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Ground Segment LCA – Methodological and Quantitative

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TABLE OF CONTENTS

		Page
LIST OF TABLES		**3**
LIST OF FIGURES		**3**
ABBREVIATIONS AND ACRONYMS		**4**
OVERVIEW		**5**
1	**OVERVIEW OF DIFFERENT GROUND SEGMENTS FOR DIFFERENT MISSION TYPES**	**6**
1.1	IDENTIFICATION OF DIFFERENT GROUND SEGMENTS	6
1.2	GROUPING OF GROUND SEGMENTS	6
1.3	IDENTIFICATION OF MAIN ELEMENTS AND SUBSYSTEMS	7
2	**LIFE CYCLE ASSESSMENT OF GROUND SEGMENT**	**9**
3	**METHODOLOGICAL GUIDELINES FOR LCA FOR GROUND SEGMENT**	**12**
4	**ECO-DESIGN**	**14**
5	**CONCLUSIONS**	**19**
REFERENCES		**22**

LIST OF TABLES

Table 2.1: List of Sites, Ground Segments and Mission Families 9
Table 2.2: Mission Names 9
Table 2.3: Missions & Facilities 10
Table 2.4: Normalization of Ground Segment of Space Missions 11
Table 3.1: Mission Families vs. Ground Segment Typologies 12
Table 4.1: List of hotspots 15

LIST OF FIGURES

Figure 1.1: ESA Mission Types and Ground Segment Resources 6
Figure 1.2: Ground Segment Families 7
Figure 1.3: RF Ground Terminal top-level architecture 8
Figure 1.4: Mission Operations Centre top-level architecture 8
Figure 3.1: Ground Segment System Boundaries 13
Figure 4.1: Example of HAC solution 16
Figure 4.2: Small reflectors 17
Figure 4.3: Reinforced concrete tower manufactured 18

ABBREVIATIONS AND ACRONYMS

Acronym	Meaning
EO	Earth Observation
EOL	End-of-Life
ESA	European Space Agency
ESAC	European Science and Astronomy Centre (Spain)
ESEC	European Space Security and Education Centre (Belgium)
ESOC	European Space Operations Centre (Germany)
ESRIN	European Space Research Institute (Italy)
ESTEC	European Space Research and Technology Centre (Netherlands)
ESTRACK	ESA Tracking Network
EU	European Union
GNNS	Global Navigation Satellite System
GS	Ground Station
GSS	Galileo Sensor Station
HAC	Hot-Aisle Containment
ILCD	International Reference Life Cycle Data System Handbook
ISO	International Organization Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MOC	Mission Operations Centre
RED	Redu Space Services (Belgium)
SOC	Scientific Operation Centre
SST	Space Surveillance and Tracking
TRL	Technology Readiness Level

OVERVIEW

This report collects all results coming from the activities performed in the course of "LCA Ground Segment" project in order to sum up its main outcomes.

Chapter 1 presents the Overview of different ground segments for different mission types, related to Technical Note 1.

Chapter 2 is related to the Life Cycle Assessment of Ground Segment, while Chapter 3 deals with Methodological Guidelines: they sum-up the activities of Task 2 (1^{st} iteration) and Task 3 (2^{nd} iteration) presented finally in Technical Note 3.

Finally, Chapter 4 provides the Eco-design results, as described in Technical Note 4.

1 OVERVIEW OF DIFFERENT GROUND SEGMENTS FOR DIFFERENT MISSION TYPES

For the development of Task 1, a three steps sequential process has been adopted; the outputs of each step constitute the inputs of the next [1].

1.1 IDENTIFICATION OF DIFFERENT GROUND SEGMENTS

This initial task aims the early identification of the various **ESA mission types** under ESA's scope of activities as well as the overall architecture of the global network of hardware resources constituting **ESA's Ground Segment** (Figure 1.1).

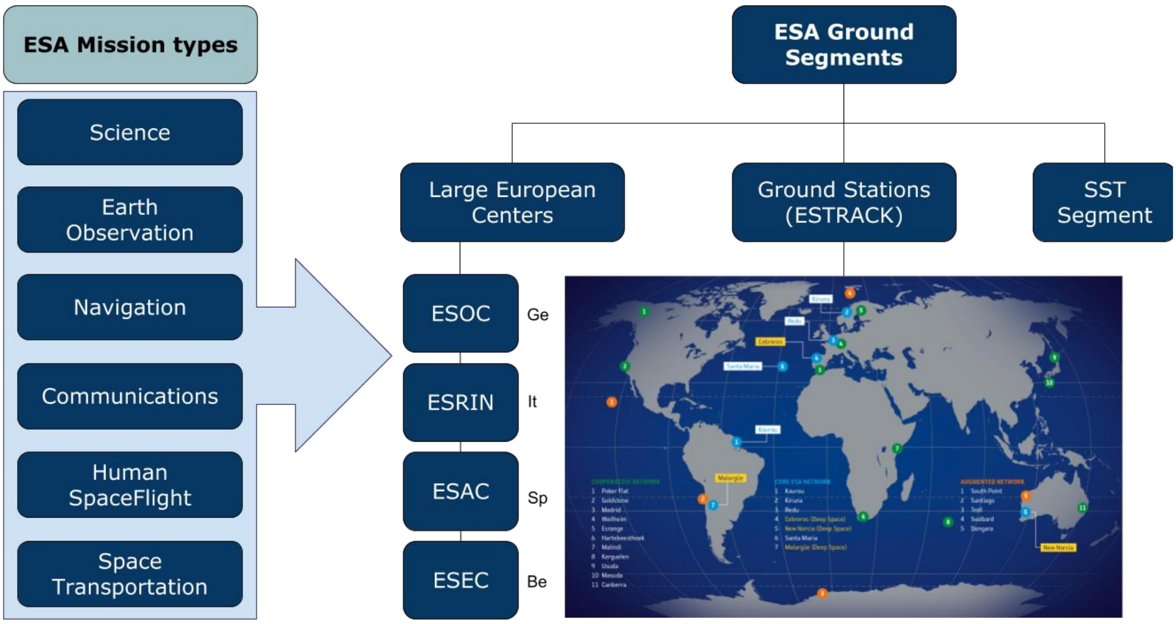

Figure 1.1: ESA Mission Types and Ground Segment Resources

A survey of ESA and non-ESA has been performed with emphasis in the identification of the different types of Ground Segment resources required for its operation.

- ESA mission types explicitly covered by the present study are: **Science, Earth Observation and Navigation.**
- The study is not limited to only ESA missions: **Communications, New Space-CubeSat Missions** are also addressed.

This is the **bottom-up approach** of the analysis: **From mission → to Ground Segment Building Blocks**

The expected output of this task is the initial identification of **Ground Segment (major) Components**.

1.2 GROUPING OF GROUND SEGMENTS

For each one of the mentioned "major components", this task has developed its top-level architecture not only in terms of the mission specific hardware resources (antennas, servers, computers etc) but also in terms of additional resources required by the space missions for its operation such as:

- Human resources (personnel),
- Material resources for the construction of the infrastructures,

- Material resources for the operation of the infrastructures.

Following the development of top-level architecture diagrams, a cross-correlation among them all has been performed to identify commonalities; as a result, the consolidation of the Ground Segment LCA Families is achieved (Figure 1.2).

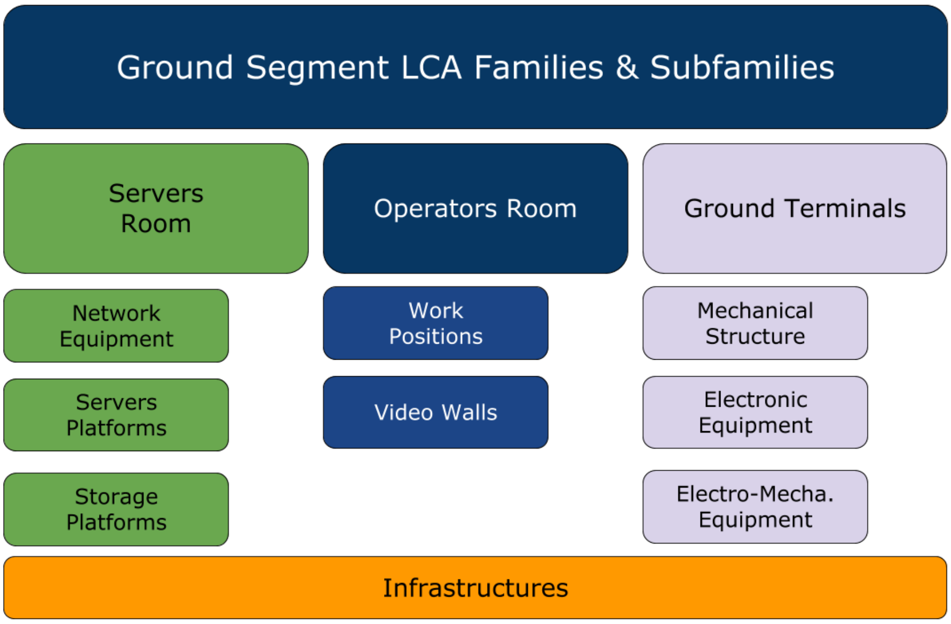

Figure 1.2: Ground Segment Families

1.3 IDENTIFICATION OF MAIN ELEMENTS AND SUBSYSTEMS

Considering that the previous task only deals with top-level architecture diagrams, this task aims to increase the granularity of the analysis, for such purpose, several study cases has been selected covering the complete range of Ground Segment facilities, for each case, detailed architecture diagrams (down to subsystem and equipment level) are developed.

This is the **top-down approach** of the analysis: **From Facility → to Equipment**

This information will be used *a-posteriori* by the LCA assessment to populate the database.

As an example, below are reported the Block Flow Diagram for a generic Ground Station (Figure 1.3) and Mission Operation Centre (Figure 1.4).

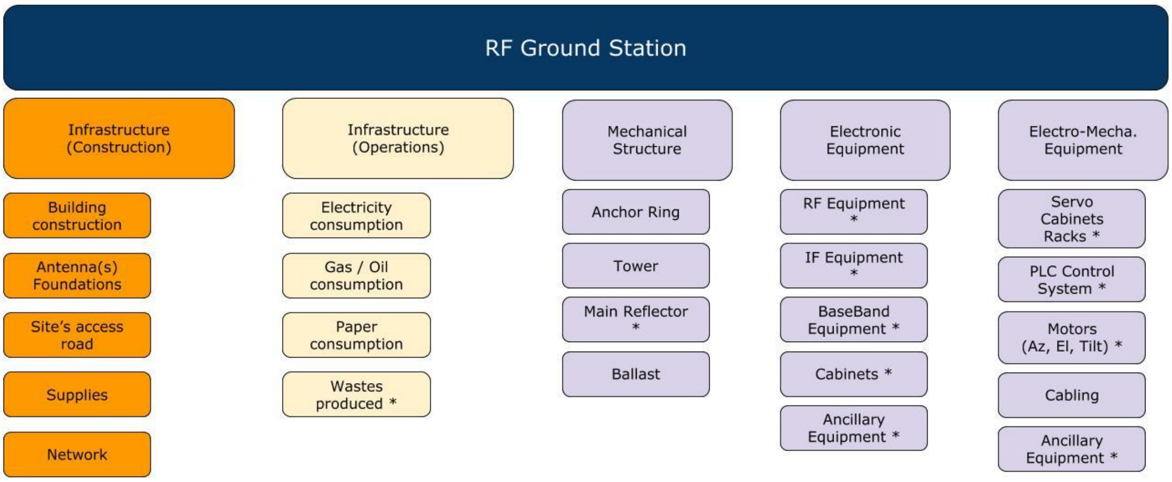

Figure 1.3: RF Ground Terminal top-level architecture

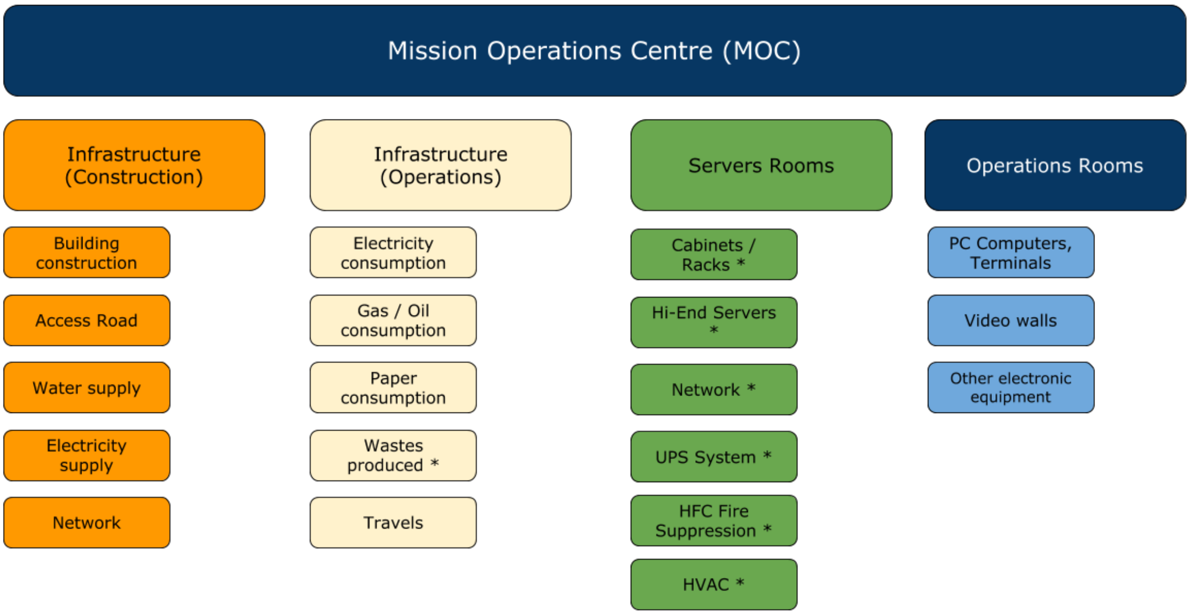

Figure 1.4: Mission Operations Centre top-level architecture

2 LIFE CYCLE ASSESSMENT OF GROUND SEGMENT

This Chapter is related to the application of LCA methodology to the Ground Segment. This is the result of two iterations made by the Consortium.

The **Goal & Scope** of the Study is to assess in a quantitative and objective manner the environmental impacts of Ground Segment related to different mission families. The selected as functional unit is “the Fulfilment of the requirements on the Ground Segment to support any ESA Space Mission, along its lifetime”.

The **Life Cycle Inventory** has been conducted for three different phases of the Ground Segment:

A) the **development phase of** the different ground systems (equipment) constituting the Ground Segment, using the cradle to gate approach to model around 170 datasets. The FU selected for this specific analysis is “1 kg of ground systems (equipment)”

B) the **maintenance and operations (M&O) phase of the ground segment**, implying also the use-phase of the different ground systems constituting the ground segment. The FU selected for this specific analysis is “1 year of M&O of the facility, considering also the Antenna Diameter (for the Ground Station - GS) or the square meters facility (for the Mission Operation Centre - MOC or Scientific/Data Centers – SOC/DPC)”.

C) the **overall ground segment, considering development phase of all the ground system installed on site.** This study has been done for Deimos Puertollano facilities (MOC and GS), Kiruna and Cebreros (both of them GS). **The FU selected for this specific analysis is “the Ground Segment facilities ready to be used for the management of one or more missions”.**

Here the list of assessed ground segment elements per site, and mission family (Table 2.1):

Table 2.1: List of Sites, Ground Segments and Mission Families

Site	Ground Segment	Mission Family
Deimos Puertollano	Ground Station 1	Earth Observation
	Mission Operation Centre	Earth Observation
Deimos Puertollano (LeafSpace)	Ground Station 2 (LeafSpace)	CubeSat
Hispasat	Ground Station	Telecommunications
	Mission Operation Centre (MOC)	Telecommunications
Kiruna	Ground Station	Earth Observation
Cebreros	Ground Station	Science
Redu	Ground Station	Navigation
ESOC	Mission Operation Centre (MOC)	Earth Observation, Science
ESAC	Science Operation Centre (SOC)	Science
ESRIN	Data processing Centre (DPC)	Earth Observation

The study assessed the environmental impact of the different mission families, using following missions as a reference (Table 2.2).

Table 2.2: Mission Names

MISSION FAMILIES	NAME
Science	GAIA
Earth Observation	Sentinel 3 (ESA mission), Deimos – 2 (non ESA mission)
Navigation	Galileo
Communication	Hispasat
CubeSat	LeafSpace mission

Each mission requires the involvement of different facilities as presented below. Not all sites have been modelled using primary data due to lack of information, thus in that case assumptions based on Ground Segment expertise have been made (Table 2.3).

Table 2.3: Missions & Facilities

Mission Family	Mission NAME	Mission Operations Centre (MOC)	Science/Data Processing Centre (SOC/DPC)	Ground Station(s)	Note
Earth Observation	Deimos 2 (non-ESA mission)	Deimos MOC (Puertollano), SP	N/A	- Deimos PL01 (Puertollano), SP - Kiruna, SW - Svalbard, NW	Kiruna, Svalbard assumed similar to PL01. (Not Kiruna/Svalbard related to ESTRACK, but managed by SSC)
	Sentinel 3	ESOC (Darmstadt), GE	ESRIN (Fucino), IT	- Kiruna, SW - Svalbard,NW; - Troll, NW	Svalbard and Troll are assumed similar to Kiruna.
Navigation*[1]	Galileo	N/A	N/A	N/A	
Science	GAIA	ESOC (Darmstadt), GE	ESAC (Villafranca), SP	- Cebreros, SP - Malargue, AR - New Norcia, AU	Malargue New Norcia are assumed similar to Cebreros.
CubeSat	Leaf Space	Deimos MOC (Puertollano), SP	N/A	- Deimos PL02 (Puertollano), SP	
Communications	Hispasat 35W	Hispasat MOC (Arganda del Rey), SP	N/A	- Hispasat (Arganda del Rey), SP	

This study [2] results in a list of the most significant issues (i.e. **hot-spots**), mainly in the domains of Global Warming Potential, Metal Depletion, Human Toxicity[2], and a quantification of their contribution with respect to overall result, i.e. the Ground Segment impacts realised for the fulfilment of the lifecycle of the selected mission.

During the M&O phase, the electricity consumption is the main hotspot in the different facilities, followed by heat production and waste treatment.

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[1] Galileo is managed by a more complex facilities structure, presented in Appendix F, whose quantitative data are in any case missing, due to confidential reasons

[2] These three indicators have been suggested as the most important for the hotspots evaluation.

For the development phase of ground Segment components, due mainly to the huge amount of stainless steel used, the mechanical structure is the most impacting contributor in Ground Segment.

Finally, as regard overall Ground Segment dedicated to a Space Mission, the phase E2 (Utilisation) appears to be the most impacting phases, even if for specific mission families, the contribution of specific equipment could be a hotspot, considering the entire mission lifetime from Ground Segment perspective.

A normalization approach has been defined in order to express the results for an easier understanding.

The approach chosen is to normalise the GWP (Global warming potential dal- [kg CO_2 eq.]) impact indicator coming from the Ground Segment LCIA, with the "km covered by a car[3]" (Table 2.4). In addition, these values have been translated also in terms of Earth-Moon distance[4].

Table 2.4: Normalization of Ground Segment of Space Missions

Mission Family (Mission Name)	GWP Impacts of the entire Ground Segment Mission, normalized through km covered by a car	Earth-Moon distance	Main Hotspot	GWP Impacts of the Mission Hotspot, normalized through km covered by a car	Earth-Moon distance
Earth Observation (Deimos 2)	1,13E+06 km	~3	Phase E2	4,28E+05 km	~1
Earth Observation (Sentinel 3)	1,62E+08 km	~421	Phase E2	1,45E+08 km	~377
CubeSat (LeafSpace)	4,88E+04 km	~0,1	Baseband System	4,64E+04 km	~0,1
Telecommunication (Hispasat)	2,01E+05 km	~0,5	Phase E2	1,92E+05 km	~0,5
Science (GAIA)	1,27E+09 km	~3304	Phases A/D	7,08E+08 km	~1842

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[3] Medium Size Car, Euro 4, Gasoline Driven

[4] 384 400 km

3 METHODOLOGICAL GUIDELINES FOR LCA FOR GROUND SEGMENT

The present chapter sums up the set of methodological rules [3] for performing a comprehensive quantitative assessment for Space Ground Segment, compliant with ESA LCA guidelines. This is a result of the LCA study presented above and it is a resume of the guidelines which can be inserted in ESA LCA Handbook.

Five mission families have been identified and studied (Table 3.1):

- Earth Observation Mission,
- Science Mission,
- Telecommunication Mission,
- Navigation Mission,
- CubeSat Mission,

and consequently, a recap on the main facilities (and their building blocks) is provided:

- Ground Station – GS,
- Mission Operation Centre – MOC,
- Science Operation Centre / Data Processing Centre – SOC/DPC.

Table 3.1: Mission Families vs. Ground Segment Typologies

Mission Family	GS	MOC	SOC/DPC
Science	X	X	X
Navigation[5]	X	X	
Earth Observation	X	X	X
Communications	X	X	
CubeSat	X	X	

The Guidelines follows the LCA structure and so a detailed overview of how to approach to Goal & Scope definition is provided. The starting point is the definition of the Functional Unit:

Fulfilment of requirements of Ground Segment for the entire mission, along its lifetime.

Then system boundaries (Figure 3.1), cut-off criteria, data quality evaluation and data collection procedure, multi-functionality and LCIA methodology have been studied and detailed in a separate document "LCA guidelines for Ground Segment".

Furthermore, one of the core activities is the creation of the Life Cycle Inventory. Ideally, the mission life cycle inventory should take into account:

- the data related to the Maintenance & Operation of the Facilities, across the Space Mission Phases, whose efforts are allocated based on hours (for GS) or man-days (for MOC/SOC/DPC) (*top-down approach*) – this includes the daily use of the facility and correspondent material and energetic consumptions;
- the contribution of Ground Systems Development, starting from a *bottom-up approach* for "building" the facilities and based on allocation for a single mission – around 169 different equipment/systems have been modelled and they can be used for building specific facilities.

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[5] Navigation mission foresees the support of different facilities, which can be classified according the main Ground Segment Typologies

Finally, the guidelines provide indications for the communication of results of environmental impact assessment in a consistent way across the different levels and information on mandatory contents of an LCA report.

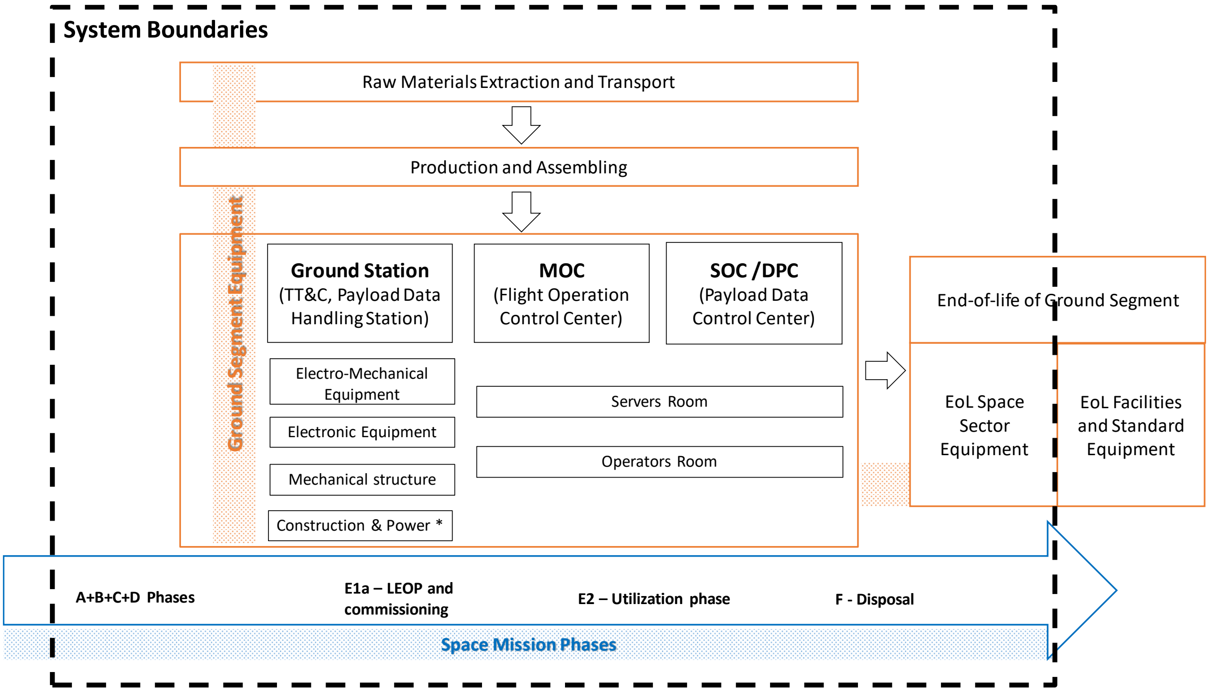

Figure 3.1: Ground Segment System Boundaries

4 ECO-DESIGN

This chapter reports briefly the activities related to LCA Results analysis and eco-design approach.

The activity starts with an in-depth analysis of the environmental impacts calculated in LCA activities. The main objective has been to identify where eco-design solutions may be more useful, in order to reduce GS environmental impact according to the three selected impact categories: climate change (GWP), metal depletion and human toxicity (carcinogenic).

The analysis, like the LCA, is divided into three impact assessments:

- Facility impact: Maintenance and Operation Phase;
- Facility impact: Development Phase;
- Mission impact.

A natural, common agreement was reached on the selection of the 3 main hotspots on which the research of eco-design options shall focus on (Table 4.1):

- ➢ Electricity consumption
- ➢ Stainless Steel manufacturing
- ➢ Printed Wiring Board manufacturing

Table 4.1: List of hotspots

Hotspot	Intensity	Assessment	Dataset name	Main contributor in	Affected indicators	Possible causes
Electricity consumption	Very high	Operation	Europe without Switzerland: market group for electricity, medium voltage ecoinvent 3.5	All facilties (except Hispasat MOC)	Climate change Metal depletion Human toxicity	- Greenhouse gas emissions from the use of fossil fuels in the electricity mix [climate change]. - The use of metals (Cu in particular) in the electric power generation, transmission and distribution [metal depletion]. - The mix production, which might include fossil sources (such as VOCs) that have processes with potential cancerigenous effects [human toxicity].
Lubricating oil consumption	Low	Operation	RER: lubricating oil production ecoinvent	Puertollano GT	Metal depletion	- The use of particles of Cu as anti-seize in oil lubricants, as well as the use of metals in general in the infrastructure throughout the production cycle.
Natural gas consumption for heating	Low	Operation	Europe without Switzerland: heat production, natural gas at boiler atmospheric non-modulating <100kW ecoinvent 3.5	Puertollano MOC, ESOC	Climate change Metal depletion	- Greenhouse gas emissions resulting from burning the NG, as well as methane leaks that happen during the drilling and transportation phases [climate change]. - The use of metals in the generation, transmission and distribution of natural gas [metal depletion].
Diesel consumption	Low	Operation	Europe without Switzerland: diesel production, low-sulfur ecoinvent	Hispasat MOC, Puertollano MOC	Climate change Metal depletion	- The use of metals for the transmission and distribution infrastructures.
Municipal solid waste treatment	Low	Operation	RoW: treatment of municipal solid waste. Sanitary landfill ecoinvent	Hispasat MOC	Human toxicity	- Emissions released during the landfilling phase (waste handling) and also the high energy demand of the sanitary treatment process [climate change]. - The highly contaminated leaches, which can mix with the environment and reach humans [human toxicity].
Stainless steel manufacturing	Very high	Equipment	stainless steel production (own creation)	Most mechanical equipment in the Ground Terminal	Climate change Metal depletion Human toxicity	- High amount of enregy needed in the manufacturing chain, specially the casting process [climate change]. - High use of metal as raw material as well as in different steps of the manufacturing process [metal depletion]. - Waste streams (containing several hazardous chemicals) and specific emissions [human toxicity].
Printed wiring board manufacturing for the IC units	Medium	Equipment	various	Most electronic equipment in the Operation Center and the Ground Terminal	Climate change Metal depletion Human toxicity	- Grenhouse gas missions from the high enregy use in the manufacturing process [climate change]. - High use of metals (such as copper and lead) as raw materials in the manufacturing chain [metal depletion]. - Highly-contaminated washwater (specially from the rinsing phase) and high amounts of hazardous waste metal that is difficult to dispose of.

Subsequently the identification of eco-design alternatives and the selection of the three most promising options is proposed. These 3 selected ideas of eco-design options are then studied in more details and finally refined both through an LCA assessment and a roadmap for their implementation.

The identification and prioritization of the eco-design options have been conducted during a series of Working Group sessions, through several eco-design activities involving brainstorming and other innovation techniques along the following steps:

- Step 1. Validation of hotspots
- Step 2. Brainstorming of alternative solutions
- Step 3. Preliminary high-screening of solutions
- Step 4. Multi-criteria analysis

Finally, four meetings were facilitated by CT and attended by RINA, Deimos and ESA.

Eighteen eco-design solutions have been identified and assessed based on several criteria, including environmental savings, costs, innovations level, maturity, scalability and others. The evaluation has been done on options that are already applied in some Ground Segment, through information found either in literature review or in other sectors.

The most promising are:

1. S2: Install HAC and adiabatic or free cooling in server rooms[6]
2. S9: Different design solutions for overall lighter design
3. S12: Use alternative material (concrete) for the GS tower and ballasts

The three main options have been further detailed in terms of technical and economic evaluations, preliminary design, implementation steps, TRL level starting from the facilities (Ground Station and/or Mission Operation Centers) assessed in the course of the project. The details are presented in the report.[4].

Hot aisle containment (HAC) (Figure 4.1) consists of a physical barrier that guides hot exhaust airflow back to the Air Cooling (AC) return. Hot aisle containment takes advantage of the natural properties of warm air rising. The HAC system directs the upward airflow to an AC return system such as a drop-ceiling void. HAC keeps hot exhaust air emitted from server racks separated so that it returns to the air-cooling system both hot and dry (low relative humidity) increasing the cooling capacity of the air-cooling system. Through HAC, the hot air is given a separate pathway back to the air-cooling intake without mixing with the cold air.

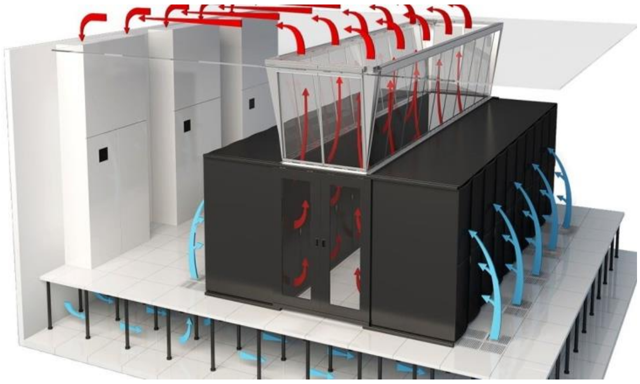

Figure 4.1: Example of HAC solution

HAC has a TRL of 9 and according to some studies, it theoretically reduces by 46% the cooling system energy and by 15% the total data center energy compared to the traditional uncontained baseline case. From an LCA point of view, the reduction of Carbon Footprint is around the 38% passing from a free cooling solution to HAC one.

The server room area in DEIMOS Mission operation Center has been taken as case study: the HAC could effectively substitute the units actually installed with minor changes in the layout and noticeable energy savings.

Lighter design for the Antenna can be reached through a reduction of the amount of stainless steel. It is possible to have, for equivalent size and performances, a much lighter design: the weight can be divided by 3. Most of the weight reduction comes from the structural parts: tower, ballasts and reflector back-structure, i.e. all the main stainless-steel parts. No information on the way the mass reduction could be achieved has been found. The proposal to have lighter design could be also adapted to MOC/SOC buildings: keeping in mind structural and safety requirements, also the civil buildings can be eco-designed. To achieve this, eco-design requirements shall be introduced, in particular to reduce of the amount of stainless steel, in order to reduce the environmental impact of these buildings, similarly as it can be done for Ground Terminals.

An alternative is linked with the proliferation of small satellites constellations (Figure 4.2). They might require new ground segments and the solution adopted by the major antenna services providers in response to this market demand is the deployment of dedicated antenna networks. The difference with respect to existing antenna networks is the significant reduction of the reflector sizes down to diameter $\Phi < 5$ m, with an increased number of antennas. A recommendation for future studies is to investigate the concept of array antenna.

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[6] As written also in the conclusion of this document, is not just a choice, but the outcome based on CT experience on GS and data centers, and among the eco-design solutions proposed, the air-conditioning for IT system gained the highest score.

The TRL for this solution (both substitution of stainless steel or use of small reflectors) is high with a rank of 8 or 9. The LCA performances (here Carbon Footprint) starting from Puertollano Ground Station, foresee a reduction of 57% for decrease of use of stainless steel and of 11% for use of small reflectors.[7].

Figure 4.2: Small reflectors

The TRL for this solution (both substitution of stainless steel or use of small reflectors) is high with a rank of 8 or 9. The LCA performances (here Carbon Footprint) starting from Puertollano Ground Station, foresee a reduction of 57% for decrease of use of stainless steel and of 11% for use of small reflectors.

The third solution is related to the identification of alternative materials for tower and ballast in Ground Station. Replacing this material by an eco-friendlier one is therefore a key track to reduce the impact of ground station.
The choice of the alternative material to replace the stainless steel is based on three criteria. It must:

- Fulfill the mechanical requirements, of the tower or the ballasts, such as stiffness, lifetime, survivability to its environment
- Have a high enough technological readiness level
- Have a lower overall ecological impact

Based on these three criteria, one convenient material to replace the stainless steel is concrete (Figure 4.3). The solution proposed is to replace the stainless steel of the tower and the ballasts, by concrete:

- For the tower pedestal, this complete part can be replaced by a reinforced concrete structure,
- For the ballasts, instead of being a full stainless-steel piece, it can be replaced by a hollow stainless-steel structure filled-in with concrete. The concrete is here simply replacing the stainless-steel weight: the antenna design should be evaluated: i.e. cassegrain vs. front feed, offset feed, Gregorian.

Environmental results on this solution, in terms of carbon Footprint, show that there is a reduction of around 30%.
The substitution of stainless-steel with alternative materials could be widened to other Ground Segment types and should be deeply investigated in future studies, taking into account the technical, economical, temporal constraints, avoiding also burden shifting.

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[7] The solution can be applied only to specific mission families, like KSAT.

Figure 4.3: Reinforced concrete tower manufactured

For these 3 solutions, the next step will necessarily be a dedicated analysis, in order to confirm the conclusion presented here and to gain more detailed insight on how and where the proposed solutions can be applied, and at what costs and risks. Then ESA can decide to use guidelines, requirements or provider selection in order to ensure that these solutions are applied.

All the proposed solutions are expected to improve the environmental performances of the ground segment. Briefly the solutions are able to provide benefits with range from 10% to 70% according different environmental indicators.. According the evaluation already done in terms of steps for a factual implementation, time and monetary resource needed, linked risks, the three solutions represent generally a good and realistic approach towards a reduction of environmental impacts. In any case, all these solutions will require additional effort to be implemented, especially from an economic point of view. In particular, a detailed cost analysis is needed to deploy HAC technology (S2) on different data centers. While solutions S9 and S12 require a technical and performance analysis in addition to a cost assessment prior to any implementation.

Moreover, even though this study did not aim at developing all the ideas, it is believed that some of the ideas that came out of the brainstorming activities might still be interesting for ESA and could be applied to reduce the GS impacts.

5 CONCLUSIONS

The main objective of this project has been to assess the environmental impacts of ground segment in the space industry and, consequently, to develop methodological guidelines for the assessment of this specific segment of the space mission, through LCA methodology. Finally, an eco-design approach for reducing overall impacts, has been applied.

The first part of the study, thanks to the combined use of the bottom-up analysis approach (from Mission up to Ground Segment major components like MOC, SOC, GS) as well as the top-down approach (from Ground Segment major components down to equipment architectures) provides an identification of the Ground Segment Families.

The main building blocks identified have been transformed in LCA datasets, useful for creating the LCA models of different missions.

The identified families, as reported in Figure 1.2, have been used for the Life Cycle Assessment, related to:

- M&O phases of the ground segment, i.e. Ground Stations, Mission Operation Centers, Data/Science Centers in terms of energy sources consumptions (electricity, diesel, gas), water and paper use, waste produced, consumables use;
- Ground Systems development phase (manufacturing);
- Overall Ground Segment of Puertollano (MOC & GS), Kiruna GS and Cebreros GS (from cradle to gate);
- Space missions' life cycle, i.e. all phases from A to F.

The main outcome from the ground segment M&O phase is that in most cases the electricity consumption represents the hotspot, so the highest impact contributor to all environmental indicators. The latter depends on the high electricity (which also contains fossils resources in its mix production) requested by the ground segment facilities during the M&O activities.

For what concerns the ground systems of selected facilities (development phase), the Ground Station has been identified as the major hotspot. The impacts depend mostly on the weight of mechanical structure of GS and consequently the stainless steel (main contributor is ballasts). MOC has lower impacts than the GS; nevertheless, the most contributing systems are high-end servers and storage platform, which reflect the amount of integrated circuit electronic units.

Regarding the space mission life cycle, by quantifying and comparing the impacts of the Ground segment on the different mission phases, the most impacting one is the E2 phase. This is due to its duration and the consumption (mainly electricity for PCs, servers), waste produced etc.: so it is recommended to adopt environmental-friendly policies applied to the ESA facility management procedures, including the supply chain (energy feed, paper, electronic devices). It is worth to notice that for missions which require a long design and development time (e.g. science missions like GAIA[8]), the phases A/D could have a valuable impact in the Ground Segment Mission Life Cycle. It can be observed that the duration of the mission phases is directly linked with the environmental impacts of the Ground segment of the mission. The environmental impacts of the Ground Segment Mission need to be integrated with the ones of the space and launch segments in order to derive complete environmental footprint of the mission and therefore derive conclusions.

A lesson learnt from this study is the need to include when possible (not always possible due to data availability), the manufacturing process of the Ground Systems. To do this, several data are needed and so a complete knowledge of facilities in terms of mechanical, electronic, electro-mechanical families is needed.

Improving and promoting specific regulation/guidelines/procedures for data collection, could help to have the most complete overview of the Ground Segment and, consequently, the highest accuracy in terms of LCA results.

Based on the results of the LCA, the final tasks aimed at identifying the environmental hotspots, i.e. the main sources of environmental impact of the ground segment. While focusing on 3 impact categories (climate change, metal depletion and human toxicity), the following 3 hotspots have been revealed:

- Electricity consumption during the operational and maintenance of the overall ground segment
- Use of stainless steel, mainly in the manufacturing of the mechanical equipment of the ground stations

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[8] GAIA is considered a non-standard mission

- Use of Printed Wiring Boards (PWB) for the Integrated Circuit Units of the electronics in the operation centers.

These three hotspots were selected in order to find eco-design solutions to reduce the impact on the environment of the Ground Segment.

The solutions were first identified during a series of Working Group sessions, which involved people from RINA, DEIMOS, CT and ESA. The different eco-design working sessions involved brainstorming techniques and followed a methodological path, starting from **functional analysis** to define the need followed by **creativity sessions** for producing ideas. These activities were successful as they resulted in the identification of 18 ideas for reducing the impact of the environment hotspots identified.

In the second part of the work group activities, the ideas were rated using a weighting criteria method. The criteria was defined to evaluate the overall interest of the ideas on 3 main topics: environment, technology, cost. Based on the score for each criteria and the weight assigned to the criteria, a global score was computed for each idea. The 3 best ranked ideas selected for further development are the following:

1. S2: Install HAC and adiabatic or free cooling in server rooms
2. S9: Design different mechanical solutions for overall lighter design
3. S12: Use alternative material (reinforced concrete) for the GS tower and ballasts

The proposed eco-design solution aim to reduce the electricity consumption (S2) and the amount of stainless steel needed in future ground stations development (S9 and S12).

A detailed analysis of these three solutions was done in order to assess their feasibility, maturity and environmental performance. During literature review and experts' interviews, RINA discovered that some of the solutions proposed are already applied in some ESA ground segments. This study confirmed the benefits of these design choices and the need of applying this procedure in future technological development for ground systems. S2 could also be applied in the existing facilities.
The LCA analysis of the 3 eco-design solutions, shows that an improvement of the environmental performances is possible if they will be implemented[9]. The environmental benefits coming from this analysis will need to be refined since they are based on literature review and assumptions, but they provide us with an order of magnitude of the benefits expected.
Together with the environmental benefits, the steps for implementation of these solutions, the risk associated and a rough estimation of their cost, were defined when possible. For these 3 solutions, the next step will necessarily be a dedicated analysis, in order to confirm the conclusions presented here and to understand the applicability, cost and risk of the proposed solutions. Then, ESA can decide to use guidelines, requirements or provider selection in order to ensure that these solutions are applied.
Moreover, even though this study did not aim at developing all the ideas, it is believed that some of the ideas that came out of the brainstorming activities might still be interesting for ESA and could be applied to reduce the Ground Segment impacts.
Some final recommendations for future work include:

- Improvement of modelling with detailed inputs to confirm preliminary conclusions from this activity at ground segment type level, mainly related to Ground system development phase: this is needed to have a detailed picture of the options before thinking about a real implementation.
- Assessment of electrical consumption reduction measures at ground segment level, for data centers by e.g. combining/sharing resources, due to the huge amount of electricity required by them;
- Increase of Research and Technological funding in development of local independent and sustainable electrical production means, like green sources (i.e. photovoltaic, wind) with use of batteries for the management of peaks.

As a first step for impact reduction of the Ground Segment, the following additional recommendations are provided. The solutions could reduce electricity consumption's environmental impact:

- Use «greener» electricity (options to be evaluated case by case, depending from application and geographical location):
  - from renewable sources (install on-site renewable electricity production, etc.),
  - purchase "clean" electricity from providers,

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[9] Ecodesign solutions modeling based on literature review and assumptions.

- compensate electricity consumption:
  - use heat from hot rooms for other purposes: for energy production or buildings' heating,
  - use cold from cold environments for refrigeration,
- reduce consumption:
  - raise awareness of electric hotspots by analyzing consumption breakdown (via energy provider's invoice and/or sensors on major branches), both on a yearly basis and as a leak/anomaly early detection,
  - from CT experience on ground segment and knowledge about data centers, server rooms need a permanent high energy amount to feed both IT systems and associated air-conditioning equipment.

REFERENCES

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[3] P0008945-1-H5_rev3 – TN3: 2nd Iteration LCA

[4] P0008945-1-H6_rev1 – Results analysis and eco-design