Life Cycle Assessment (LCA)

Conducting an LCA on the upcoming
X-ray Integral Field Unit (X-IFU) space instrument

Andreas Wolnievik, in collaboration with

Jürgen Knödlseder – Research Director
Didier Barret – PI of X-IFU

E-SWAN webinars on Sustainability of space activities
20 November 2024

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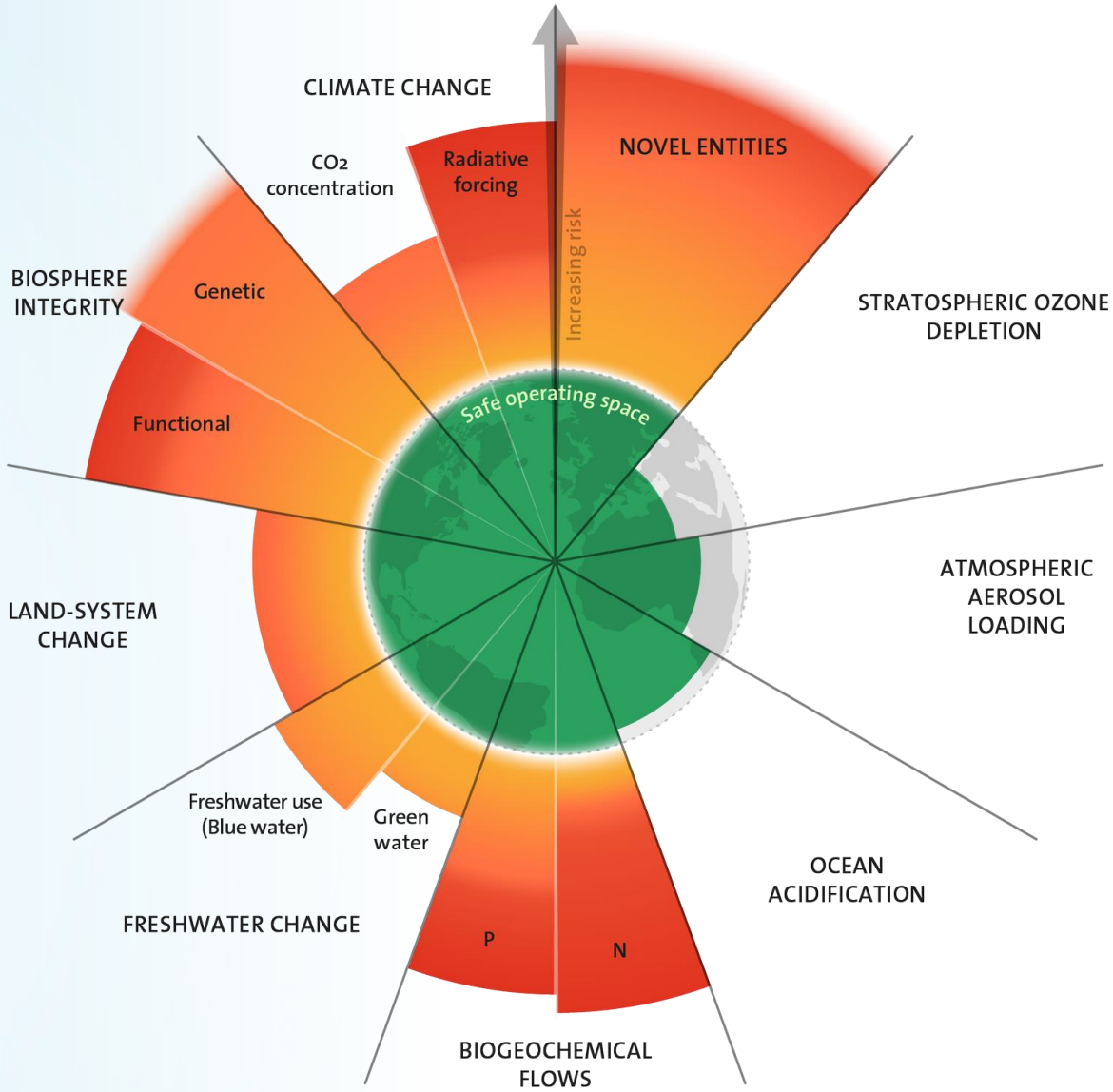
Part 1: Introduction to *Life Cycle Assessment (LCA)*

Planetary Boundaries

- **3 out of 9** Planetary boundaries still in safe operation stage
- 6 out of 9 has exceeded the limits
- **Novel Entities and Waste** – Residues from rocket fuels, microplastics, and orbital debris
- **Climate Change** – Space related experiments & the contribution to climate change



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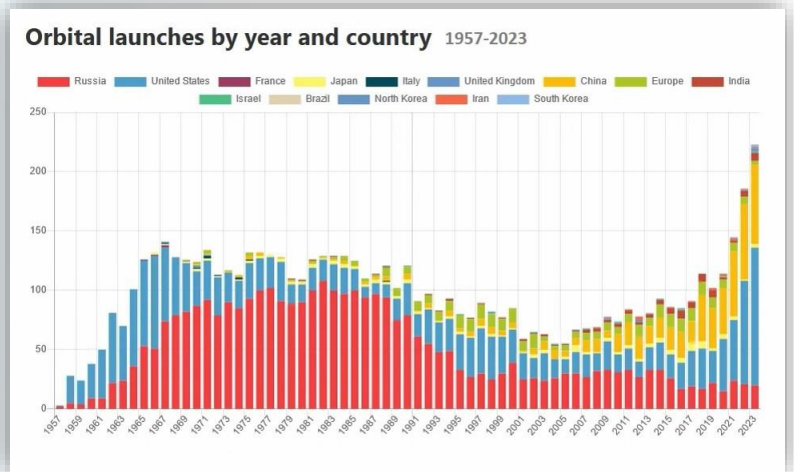
The space sector is expanding quicker than ever…

- Number of launches & objects put in orbit are growing rapidly each year, but **information surrounding the effects** on the climate is limited in the space sector
- Rocket launches have a **direct impact on the upper atmospheric layers**, yet research in this area remains limited
- Different **tools are under development** to deal with the arising concerns in the space sector regarding the climate and to **quantify the impacts**



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What is the background and applications behind Life Cycle Assessment (LCA)?

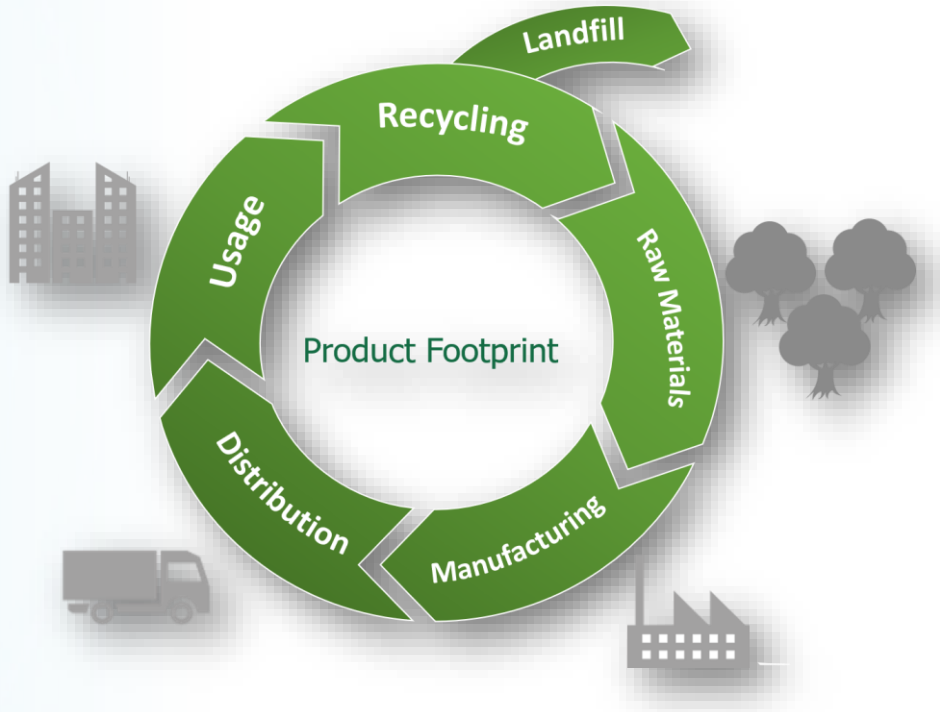
Life Cycle Assessment - Evaluate the environmental impacts of a product, process, or service throughout its life cycle. It's a multi-phase & multi-criteria tool!

- **Environmental Impact** – Environmental concerns, particularly around pollution and resource depletion, became more prominent
- **Life Cycle Thinking** – Full environmental and social impact from raw materials to disposal to find sustainable improvements across all stages
- **International Standards**

ISO 14040 - Environmental management — Life cycle assessment — Principles and framework

ISO 14044 - Environmental management — Life cycle assessment — Requirements and guidelines

- **Environmental Policy** – Used for decision-making, and sustainability reporting



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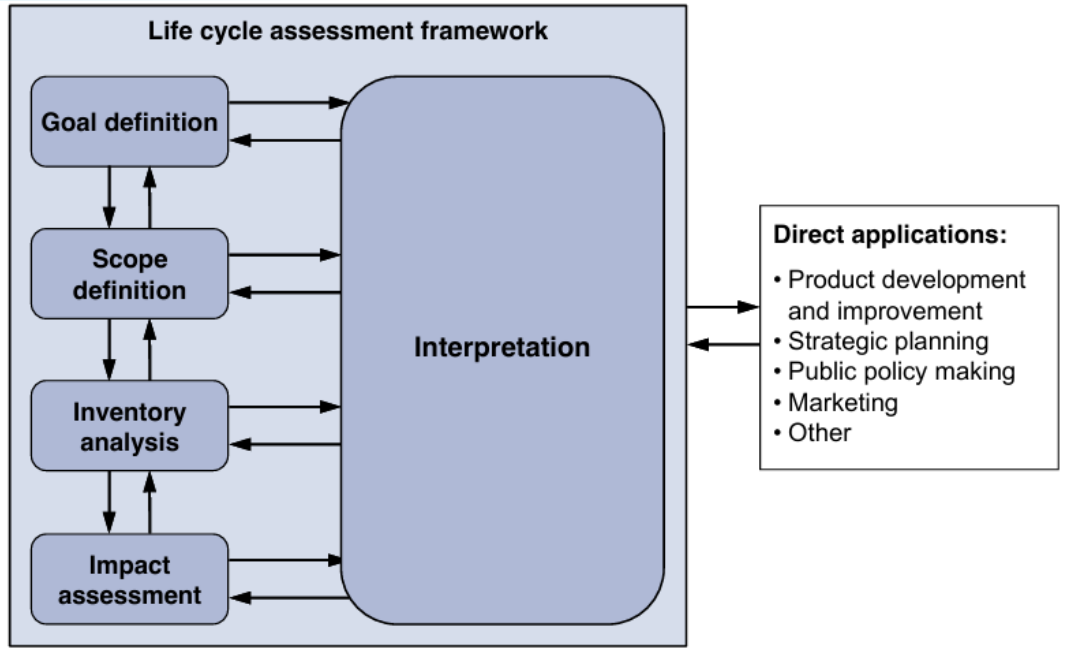
Steps of an LCA study

1. **Goal & Scope** - defining the purpose and boundaries of the LCA study
   - **Functional Unit** – Defines what is being assessed (e.g. " 1 launch of rocket XXX" or "1 kg of space segment put in orbit")
   - **System boundary** – Defines the scope of the LCA study
   - **Data quality and sources** – Data quality considerations include data completeness, accuracy, precision…
2. **Life Cycle Inventory (LCI)** - compiling an inventory of all inputs and outputs associated with the product or process throughout its life cycle.
   This is the most time-consuming step!
3. **Life Cycle Impact Assessment (LCIA)** - evaluates the potential environmental impacts associated with the inputs and outputs
4. **Interpretation** - analyzing and synthesizing the results of the LCA study to draw conclusions and make recommendations



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Differences in LCA on a Space project

- **Low production volumes** – For the complete mission span only a few models are carried out (EM, QM, FM…). Addressed in study.
- **Direct emissions into the high atmosphere** – Emissions released by rockets during launch have direct effects on the high atmosphere, including ozone depletion and increased radiative forcing. Not relevant for X-IFU study.
- **Specialized materials & processes** – Standard databases are missing space specific materials, and exotic materials can contribute significantly to environmental impacts, even in small quantities. Addressed in study.
- **Long development cycles and R&D** – A space instrument can be under development for 20 years. Addressed in study.
- **Testing** – Specific criterions for testing & long test campaigns Addressed in study.

Part 2:

International Reference Life Cycle Data System (ILCD) Handbook
ESA Handbook

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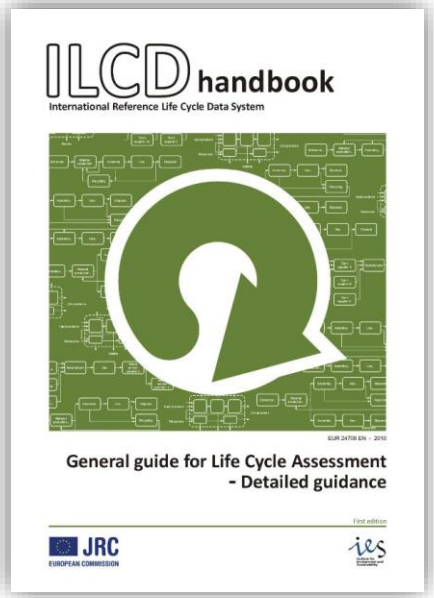
ILCD Handbook – General guide for LCA

- **Purpose** – Provides a common basis for consistent, robust and quality-assured life cycle data and studies
- **Guidance** - Help the user in dealing with environmental decision support related to services, products, resources, or waste management

- Published by Publications Office of the European Union



ESA Handbook – For space applications

- **Purpose** – Provides a framework for applying Life Cycle Assessment (LCA) in the space sector, specifically designed for ESA missions and projects.
- **Comprehensive Guidelines** – Offers step-by-step instructions for assessing environmental impacts across all mission phases, from material extraction to end-of-life disposal.
- **Standardization** – Promotes consistent and comparable LCA practices within the space industry, aligning with ESA's Clean Space Initiative to reduce environmental impacts.

- Published by the Clean Space initiative

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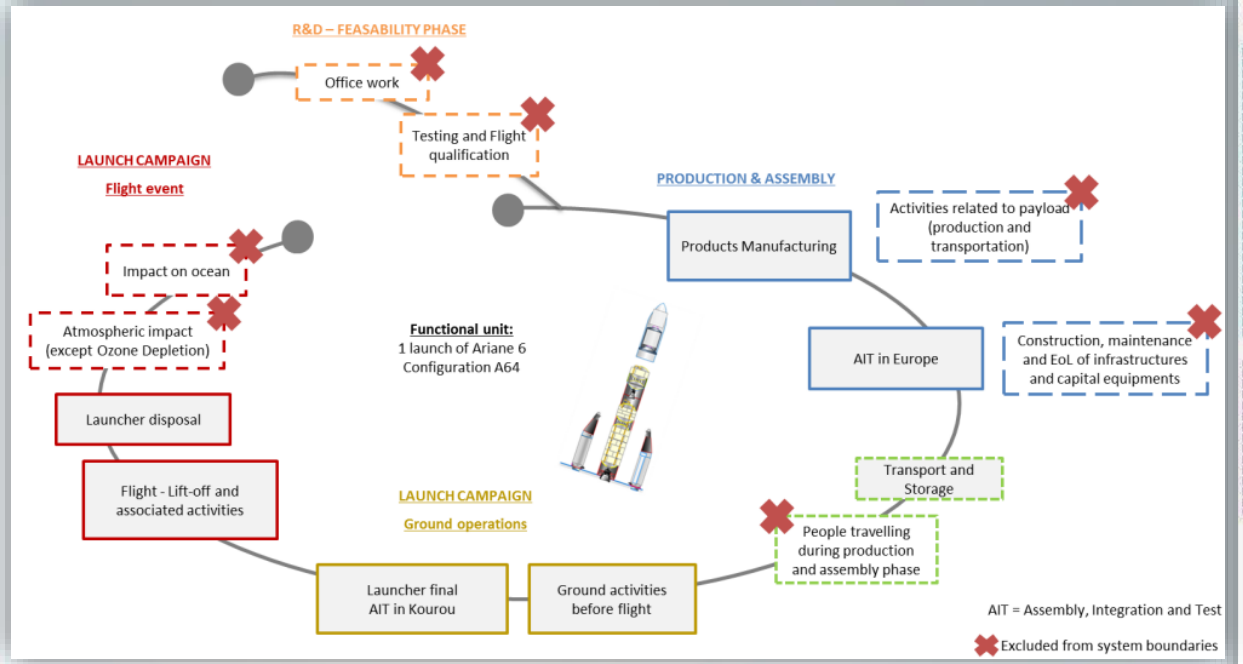
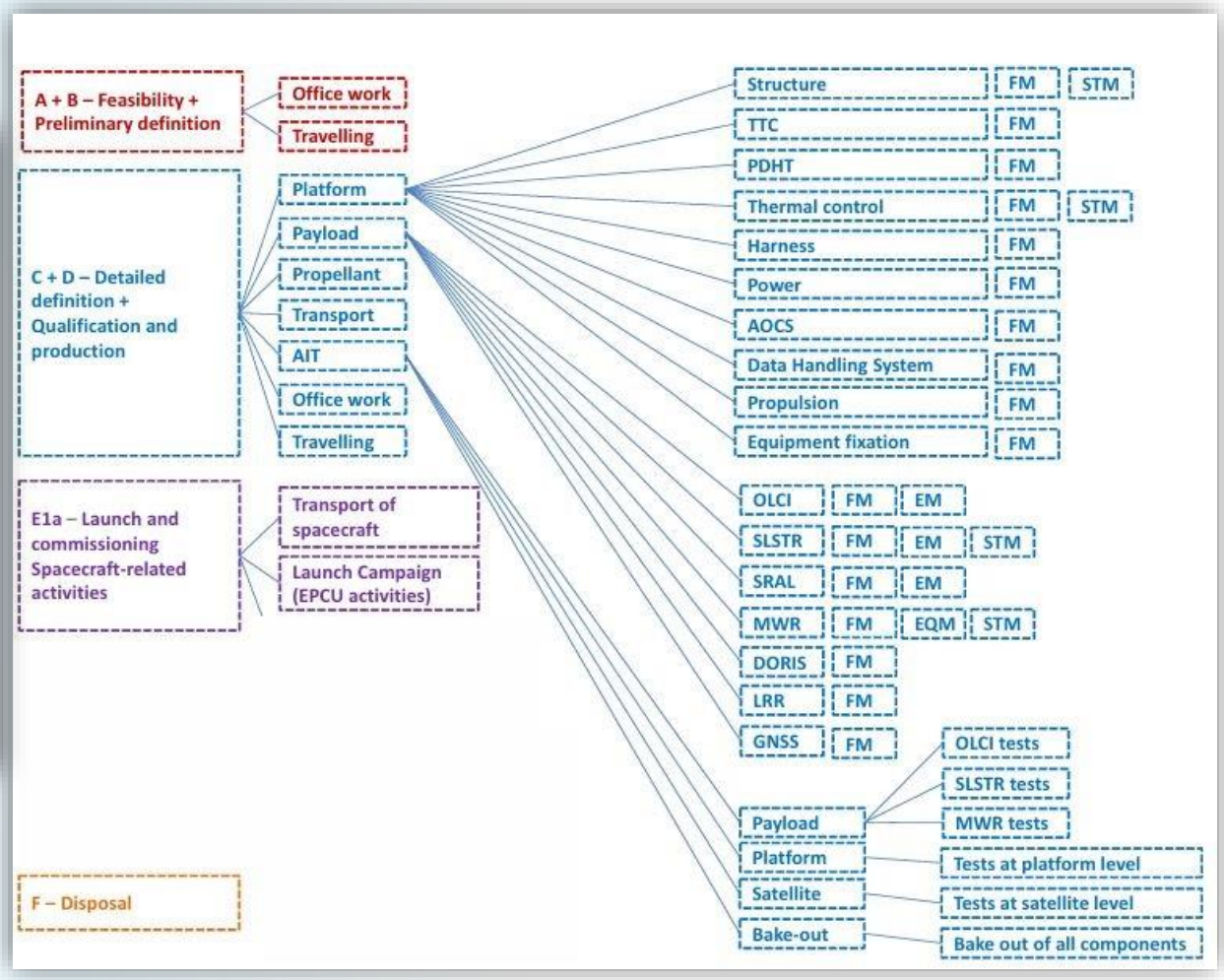
Example: Breakdown of a rocket mission for LCA

"1 launch of Ariane 6"



ESA Handbook – Breakdown of Ariane 6



ESA Handbook – Example of breakdown overview of a system

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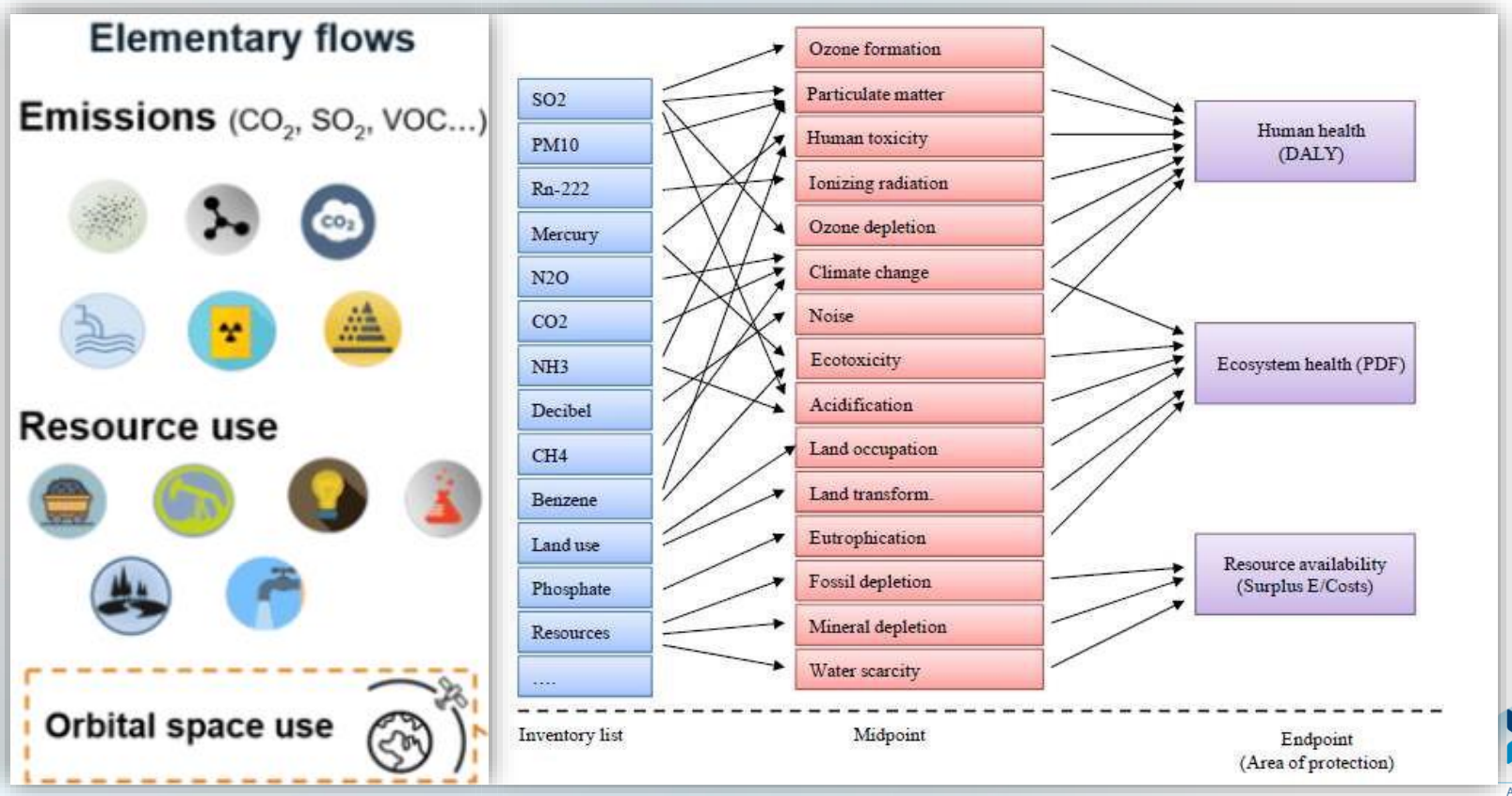
Indicators for LCA results

- **Midpoint indicators** - Measures environmental impacts at an ***intermediate stage*** in the cause-effect chain
- **Endpoint indicators** - Measures environmental impacts at the ***end of*** the cause-effect chain, focusing on damage to overall areas of protection



Part 3: Software's & Databases for LCA

Options when conducting an LCA?

- **SimaPro, Gabi & OpenLCA** are 3 of the more widely used software's for LCA practitioners
- **OpenLCA is free to use** but requires specific databases (some are free, some are not!) while other software options are often prohibitively expensive for the average practitioner
- Don’t know where to start? Go for OpenLCA!

	GaBi Product Sustainability Performance	SimaPro	openLca
Developer	Sphera	PRé Sustainability	GreenDelta
Database Quality	High	High	Varies, supports free and paid datasets
Cost	High	High	Free (open-source)
Target Users	Industry (especially manufacturing)	Academia, industry	Small businesses, academia
User Interface	User-friendly	Modular, complex	Less polished
Flexibility	Moderate	High	High
Transparency	Lower due to proprietary data	Moderate	High
Learning Curve	Moderate	High	Moderate

Processes used for X-IFU study: *Ecoinvent & ESA database*

SimaPro: Included

- Agri-footprint (economic allocation)
- ecoinvent (allocation, cut-off by classification - included by default if your SimaPro license also includes an ecoinvent license)
- EU and Danish Input Output
- Industry data 2.0
- US Life Cycle Inventory database

SimaPro: Additional datasets

- AGRIBALYSE
- Agri-footprint (mass and energy allocation)
- Carbon Minds cm.chemicals database
- DATASMART LCI package
- ecoinvent (APOS and consequential)
- ecoinvent (allocation, cut-off, EN15804)
- Environmental Footprint database
- ESA database

Foreground and background systems

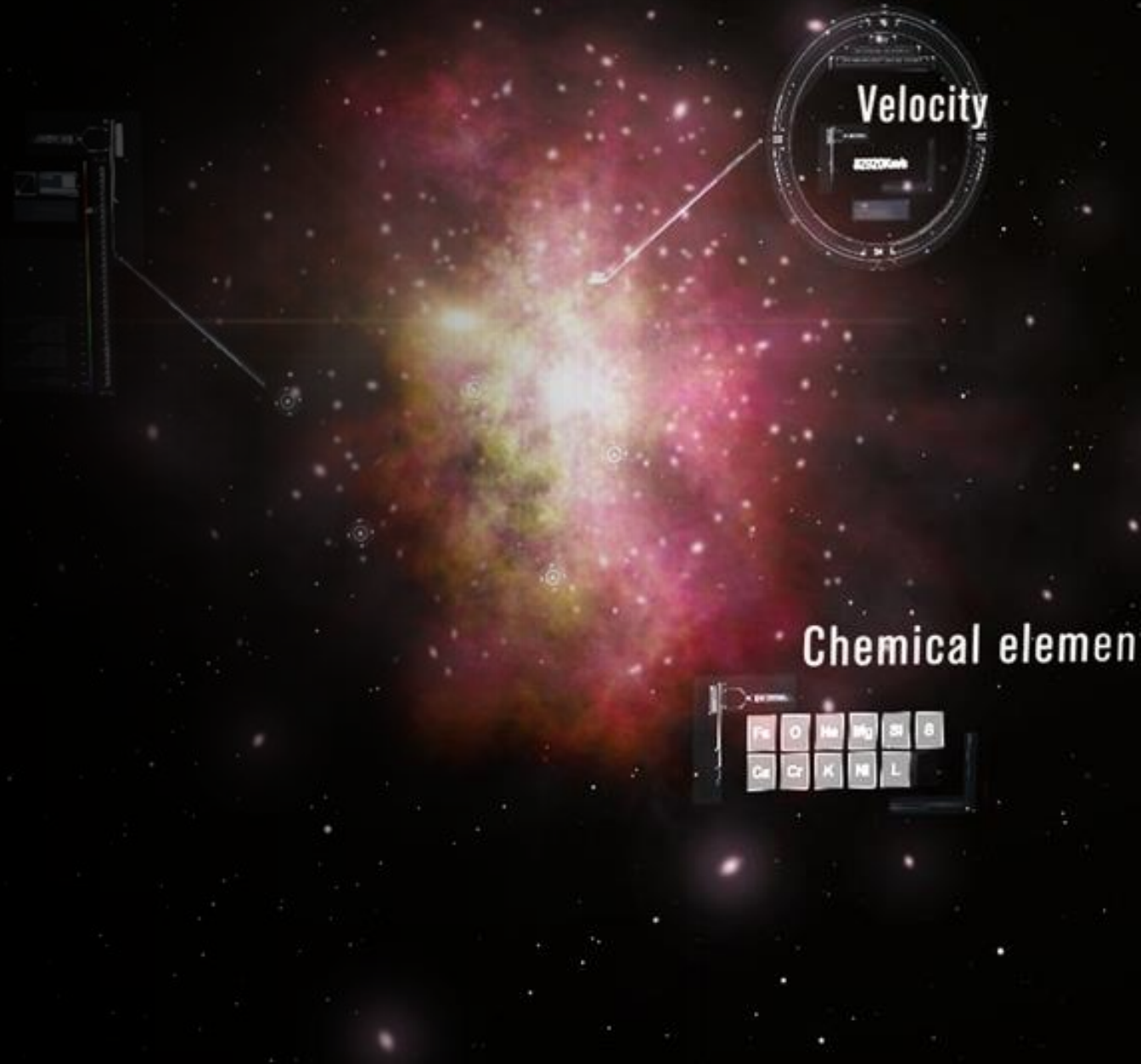
Foreground system: Processes and activities that are **directly controlled or influenced** by the entity. For us, the X-IFU system.

Background system: Processes and activities that are **outside the direct control** of the entity. For us Ecoinvent and the ESA database.

PART 4: X-IFU Project onboard the Athena Telescope

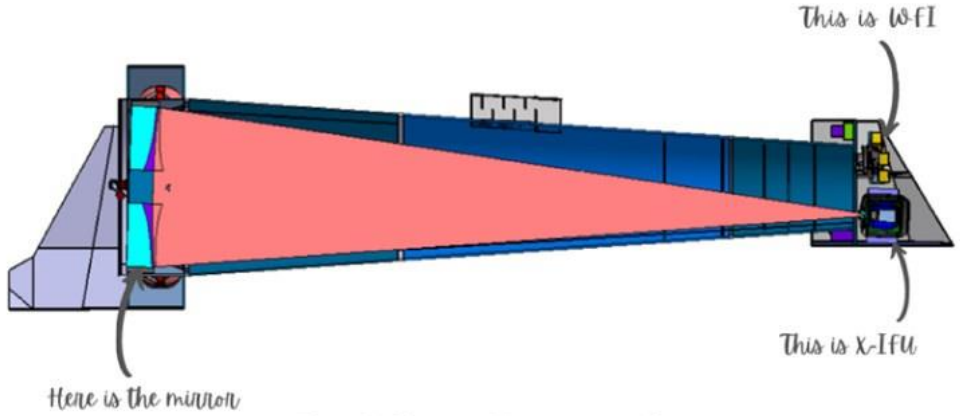
LCA of X-ray Integral Field Unit (X-IFU) on board Athena

- High spectral resolution
- High quality imaging
- X-IFU will observe the hot and energetic Universe: clusters of galaxies, black holes, exploding supernovae…
- Transition Edge Sensors operating at 50 mK for precise measurements
- Will help answering questions about the universe!

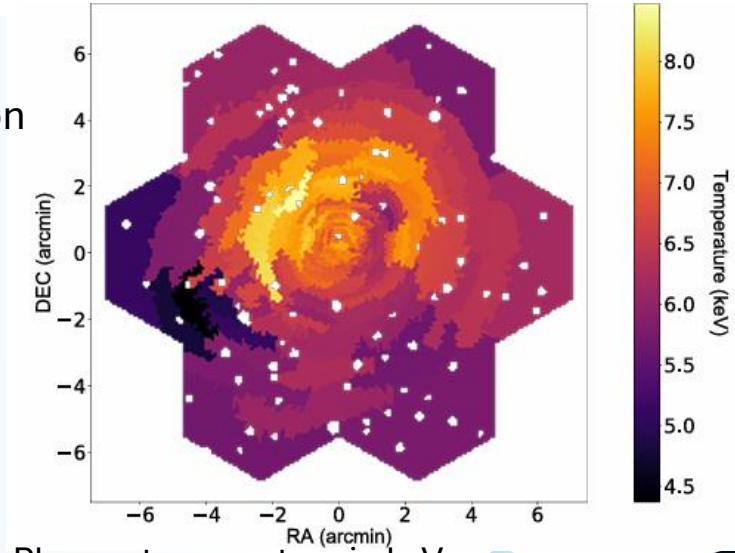


Athena and The X-ray Integral Field Unit (X-IFU)

- **X-IFU & WFI:** Both X-IFU and WFI (Wide Field Imager) will be located on the Athena spacecraft.
- **Development Timeline:** Studied since mid-2014; X-IFU reached its System Requirement Review (SRR) phase in June 2022
- **Athena Mission Purpose:** Designed to explore the "Hot and Energetic Universe" science theme, selected by ESA in November 2013
- **Mission Challenges:** Due to unexpected cost overruns, ESA initiated a mission redefinition, leading to significant redesigns for X-IFU after the SRR
- **Performance Adjustments:** The Athena Science Redefinition Team (SRDT) evaluated reductions in X-IFU's capabilities (e.g., spectral resolution, field of view, count rate)



The Athena Spacecraft
(Credit: ESA)



Plasma temperature in keV

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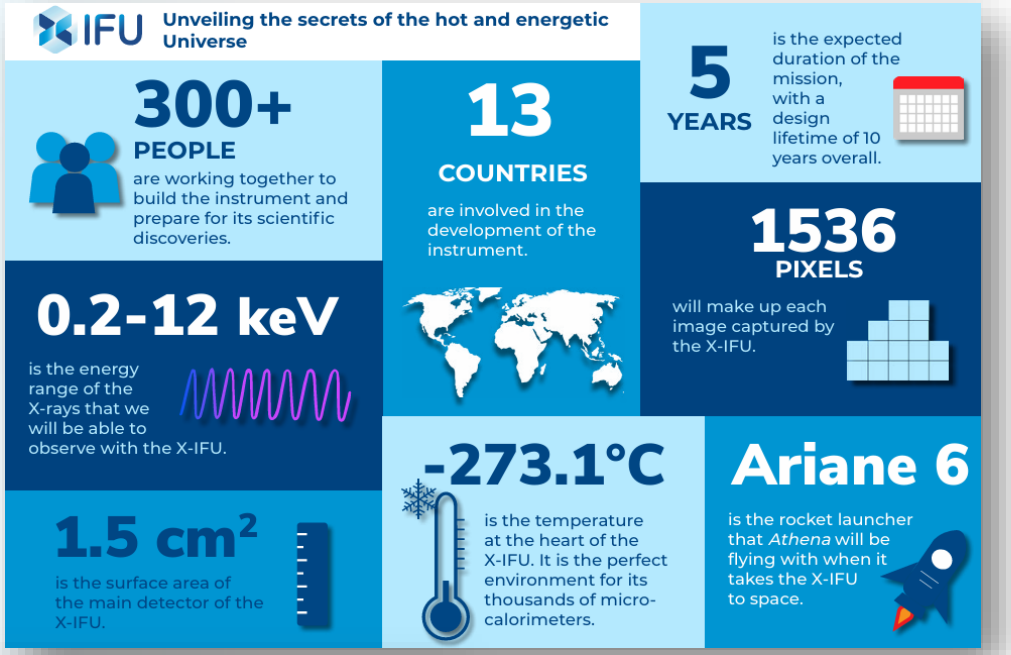
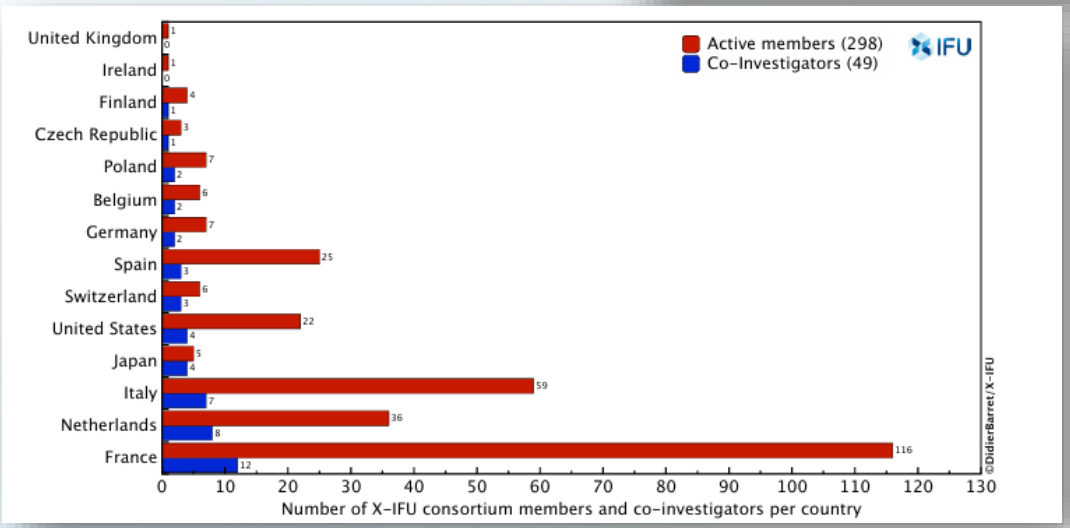
The X-ray Integral Field Unit (X-IFU)

- ***Over 300 people active*** – Large variation of FTE during test campaigns and close to operation phase
  FTE: 2016-2023 for a total of more than 1000 FTE's
- ***Launch campaign expected ~2036*** – Expected launch can be object of change (previously delay due to the reformulation of the project in 2022 following the SRR)
- ***13 countries involved*** – Large corporation between different companies, facilities & countries
- ***Mission duration:***
  Expected - 5 years
  Design allows - 10 years

All above is relevant for the LCA study*





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Part 5:

Step breakdown for X-IFU LCA study

System breakdown of X-IFU

(1) Models & logistics – Including all the Intermediate models & flight models required for the full phase (C-D), including relevant logistics.

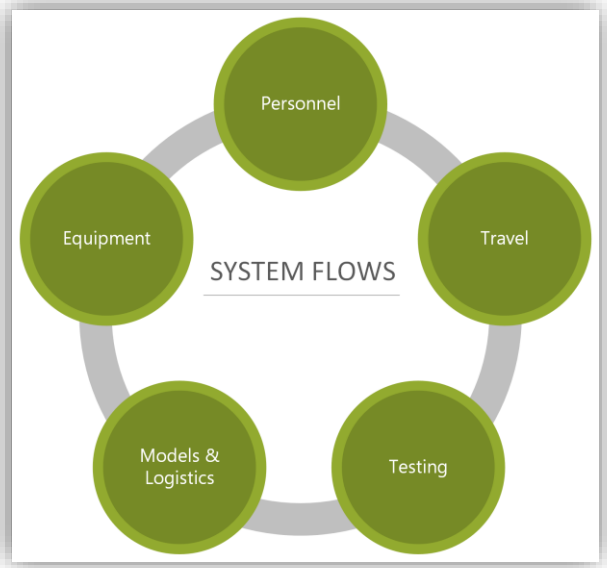
(2) Equipment – The specific test equipment dedicated to X-IFU (cryogenic test bench, cryocoolers, data equipment…)

(3) Personnel – All the dedicated FTE working on X-IFU inside the consortium and expected personnel until 2036.

(4) Traveling – The travel within the consortium dedicated to X-IFU (conferences, system meetings, consortium meetings…) (https://travel-footprint-calculator.irap.omp.eu/home.html)

(5) Testing – Clean rooms (area dedicated for the system), vibration tests, thermal vacuum tests…

Model breakdown in pieces



Previous IRAP data / person implemented for model:

	Values	Units
Country	France	
Inputs from technosphere: Materials/fuels		
Computer, laptop {GLO}| market for computer, laptop | Cut-off, S		p
Tap water {Europe without Switzerland}| market for tap water | Cut-off, S		kg
1,1-difluoroethane, HFC-152a {GLO}| market for 1,1-difluoroethane, HFC-152a | Cut-off, S		kg
Transport, passenger train {GLO}| market for transport, passenger train | Cut-off, S		personkm
Transport, regular bus {RoW}| transport, regular bus | Cut-off, S		personkm
Transport, tram {RoW}| transport, tram | Cut-off, S		personkm
Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, S		km
Transport, passenger car, small size, diesel, EURO 3 {RER}| transport, passenger car, small size, diesel, EURO 3 | Cut-off, S		km
Transport, passenger car, medium size, natural gas, EURO 3 {RER}| transport, passenger car, medium size, natural gas, EURO 3 | Cut-off, S		km
Transport, passenger car, electric {GLO}| transport, passenger car, electric | Cut-off, S		km
Transport, passenger, electric bicycle {RoW}| transport, passenger, electric bicycle | Cut-off, S		personkm
Transport, passenger, motor scooter {RoW}| transport, passenger, motor scooter | Cut-off, S		personkm
Inputs from technosphere: Electricity/heat		
Electricity, low voltage {FR}| market for electricity, low voltage | Cut-off, S		kWh
Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, S		MJ
Heat, central or small-scale, other than natural gas {RoW}| heat production, mixed logs, at furnace 100kW | Cut-off, S		MJ
Outputs to technosphere: Waste treatment		
Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, S		m3
Municipal solid waste {ES}| market for municipal solid waste | Cut-off, S		kg

X-IFU: Inputs & outputs used for FTE

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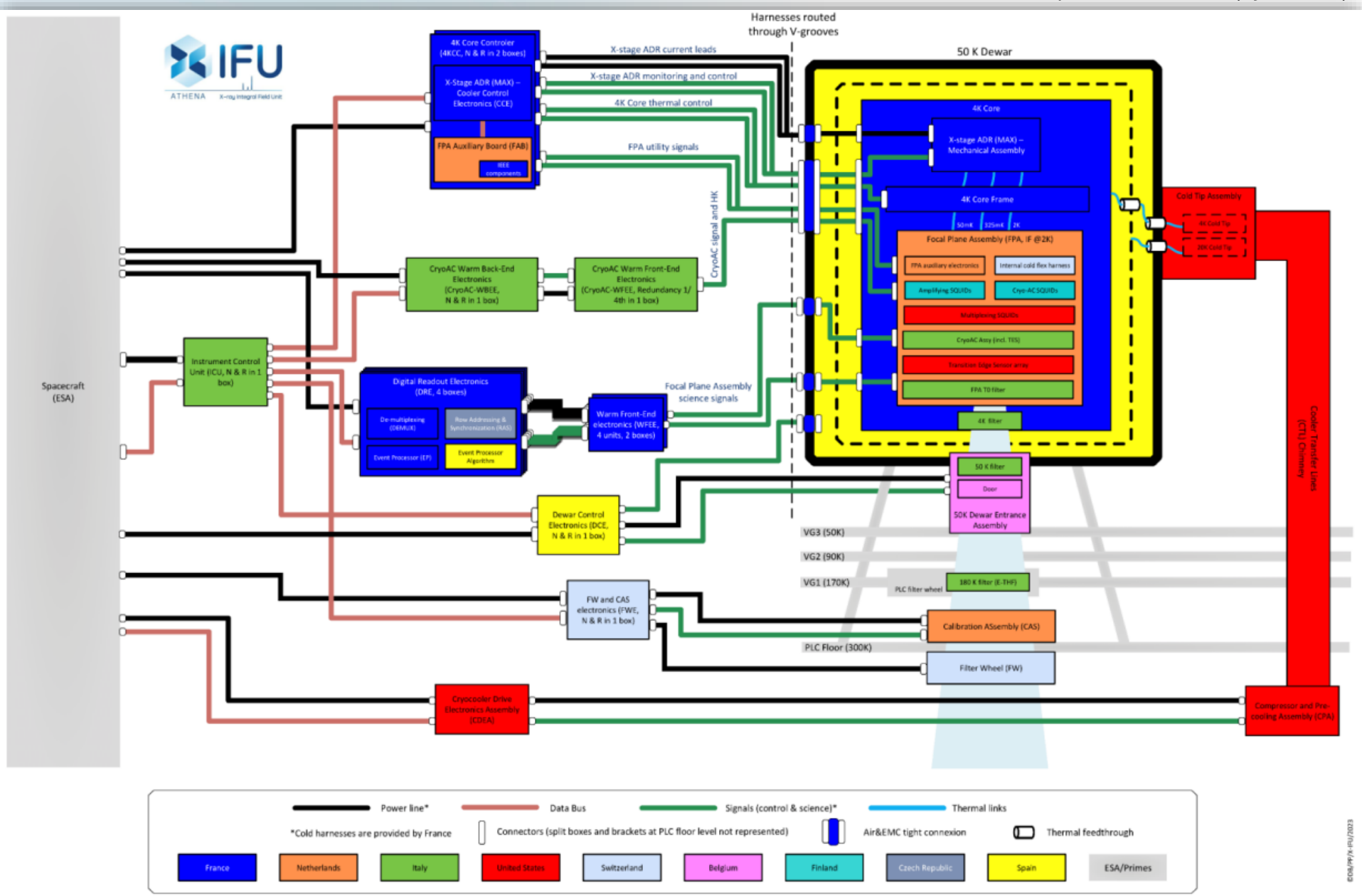
What subsystems were under study?

- We had **23 different subsystems** under study
- **Included;**
  Meetings
  Data collection
  Information about LCA
  …

Overview of the X-IFU instruments, split into countries (by colours)



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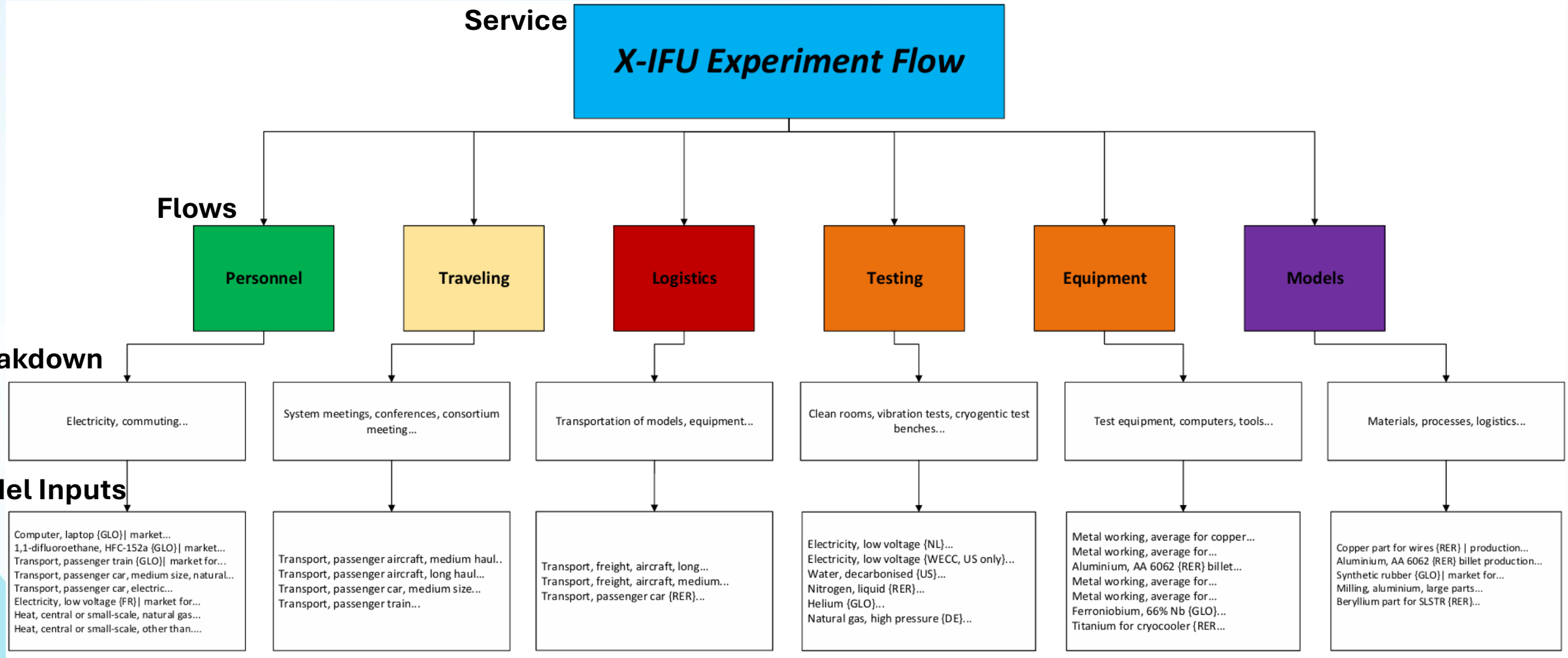
System breakdown of X-IFU



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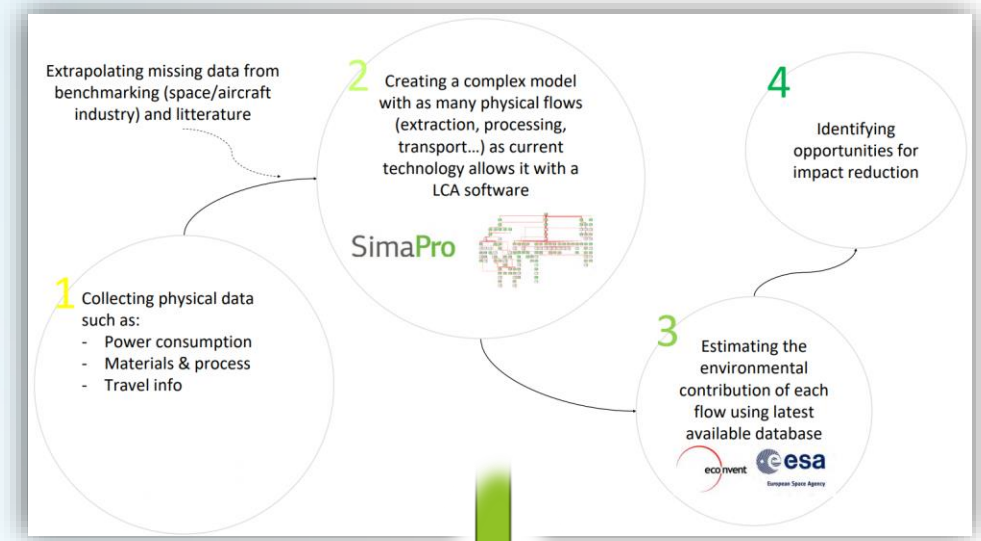
Data collection phase (LCI) of X-IFU

1:st version:

Collect data (LCI) – Explain process and what is required through meeting and exchange
Gaps – Fill in gaps from literature or project of similar character
Create model – Use all collected information to create the model in SimaPro at current stage of system level
Impact method – CO2, Ecotoxicity, mineral use…
Correct error where necessary.
Interpretation– Identify different hotspots and understand how impact reductions can be made



2:nd version:

Collect data – Use previous data & update the collection where changes has occurred. Introduce new flows & updates to the template where necessary.
Model – Update the SimaPro model with the new data
Results – Is the results in ambitions with expected results? What can be done in the future to improve towards the set goals?

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Main goals related to the second version of the LCA study

- ***Reformulation of project*** - Reformulation of the project after the SRR resulting in changes in the system (during 2022)
- ***In-house*** – Previously carried out by a company (SCALIAN), but not a full comprehension of the data from IRAP side
- ***Impact assessment*** - Minimize the environmental impacts related to the consortium members development of the X-IFU project
- ***Alternative scenarios*** – Research changes in travel, change in testing facilities, adapted energy mixes, reduction in models… and how this affect the projects impact
- ***Future iterations*** – Potential for updated version when the project is further along in the development phase
- ***Community*** – Plan to publish in form of a scientific publication

https://arxiv.org/abs/2404.15122
previous paper: Life Cycle Assessment of the Athena X-ray Integral Field Unit [3 Apr 2024]

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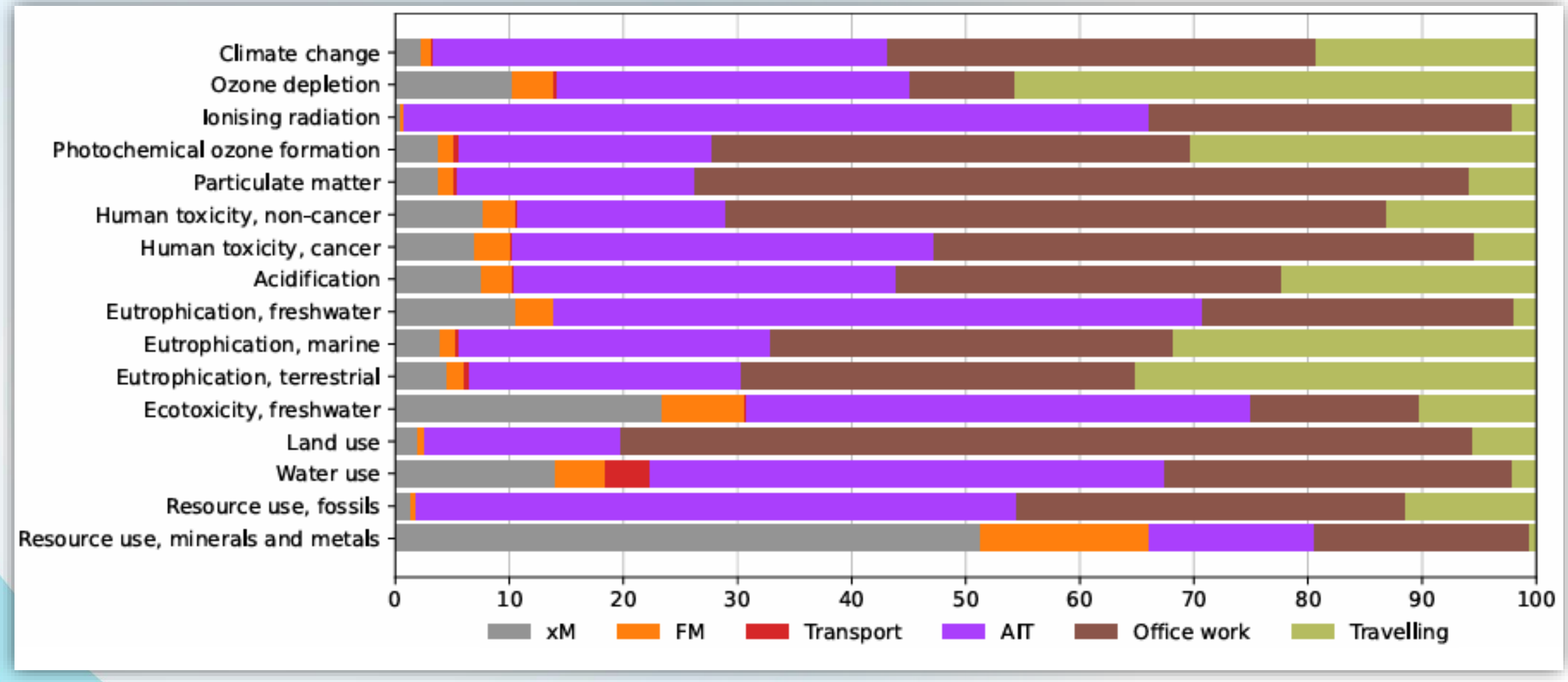
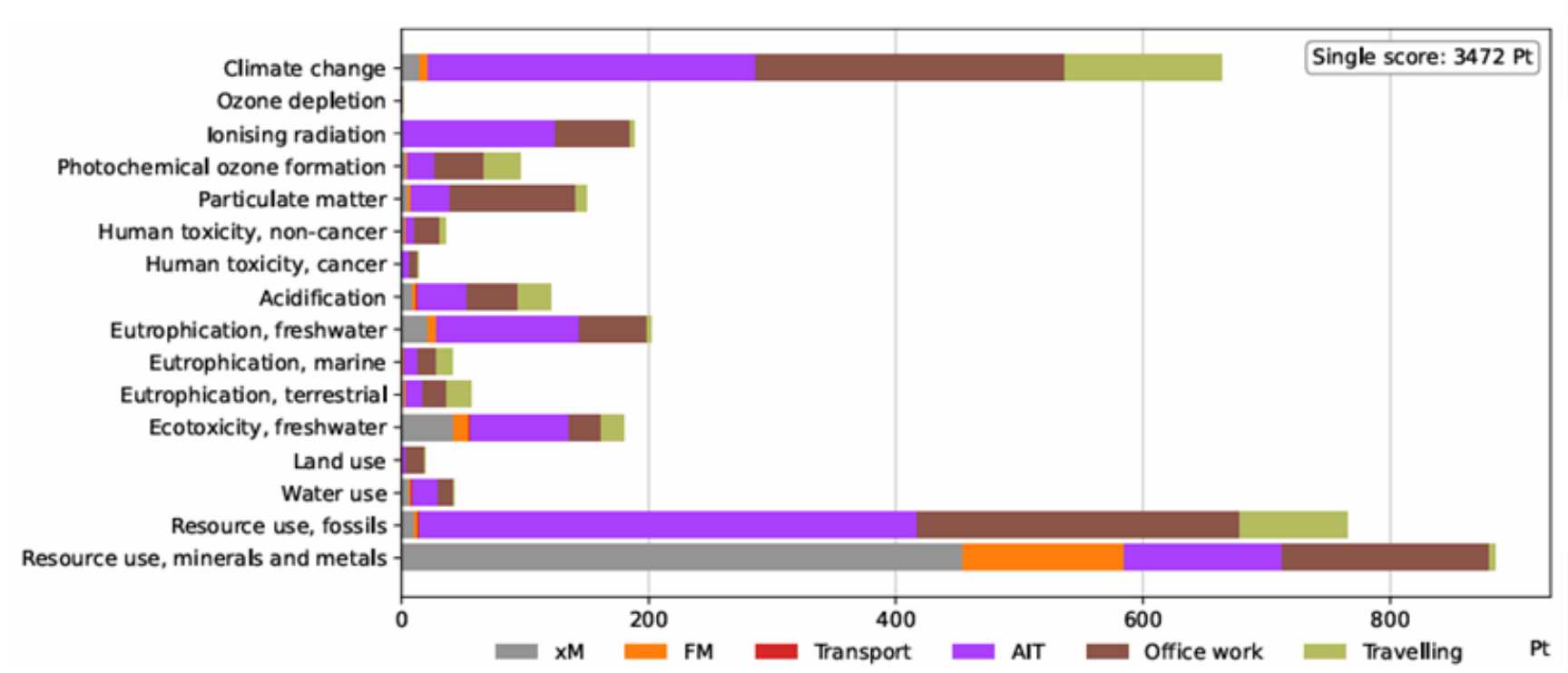
Part 6:
Results for V1 and V2 of the LCA

Version 1: Damage assessment



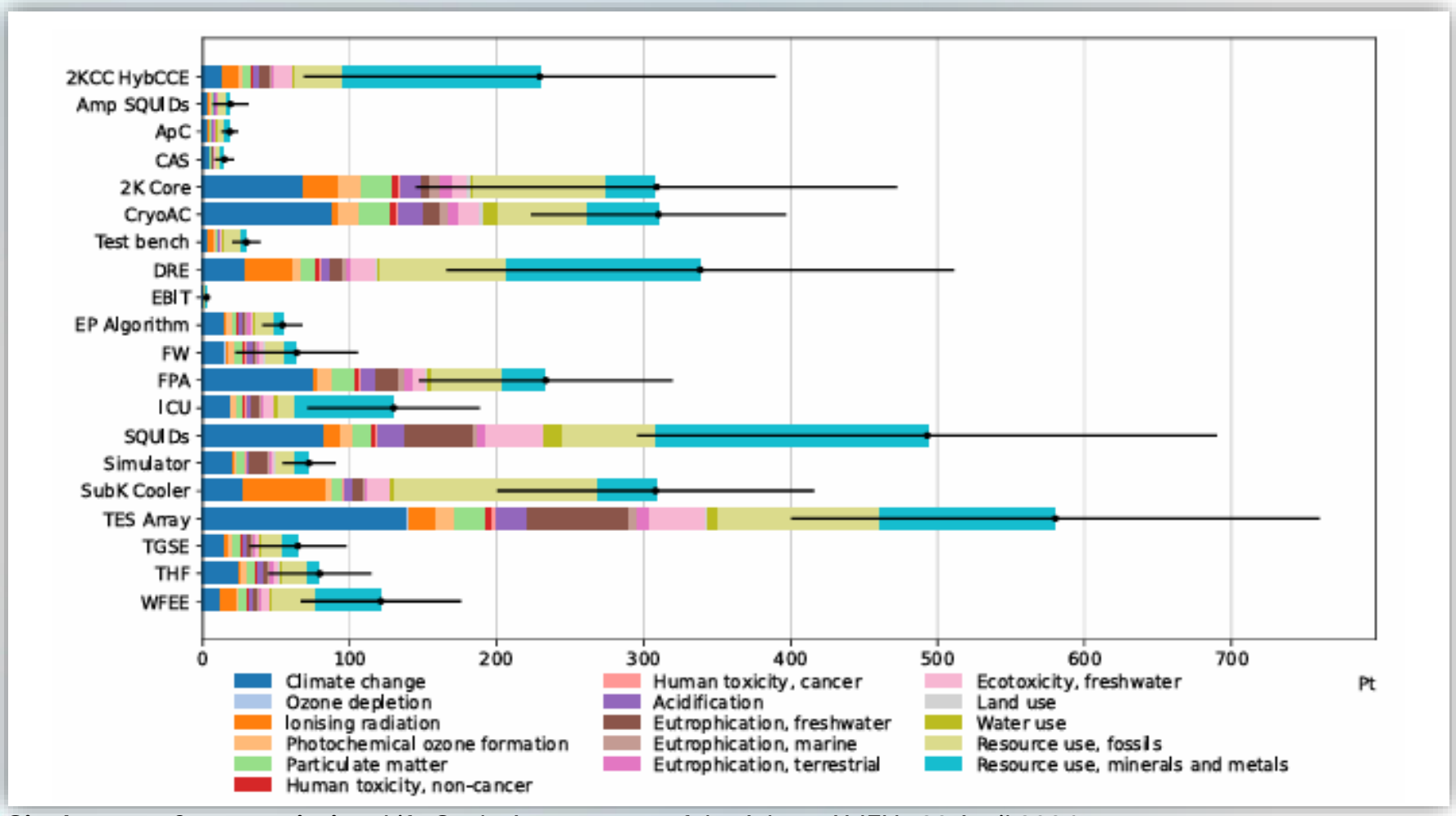
Version 1: Weighted Results



Indicator	Normalisation factor	Weighting factor
Climate change	0.0001235	0.2106
Ozone depletion	18.64	0.0631
Ionising radiation	0.0002370	0.0501
Photochemical ozone formation	0.02463	0.0478
Particulate matter	1680	0.0896
Human toxicity, non-cancer	4354	0.0184
Human toxicity, cancer	59173	0.0213
Acidification	0.01800	0.062
Eutrophication, freshwater	0.6223	0.028
Eutrophication, marine	0.05116	0.0296
Eutrophication, terrestrial	0.005658	0.0371
Ecotoxicity, freshwater	0.00002343	0.0192
Land use	0.000001220	0.0794
Water use	0.00008719	0.0851
Resource use, fossils	0.00001538	0.0832
Resource use, minerals and metal	15.71	0.0755

Table 2 Normalisation and weighting factors of the EF3.0 method that were adopted in this study.

Version 1: Breakdown of subsystems for indicators and uncertainties



Single score & uncertainties: Life Cycle Assessment of the Athena X-IFU, 23 April 2024

SCALIAN Results from the first version

Total footprint from X-IFU

- ***Project timeline –*** from 2019 to 2034 (timeline including early stages)
- ***25 000-ton CO2*** emission from the entire mission
- ***600 000 000 MJ*** from Resource use, fossils

Indicator	Unit	Total
Climate change	kg CO_2 eq	25 536 128
Ozone depletion	kg CFC11 eq	2.299
Ionising radiation	kBq U235 eq	15 945 955
Photochemical ozone formation	kg NMVOC eq	81 952
Particulate matter	desease incidents	1.001
Human toxicity, non-cancer	CTUh	0.454
Human toxicity, cancer	CTUh	0.01164
Acidification	mol H^+ eq	109 898
Eutrophication, freshwater	kg P eq	11 615
Eutrophication, marine	kg N eq	27 103
Eutrophication, terrestrial	mol N eq	267 762
Ecotoxicity, freshwater	CTUe	401 284 747
Land use	Pt	200 962 056
Water use	m^3 depriv.	5 910 066
Resource use, fossils	MJ	598 393 056
Resource use, minerals and metal	kg Sb eq	746.4

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What subsystems were under study?

Collected data (23 systems total) for V2:
Updated data: **17**
New system added: **4**
No updates: **2**

Different quality in data collected:

- **Primary Data** - Direct data collected from specific processes or operations being studied
- **Secondary Data** - Generic or averaged data sourced from existing databases or literature

Subsystem	Data collected
4.5 K cooler and drive electronics	New system & data
4KCC (Hyb CCE)	Updated data
50 K Dewar Cryostat + DCE	New system & data
50 mK Test Bench	Updated data
Amp SQUIDs	Updated data
Calibration Assembly	Updated data
CNES	Updated data
Cryo AC Detector	Updated data
Dewar Entrance Assembly	Updated data
DRE box + DEMUX	Updated data
DRE EP	Updated data
DRE EP Algorithm	Updated data
DRE RAS	New system & data
Filter Wheel	No new data
FPA	No new data
ICU	Updated data
Multiplexing SQUIDs	Updated data
Multi-stage ADR for X-IFU	Updated data
X-IFU end-to-end simulator	Updated data
TES Array	Updated data
Thermal Filters	Updated data
WFEE	Updated data
X-ISC (Instrument Science Centre)	New system & data

Subsystems: Identified systems under study for X-IFU.

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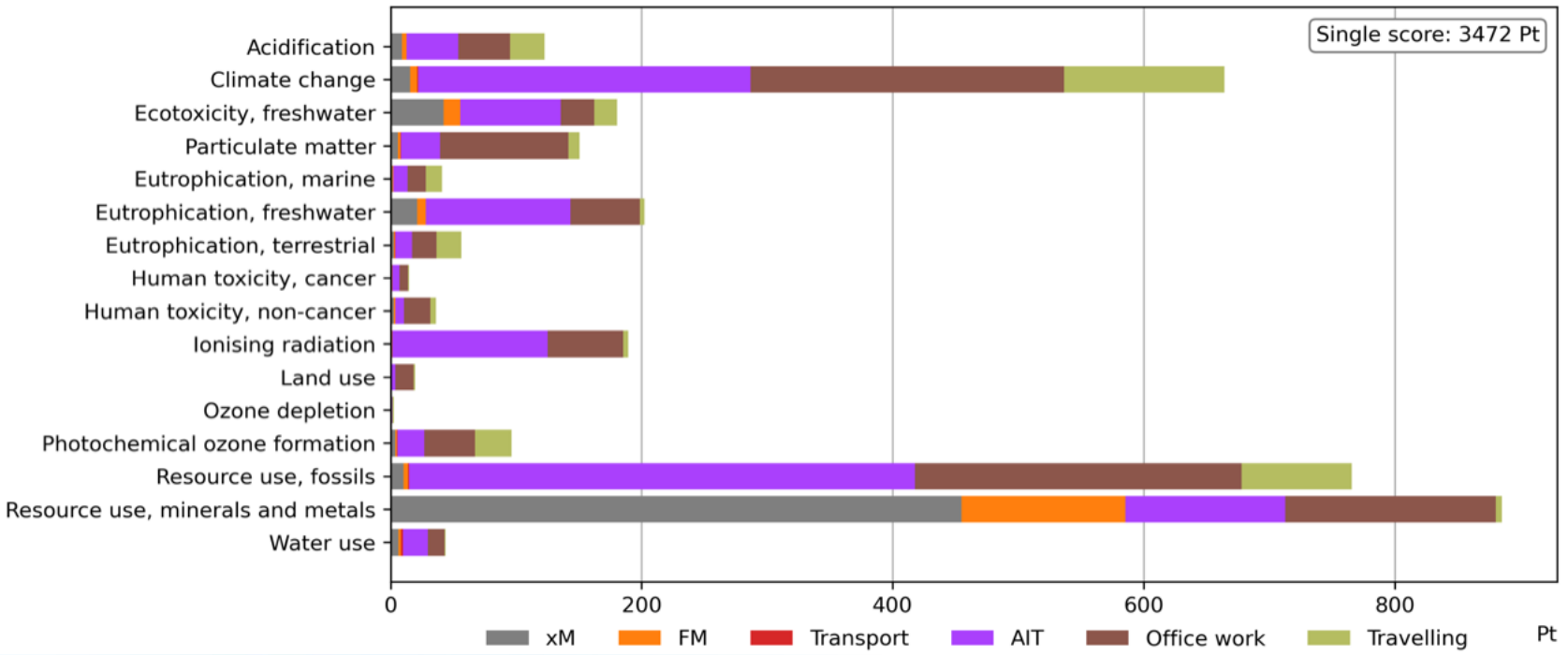
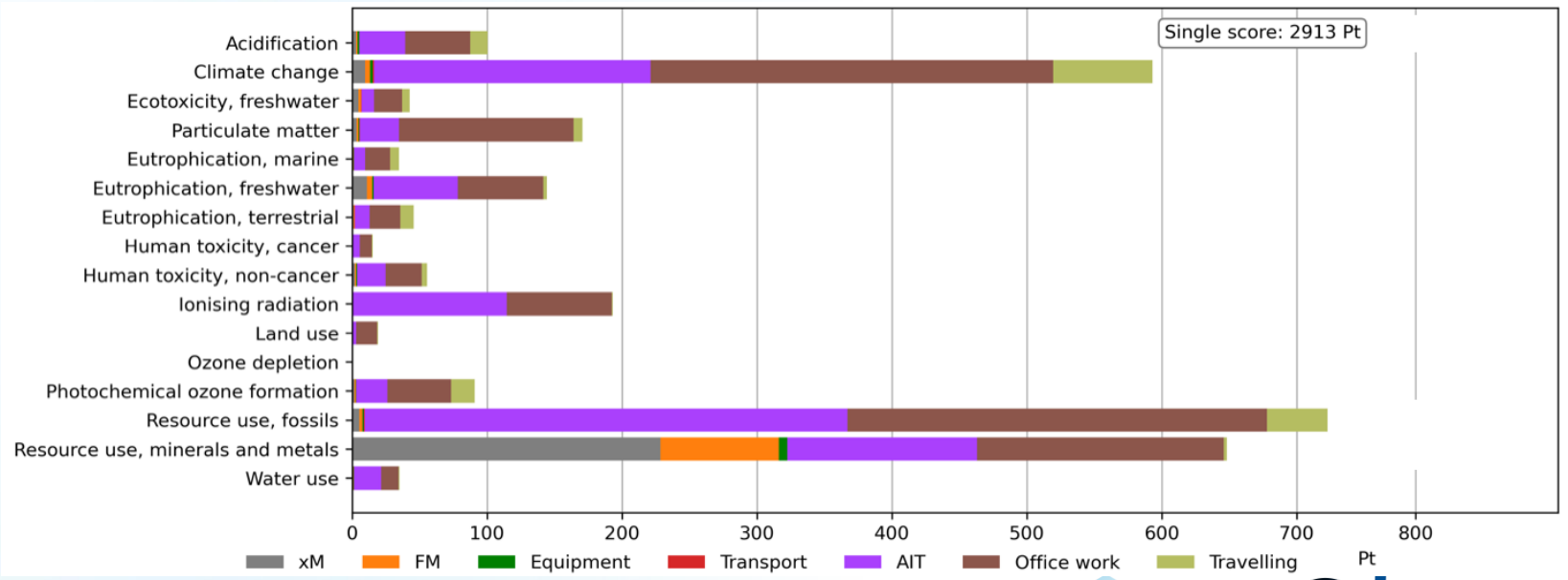
Version 1 (2022):

- Reduced CO2 footprint – traveling, testing,
- Reduced minerals & metals – More information about the models & more accurate representation



Version 2 (2024):

- New flow: Equipment
- Ecotoxicity reduced – Due to changes in database



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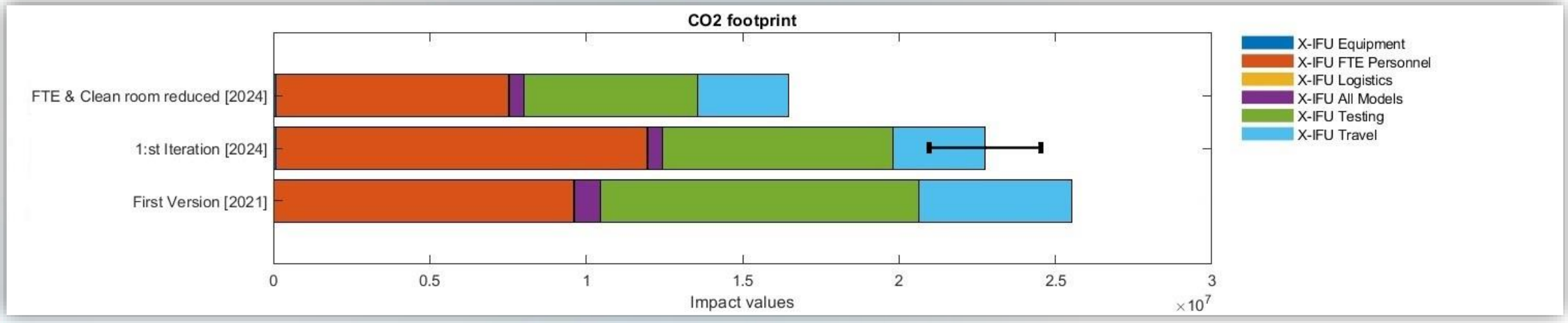
Comparison in carbon footprint [CO_2]

- **Version 2, 2224:** (22 742 985 kg CO_2 eq.) – with the uncertainty of the full system included

- **Version 1, 2021:** (25 536 127 kg CO_2 eq.) – higher impact but also larger uncertainties, as project was less developed

Points:

Large change in CO_2 from the 2 studies.
Increase in FTE
Reduced in Travel & FTE

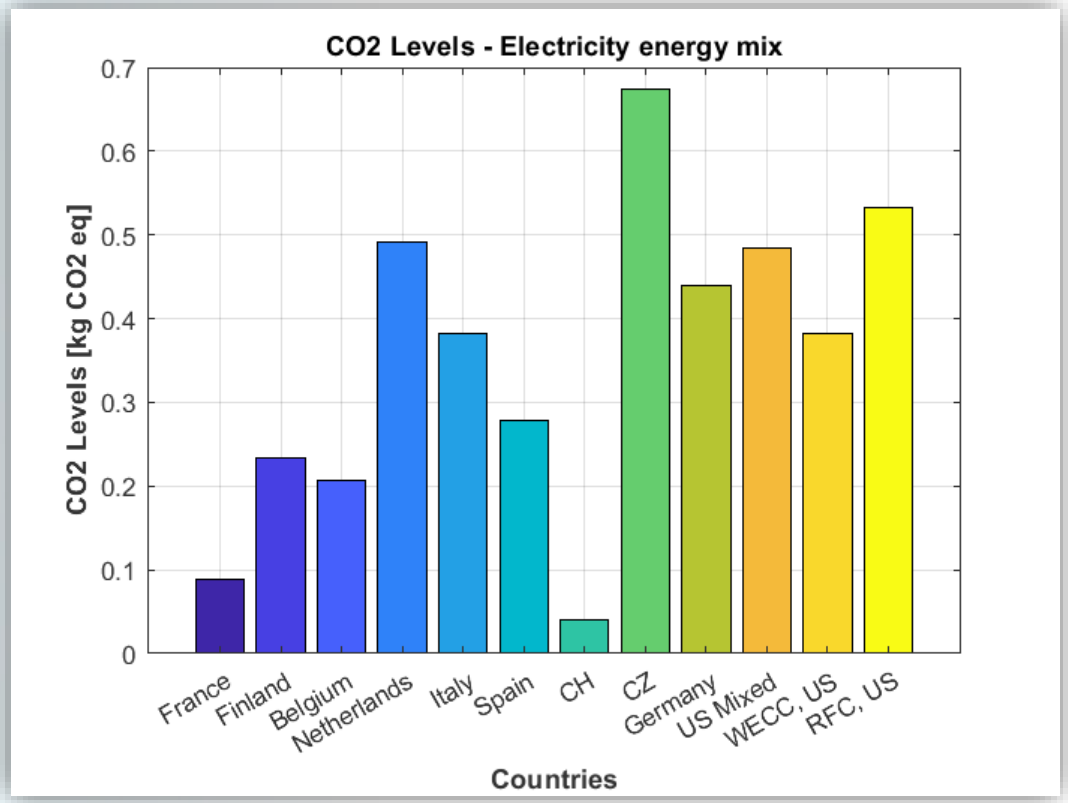


X-IFU SCALIAN study 2022 & Ongoing study 2024

Electricity mixing: Country specific

Difference in data sets – Differences between data sets in Ecoinvent & how this affect the results

Climate change
5 kWh US mixed = 1 kWh France
Have a fair view of the results.



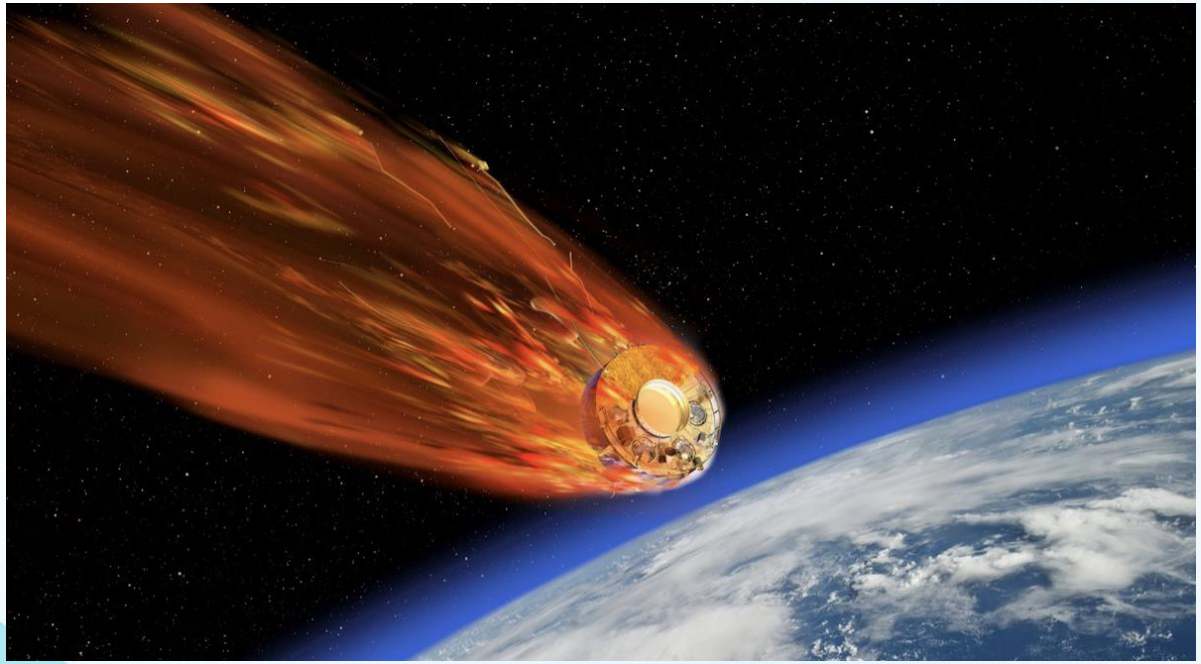
1 kWh, Ecoinvent 3.1 (adapted) version

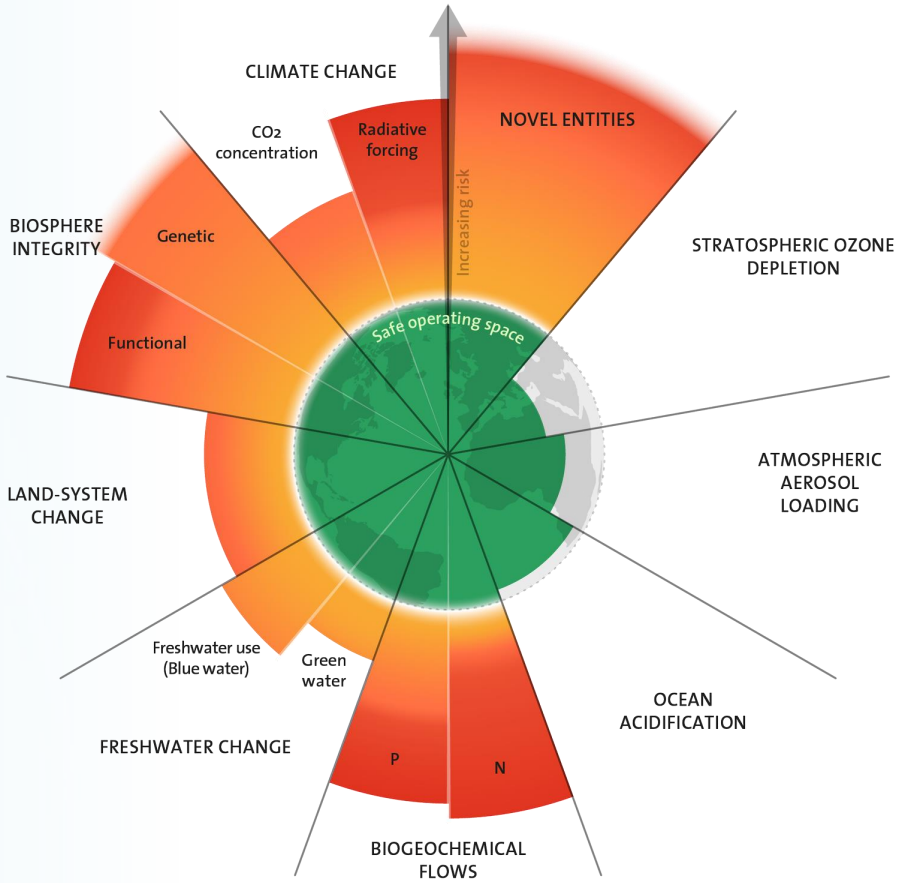
Electricity mixing: Evolution from datasets

How are the results affected by the evolution and changes in datasets & methods?

Conclusion & Final Remarks

- **From X-IFU:** High impact from testing & traveling
- **How are the Planetary boundaries affected?**
- **Data gaps:** Substantial gaps in key areas
- **Benchmark**





"As we venture further into space, it's crucial that we ask ourselves: How can we make space exploration not only possible but sustainable for future generations?"

LULEÅ UNIVERSITY OF TECHNOLOGY

IFU ATHENA X-ray Integral Field Unit

irap astrophysique & planétologie

Thank you!