SUSTAINABILITY AND ASTRONOMICAL INSTRUMENTATION: CURRENT ESTIMATE ON THE ENVIRONMENTAL IMPACT OF ELT'S MOSAIC

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MOSAIC SUSTAINABILITY PRINCIPLE

Requirements:

- Regularly update and report the environmental assessment to ESO & actively minimize the overall carbon footprint where possible

Past actions

- Held a sustainability workshop during systems engineering week
- Regularly presented sustainability topics during QPR
- First environmental assessment of MOSAIC performed in 2024

Current actions

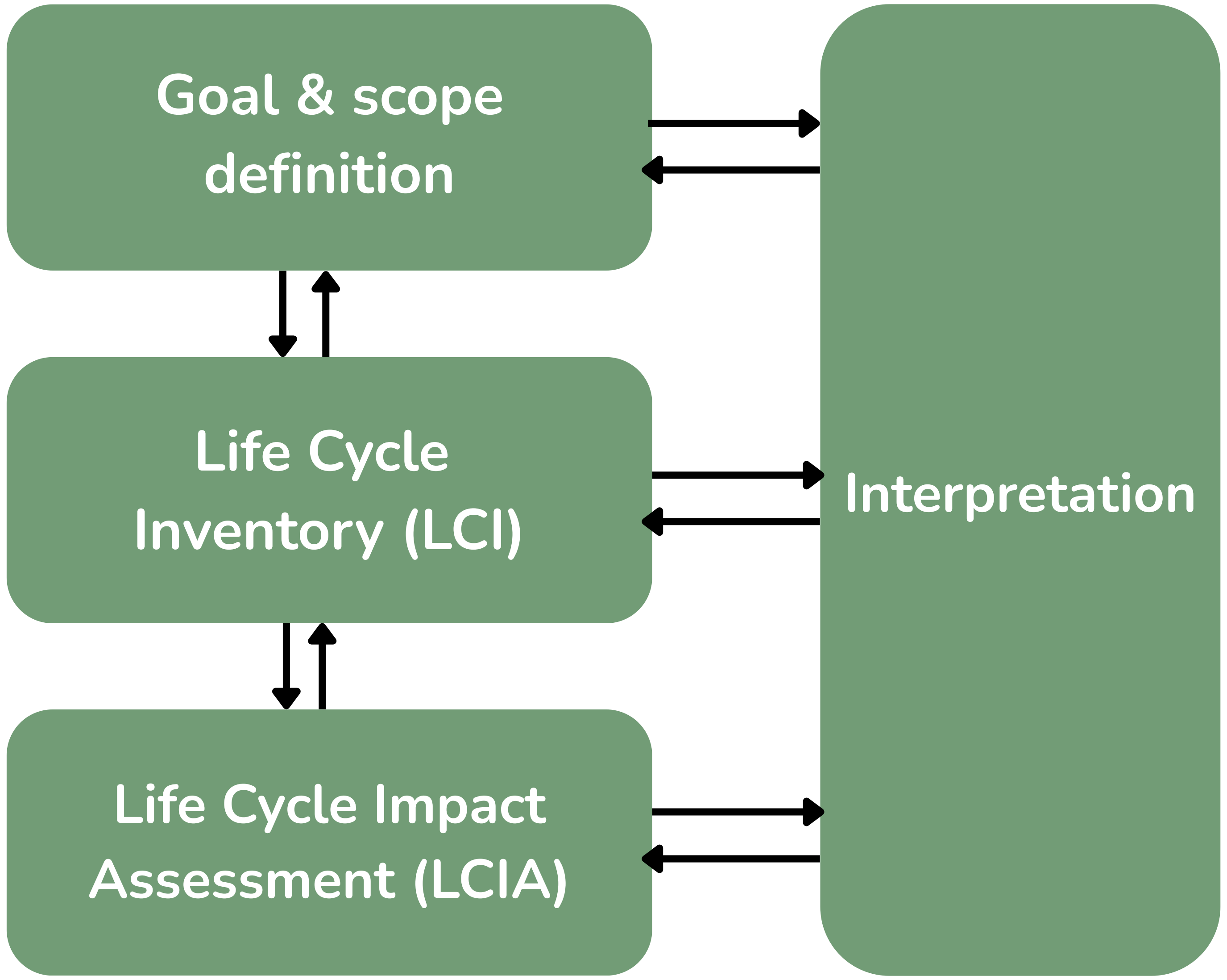
- Improving and updating environmental assessment using Life Cycle Assessment (LCA)
- Building the LCA workflow

LIFE CYCLE ASSESSMENT

Technique for assessing the environmental aspects and potential impacts associated with a product

Stages

- Goal & scope definition
- Life Cycle Inventory (LCI)
- Life Cycle Impact Assessment (LCIA)
- Interpretation



Iterative phases of Life Cycle Assessment, according to ISO14040

GOAL & SCOPE DEFINITION

Functional unit

The quantified performance of a product system for use as a reference unit.

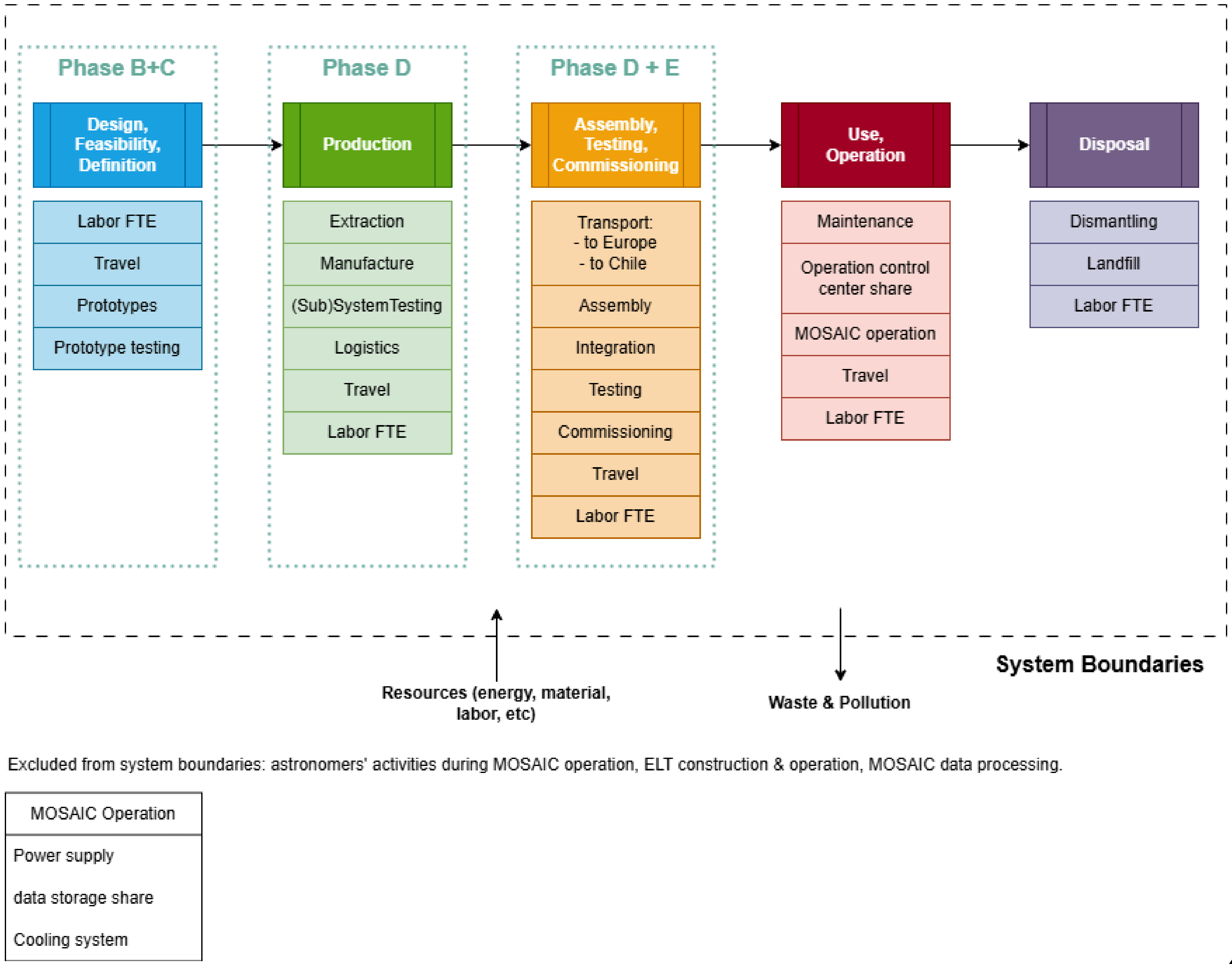
Mosaic functional unit

"One MOSAIC instrument designed, tested, manufactured, delivered, operated, and disposed of, providing multi-object spectroscopy and integral field imaging on the ELT over a minimum operational lifetime of 15 years."

System boundaries

Set of criteria specifying which unit process are part of a product system.

MOSAIC LCA system boundaries



INTEGRATING SUSTAINABILITY AND LCA IN MOSAIC CONSORTIUM

CHALLENGES & LIMITATIONS

Project structural constraints

- International project
- Limited to project’s scope
- Strict requirements

Practical challenges encountered:

- Additional workload for the consortium
  - disengagement & tension
- Data availability and maturity
- Lack of confidence in the data
- Uncertain or sensitive data
- Risk of micromanagement

Data collection needs to be progressive !

PROGRESSIVE LCA APPROACH

Goal

Useful LCA results at the right time, without overloading the consortium.

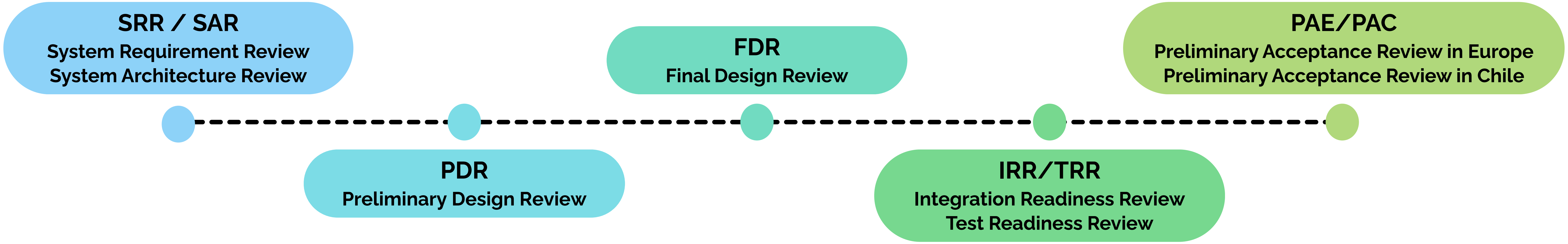
Why?

- Standardized data collection
- Improve transparency between LCA assumptions and project evolution
- Make the process reusable for future instruments

How?

- Start with available data and proxies
- Update the model at project milestones
- Focus detailed collection on hotspots

DATA COLLECTION SCHEME BY MATURITY



Project stage	LCA objective	Typical data maturity
Early design SRR/SAR	Screening & hotspot identification	Instrument architecture, budgets, proxies
Design consolidation PDR/FDR	Trade-offs support	Module mass, material split, process assumptions
Integration & acceptance IRR/TRR	Update testing & logistics	Confirmed test setup, planned energy use + logistics
Acceptance & final update PAE/PAC	Actuals + final inventory before use	Final product data, acceptance configuration

Uncertainty decreases as project maturity increases:
Early LCA supports decisions, later LCA consolidates actual impacts.

PROPOSED LCA DATA COLLECTION IMPLEMENTATION

Management

- Office work resource
- Full time equivalent (FTE)
- Travel

Source:
WP PM / PO / institutes

When:
QPRs + yearly updates

QPR = quarterly progress report
WP PM = work package project manager
PO = project officer

Engineering

- System architecture
- Prototypes
- Testing

Source:
WP SE / Instrument Architect

When:
SRR/SAR → PDR → FDR

WP SE = work package system engineer

AITV & Operation

- Final AITV setup
- Logistics
- Operation scenario

Source:
AIV PM&SE / Client (ESO)

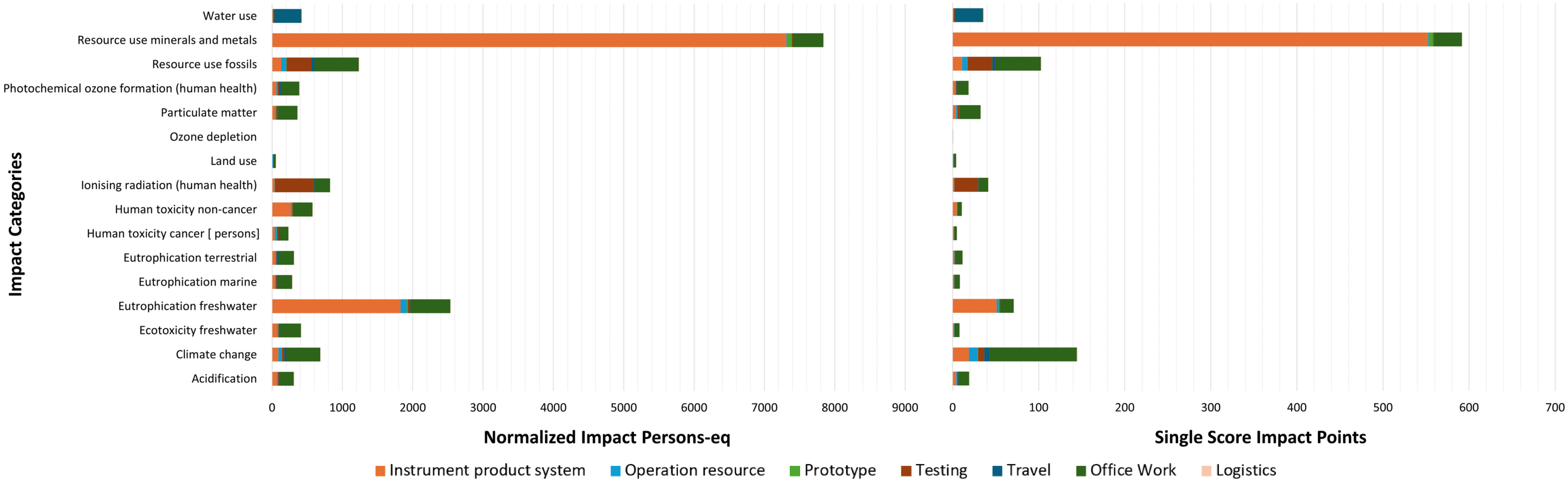
When:
IRR/TRR → PAE/PAC

AIV = assembly, integration, verification

Collect LCA data through existing SE and PM reporting, instead of creating a separate reporting process

MOSAIC LIFE CYCLE IMPACT ASSESSMENT RESULTS

NORMALIZED   WEIGHTED



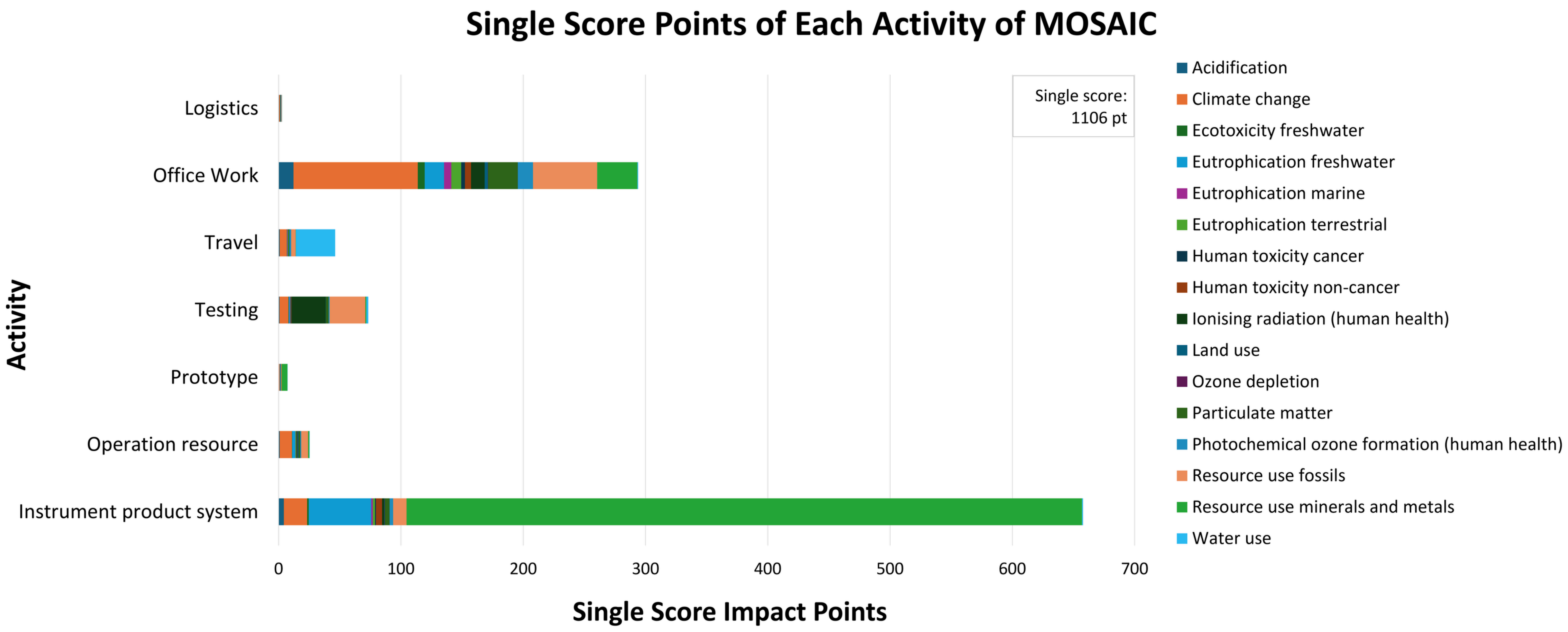
Total single score:

1106 pt

Most affected impact categories

- Resource use - minerals and metals
- Climate change
- Eutrophication freshwater
- Resource use fossil
- Ionizing radiation

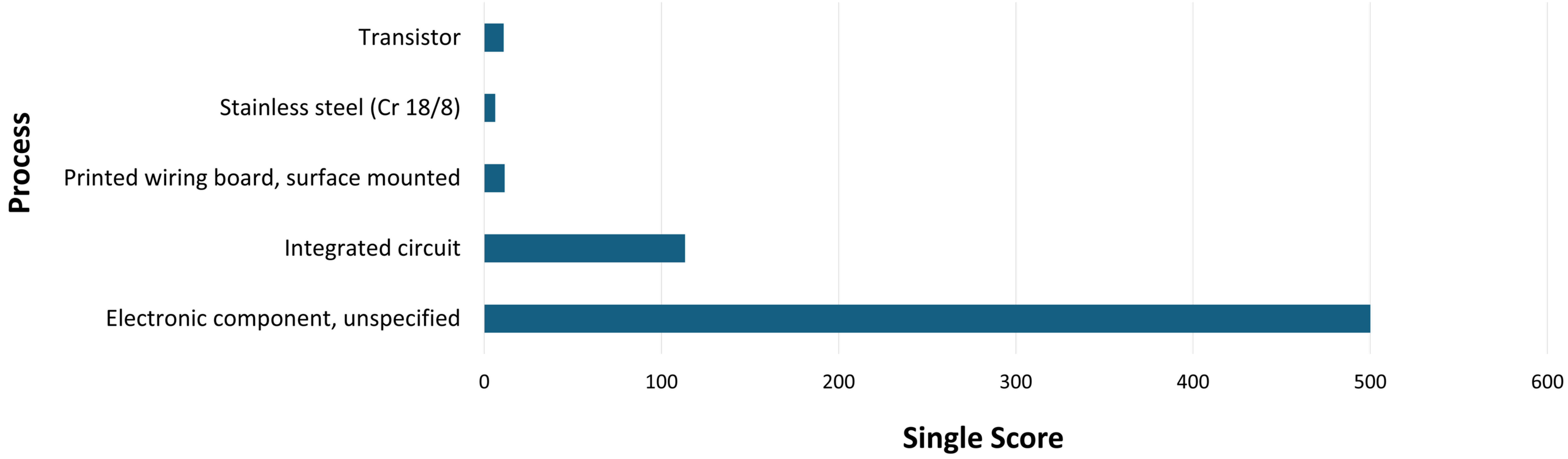
SINGLE SCORE PER ACTIVITY



Hotspots:

Instrument product, office work, testing

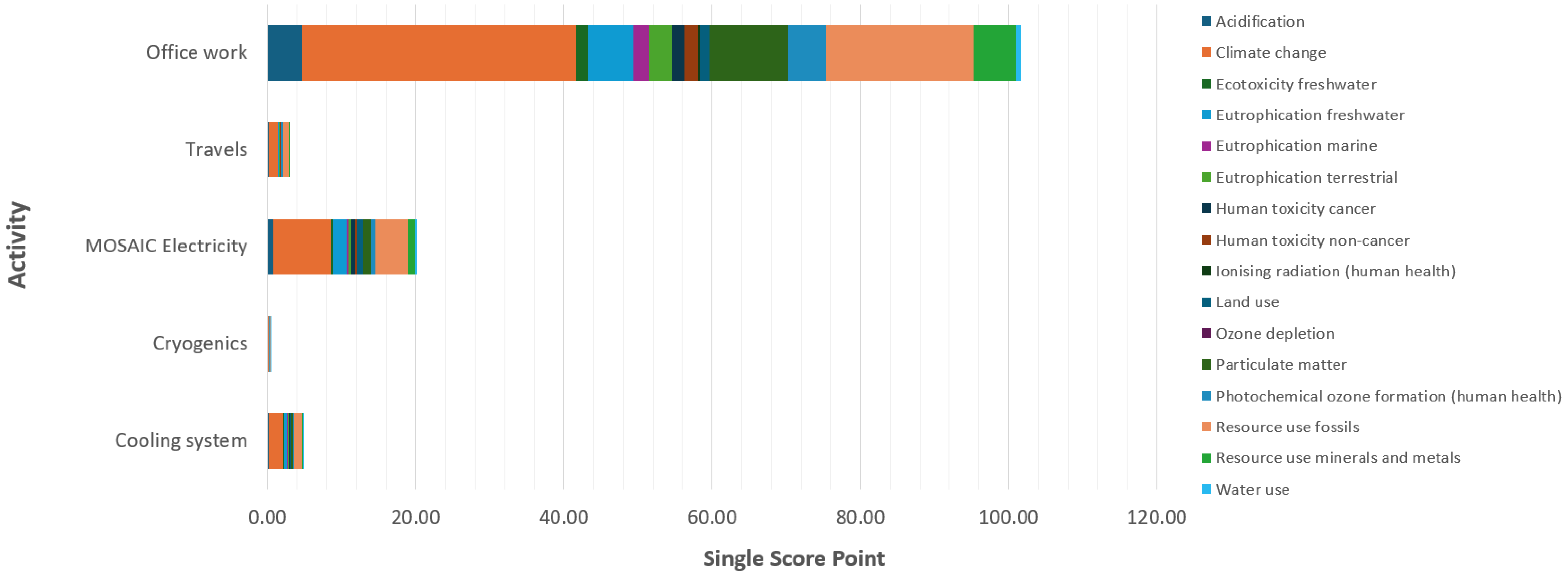
MAIN CONTRIBUTORS IN INSTRUMENT PRODUCT SYSTEM



Hotspot:

Electronics

OPERATION PHASE



Hotspot:

Office work and electricity

DISCUSSION

LCA INTEGRATION AS A GOVERNANCE ISSUE

Implications on integrating LCA to the project governance

- Sustainability and LCA expectations should be defined from the beginning.
- Separate actuals, approximations, and estimations.
- Data collection needs clear ownership, timing, and proportional requests.
  - Linked to project milestones
- LCA must support decisions, not police the project.

The challenge is not only to calculate impacts, but to make environmental information usable inside the project workflow.

CURRENT LCA CAVEATS

Needs to be improved

- Bill of Materials (BOM): especially electronics as main contributor
- Testing means
- Prototypes

Needs to be included:

- Buy-to-fly ratio
- More detailed processes
- Suppliers activities
- Final AITV activity

Buy-to-fly ratio: the ratio between the quantity of material required to manufacture a product and the final mass of the finished product.

PERSPECTIVE ON ACTIVITIES' IMPACT

Instrument System

- Environmental impact is driven by component type, not only mass.
- Subsystems hotspots are the one that needs lots of control system.

Testing

- Large energy needed for testing and clean room use.

Work-related activity

- Large consortium leads to big value of FTE and travels.
- However, impact caused by office work is ***not*** because of the amount of FTE, but the impact of one person working themselves.

Large astronomical instruments' footprint comes from both the **hardware** and the **development ecosystem** around it.

REDUCTION POSSIBILITIES

Instrument System

- Investigate electronics, detectors, and control systems more carefully
- Choosing less impactful materials.
  - Different alloys or manufacturing route.
- Manufacturing could be done in a country with lower emission from energy
  - Needs to count also the cost and impact of logistics

Work-related activity

- Reduce amount of travel and choosing smartly meeting location can reduce the impact.
- Cheat-sheet on how to be more eco-friendly (?)

FROM PROJECT-LEVEL TO STRUCTURAL LIMITS OF SUSTAINABILITY

Project level Eco-design

- Sustainability effort is not only about recommendations as options are constrained by requirements.
- The objective should not be to put responsibility only on individuals.

Structural issues

- Office work systematic issues: electricity, heating, commuting, waste management.
  - Depends on location, infrastructures, and work habits.
- Supply-chains and manufacturing are often outside project control.
- Material and electronics impacts depend on global production systems.
- Research and science infrastructure is still undeniably part of the whole global economic system.

Project-level LCA can make impacts visible, but deeper reductions depends on governance, procurement, funding priorities, and limits to infrastructure growth.

CONCLUSION
& FUTURE WORKS

CONCLUSIONS

MOSAIC impact is multi-dimensional, main categories:

Resource use, minerals/metals: 5.0×10^{2} kg Sb eq
Eutrophication freshwater: 4.1×10^{3} kg P eq
Climate change: 5.2×10^{6} kg CO_2 eq
Resource use, fossil: 8.0×10^{7} MJ
Ionizing radiation: 3.5×10^{6} kBq U235 eq

Main hotspot activities & their most affected categories

Instrument product system - resource use, minerals/metals & eutrophication freshwater
Office work - climate change & resource use, fossil
Testing - ionizing radiation & resource use, fossil

LCA could be progressive and integrated:
We are building a progressive LCA integrated into the project in order to support trade-offs and updates throughout the instrument development.

Sustainability therefore can be part of design and governance parameter for future astronomical instruments.

FUTURE WORKS

Improve priority data quality
Focus on electronics, detectors, control systems, testing means, and final AITV activities.

Track data maturity over time
Track actuals vs estimates and update the model as the project matures at project milestones.

Develop scenarios and sensitivity analysis
Test alternatives scenarios for different materials and activities and do sensitivity analysis to optimize in reducing MOSAIC's environmental impact.

Translate LCA into project guidance and generalize the method
Create practical eco-design recommendations for MOSAIC and transform the workflow for future astronomical instruments

THANK YOU

BACKUP SLIDES

DATA COLLECTION TEMPLATE

Purpose

- Collect foreground data from the work packages
- Translate instrument system information into LCA inputs

Structure

- **Materials & prototypes:** components, materials, masses, manufacturing, prototypes
- **AITV:** clean room use, cooling systems, test equipment
- **Logistics:** transport of modules, prototypes, or test items
- **Appendix:** helper tables, densities, processes, confidence levels

Priority level

Prioritizing actuals and minimum data for LCA modeling

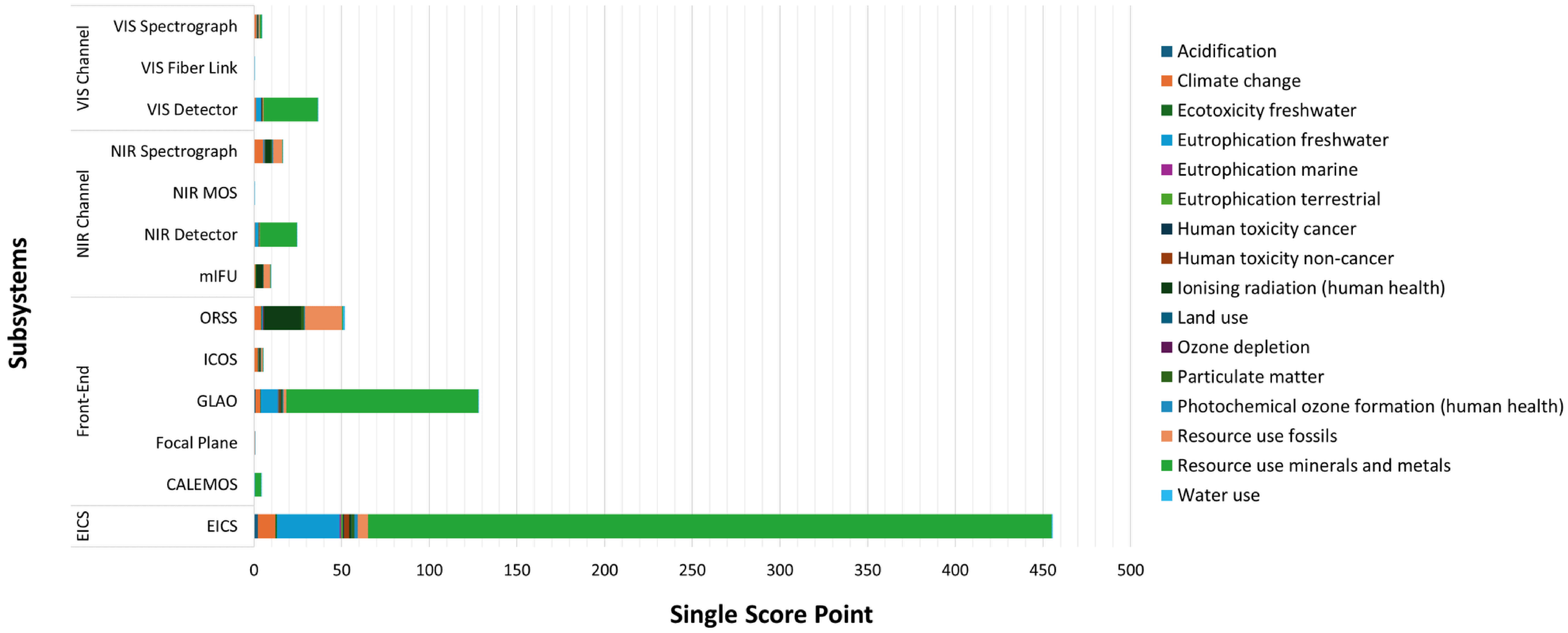
FROM DATA TO MODEL

- **WP input** — materials, mass, tests, prototypes, etc
- **Data Treatment** — cleaning, additional assumptions
- **LCI Structure** — materials, prototypes, AITV, logistics, FTE, travel, operation
- **LCA Model** — foreground data x background database processes
- **LCIA Results** — impact categories, hotspots, interpretation

ABSOLUTE & NORMALIZED IMPACT

Impact Categories	Impact Unit	Total	Normalised (persons)	Contributions (%)						
				Instrument product system	Operation resource	Prototype	Testing	Travel	Logistics	Office work
Acidification	mol H+ eq	1.72E+04	315	22	5	<1	4	4	2	62
Climate change	kg CO2 eq	5.17E+06	688	13	7	<1	5	4	<1	70
Ecotoxicity, freshwater	CTUe	2.32E+07	411	18	4	<1	4	2	<1	72
Eutrophication, freshwater	kg P eq	4.07E+03	2540	72	3	<1	1	<1	<1	22
Eutrophication, marine	kg N eq	5.58E+03	291	15	4	<1	4	5	2	70
Eutrophication, terrestrial	mol N eq	5.46E+04	315	15	4	<1	4	6	2	69
Human toxicity, cancer	CTUh	3.98E-03	231	17	13	<1	10	<1	<1	60
Human toxicity, non-cancer	CTUh	7.39E-02	575	47	2	1	2	<1	<1	47
Ionising radiation	kBq U235 eq	3.48E+06	825	4	<1	<1	67	<1	<1	27
Land use	Pt	4.29E+07	52	10	20	<1	7	<1	<1	63
Ozone depletion	kg CFC11 eq	2.05E-01	4	29	<1	<1	3	2	<1	64
Particulate matter	disease incidence	2.15E-01	363	12	4	<1	7	<1	<1	75
Photochemical ozone formation	kg NMVOC eq	1.57E+04	393	16	4	<1	4	7	2	66
Resource use, fossils	MJ	8.01E+07	1240	11	6	<1	28	4	<1	51
Resource use, minerals and metals	kg Sb eq	4.99E+02	7840	93	<1	<1	<1	<1	<1	6
Water use	m3 world eq	4.79E+06	418	2	<1	<1	4	90	<1	2

SINGLE SCORE PER SUBSYSTEM



Hotspots:

EICS, GLAO, Detector model, ORSS