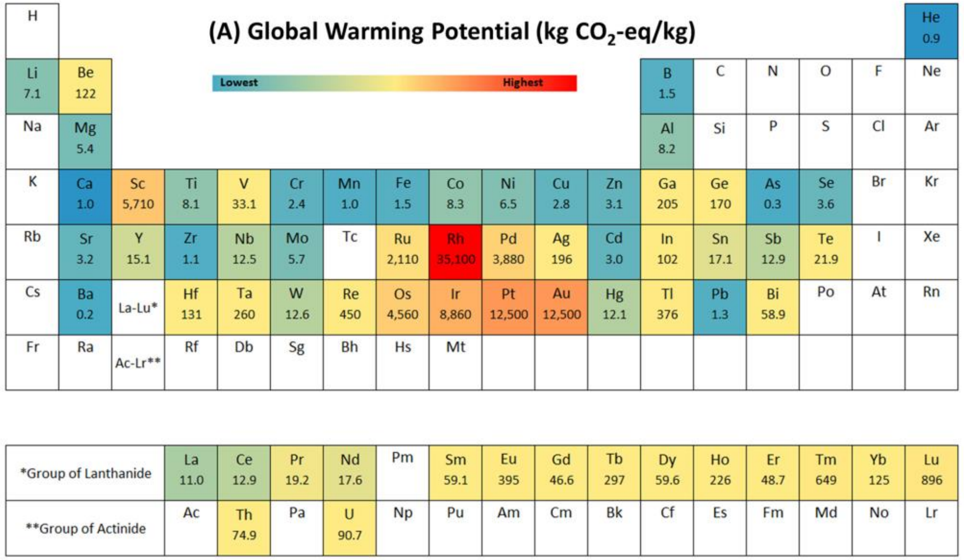
- Dipole magnets change the direction of moving charged particles
- H6BA lattice: DLQs combine the function of a dipole and quadrupole magnets to save space
- Soft iron poles and yoke; SmCo magnets
- Thermal shims for temperature compensation
- Modular concept, unification across the 3 DLQ types as much as possible (yoke, block size, mounting, shimming etc.)
- **144** DLQs of each type to build, i.e. ~**2000** modules
- Energy savings: **nearly 2.87 GWh/year**
  (calculated with 6500 h operation time per year; without cooling and heating)
- For all electromagnets in PETRA IV nearly 6.4 GWh per annum
  (6500 h operation time)



Global warming potential

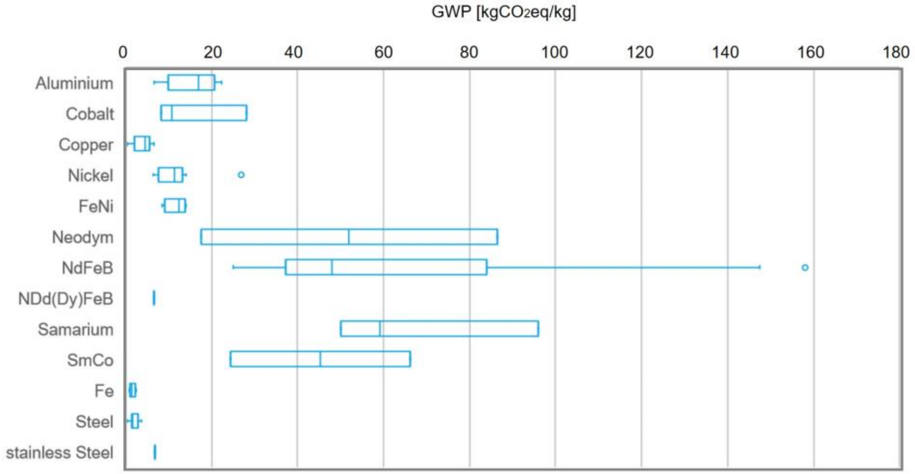
Literature research

- Round about 100 papers
- Different regions, techniques, data bases, calculation programs
- Cradle to gate LCA´s
- Dependend on material more or less publications (Cu more than 20, Sm 3)
- Good overview to judge the values is shown in the picture



Life Cycle Assessment of Metals: A Scientific Synthesis
Philip Nuss1*, Matthew J. Eckelman
www.plosone.org 1 July 2014 | Volume 9 | Issue 7 | e101298

Justment of values



- Large spreading in values
- Permanent magnetic material from LCA for electromotors
- Accuracy of values only makes sense in integers
- GWP for SmCo should be calculated by GWP from the incredencies

Calculation of the Global warming potential

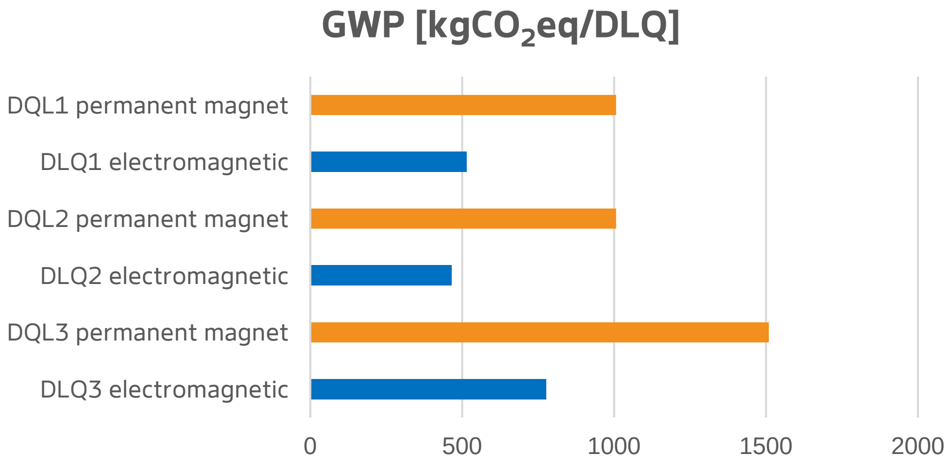
		DLQ1		DLQ2		DLQ3	
Material	GWP [kgCO_2eq]	amount	GWP	amount	GWP	amount	GWP
Al	16	20	320	20	320	30	480
pure iron	2	112	224	112	224	168	336
FeNi	11	1,21	13	1,21	13	1,81	20
SmCo	27	16,47	445	16,47	445	24,70	667
Steel	2	2,42	5	2,42	5	3,63	7
Sum for material		152	**1007**	152	**1007**	228	**1510**

Permanent magnetic design

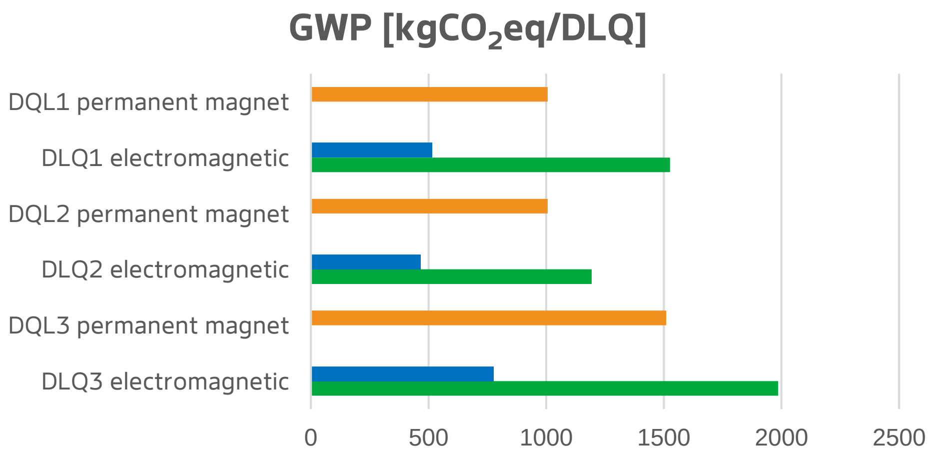
		DLQ1		DLQ2		DLQ3	
Material	GWP [kgCO_2eq	amount	GWP [kgCO_2eq	amount	GW [kgCO_2eq	amount	GWP [kgCO_2eq
Copper (Cu)	4	34kg	134	31kg	124	50kg	200
Steel	2	189,6kg	379	170,6kg	341	287,6kg	575
Sum for material		224 kg	**515**	202 kg	**465**	338 kg	**776**
power consumption per year (6500h)	0,410 [1]	8255 kW	3384	4355 kW	1795	7215 kW	2967
power consumption per year (6500h)	0,03 [2]	8255 kW	248	3095 kW	131	7215kW	217
Sum GWP (n)			**3900**		**2260**		**3743**
Sum GWP (e)			**763**		**596**		**993**

Electromagnetic design

(a)



(b)



GWP for (a) material (electromagnets- blue and permanent magnets – orange)
and (b) including estimated energy consumption (material + renewable electricity for 2 years – green)

Energy GWP from UBA for renewable electricity

Energy savings

1. Operation of magnets

- per cell 2 magnets from each kind, 72 cells in the ring
- $P=72x2x(P_{DQ1}+P_{DQ2}+P_{DQ3})$~440kW
- Per year (6500 h operation time per year): **2.86GWh/year**

2. Cable losses

- Each magnet needs an average cable length of 20m to the media shaft and 70m to the power supply
- Cable losses per magnet: DQ1~ 331,29W (120mm^2=262,67W),DQ2 ~ 195,23W (120mm^2=154,8W) DQ3 ~ 200,4W (120mm^2=158,89W)
- $P=72x2 (P_{DQ1cable}+P_{DQ2cable}+P_{DQ3cable})$~ 104,98kW (120mm^2=83kW)
- Per year (6500 h operation time per year): **0.68GWh/year** (120mm^2=0.54GWh/year)

Challenges in the use of permanent magnets

PETRA IV. NEW DIMENSIONS

Basis

Energy monitoring

Civil construction

LCA for technical components

At work

Infrastructure

Operation

Finale

Research

Beginning of life cycle: Mining and Processing

- Rare earths are mined and processed under destructive social and environmental conditions
- No alternative sources or certified mining and processing available

In operation

- Temperature fluctuations and radiation damages reduce the life span
- Magnetic field is not adjustable, so changes in trajectories can not be compensated
- Magnetic field can not be switched off (Safety aspects like maintenance)

End of life cycle: Recycling

- So far no industrial recycling chain

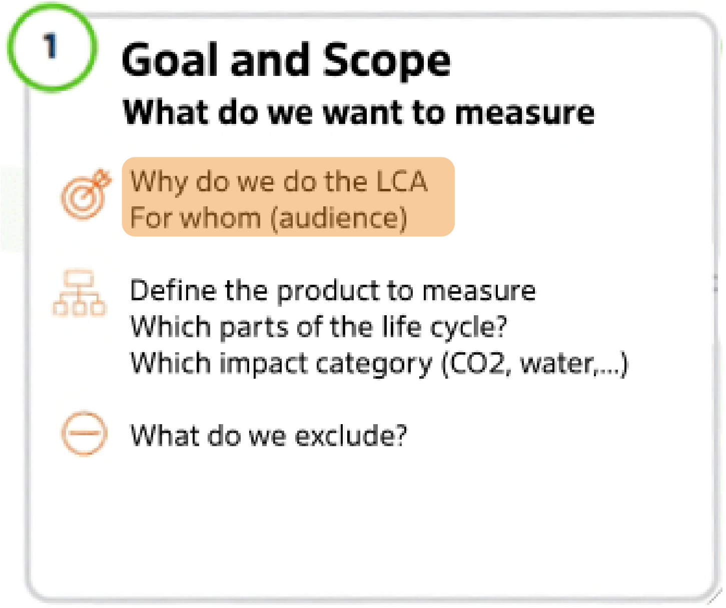
Workshop at DESY 6^{th}–8^{th} February 2023
https://indico.desy.de/event/35655/

a) **Private, illegal minning in China**; http://www.chinahush.com/2009/10/21/amazing-pictures-pollution-in-china/; 2009 - 2011 ChinaHush is licensed under a Creative Commons License *Copyright:* Lu Guang;
b) **air pollution by heavy industries**; Quelle: china-digital-times *Copyright:* My Essentia com blog;
c) **In-Situ-Leaching**; Quelle: Web-Page Bellona *Copyright:* Andrej Ozharovsky;
d) **Entrance to waste disposal for radioactive waste from REE production in Bukit Merah** in Kledang mountains; built for 20 years storage of radioactive waste (14 Mrd years radioactive half-life); 1985 *Copyright:* Consumer Assciation Penang

iFAST
"This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 101004730"

SUSTAINABLE DESY.

Goal and scope definition



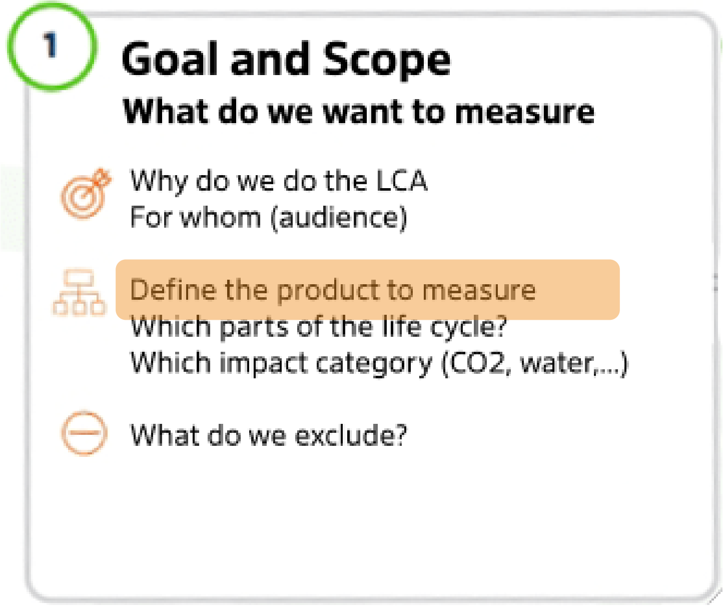
Ökobilanz (LCA) - Vollständiger Leitfaden für Einsteiger - Ecochain - DE

- Experience with LCA:
  - How to proceed?
  - Which indicators are useful?
  - Which programme fits best?
  - What can we learn from LCA?
  - What to look out for?
  - How much work is it?
  - What are the difficulties?

- Evaluation of the sustainability of the device

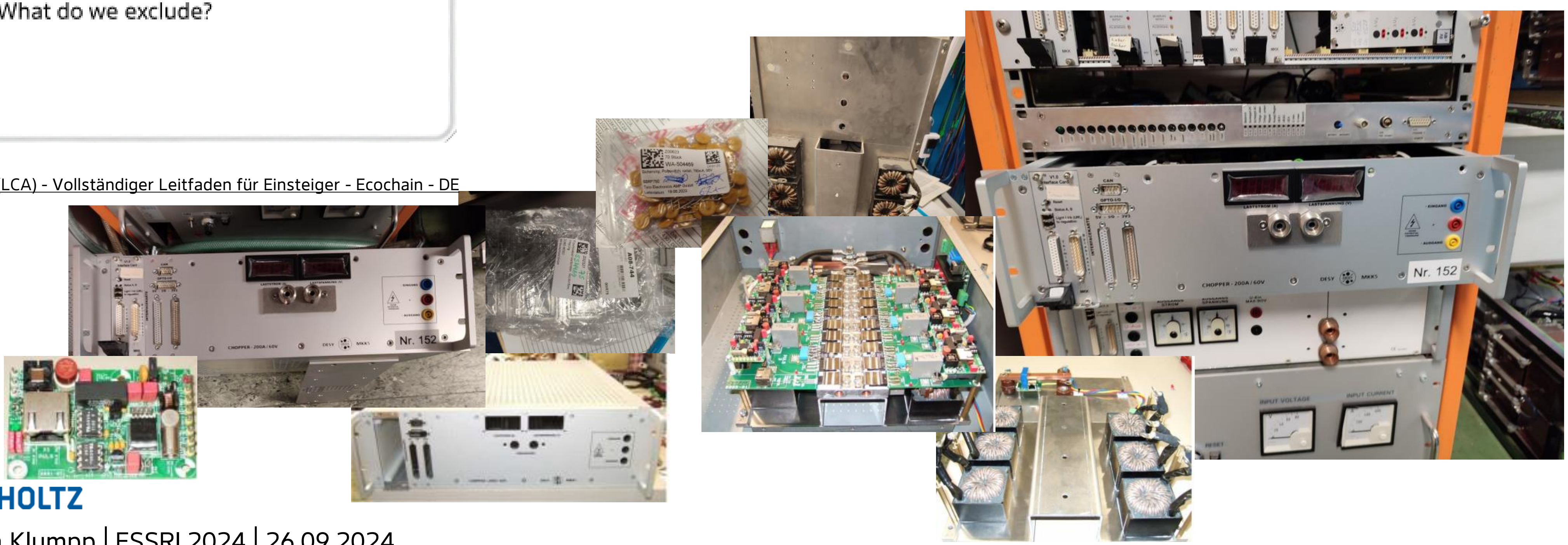
- Identify the sustainability potential of the device

Goal and scope definition



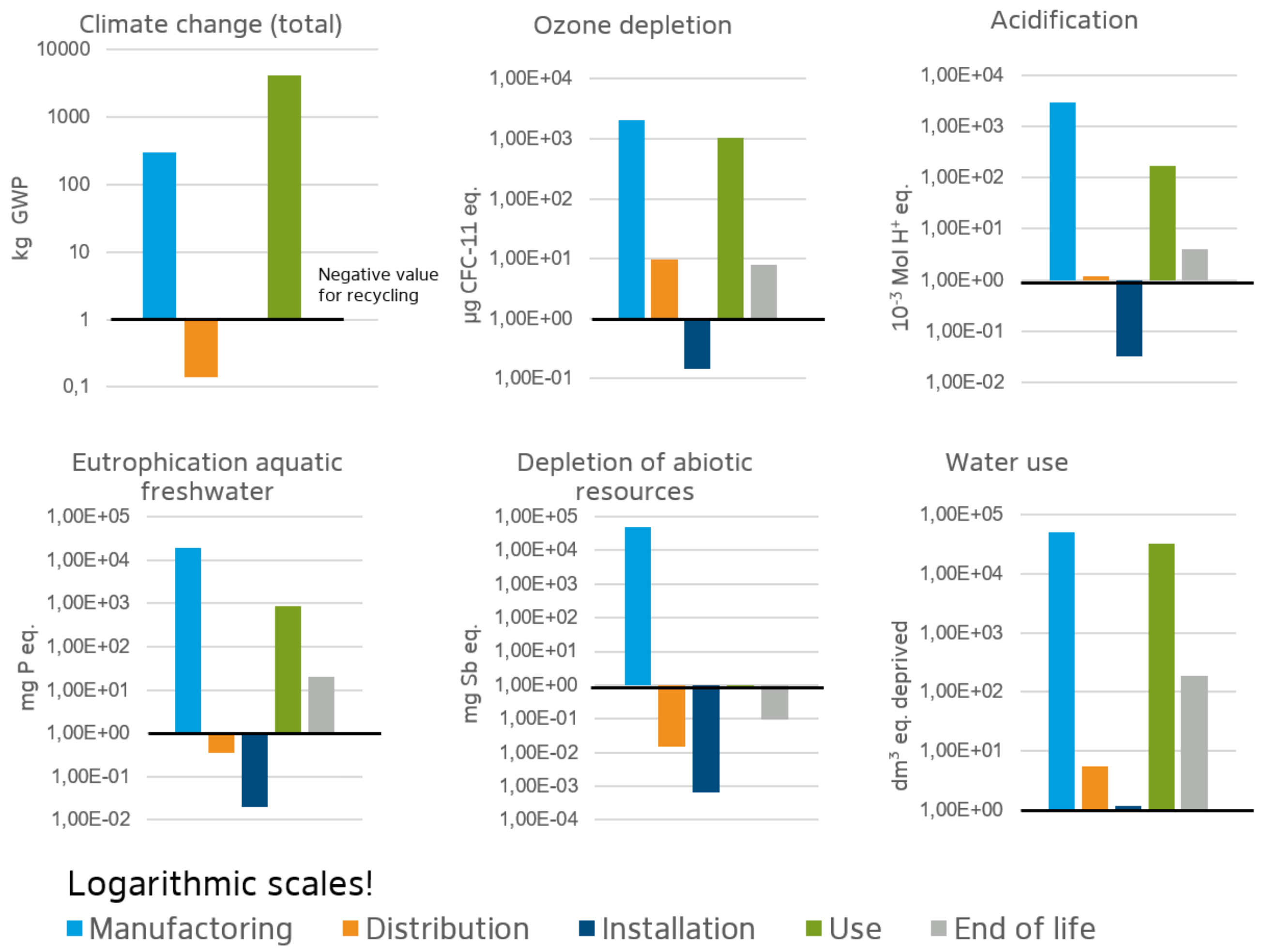
Ökobilanz (LCA) - Vollständiger Leitfaden für Einsteiger - Ecochain - DE

- More than 4000 power supplies will be needed for PETRA IV
- Up to 3 power supplies have to be replaced weekly
- Hot-swap system also requires some devices
- Decision: A home-built and -designed power supply should be used
- Reasons: longer life, easier to repair, tailored to requirements



LCA for a power supply

- Detailed Life Cycle Assessment of a power supply at PETRA IV
- More than 4000 power supplies for PETRA IV needed
- Included are extraction of material (mining, processing…), production, transport, operation, dismantling, recycling, disposal
- More than 1730 parts (approx. 400 capacitors and 280 resistors)
- The weight 22.6kg, P= 2.3- 4.5 kW, Pv_Standby= 50 W, service life: 20 years
- Energy consumption : 160.180 kWh



Biological inspirated Girder

- Inspired by corals
- Design a girder structure with high eigen-frequencies, a high stiffness, and a low mass
- Using topological optimisation program
- Casting the girder with casting iron

	Material	Weight	CO_2 Footprint
ESRF[1]	Steel (S235 JR)	Approx. 6 ton +15% offcuts	7.8 tons CO_2eq/ton[2]
PETRA IV	Steel (EN-GJS-600-3U)	5t no offcuts	4.4 tons CO_2eq/ton[3]

(1) The Girders System for the New ESRF Storage Ring (cern.ch)
(2) OEKOBAU.DAT (oekobaudat.de) 1.125 ton CO2eq/ton
(3) co2-leitfaden.pdf (guss.de) 0.881 ton CO2eq/ton

Heritage from PETRA I

PETRA I tunnel reused for Petra IV.

Basis

Energy monitoring

Civil construction

LCA for technical components

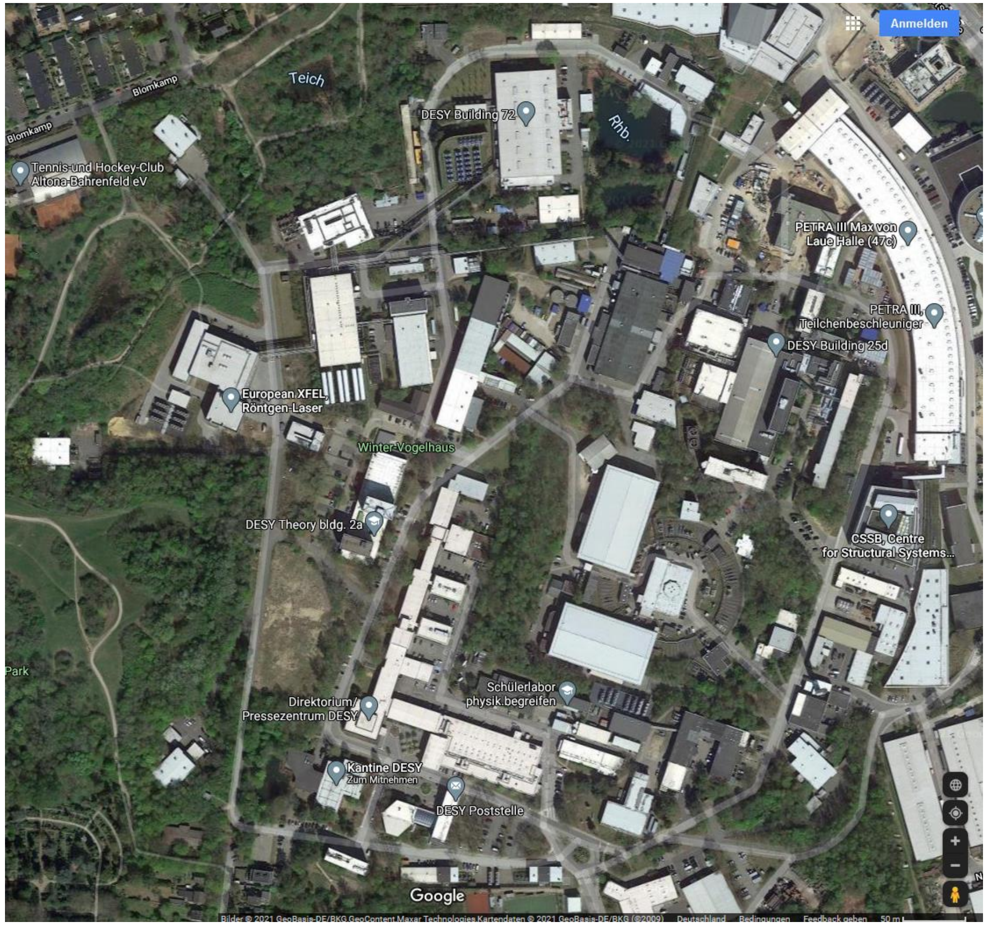
At work

Infrastructure

Operation

Finale

Research



PETRA IV Tunnel

Outside the experimental halls the old PETRA I tunnel will be reused

- 6 old sections, 100 – 300 m long, in total ~1 km
- The old sections of the tunnel are below streets, buildings, a park.
- The tunnel is covered by 3 – 10 m of soil.

Tunnel temperature PETRA III

Heated and unheated sections

Basis

Energy monitoring

Civil construction

LCA for technical components

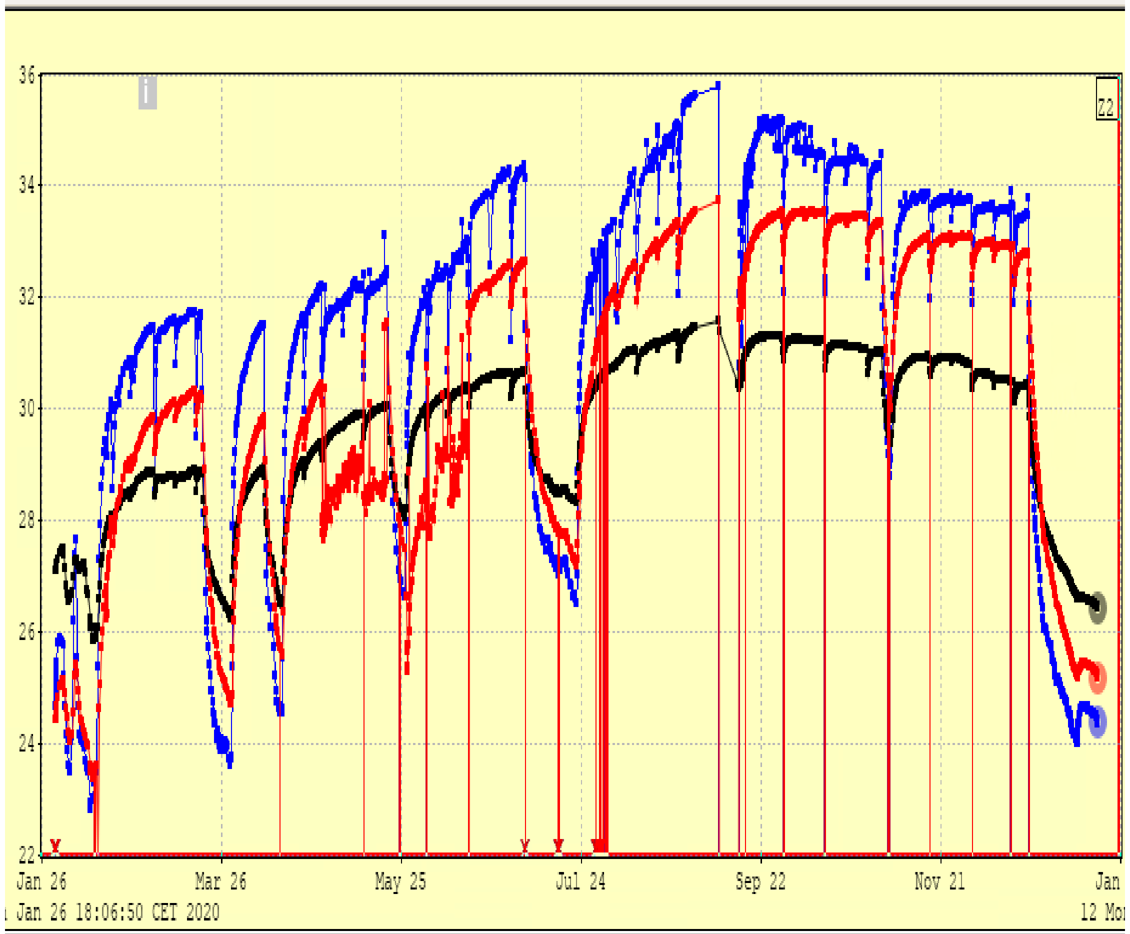
At work

Infrastructure

Operation

Finale

Research



Black curve, 26° – 31° C: Concrete floor, OR59, air temperature regulated (30° C)
Red curve, 23° – 34° C: Concrete floor, SOR87, air temperature unregulated
Blue curve, 23° – 36° C: Air temperature, SOR85, air temperature unregulated

Tunnel Climatization today:

- Air (25° C) blown in every 300/600 m
- Cooling water inlet: 25° C

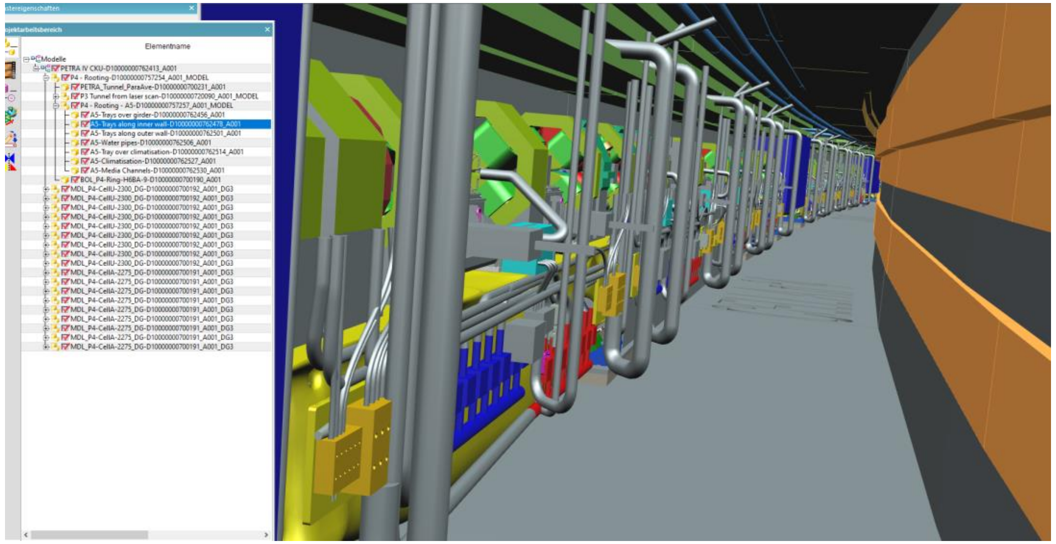
Temperature over one year

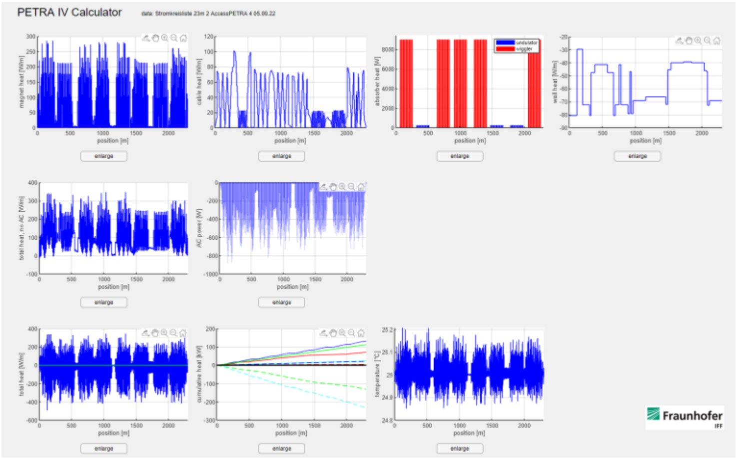
- Temperature difference between positions **up to 5°C**
- Operating schedule of PETRA clearly visible
- Summer and winter time visible

3D calculation of tunnel air and heat flows

Cooperation with Fraunhofer Magdeburg for CFD-simulation (fluid dynamic)

- **Digital Twin** of the tunnel in CAD (not yet completed)
  Single parts can be selected and hidden
  It can be rotated etc.
- A list with all consumer of electricity with their heat input
  (called **Stromkreisliste**)
- Including the cooling capacity and the position of air conditioners
- **Fluid dynamical simulations:**
  - Heat distribution also for corners and hidden places
  - Optimization for cooling and heating (in shutdowns)
  - Optimization of cabeling



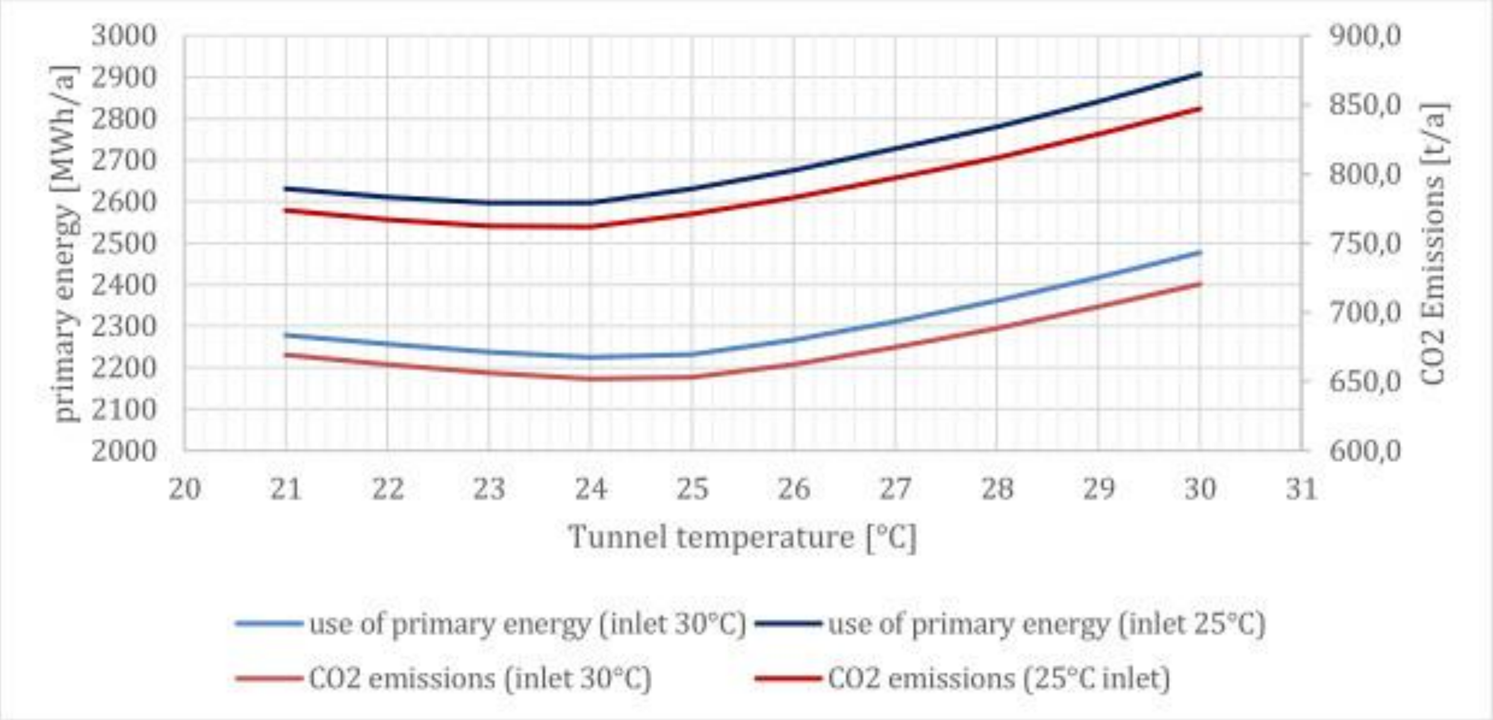


(Cedric Kula TAC)

screenshot of the app and first test results
(R. Zimmermann)

Energy consumption for different tunnel temperatures

PETRA IV. NEW DIMENSIONS



Primary energy consumption and CO_2 emission for different tunnel temperatures and cooling water inlet temperatures with reference PETRA IV operation
(T. Warnecke „Report on thermal parameters of PETRA IV")

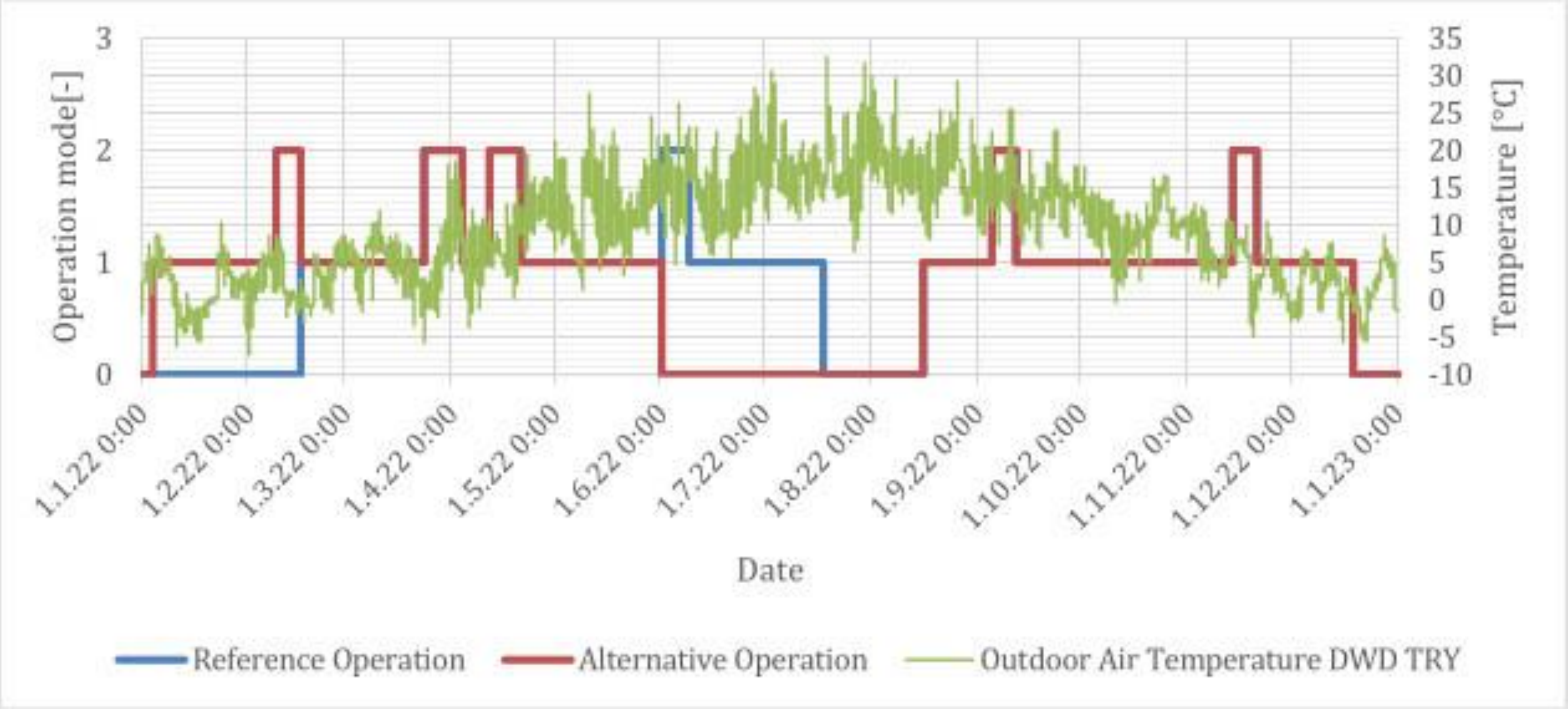
Including shutdowns, when we have to heat for a constant temperature.

Optimal temperature in the tunnel are:

Water: 30°C
Air: 25°C

SUSTAIN ABLE DESY.

Temperature vs. operation mode



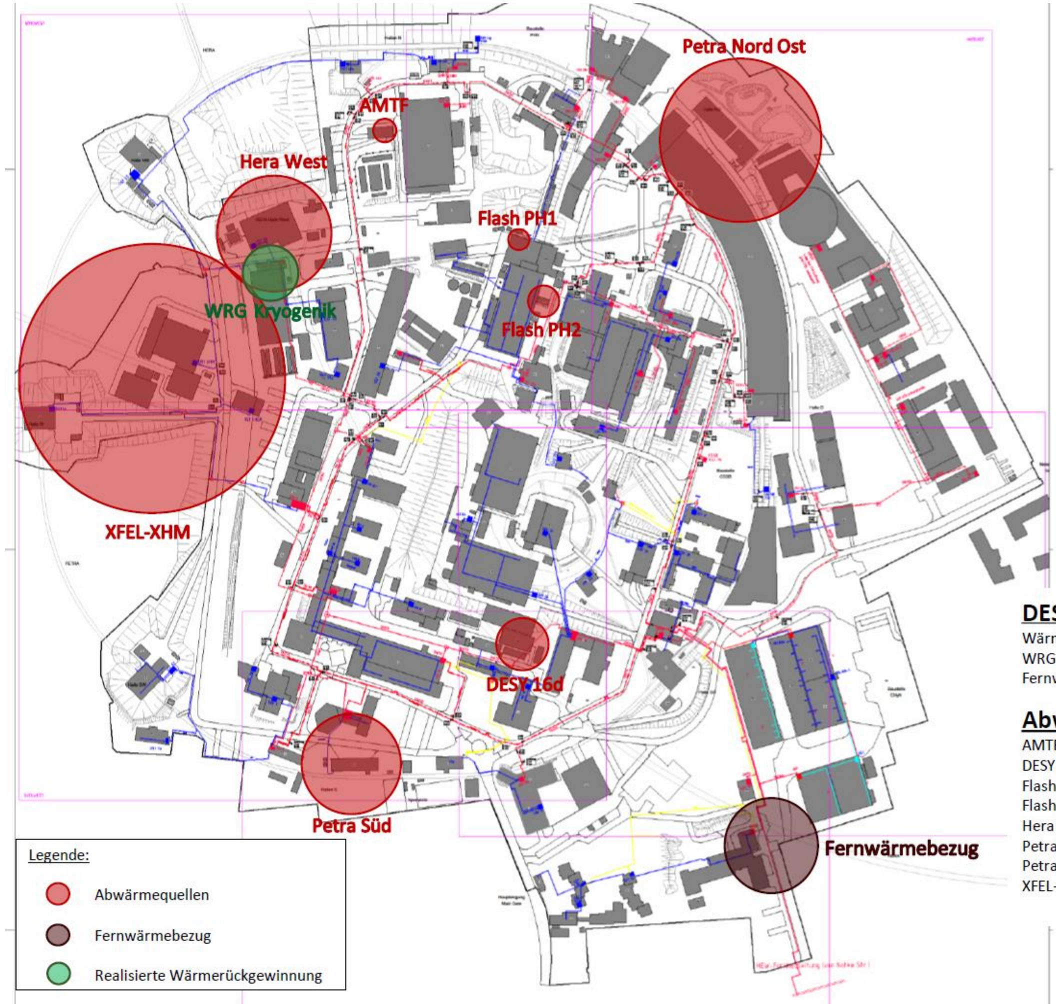
Reference and alternative operation schedule and outdoor air temperature
(T. Warnecke „Report on thermal parameters of PETRA IV")

More …

Waste heat usage

Potential at DESY Campus in Hamburg

- Currently heating is DESYs 3rd biggest CO_2 emission source
- Project with University of applied science in Hamburg (HAW) to identify potential
- Result: 129 GWh/y of waste heat available at a temperature level of 30°C - 40°C
- Possible CO_2 savings at DESY campus of about 4.000 tons/y
- Surplus can be used in neighborhood; if we get the 129GWh in use saving will be up to 40.000 tons CO_2/y



DESY Hamburg[1]:

Wärmebedarf:	23,13 GWh
WRG Kryogenik:	9,40 GWh
Fernwärmebezug:	15,73 GWh

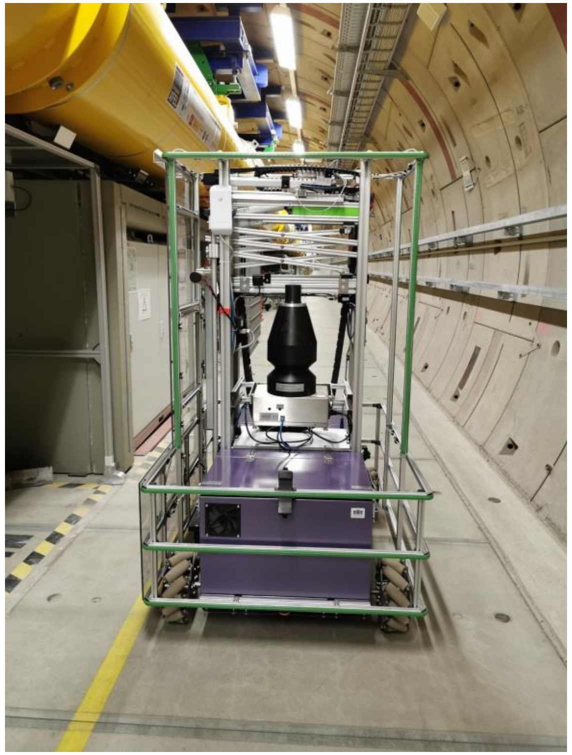
Abwärmequellen[2]:

AMTF:	3,86 GWh	(22°C)
DESY 16d:	8,74 GWh	(30°C)
Flash PH1:	3,77 GWh	(30°C)
Flash PH2:	5,44 GWh	(30°C)
Hera West:	19,6 GWh	(29°C)
Petra Nord Ost:	26,8 GWh	(30-38°C)
Petra Süd:	16,3 GWh	(35°C)
XFEL-XHM:	44,9 GWh	(34-38°C)

1: Daten aus dem Jahr 2019 (Zertifizierung TU Dresden).
2: Daten aus dem Zeitraum ab dem 01.04.2019 bis zum 01.04.2020.

Reliability in operation

Use of robotics and telepresence of experts



MARWIN2

MARWIN3

(Reinhard Bacher)

MARWIN: Mobile Autonomous Robot for Maintenance and Inspection

- Routinely used for radiation measurements with the EuXFEL accelerator switched on

Project Proposal RobotiX: Robotics and Immersive User Experience

- Versatile platform based on MARWIN3 that provides
    - Multiple sensors
    - Multi-axis manipulators
- Immersive remote control interface using mixed reality technologies
- Project partners: Hochschule21, HAW, UHH, DESY

KAI Kooperation für Anwendung und Innovation der HAW Hamburg und DESY

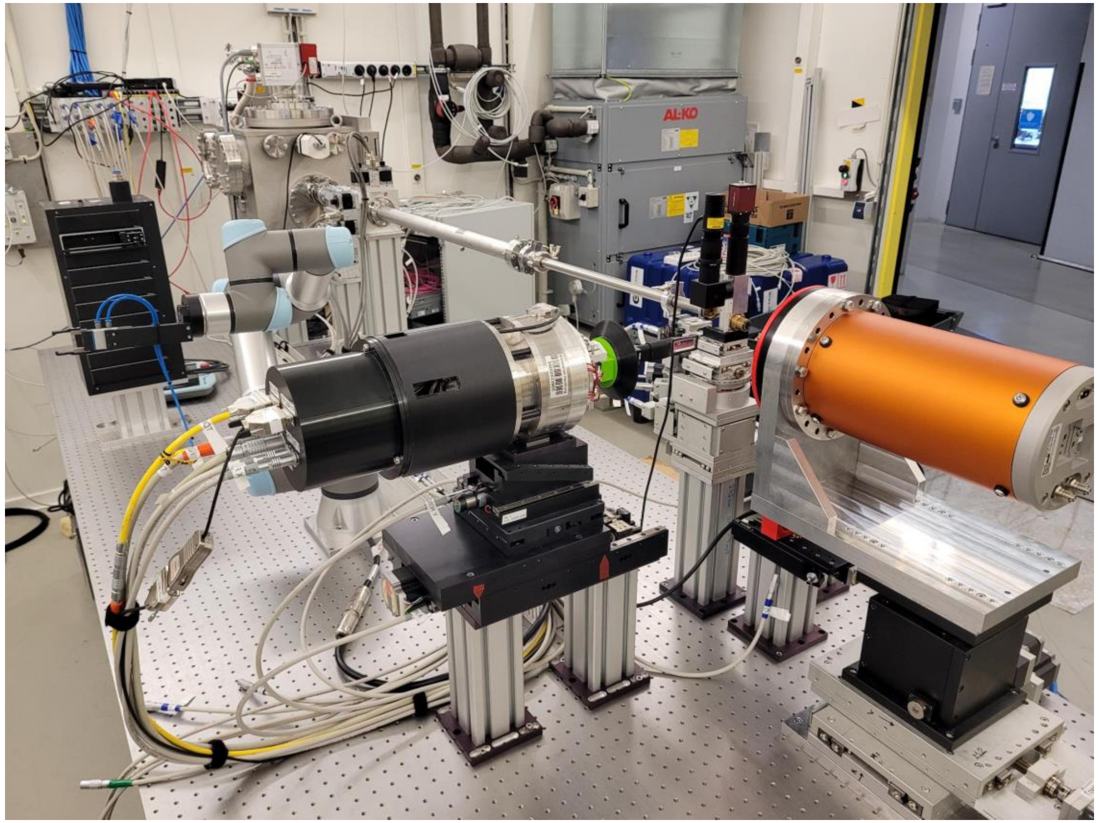
SUSTAINABLE DESY.

Efficient use of beamtime – every photon counts

HiPhax: Highly automated pharmaceutical screening beamline for room temperature measurements

PETRA IV.
NEW DIMENSIONS

- Designed for high-throughput pharmaceutical screening at cryogenic temperatures and room temperature
- >1000 samples/24 h
- Goal: Fully automatic, AI- supported data collection
- Multicrystal samples holders (Si-chips) for highest throughput
- Robotic exchange of chips
- Hotel for chip storage
- Sample delivery format compatible with installation at SPB/SFX at EuXFEL



First successful test experiments in June/July 2022 at beamline P09 at PETRA III

Hardware installation of automatic sample changer: HIR3X milestone M1.1

SLAC HIR³X SUSTAINABLE DESY.

Petra IV. - Remote access – high-troughput MX

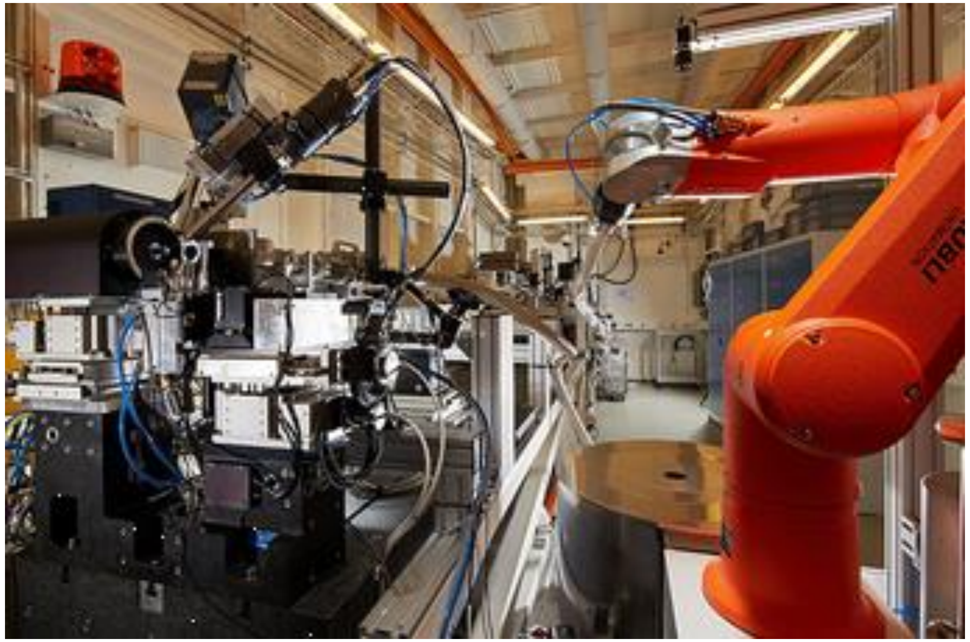
Petra IV. will enable remote access for mature and highly standardizes X-ray techniques

Prime example P11 beamline PETRA III:

- Experienced users have the possibility to collect data remotely
  - No travel of persons, just sending samples
  - Access via remote session from internet browser
  - Guidelines for remote access (safety aspect)
  - Need to register for access

If all scheduled beamtimes would be remote (example):

- Users just from EU (only single P11 beamline)
- Ca. 17 tons CO_2 savings from flight travels / year (https://www.carbonfootprint.com)



The technical equipment at PETRA III's P11 beamline includes a robotic arm that can execute fully automated sample changes

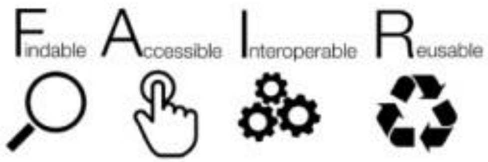
(Johanna Hakanpää)

Keeping Data

Value of data

- Academic tradition
- ’Good scientific practice’
- Sometimes mandated by law (USA)?
- Typically archive all ‘raw’ data for 10 years
- Including data known to be ‘dud’
- A ‘nice to have’ or ‘must have’

- Keeping raw data costs significant money (M€) and energy (MW)
- Keeping all data for lots of experiments becomes expensive very quickly
- Facility cost or user’s own cost
- Sustainability?



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of the International Union of Crystallography

Data management

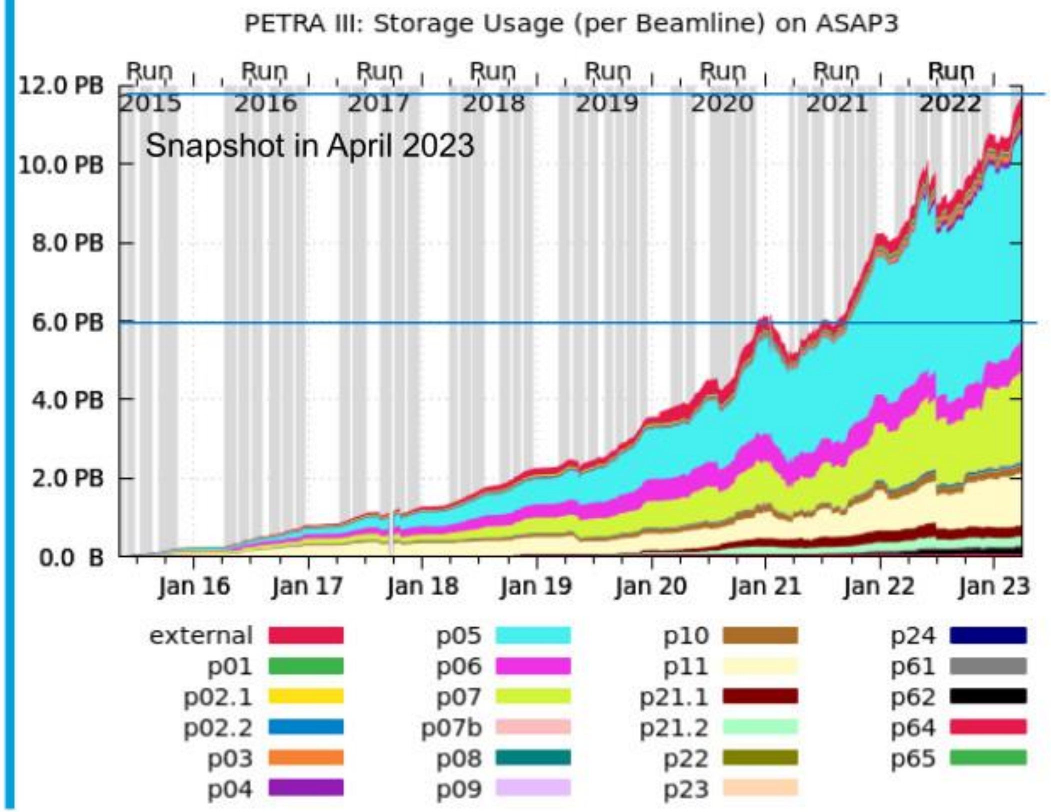
A snapshot of the status quo

- Data policy
  - ➢ Data on disk for 180 days after measurement (was :180 days after last access)
  - ➢ Data migrated to tape after 180 days
    - ▪ retention on site (dCache), dual tape copy
    - ▪ 4.5 PB ingested to GPFS in past 12 months
    - ▪ 6 PB/year archived to tape
    - ▪ 12 PB tapes/yr with dual copy (€20K/PB/10YR)

- Usage highly variable between instruments

- Time to analyse data often limits publication rate
  ~2 years from measurement to publication

- Hardware typically has a 5 year lifetime
  Budget for regular replacement



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Projection for Petra IV. operation in 2028

Petra IV. science output should not be storage or compute limited

Peak total daily data generation will exceed 1PB per day based on actual peak 2021 GPFS usage

- Operation of any one instrument should not jeopardise operation of other instruments

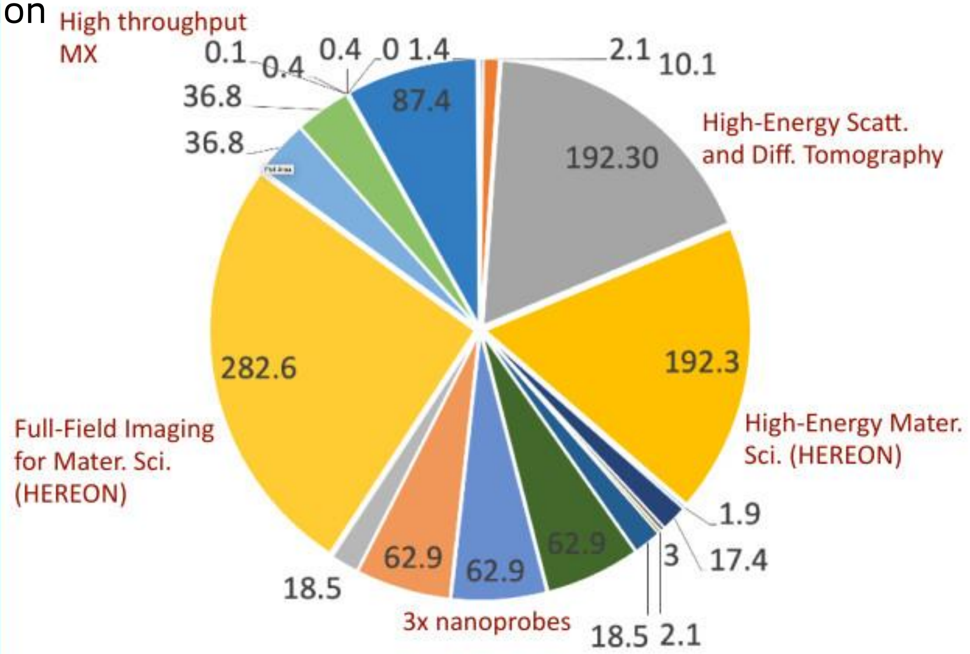
By 2028, detectors will be larger and faster:

- Planned 130 kHz detector with a frame size of 10 MP and dynamical range of 2 Bytes, would produce 2.5 TB/s
- Some individual instruments will produce >1PB per day
- Luckily, not at all instruments are data volcanoes
- Increase inevitable almost regardless of PETRA-IV project

Reality check:

- Some instruments at ESRF already produce 1 PB per day
- In 2022, EuXFEL operating only 3 instruments simultaneously has produced 7 PB in a week (=364 PB/yr)
- 1 PB/day * 5 big data instruments * 180 days = 900 P

Peak daily data generated (in 2021)



Numbers are the **actual peak TB generated in 24 hours** by the comparable PETRA-III instrument in 2021

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Petra IV. will offer services for the complete data life cycle

Data management by the facility

Integrated data capture
- Electronic log books
- Sample ID database
- Standard file formats
- Integration to instrumentation
- Integrated metadata harvesting

Infrastructure for data evaluation
- Central HPC resouces
- Sustainable and reusable software ecosystem
- Remote data evaluation
- Containerisation

(Open) data repositories and catalogues
- Raw data can be made open
- Searchable federated catalogues (with access control)
- Common user Ids (AAI)
- DOI minting
- Place to put open results with process data

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Research for Sustainability

Petra IV. - Research for sustainability

Petra IV. enables research to tackle sustainability challenges and develop global solutions

Future trend: long-lasting solar cells and new batteries

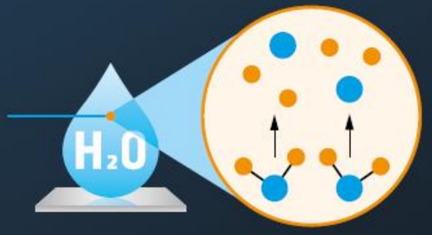
Improve solar cell and battery materials: PETRA IV will make it possible to optimize the electronic structure of materials of solar cells and batteries. This can be accomplished by using atomic-level imaging and spectroscopy to follow the processes of energy transfer in specialised materials, so improved versions can be built from the ground up. This could enable longer lasting and more efficient energy generation and storage.

Future trend: plastic alternatives

Plastics as we know them are almost entirely derived from fossil fuels. Reasonable alternatives are on the doorstep: cellulose nanofibres derived from wood make for a sustainable version of our everyday plastics. However, the production of these fibres is still complex and time-consuming since the individual fibres are 10,000 times thinner than a human hair. Using the light from PETRA IV, the production process can be followed in much greater detail. Since PETRA IV will enable measurements to be made 100 times faster than before, the movement towards a market-ready alternative will also be faster. The cellulose fibres can also be used for textiles and packaging, as a matrix for construction composites.

Future trend: green hydrogen

Currently, the processes for generating hydrogen fuels are not sustainable, as they are most commonly produced using methane. By using PETRA IV to examine water-splitting reactions in nature and understand at the atomic level how they progress, we can develop more efficient processes by better understanding photochemical reactions – for example, how plants accomplish the same process, without the use of fossil fuels.



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