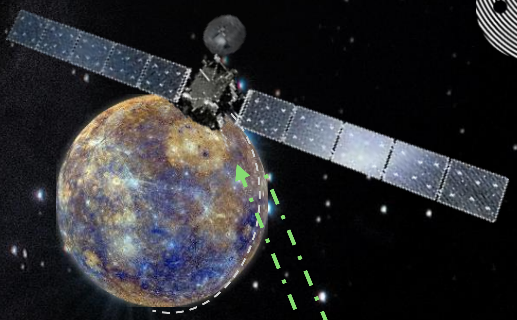
Ground Station Life Cycle Assessment

Clean Space Industrial Days, September 21, 2021

Deloitte Sustainability

Introduction

Ground Segment

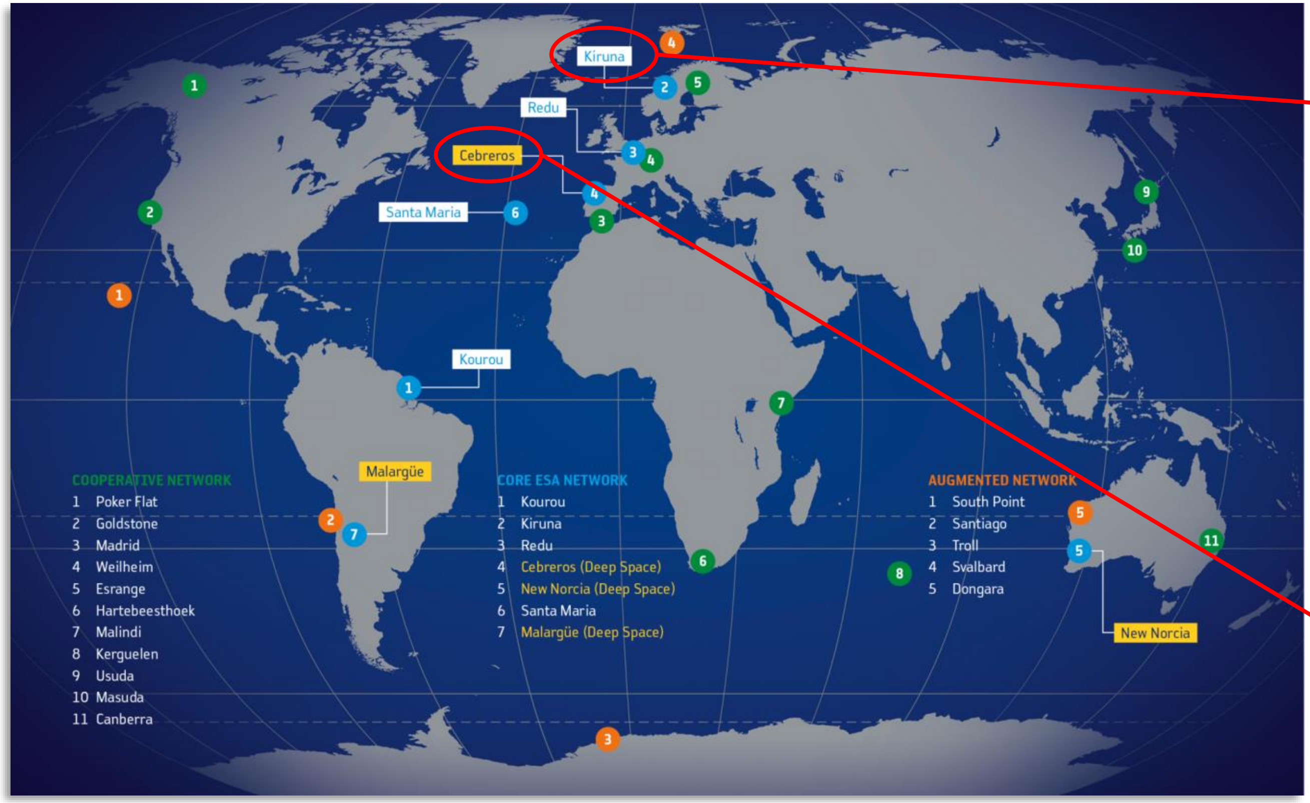


- July 2018: ESA commissioned the study "Ground Segment Life Cycle Assessment – Methodological and Quantitative" to assess the environmental impacts of the ground segment.

- September 2019: ESA triggered the Ground Station Life Cycle Assessment activity aiming at detailing these results with a focus on the ground stations.

Goal & scope

Kiruna and Cebreros as part of ESA Tracking Network (ESTRACK)



Goal & scope of the study

Goal & scope

Objectives of the study

- **The main objectives of this study were:**

Main objectives of the Ground Station LCA project

To define families of ground stations covering all types of space missions

To perform a Life Cycle Assessment of two Ground Stations

Which are of two different types:

- **Kiruna** with its 15m **KIR-1** terminal designed for Near Earth and Low Earth Orbit missions
- **Cebreros** with its 35m **CEB-1** terminal designed for Deep Space missions

To identify environmental mitigation options

In order to reduce the environmental impacts of Ground Stations, by performing a trade-off analysis to select the three most promising options

Agenda

Introduction: Goal & scope of the study	2 mins
LCA of Kiruna-1 and Cebreros • Methodology • LCA results (only KIR-1 results presented)	15 mins
How to derive the environmental impacts of other ground stations?	3 mins
Solutions for reducing environmental impacts of ground stations	3 mins
Conclusions and recommendations for future work	2 mins
Questions & Answers	10 mins

Key methodological aspects

Key methodological aspects

Setting the system boundary of a ground station

System boundary of a ground station

Production of equipment

- Production of all the terminal front-end signal processing systems
- Production of all the back-end and monitoring & control systems

Operations

- Energy consumption
- Commuting
- Business & visitor travels

Infrastructure

- Production of the buildings, auxiliary and support systems
- Production of the antenna structure

Maintenance

- Travel of technicians
- Transport of spare parts

Key methodological aspects
Defining the functional unit

To compare several ground stations in LCA, a "**functional unit**" is used to quantify their relative performance for the same provided service:

To fulfil the requirements of operating the 15m antenna Kiruna-1 during one year

or

To fulfil the requirements of operating the 35m antenna of Cebreros during one year

+

To fulfil the requirements of 1 year of ground station operation for the space mission [NAME]

Key methodological aspects

Overall approach of data collection for the Production of Equipment and Infrastructure

Challenge: large number of electrical and electronic equipment in ground stations, of various types and compositions

Solution: grouping similar equipment into "families"

1. **Equipment inventory**
2. **Family grouping: *35 families***
3. **Average weight & lifetime**
4. **Material compositions**

Production of Equipment & Infra-structure

Data inputs

- ESA ECDB* extracts & experts
- ESA database
- Ground segment LCA
- EU preparatory LCA studies
- Product environmental profiles (PEP)
- Telespazio expert advice
- ecoinvent3.3
- Literature review

** ECDB = ESTRACK Configuration Database*

Key methodological aspects

Modelling of equipment families: annual weights and material compositions

- A pro-rata "annual weight" of each equipment was calculated to assess the impact over one year (functional unit):

System	Equipment	Family	Number	Weight (kg)	Lifetime (yr)	Annual weight (kg/yr)
System	Equipment 1	Family A	N_1	W_A	L_A	$\frac{N_1 W_A}{L_A}$
	Equipment 2	Family B	N_2	W_B	L_B	$\frac{N_2 W_B}{L_B}$
	Equipment 3	Family C	N_3	W_C	L_C	$\frac{N_3 W_C}{L_C}$

$$\boldsymbol{Annual\ weight} = \frac{\boldsymbol{Number \times Family\ weight}}{\boldsymbol{Family\ lifetime}}$$

- Material compositions of each family were determined from a variety of sources: ecoinvent, manufacturers' Product Environmental Profile (PEP), EU Preparatory Studies for information provided directly by ESA, and some data from the parallel activity Ground Segment LCA.

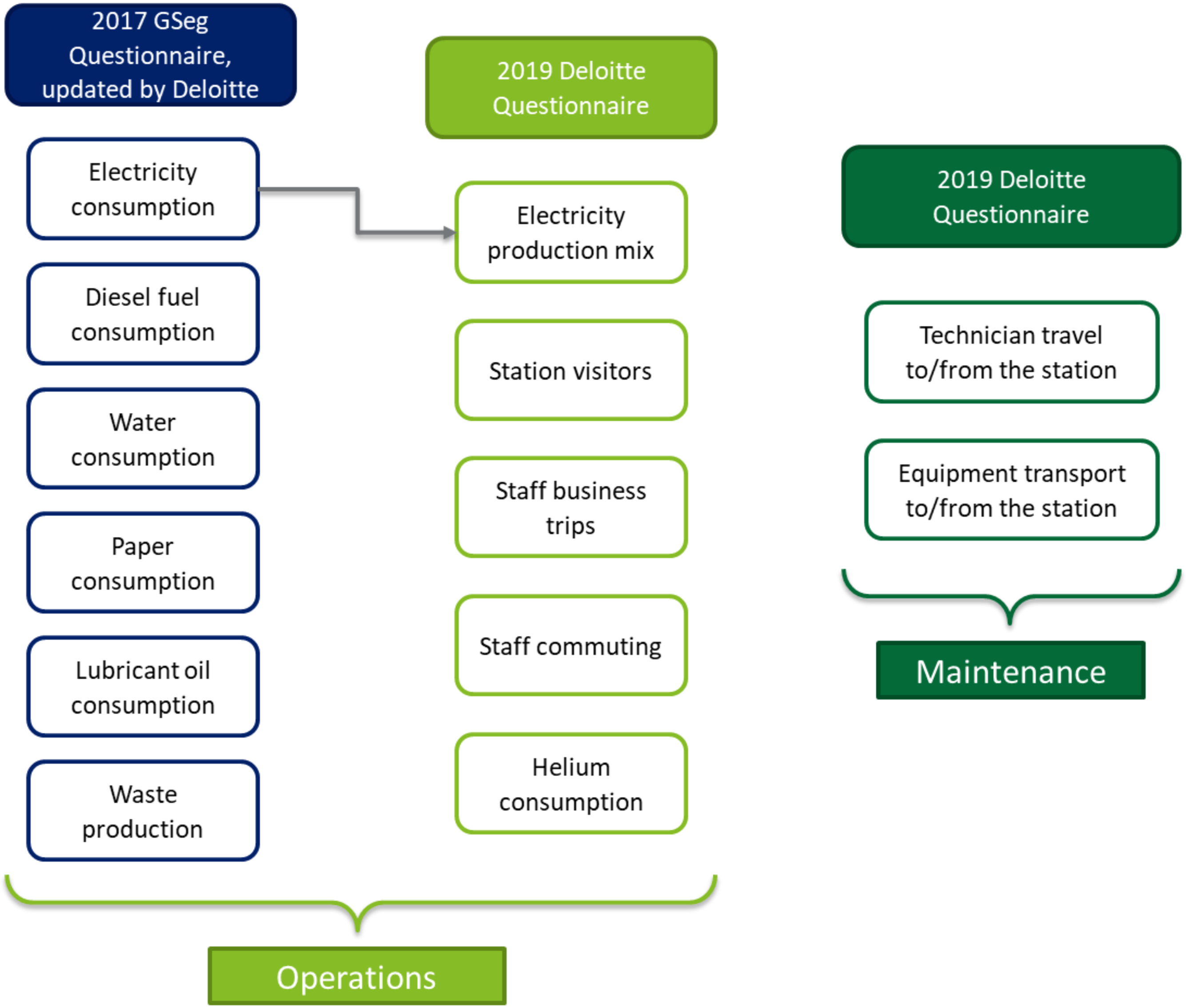
Examples of families include:

- Amplifiers (High Power Amplifier, Low Noise Amplifier, Low Power Amplifier, Solid-state Power Amplifier)
- Antenna (mirrors, reflector and structure)
- Electro-mechanical unit
- Waveguide component
- Maser
- Other signal processing equipment (cables, fibre optics, electric switch)
- Electronic equipment (Computer, Control unit, Server, Screen, Laptop, electronic circuit board, Signal processing unit, Network device, Signalling switch)
- Equipment for building operations (Atmosphere control unit, diesel generator, building, chiller, batteries, Power and electric unit, vehicle, mechanical part)

Key methodological aspects

Data collection approach for Operations & Maintenance

- Yearly consumption data was initially obtained from the 2017 Ground Segment (GSeg) LCA questionnaire for Kiruna & Cebreros
- Kiruna was contacted directly for additional information regarding maintenance and electricity mix
- Cebreros was contacted directly to update values provided in 2017 and to provide extra information



Key methodological aspects

Advantages of our methodological approach

The main advantages presented by this approach are threefold:

- ✓ All equipment contained in the EPTI are covered by the modelling, meaning there is a **100% equipment coverage rate**
- ✓ Environmental impacts can be **traced back to each product tree system**
- ✓ The modular nature of this LCA model means **it can be generalised and applied to other stations in the ESTRACK network** given that the overall architecture, systems and components remain very similar in each ground station.

LCA Results – Example of KIR-1

Kiruna-1 LCA results

The environmental impacts of Kiruna-1, in absolute values

~73 passenger round trips from Paris to New York in an A380

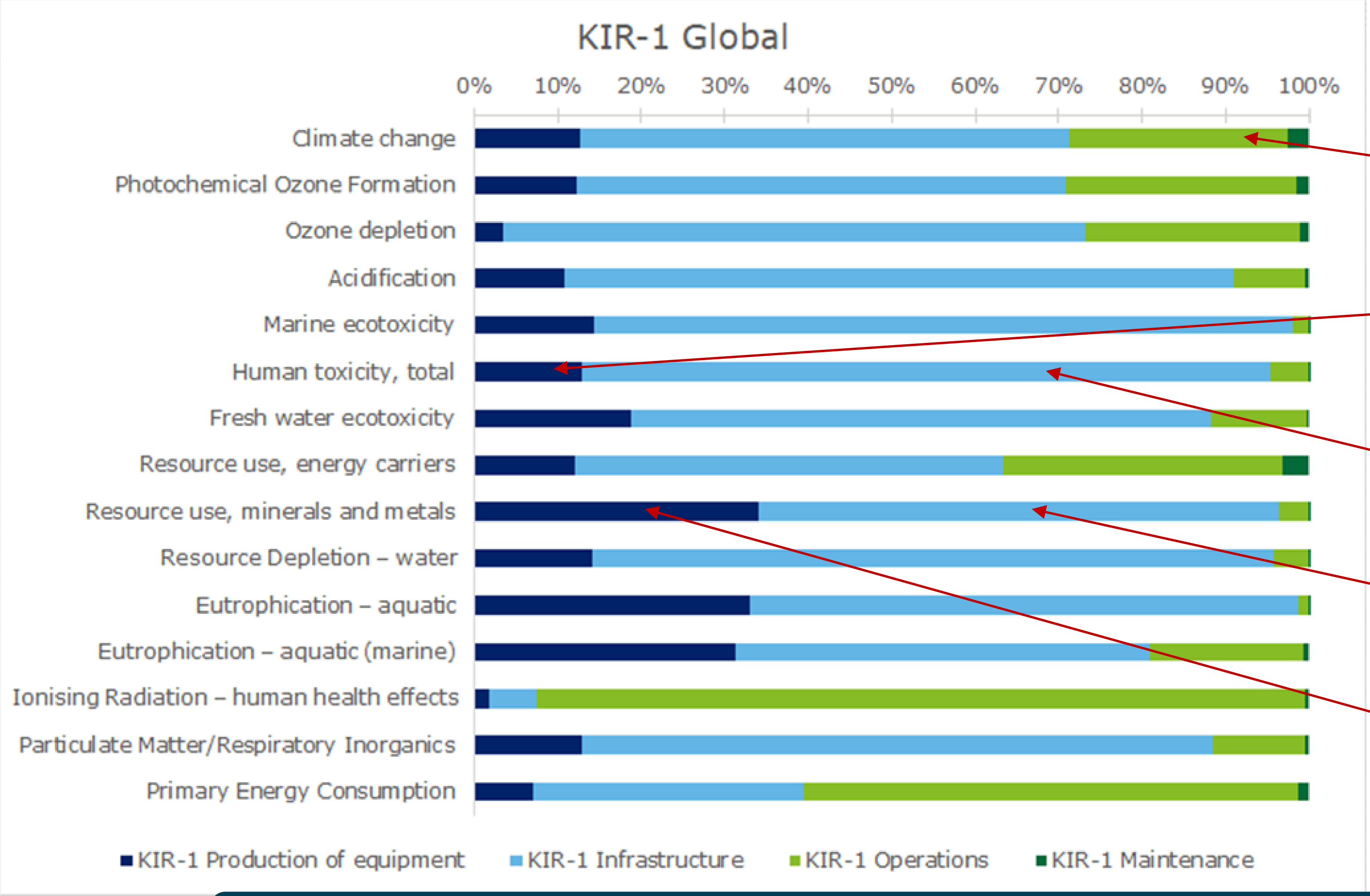
*Indicators **in bold** are of particular interest to ESA*

Impact category	Total	Unit
Climate change	**190 710**	**kg CO2 eq**
Photochemical Ozone Formation	819	kg NMVOC eq
Ozone depletion	**0,09**	**kg CFC-11 eq**
Acidification	2 230	kg SO2 eq
Marine ecotoxicity	452 052 490	kg 1,4-DB eq
Human tox. – non-cancer effects	0.07	CTUh
Human tox. - cancer effects	0.01	CTUh
Human toxicity, total	**0.08**	**CTUh**
Fresh water ecotoxicity	**354 206**	**CTUe**
Resource use, energy carriers	2 229 376	MJ
Resource use, minerals and metals	**127**	**kg Sb eq**
Resource Depletion – water	1 429 118	m3
Eutrophication – aquatic	90	kg P eq
Eutrophication – aquatic (marine)	50	kg N eq
Ionising Radiation – human health effects	79 733	kBq U235 eq
Particulate Matter/Respiratory Inorganics	698	kg PM10 eq
Resource use, minerals and metals	122 968	kg Fe eq
Primary Energy Consumption	5 224 744	MJ

Functional unit: To fulfil the requirements of operating the 15m antenna KIR-1 during one year

Kiruna-1 LCA results

Overall, the largest contributor to Kiruna-1's environmental footprint is the Infrastructure category, which contributes to more than 50% of impacts for most indicators.



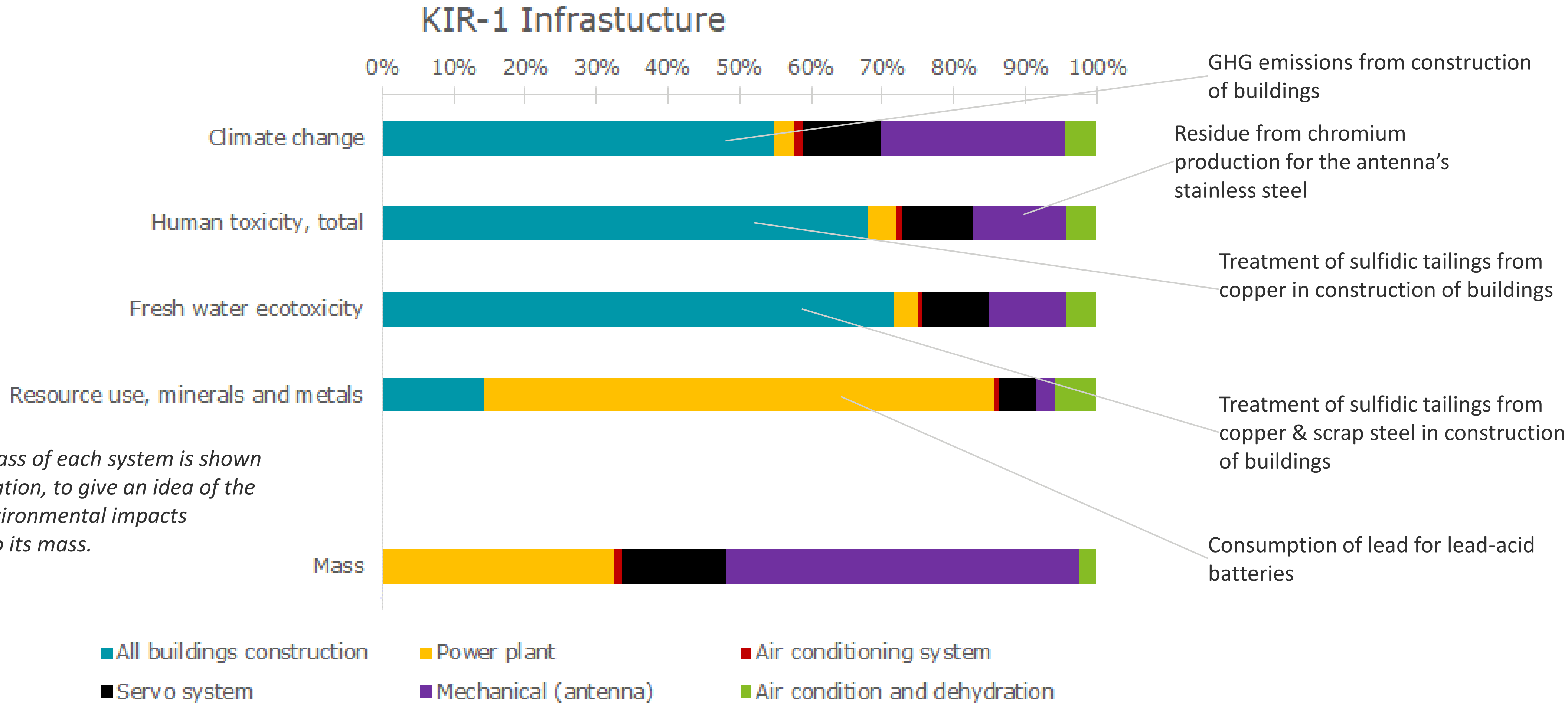
Main identified hotspots:

- **Visitor and business travels** account for ~25% of all impacts to climate change
- The extraction of **metals for electronic circuits** is responsible for more than 95% of Production of Equipment impacts to toxicity
- The **stainless steel in the antenna** is responsible for ~40% of impacts to human toxicity (cancer)
- The **lead-acid batteries** account for ~45% of all impacts to mineral resource depletion
- The significant mass of **cables** accounts for 11% of all impacts to mineral resource depletion

Functional unit: To fulfil the requirements of operating the 15m antenna KIR-1 during one year

Kiruna-1 LCA results

Lead-acid batteries constitute a significant impact to mineral resource use, and the relatively "small" 15m antenna contributes less than 20% of impacts on the indicators of interest.

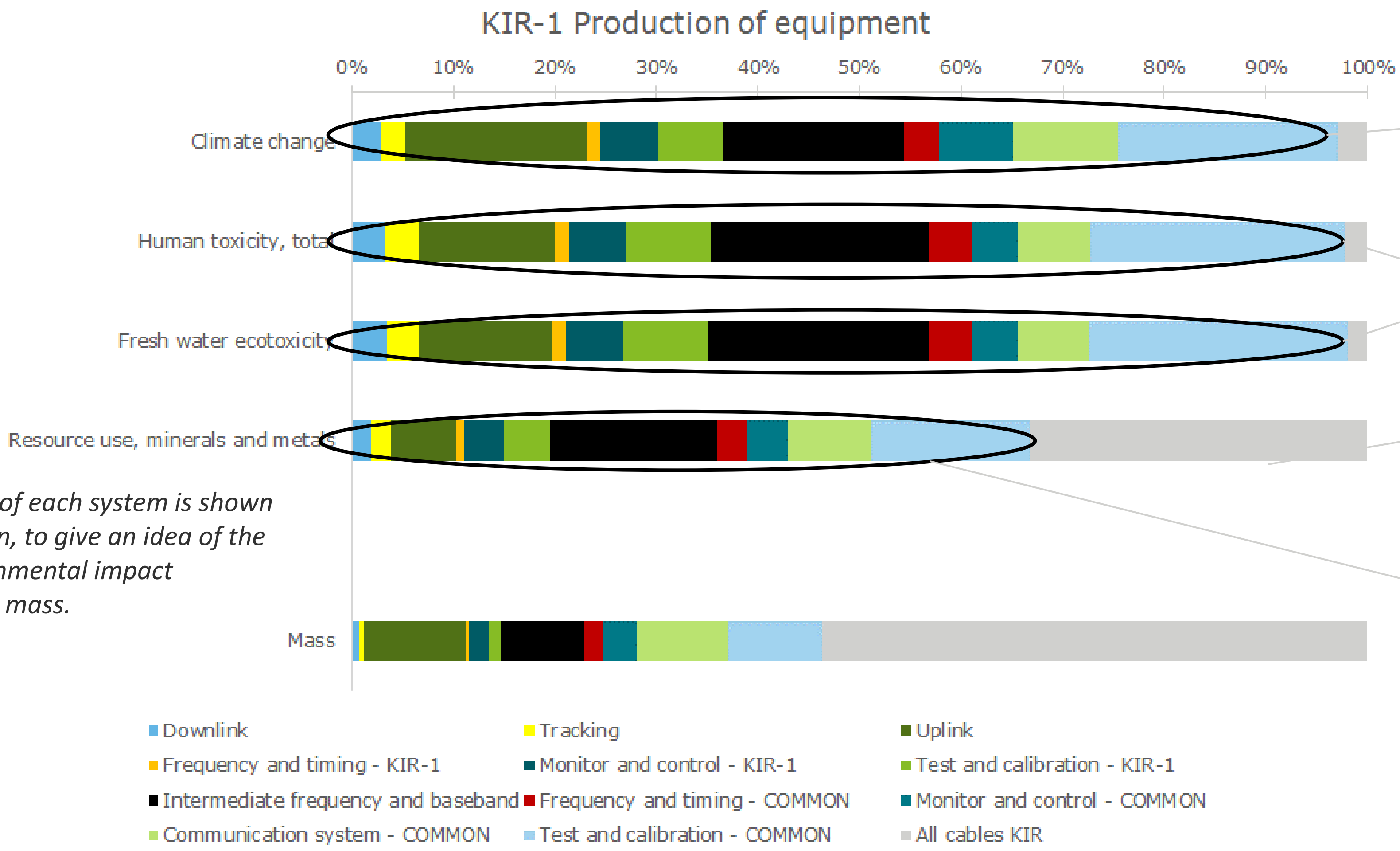


Note: the mass of each system is shown as an illustration, to give an idea of the system's environmental impacts compared to its mass.

Functional unit: To fulfil the requirements of operating the 15m antenna KIR-1 during one year

Kiruna-1 LCA results

Metals in electronics and cables contribute the most to environmental impacts of “Production of equipment”



GHG emissions from electricity use in printed wiring board manufacture

Treatment of sulfidic tailings from gold in in printed wiring board manufacture

Zinc consumption for electronic cables

Consumption of gold and tantalum in printed wiring boards manufacture

Note: the mass of each system is shown as an illustration, to give an idea of the system’s environmental impact compared to its mass.

Functional unit: To fulfil the requirements of operating the 15m antenna KIR-1 during one year

Conclusions

The main takeaways from LCA results

- Differences between the two stations can mainly be attributed to **difference in antenna size & weight.** The antenna contributes to most of the environmental impacts for Cebreros, but not as much for Kiruna-1 *(CEB-1 is more than 40 times heavier than KIR-1)*

- Mineral resource depletion and toxicity are significantly impacted due to the high quantity of **batteries, cables, and electronic equipment**

- The **green electricity certificates** from Kiruna and Cebreros mean that the stations' electricity consumption does not have a significant impact to climate change

- Instead, **plane and car travel from visitors and staff** account for a non-negligible amount of impacts to climate change

How to derive the environmental impacts of other ground stations?

How to derive the environmental impacts of other ground stations?

Similarities and differences between ground stations

From our analysis, the following high-level similarities and differences between all ground stations have been identified:

Main similarities
• Overall station and signal processing architecture
• Front-end, back-end and support systems and equipment

Main differences
• Antenna size
• Location, latitude and climate and hence energy requirements for air conditioning and heating • More precisely on the influence of the location, environmental impacts from energy consumption are predominantly defined by the local electricity mix
• Space missions and services provided, which determines if there are some specific equipment (e.g. cryogenic LNA or maser)

How to derive the environmental impacts of other ground stations?

Developing a simplified LCA for other ground stations

To evaluate the environmental impacts of ground stations other than Kiruna and Cebreros, there are two cases to be considered:

Ground station	LCA method	Objective	Data required
Other ESTRACK ground stations	Method used in this study	Focus on the ground station itself, and implement environmental mitigation options	EPTI extracts, allocation of equipment into families, a significant amount of station-specific information
ESTRACK or Non-ESA ground stations	Simplified method	To have a general idea of the station’s impacts within the greater context of a space mission (for example, the specific contribution of different equipment cannot be known)	A small number of key station-specific parameters

How to derive the environmental impacts of other ground stations?

"Recipe" for simplified LCA of non-ESTRACK ground stations

This simplified LCA method can be devised by using extrapolations and assumptions based on the results obtained for Kiruna and Cebreros stations and adapting several key parameters in each category:

Production of equipment

- Ground station for NE/LEO missions with small terminal ≈ Kiruna proxy
- Ground station for DS missions with large terminal ≈ Cebreros proxy

Operations

- Yearly station energy consumption
- Local or country grid electricity mix
- Number of yearly station visits and business trips
- Commuting

Transport and distance modes to be adjusted

Infrastructure

- Extrapolation of antenna size based on diameter
- Small terminal ground station ≈ Kiruna
- Large terminal ground station ≈ Cebreros

Maintenance

- Assumptions on number of yearly technician visits
- Assumptions on number of equipment pieces sent to maintenance (ESOC)

Transport and distance modes to be adjusted

Solutions for reducing environmental impacts of ground stations

Solutions for reducing environmental impacts of ground stations

How environmental mitigation options were identified

Objectives

- To identify ecodesign options (i.e. modifications of the design of a ground station system) or environmental mitigation options to reduce the environmental impacts of Ground Station (GSt) systems.
- Focus on existing stations, but options for future stations also welcome

Workflow

1. Summary of identified hotspots
2. Brainstorming sessions with GSt operators and ESA experts
3. Identification of enviro. mitigation options
4. Environmental & technical-economic criteria
5. Trade-off & ranking options with global score

Solutions for reducing environmental impacts of ground stations

Identified environmental mitigation options

Based on the brainstorming sessions with ESA experts and Ground Station operators, a range of environmental mitigation options were identified.

Hotspot	Option
HS 1 – Visitors travels	Option 1: Reduce the number of visitors
HS 2 – Equipment lifetime	Option 2a: Increase equipment maintenance to prolong their lifetime
	Option 2b: Increase testing of batteries to prolong their lifetime
HS 3 – Cooling fluids	Option 3: Use new cooling fluids
HS 4 – Batteries	Option 4: Use new generations of batteries
HS 5 – Electronics	Option 5a: Switch from analogic to digital
	Option 5b: Implement virtualisation of ICT equipment
HS 6 – Energy consumption	Option 6a: Produce on-site green electricity with photovoltaic panels
	Option 6b: Decrease / Increase the AC temperature setting by 1 or 2°C
	Option 6c: Improve the thermal insulation of the buildings
	Option 6d: Improve the efficiency of high power amplifiers
HS 7 – Mass of cables	Option 7: Reuse old non-used cables still in the station
HS 8 – Shipping of items	Option 8a: Implement local / regional maintenance
	Option 8b: Group the items to be shipped for repair
	Option 8a: Implement local / regional maintenance
HS 9 – Antenna	Option 9a: Further optimisation of the structure through computer-aided design tools
	Option 9b: Switch from steel to another material
	Option 9c: Use recycled steel

Solutions for reducing environmental impacts of ground stations

Conclusions

- The three identified options with the highest potential of reducing environmental impacts while remaining feasible are:

    - **Produce on-site green electricity** (this solution has already been implemented at the ESA site in New Norcia, Australia, via solar panels) *(Option 6a for reference)*

    - **Implement virtualisation of ICT equipment**, to reduce the number of physical PCs and monitors *required (Option 5b for reference)*

    - **Improve the efficiency of high-power amplifiers** *(Option 2d for reference)*

- It appears that **many of the identified ecodesign options remain rather generic** and do not specifically apply to ground stations. The main reason behind this is the fact that **the technical requirements applicable to ESTRACK stations are so specific and peculiar that little room is left for the exploration of innovative measures**.

- It was not possible to perform an in-depth analysis of the ecodesign options in the frame of this study, nor their quantitative environmental assessment (mainly due to a lack of data/specifications concerning the ecodesign options).

Conclusions & recommendations

Conclusions of the project

- The **LCA of two very different ground stations** was performed, allowing for a better understanding of the hotspots and the sources of their environmental impacts.
- The **methodology** used for this detailed assessment has **various advantages**:
  - ✓ All equipment contained in the EPTI are covered by the modelling, meaning there is a 100% equipment coverage rate
  - ✓ Environmental impacts can be traced back to each product tree system
  - ✓ The modular nature of this LCA model means it can be generalised and applied to other stations in the ESTRACK network given that the overall architecture, systems and components remain very similar in each ground station.
- A **simplified methodology** was also proposed to derive the environmental impacts of other ground stations in a more simplified way.
- Different high-level **environmental mitigation options** were identified, their relevance could be further investigated through a more detailed environmental and economic assessment.

Recommendations for future work

Life cycle assessment (LCA)

- **Refine the weights considered for the equipment**, and include the weights in the ECDB?
- Include a **bottom-up approach for electricity consumption of equipment** and air conditioning to identify which equipment use the most electricity
- In some cases, the inventory data could be more representative of the systems studied. **Later versions of the available LCA databases** might help to use more recent data or more specific inventories, especially regarding the electronics.
- The **breakdown of transport modes of different types of visitors** to the station could also be refined.

Ecodesign & environmental mitigation

- Perform a **more detailed assessment of the different proposed options** to refine and adapt their relevance to the context of each specific ESTRACK station.

Thank you for your attention!

Any questions?

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