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CleanOrbit: Laser-based Space Debris Deorbiter

(CO-LSDD)

Horizon Europe Programme

Project proposal – Technical description and Budget

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Laser-based Space Debris Deorbiter

A summary of the consortium members involved in this proposal are listed below.

List of participants

Participant No.	Participant organisation name	Country
1 (Coordinator)	CleanOrbit	Spain
2	TU Delft	Netherlands
3	ISAE-SUPAERO	France
4	Universität Bremen	Germany
5	IAC	Spain
6	DIGOS	Germany
7	CILAS	France

1 Excellence

1.1 Objectives and ambition

Since the early days of space exploration, the aim and attention have been set in getting equipment out in space without actually considering what happens when it is not useful anymore. That is why most satellites and systems have been forgotten once they have reached the end of their service life. According to ESA, in recent years there has been a noticeable increase in the number and size of launches performed. While missions in higher orbits are usually successfully disposed of, more than half of the operators with equipment in Low Earth Orbits (LEO) take no action in that direction.

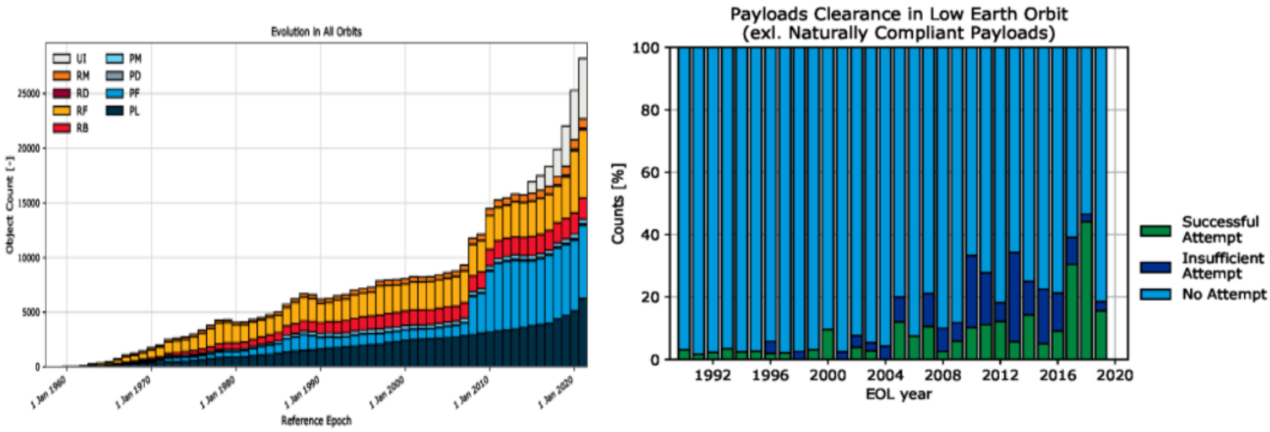

Figure 1: Number of launches along the years (left), deorbiting attempts with time (right) [1]

In-space collisions can be a very alarming debris generation mechanism. An example of that is the case when in 2009, an American Iridium satellite collided with a russian Kosmos satellite, and the resulting cloud of debris combined with that from the Chinese Fengyun 1C ASAT test in 2007, greatly increased the density of debris around the earth, prompting concerns about the safety of the final Hubble servicing mission. Orbital debris are now sufficiently dense that the use of LEO space is threatened by runaway collision cascading. A problem predicted more than forty years ago. The instability predicted by Kessler and Cour-Palais (1978) often called the Kessler syndrome is a scenario in which the density of objects in LEO space due to space pollution is high enough that collisions between objects could cause a cascade in which each collision generates space debris that increases the likelihood of further collisions.

The combination of the trends stated before with the Kessler syndrome has led to an enlargement of the amount of debris humankind has left on orbit. If not taken any action, the safe operation in space will become increasingly harder, making space exploration unsustainable.

While improved debris tracking and orbit prediction can temporarily improve threat avoidance via maneuvering, effective debris clearing strategies will be necessary.

In response, this project aims the implementation of an ecosystem oriented both to tracking and analysis of orbit debris to deorbiting action of light and heavy objects which could present a hazard to the orbiting satellites and their trajectory.

In order to achieve our goal the project is divided in to the following objectives:

- Creation of a passive and active system that monitors anticipates the potential danger towards orbiting satellites and acts accordingly using laser technology.
- Design of a high-powered ground-based plasma laser technology as a means of acting on targets with the aim of deorbiting them or reducing the risk of impact on other objects of interest.

- Develop this project efficiently in order to became a potential European resource in the competitive market of the aerospace sector.
- Built and construct the laser system with the latest technology while guaranteeing the least environment impact.
- Implementation of a prototype and testing protocol as a means of guarantee the security and the efficiency of the laser system and its software.
- Definition of documentation and maintenance information to ensure the correct behavior of the system.
- Design a service model for European users and different operators (as well as public entities) capable to protect the physical integrity of the current satellites in orbit using the laser technology designed through this project.
- An extensive study of the feasibility and its relation with ESA regulations and other legal concerns regarding environmental parameters and airspace coordination.
- Create a marketing plan strategy to bring visibility to this project and promote its vision toward possible investors from companies out of the consortium.

Aside from the laser-based approaches, a variety of solutions have been proposed. These have included chasing and grappling the object, attaching deorbiting kits, deploying nets to capture objects attaching an electrodynamic tether and deploying clouds of frozen mist, gas or blocks of aerogel in the debris path to slow the debris. ClearSpace-1 is a space mission to remove an item of debris from orbit, planned for launch in 2025. The ClearSpace-1 will be launched to the target orbit for rendezvous and capture using a quartet of robotic arms and then will be deorbited to burn up in the atmosphere.

Studies have been carried out that suggests that laser orbital debris removal is the most cost-effective way to mitigate the debris problem. No other solutions have been proposed that address the whole problem of large and small debris.

The technology concept for the idea is formulated. Therefore, we could say that in the Technology Readiness Level scale this project is in level 2. Although, for example, in the area of tracking and monitoring there is already technologies functioning. The objective is to have a full developed technology by the end of the project.

1.2 Methodology

The aim of this project is to develop a ground-based laser system to deorbit satellites which are no longer in use, as well as other sorts of debris.

In recent years the increase of launches and accidental collisions has led to a noticeable rise in the amount of debris that has been left in outer space, specially at low orbits (LEO). The laser developed in this project will contribute in successfully deorbiting satellites and equipment that is no longer being used, and dispose of it safely.

For that purpose, said laser system will track with precision the object to be deorbited and it will slow it down. Ultimately, it will burn down while reentering the Earth's atmosphere, thus being no longer an issue. The main target of this kind of technology is going to be equipment up to 1000 kg which is located in lower orbits, in particular within a maximum altitude of 900 km.

During the early stages of the project, the focus will be set on research so as to assess the state of the art and further expand the knowledge in the field. Additionally, an in-depth assessment has to be performed on the impact that operating this kind of laser is going to have in the area where it will be located, so as to avoid any disruptions to the surrounding air operations or the environment.

Later on, the necessary equipment will be developed by the members of the consortium as stated in the following sections, along with the required software, especially for tracking. Every area within the project is covered by the universities and companies of the consortium. They are experts in the field, with a remarkable background in laser systems, the specific mirrors they require and in satellite observation and tracking.

All in all, the expected outcome of this project is an on-ground laser system which is capable of tracking in-orbit objects with precision, so as to be able to slow them down and dispose of them safely. This will contribute to reduce space debris and promote a cleaner environment, making future operations easier, as the probability of collision will be significantly decreased. Additionally, a paradigm shift is also expected to be derived from this initiative, as it will set the grounds for a more sustainable space infrastructure, and it will promote the protection of the Earth's orbit.

Although STEM field has historically been more occupied by men, the consortium will not take into account gender roles. The main goal in the human resources field of the project is to hire the best people only considering their academic/professional preparation and capabilities within the budget established. As the features searched do not depend on the gender,religion, origins or sexual orientation, they will be expressly not considered.

In this project will be participating some different disciplines that are not science-related. For example, human resources is a key factor of improvement for communications among the personnel and also to enhance the efficiency of the work performed by means of creating a proper work space. Also other disciplines such as politics and law must be involved in the process, maybe as external advisors, but with a strong presence due to the importance to be compliant with all the regulations and laws that are currently ruling the orbit and the objects that are there. Also as the project is to perform a ground-based station, the laser will be taking part of the aerial space of a country (or more than one), and that must be revised and assessed by a group of experts in this law field. Thus, the consortium will be multidisciplinary, creating higher value for the project and for the dissemination purposes.

As the main goal of this project is to enhance the availability of the future space missions by reducing the risks of them, the results will be scientifically open. Meaning that all the relevant information that will be produced by the research and operation of the project will be published in an open access way. This availability of the data is to enhance the probability of other companies or projects trying to create a better space environment and through the dissemination of the results this outcome can be achieved.

All the parts involved in this project responsible for collecting or generating data will be managing the data according to the following principles: Findable, Accessible, Interoperable, Reusable. For example, observational data of the objects that are going to be deorbited can be found on open access beforehand this project and is accessible for every organisation with scientific purposes. The standards for vocabularies is the current scientific language using the English as a standard language for this project. Almost all the data produced will have open access privileges, for example using non-profitable Creative Commons licences. Furthermore, the quality assurance team will be performing continuous assessments to preserve the quality of the data and identify that all of it is scientific and non-corrupted by plagiarism or other dishonest activities.

2 Impact

2.1 Project's pathways towards impact

2.1.1 Contribution of the project, outcomes and impacts

For years, humanity has explored space and Earth's orbits with the aim of establishing a system of communication, scientific exploration, guidance and surveillance by launching satellites, capsules and rockets. Despite the great scientific-technological progress brought about by the exploration of the aerospace sector, the generated waste has been accumulating over the years without being managed or controlled in any efficient way. This space debris is known to cause serious damage to satellite structures and orbital modules, such as solar panels and antennas.

This project was born with the motivation of finding a solution to space debris generated by human beings, not only with the aim of making the aerospace industry a more sustainable environment but also to protect the integrity of the current and future European projects in orbital management, launching procedures and orbiting of satellites, both from private companies and administrations and public entities.

With the creation of Clean Orbit, a fully featured system is presented consisting of precise orbit tracking software, high-technology mechanical assembly, and a precise and powerful laser system capable of targeting targets as small as a square meter or up to a ton of mass.

An important part of this laser system is the orbit tracking software, which identifies the parameters and characteristics of space debris to determine its orbit. A subpart of this software has remote access to a database of the ephemeris and other parameters of the satellites to be deorbited, which are necessary for tracking. Once the laser has been aligned with the target, the deorbiting process will proceed within the established time frame and as long as there is line of sight. The trajectory of the target will be monitored once it begins to deviate from its orbit to guarantee, through a controlled process, that it does not collide with other satellites or objects of interest or compromise its safety. Clean Orbit is aimed at public and private companies that want to eliminate space debris that could cause a potential danger to current or future projects and to deorbit satellites that have reached their useful life to reuse that orbit with a new one. But his goal goes further.

The result of this project will create a great impact - not only in the short term but also in the long term - on European society and will create a new concept of spatial waste management, establishing a precedent in the aerospace industry and opening new horizons of research and exploration.

A new line of research based on statistical analysis of the results collected from the deorbiting system will open space through a new discipline of science and engineering. An opening for educational and university research projects will also be created, in which doctoral students can participate and agreements can be made with European universities.

The small-mass space debris deorbiting and initiation to deorbiting the large-mass ones will be leaded. The deorbiting of smaller objects whose orbit has been specially selected to reduce the potential danger of impact to other objects of interest, despite the large number currently present in the closest orbits, will mean a great improvement towards the operability of satellites working.

This project will make a great scientific contribution such as advances in different specialties of engineering (aerospace, telecommunications, mechanics, industrial, etc.), physics and astrophysics, as well as in laser systems. Equipment and instrumentation will be reinforced and rethought to adapt it to this new discipline. The software created especially for this project is expected to establish a path of study in computation engineering and data science to be able to advance in guidance and tracking systems.

On the other hand, the construction and assembly of the system that will harbour the laser could open a new line of research in terms of structures and materials, as well as the construction of the infrastructures to contain other deorbiting systems if future challenges require the expansion of this project. In addition, the creation of a new system and provision of services will bring new business and investment opportunities and will mean a new addition to the market, thus contributing to the European economy.

Finally, the environmental impact is taken into account. This it is a project whose one of its requirements to make it a reality is that it must be sustainable and low-footprint. But also, the socio-cultural impact is present in the objectives. A new line of education and awareness will be created towards society on the generation of space debris and give visibility to the need to manage it to make the space environment a more sustainable environment.

2.1.2 Requirements and potential barriers

Factors beyond the scope and duration of the project might determine whether the desired outcomes and impacts are achieved. From that fact several requirements and potential barriers may arise.

Requirements

The first critical requirement to meet is that the project shall develop and balance 4 areas of technological interest which completely define the field of application of the project. First and foremost, the acquisition and tracking of the object to deorbit shall be one of the main concerns of the program since this will determine the success and accuracy of the technology being developed.

Secondly, the process consisting in aiming and shooting with the laser at the debris target, known as illumination of the targeted debris, shall be not only extremely accurate ($\pm$3cm tolerance), but also capable of providing a fast re-targeting time (less than 1 minute) in order to become one of the most reliable and fast-action systems of the deorbiting technology market.

Finally, the project shall ensure a deep analysis and clearance of the re-entry location and assurance of the laser clearing and tasking approval. In this aspect, before deorbiting equipment, it has to be ensured its full disintegration when reentering the Earth's atmosphere. That is because object retrieval isn't considered in this project, as it requires a different technology from the one that is going to be developed. The mitigation measure established for this scenario is a detailed study of the equipment to be deorbited and the process itself. Furthermore, an assessment of the possibility of several parts surviving the re-entering should also be performed.

As regards the technical specifications the project must meet, the debris-deorbiter system shall be based on a Laser Orbital Debris Removal (LODR) groundbased technology. Hence, the system shall be capable of removing small category objects of up to 0.75 kg and located at a maximum apogee of 700 km (LEO orbit), and large debris objects of up to 1000 kg and located at a maximum apogee of 900 km (LEO orbit). In this aspect, the technical solution developed shall be modular and capable of mounting different types of laser according to the characteristics of the debris target to be deorbited.

Constraints

In terms of schedule, the main potential barrier is the time constraint as the duration of the project shall not exceed 4 years. In order to address that, a schedule has been accurately designed. Additionally, an estimation of the overall duration has been performed with a safety factor so as to be conservative. Therefore, there will be margins to adapt to any issues that might come up in the process.

In the matter of the budget and economics, the budget contribution provided by the EU commission shall not exceed 2 million euros, whereas the budget contribution coming from outside the European Commission shall not exceed a 60% of the entire budget. To assess this constraint, the accounting manager will deliver a document specifying the economic contribution from each member of the consortium and the treasury will periodically verify that funding is provided on time.

As regards the legal concerns, if sensitive information is treated along the development, the project will have to go through the security appraisal process to authorise funding and may be made subject to specific security rules. To this matter, a legal study concerning data protection and competencies regarding tracking of satellites shall be performed, along with a preliminary study of the Security Regulations of the European Space Agency.

Finally, in order to assess the environmental restrictions, an environmental and legal study that ensures this project meets the standards imposed by ESA and does not become in conflict with European airspace shall be carried out. Apart from this, no unexpected airspace interferences shall occurs as well as no external space vehicles shall be affected during the operation of the LODR system.

2.1.3 Scale and significance of the project's contribution to the expected outcomes and impacts

As we pursue different objectives, not only the main one, this project is expected to have different target groups depending on the benefit that would be obtained by each of them.

Otherwise, the target size in terms of tenders and new contracts is the biggest, as it will be the main source of investment and opportunities. Scientific devaluation, an thus, educational area users, is important in order to gain visibility towards space debris and our way to manage the human generated waste. In spite of the fact that the scientific dissemination and the educational purposes are not the main source of benefits and incomes, must be taken into account as we do not pursue one unique objective, but also to contribute to the European Union countries with a system which can leave a safe and sustainably space in our nearest orbits.

In the following figure it can be appreciated how the explained outcomes in subpart 2.1.1 has been studied and reported and organized in function of its importance in a scale color format.

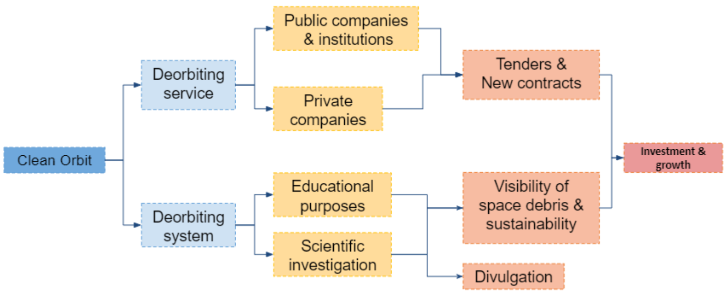

Figure 2: Color scheme of significance of contributions and outcomes

2.2 Measures to maximise impact

2.2.1 Dissemination and exploitation of results

Although the goal of the project is actually achieving the objectives (assembling a ground-based laser system to deorbit all sorts of debris), the dissemination of the different advances is crucial in order to reach the target group(s) addressed and exploit the results in a profitable way.

The manner of doing it can vary from social media or ads to the publication of the results: giving talks in specific conferences, with scientific articles or making regular reports with the project updates. What will change the impact this dissemination has is how effective and fluent the communication is, both internally and externally, which is directly established by the Communication Management Plan. This plan must be periodically modified in order to keep up with the project's development, so that the information provided is always relevant.

Plan Communication Management

In Figure 3, all the plan's participants, as well as the relationships between them and the kind of meetings they would conduct, are presented in a schematised way.

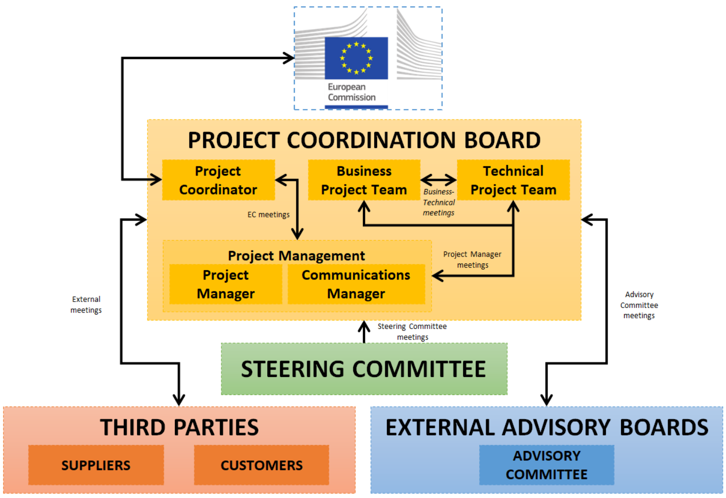

Figure 3: Communication plan scheme with the oversight agencies involved

The roles and responsibilities of the CO-LSDD staff with regard to the Communication Plan are:

Communications Manager:
The CO-LSDD communications manager is responsible for the definition of the internal tools and procedures which will be used to make announcements and transmit/receive information and data inside the company, in order to ensure a fluent communication between all the parts, as well as defining the meetings between the departments in terms of frequency, agenda and participants.

Project Manager:
The CO-LSDD project manager is responsible for communicating status for scope, schedule, and cost, as well as monitoring, controlling, and communicating the risks. The manager must also guarantee that all information related to the project is consistent, correct, accurate, and timely; and will be in charge of reviewing and approving all the information that is being provided to the various stakeholders.

Steering Committee:
The CO-LSDD Steering committee will be responsible for providing and maintaining the necessary resources needed for the successful completion of the CO-LSDD project, especially in terms of strategic direction, as well as resolve conflicts or expedite processes which may not be resolved at a lower level.

Advisory Committee:
The CO-LSDD Advisory Committee will provide leadership and direction by communicating directly with the Project Management team and making recommendations to the project sponsor. From an external (and more independent) point of view, it will be in charge of reviewing the progress, risks, and issues as well as recommend resolutions to those.

Business Project Team:
The CO-LSDD Business Project Team is responsible for defining the adequate requirements based on the market demands and provide the information of the CO-LSDD viability to the project manager.

Technical Project Team:
The CO-LSDD technical project team will design and manufacture the laser infrastructure, document the whole process, implement the software and assembly, and provide the ongoing operational support of the CO-LSDD. It is also responsible to report any issues impacting the project, especially in costs/time aspects, provide recommendations to resolve the issues that may appear, and assist and collaborate with the project manager by providing all the information related to the technical side to him/her.

Oversight:
The CO-LSDD project will be supervised by the European Commission through the whole duration by means of the Project Coordinator (EC National contact point). The CO-LSDD Project Manager will be in charge of notifying the European Commission with the updates and/or changes in the project schedule. The European Commission will make sure the project is correctly developed following the predicted schedule and costs.

Communication process

Here, the different procedures are proposed in order to ensure an effective communication between all the agents of the project, both in an informal and a formal environment. To avoid restricting the communication internally, upward, downward, horizontal and diagonal communications will be encouraged to promote a creative and free atmosphere.

Informal

Due to the nature of informal communications, it is difficult to track and monitor them and, consequently, they are not explicitly discussed in the plan and there will not be an official record of them, even though they are essential. Its usage avoids misunderstandings and clarifies aspects of the project, enhancing in this way the formal procedures. The types of informal communication channels recommended are e-mails, phone calls and informal meetings and conversations that can take place at any moment.

Formal

The formal communication, unlike the previous, can be planned and controlled, so it is possible to define several aspects related to it, such as its frequency or objective. In this way, the different channels that will be used to keep the internal agents and stakeholders informed are described below, alongside its main characteristics.

Meetings

Meetings are fundamental to track the project, but also to discuss important aspects of it and make decisions. Throughout the development, different types of meetings will be carried out between the project coordination board, the external advisory boards, the steering committee and third parties.

It is worth emphasising that these meetings will have a clear objective/s and will follow a pre-established agenda to avoid wasting any time and resources on them.

- **General meetings**
- **Design review meetings**
- **Technical status meetings**
- **Team meetings**
- **Business-Technical meetings**
- **Advisory Committee meetings**
- **Steering Committee meetings**
- **EC meetings**
- **Exceptional meetings**

Both the Project Manager and the Communications Manager will attend some meetings mentioned previously, avoiding additional meetings between them and the rest of agents. They will be part of the meetings conducted between the Business and Technical Project Teams, in those of the Advisory Committee and the Steering Committee, in meetings with the stakeholders and in the external ones.

Status Reports

The status reports are essential to provide regular information on the project. They will address multiple topics and will be delivered to different agents (stakeholders, team members, managers, Project Teams) during specific moments of the development depending on their type. Hence, the status reports (together with their frequency) are listed below:

- **Research Report (4.1):** Delivered every two weeks.
- **Mechanical Design Report (4.2.1):** Delivered every week.
- **Laser Design Report (4.2.2):** Delivered every week.
- **Mirror Design Report (4.2.3):** Delivered every week.
- **Software Functionality Report (4.2.4):** Delivered every week.
- **Production Report (6.3):** Delivered every week.
- **Maintenance Checklist (4.4.2):** Delivered every two weeks.
- **Maintenance Report (4.4.5):** Delivered every two weeks.
- **Economic Monitoring Report (1.3.6):** Delivered every month.
- **Monthly Control Report (1.6.6):** Delivered every month.
- **Project Management Monthly Report (PM):** Delivered every month.
- **RCA Report (6.6):** Delivered every two months.
- **Biannual Control Report (1.6.7):** Delivered every six months.

2.2.2 Intellectual Property, knowledge protection and regulatory issues

According to the European Commission [2], a trusty intellectual property (IP) model is the best way to exploit creativity and empower innovative enterprises. If these ideas, businesses and individuals were left unprotected, they would probably never collect the benefits of their creations/inventions, therefore investing less on research and development.

Intellectual property, which includes all exclusive rights to individual creations (industrial property and copyright), is considered as crucial because of its role in promoting innovation and investment, especially in the digital and green economy. For this reason, the EC works to harmonise and enhance laws relating to IP rights in the EU, like the ones affecting trade mark or industrial design protection, both at national and at EU level.

This legal framework and IP system offers incentives for EU companies to finance the supplying of goods and services with high standards of innovation, design, quality and creativity.

The IP items are the following ones:

- Patent: the granting of an exclusive property right for an invention, which can be a product or process. In exchange for a disclosure of the invention, the inventor is provided with exclusive rights to the design for a designated period of time.

- Trademark: a recognizable and unique insignia, phrase, word, or symbol that identifies a specific product in order to differentiate it from others from its kind. It also acknowledges the ownership of the product to the specific company.
- Copyright: the actual legal right of the IP owner and the way of protecting an author's work. It does not only provide exclusive publication, distribution and using rights for the author, but also for whoever with explicit authorization and `right to copy` or reproduce the work.
- Trade secret: a commercially valuable piece of information (any practice or process not known outside the company) for an enterprise, which is treated as confidential (although it may be sold or licensed) and gives the enterprise a competitive advantage over its competitors.

2.2.3 Communication activities

Announcements

To make important announcements of both organizational and technical aspects that different agents of the project have to be aware of, two main mechanisms will be used: emails and notice boards. The emails will be used to inform about general and specific aspects. In the latter case, this channel is preferred, as it is easier to attach support documents to complement the main data or include sensitive information. Regarding the notice boards, they will be used to inform about more general aspects that have to be known by a whole department or team and they will work as a reminder.

External Communication

The external communication will be used to interact with the companies outside the consortium, the customers and the general public. It will be used as a way to develop the project, as subcontractors and external companies outside the consortium also play an important role, like providing electronics or assembling different parts of the laser structure, but also to expand it and disseminate the results to a wider audience in order to exploit and obtain an economical benefit from it.

External companies

This type of communication is related to the procurement sub-project (or department). In this way, there will be different channels to contact the external companies with whom the consortium have agreements when necessary. Hence, emails and phone calls will be the preferred channels, however, it will be also possible to set physical or online meetings in case the content under discussion requires it.

The importance of having a relatively frequent contact with other companies is positioning CleanOrbit as the most reliable solution to space debris, gaining notoriety and recognition in the sector, which may help reach better positioned companies to work with in the future as well as attracting new investors.

Customers

It is necessary to establish some channels and procedures to contact the customers in order to receive their feedback or inform them about any relevant data they need to be aware of. Thus, the communication by email will be the predefined one, and it will be mainly used to transmit general information, obtain feedback (by means of surveys) or exchange information with the customer. In addition to this, meetings and phone calls will also be allowed and encouraged if the situation requires it, to provide a closer and personalised service.

The feedback received must be transformed into observable improvements within the CO-LSDD project, in order to materialise and satisfy the customer's needs. By giving response to the customer's claims, CleanOrbit shall earn a better reputation, and seen as the first-line option in the market.

General public

In this case, the communication with the general public is comprised inside the dissemination plan and, in consequence, techniques and methodologies of this field will be used to promote the service and the system used among not only possible customers and future stakeholders, but also the society.

Thus, the external communications considered under this classification are:

- **Congresses and Fairs:** The company and the consortium will participate in congresses and fairs to publicise the service in specialised segments, both before and after the system starts to operate.
- **Specialised media/press:** It is expected to make publications in research journals and magazines to explain the system developed and prove its strengths among the scientific community.
- **General media/press:** The presence in printed (newspapers) or visual (documentaries, outreach programs) formats addressed to the general public is essential to gain visibility.
- **Social media:** Multiple profiles in different social networks will be created. This will allow having visibility among the general and non-specialized public by means of regular posts during the development of the project, but also once it is functional. The creation of a website will also be necessary to have a dedicated source to inform about the service, the consortium and other aspects.
- **Awareness campaigns:** Conferences and talks aimed at both private companies and public institutions will also be of high importance. The objective of these campaigns is to raise awareness of the danger of space debris and how the system proposed minimises their hazardous effects.

By advertising the CO-LSDD project in all of these environments, its cognisance should be raised not only inside the scientific community or interested individuals, but also non-related public, which at the end help disseminate the project and company's branding and recognised as a pioneer in the near future. Participating in campaigns in favour of fighting the space pollution will at the end generate a good perception of the company name, impacting positively in terms of possible collaborations as well as exploiting a real and already incipient problem, which will do nothing but become more common as the number of satellites and the facility to launch them increases. This combination of factors is leading to the cost of launching new spacecraft being less than investing in longer-life orbital devices, a threat to space exploration.

2.3 Summary

The canvas below presents a summary of this section, as a compilation of the project's impact pathway and of the measures to maximise its impact.

KEY ELEMENT OF THE IMPACT SECTION

SPECIFIC NEEDS

What are the specific needs that triggered this project?

According to ESA, in recent years there has been a noticeable increase in the number and size of launches performed.

While missions in higher orbits are usually successfully disposed of, more than half of the operators with equipment in Low Earth Orbits (LEO) take no action in that direction.

Equipment in LEO orbits should be safely disposed of, in order to enhance operational safety and promote a healthier space environment.

EXPECTED RESULTS

What do you expect to generate by the end of the project?

A **ground-based laser system** capable of deorbiting space debris, which can be categorized as:

- **Small debris**: up to 0.75 kg at a maximum apogee of 700 km.
- **Large debris**: up to 1000 kg at a maximum apogee of 900 km

To ensure that the system works properly, the corresponding **software** will be developed, along with **maintenance guidance** in manuals.

D & E & C MEASURES

What dissemination, exploitation and communication measures will you apply to the results?

Dissemination towards the scientific community: Scientific publications regarding the results of the studies and tests carried out, as well as publications in specialised media and press.

Exploitation: The laser system will be patented, as well as its software.

Communication towards potential customers: The company and the consortium will participate in congresses and fairs to publicise the service in specialised segments, both before and after the system starts to operate. It will also have an important presence in general press and social media to enhance visibility within a less specialised public.

TARGET GROUPS

Who will use or further up-take the results of the project? Who will benefit from the results of the project?

European Union Commission

Scientific Community: The European Space Agency and its counterparts around the world, along with all the scientists and researchers involved in this field.

End-users: Aerospace companies and entities that operate satellites and other kinds of equipment in LEO orbits.

OUTCOMES

What change do you expect to see after successful dissemination and exploitation of project results to the target group(s)?

High use of the scientific discovery published

PhD students **network** + further **research projects.**

The **main space agency** in europe (ESA) **using** this **service**.

Space debris reduction in LEO orbits, which will lead to a **cleaner environment** and **safer operations** (less collision probability)

IMPACTS

What are the expected wider scientific, economic and societal effects of the project contributing to the expected impacts outlined in the respective destination in the work programme?

Scientific: New breakthrough scientific discovery on how to safely deorbit space debris from the Earth's surface.

Economic: Increased operational efficiency as the risk of collision of functional equipment with space debris will be significantly reduced.

Societal: A **paradigm shift**, as this initiative sets the grounds for a **more sustainable space infrastructure**, thus promoting the **protection** of the Earth's orbit.

3 Implementation

3.1 Work plan and resources

In this section the work packages (WP) of the project will be described alongside some organizational aspects relate to them, their objectives and the deliverables associated to them. Whereas in Table 1 a summary of the WP is provided, detailed information about them is presented in the following tables.

As it will be seen, CleanOrbit will be focused on the management tasks of the project and other specific fields. Furthermore, several WP are considered in order to make sure that all the dimensions of the project are properly covered by a department/consortium participant.

Within each WP, the tasks are grouped in one or two sub-divisions, generating in this way four levels of work, as it can be seen in the Work Breakdown Structure of Appendix A. In addition to this, a Gantt Diagram is also provided in Appendix B, showing the timing of the WP and the next first level. Finally, to see the relationship between the tasks at the innermost level, multiple Network Diagrams are also presented after the Gantt Diagram (Appendix B).

Table 1: List of work packages.

Work Package No	Work Package Title	Lead Participant No	Lead Participant Short name	Person-Months	Start Month	End Month
1	Project Management	1	CleanOrbit	76.75	1	48
2	Environment	2	TU Delft	52.75	11	39
3	Marketing	1	CleanOrbit	23.50	10	43
4	Technical	7	CILAS	358.50	4	39
5	Procurement	1	CleanOrbit	12	19	23
6	Prototype	7	CILAS	262	19	33
7	Testing	1	CleanOrbit	171.75	29	46
				957.25		

Referring to the calculation of the Person-Months parameter, 2022 will be considered as a year with 249 working days ([3]). This will mean that, for a given task, if one person takes N working days to complete the task, it will be said that it should take

$$t = \frac{12N}{249} \text{ Person-months} \tag{1}$$

Since a month is comprised by, approximately four weeks, the Person-Months value will be rounded to the nearest quarter, which will make it easier to the reader to grasp the concept of how much time would be required for each WP.

In Table 2 the Project Management work package is detailed.

Table 2: Project Management work package.

Work package number	1	**Lead beneficiary**	CleanOrbit
Work package title	Project Management		
Participant number	1		
Short name of participant	CleanOrbit		
Person months per participant	76.75		
Start month	1	**End month**	48
Objectives			

Table 2 continued from previous page

To prepare the main project management documents (general and organizational aspects), to develop some more specific reports related to security, economic and risk issues, and to manage the consortium.	
Description of work	
The first months will focus on develop the main management documents that will be essential to organise internally and externally the consortium, as well as establish strategies in specific fields. In addition to this, the documents will also be useful to apply for the H2020 proposal. The participant in charge of this work package will be CleanOrbit, which will develop a management role during the whole project.	
Deliverables	
Project Charter	Document with the description of the core aspects of the project, such as the purpose, objectives, stakeholders, requirements, risks and internal organization, among others.
Project Scope Statement	Document that will detail the scope of the service and the project, the main deliverables and the assumptions, accepted criteria and constraints to take into account before starting to develop the project.
Work, Resources and Time Management Plan	Hierarchical diagrams that will define the work-packages and tasks to carry out, the internal organisation of the consortium, the identified resources and the schedule of the project.
Risk Management Plan	Document focused on identifying the main aspects of the different risks associated to the project and their corresponding response and re-assessment.
Budget	Document with information relative to the funding of the project and the estimated cost of each task.
Communication Plan	Document with the strategies and procedures to ensure an effective and fluent communication inside the company, inside the consortium, with the stakeholders and with the external companies.
Data Management Plan	Document in which detailed explanations regarding how the tracking data will be collected, processed, protected and stored will be provided, as well as the methodology and standards that will be applied to the processes.
Security Regulations Study	Preliminary study of the security regulations of the European Space Agency.
Safety Environment Report	In-depth study to ensure a safe debris re-entry and clearance of the impact location.

In Table 3 the work package associated to the environmental side of the project is detailed.

Table 3: Environment work package.

Work package number	2	**Lead beneficiary**	TU Delft
Work package title	Environment		
Participant number	1 / **2** / 5		
Short name of participant	CleanOrbit / **TU Delft** / IAC		
Person months per participant	See table 14		
Start month	11	**End month**	39
Objectives			
To study the effects on the environment of the system developed and the service provided.			
Description of work			

Table 3 continued from previous page

First an environment policy will be established and then a study of the impact of multiple items, such as the materials and industrial processes used, the system operation and the logistics, will be developed. Based on the conclusions of the previous analysis, nonconformance and corrective/preventive actions will be designed, as well as a plan to monitor and control critical aspects.	
Deliverables	
Environmental Study	Analysis of the environmental impact that the manufacturing and operation of the system designed could imply and proposal of corrective/preventive actions if necessary.

In Table 4 the Marketing work package is detailed.

Table 4: Marketing work package.

Work package number	3	**Lead beneficiary**	CleanOrbit
Work package title	Marketing		
Participant number	1		
Short name of participant	CleanOrbit		
Person months per participant	23.50		
Start month	10	**End month**	43
Objectives			
To study the market where the service will operate and to design an effective plan to develop multiple marketing action that aim to publicize the service among different segments.			
Description of work			
To determine whether the service developed will satisfy the necessities of the market in which it will operate and identify potential clients, a market research will be carried out in the first place. It will include the market evolution, an offer and demand analysis and a SWOT study, among others. Satisfactory conclusions of these first tasks will lead to the development of essential marketing actions to publicise the service, by means of congress/fairs attendance, social media or specialised media. An evaluation of the success of the previous actions will also be performed.			
Deliverables			
Market Research	In-depth analysis of the market in which the service will operate, focusing specially on the offer and demand and its evolution. In addition to this, a forecast of the future situation of the industry will also be provided along some conclusions that could be drawn from the study.		
Dissemination plan	Document with detailed actions (presence in congress/fairs, social media, general press) that will be carried out to make the CO-LSDD system and the service visible to different segments, such as the potential clients and the general public. The participants of this work package will focus on purely marketing actions, whereas those of the Technical work package will be in charge of developing those actions aimed to specialised sectors, such as the presence in research journals and magazines.		

Table 5: Technical work package.

Work package number	4	**Lead beneficiary**	CILAS
Work package title	Technical		
Participant number	1-7		
Short name of participant	All - **CILAS** (main)		
Person months per participant	See table 14		

Table 5 continued from previous page

Start month	4	**End month**	39
Objectives			
To design all the aspects related to the CO-LSDD system and its main components, as well as the manufacturing processes, the quality control and the subsequent maintenance.			
Description of work			
This WP refers to all of the tasks from research, to design and maintenance of the systems. Once the research protocol is defined, the research begins in parallel for the mechanical design, the laser, the mirrors and the software. After defining the quality management plan and developing the prototypes, the maintenance plan will be written, both involving preventive and corrective maintenance.			
Deliverables			
Quality Management Plan	Analysis of the main aspects in terms of quality, such as the required tools to carry out an effective control of the service, the costs associated or the possibles improvements of the process.		
Software Design Report	Document in which the design and creation of the software necessary to monitor space debris and operate the LODR system is described in detail.		
Design and Production Report: Mechanical System	Report with in-depth explanations of the design of the mechanical components that will be part of the LODR (e.g., properties, materials, geometry, physical principles), as well as of the production procedure (e.g., techniques, equipment).		
Design and Production Report: Laser	Report with in-depth explanations of the design of the laser/s that will be part of the LODR (e.g., properties, materials, geometry, physical principles), as well as of the production procedure (e.g., techniques, equipment).		
Design and Production Report: Mirror	Report with in-depth explanations of the design of the mirror/s that will be part of the LODR (e.g., properties, materials, geometry, physical principles), as well as of the production procedure (e.g., techniques, equipment).		
Certification Report	Report in which the ISO and non-ISO norms applicable to the project will be collected to ensure the certification of the design of the CO-LSDD system and its performance.		
Maintenance Plan	Document with the schedule and the description of the actions that have to be carried out periodically on the LODR system to ensure a good functioning and the accomplishment of the requirements established in the Quality Plan.		

In Table 6 the Procurement work package is detailed.

Table 6: Procurement work package.

Work package number	5	**Lead beneficiary**	CleanOrbit
Work package title	Procurement		
Participant number	1		
Short name of participant	CleanOrbit		
Person months per participant	12		
Start month	19	**End month**	23
Objectives			
To find suppliers and agree to terms with them to acquire their goods or services.			
Description of work			

Table 6 continued from previous page

The Procurement work package will comprise three basic sections. The first one is the definition of the specifications, where all of the electronic, mechanic, assembly and logistic needs will be defined based on what is required after the design, especially when outsourcing the manufacturing and/or design of certain parts. This is thoroughly explained in the procurement guides, both for the electronics, the assembly/integration and the logistics. The last part will be the hunt for possible additional investors to our project, since those might appear due to the attraction and interest caused by the project.	
Deliverables	
Procurement Guidelines	Standards that will be delivered to all the supplier companies with core aspects related to their respective field. The electronics section will address the materials chosen for the components, the stock prioritisation and the lot-sizes; the integration one, the assembly conditions; and the logistics one, the delivery times and possible collaborations with transport companies.

In Table 7 the work package related to the prototype is detailed.

Table 7: Prototype work package.

Work package number	6	**Lead beneficiary**	CILAS
Work package title	Prototype		
Participant number	1 / 6 / 7		
Short name of participant	CleanOrbit / DIGOS / **CILAS**		
Person months per participant	See table 14		
Start month	19	**End month**	33
Objectives			
To manufacture a prototype of the system design to perform tests on it.			
Description of work			
The prototype work package will include all of the post-design activities, such as the manufacturing of the different prototypes (including the final product). Since more than one prototype will be built, and not all of them will be full-sized, the downscaling and upscaling processes are a fundamental part of the result extrapolation of WP 7 (testing). Once all of the parts of the deorbiter are built they will be assembled with the electronics following the guidelines shown in WP 5 (procurement).			
Deliverables			
Prototype Proposal Selection and Manufacturing	Report with the technical and physical details of the prototype that will be used to conduct different types of tests and the manufacturing procedures.		
Prototype	LSDD system prototype with the characteristics required.		

In Table 8 the Testing work package is detailed.

Table 8: Testing work package.

Work package number	1	**Lead beneficiary**	CleanOrbit
Work package title	Testing		
Participant number	1		
Short name of participant	CleanOrbit		
Person months per participant	171.75		
Start month	29	**End month**	46
Objectives			
To carry out different types of test (software, thermal, mechanical, performance) in order to ensure that the prototype and all its components and systems meet the requirements.			

Table 8 continued from previous page

Description of work	
Similary to how WP 4 (shown in table 5) finished, the starting point of testing is to set which standards and which requirements will be followed when testing the prototype. A test plan will be written, where the guidelines of each test and its reporting will be given. Mechanical, thermal, software and performance tests will be made, and the results obtained will be compared to those obtained via numerical simulations. A further study regarding troubleshooting must be performed to clean up errors between the two to avoid future mistakes, such that simulation parameters must be readjusted based off the obtained feedback.	
Deliverables	
Testing Report	Document with the results of the tests conducted on the prototype and the conclusions that can be drawn from them, as well as a comparison with some expected numerical results. This report will dictate if the system and/or the components designed have to be modified because they do not meet the established requirements.

Table 9: List of deliverables.

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date (in months)
1.1	Project Charter	1	CleanOrbit	R	PU	3
1.2	Project Scope Statement	1	CleanOrbit	R	PU	4
1.4	Work, Resource and Time Management Plan	1	CleanOrbit	R	SEN	5
1.4	Risk Management Plan	1	CleanOrbit	R	SEN	6
4.1	Quality Management Plan	4	CleanOrbit	R	SEN	6
1.5	Budget	1	CleanOrbit	R	SEN	7
1.6	Communication Plan	1	CleanOrbit	R	SEN	7
1.7	Data Management Plan	1	IAC	DMP	C-UE	11
1.8	Security Regulations Study	1	CleanOrbit	SEC	SEN	11
1.9	Safety Environment Report	1	CleanOrbit	SEC	SEN	11
3.1	Market Research	3	CleanOrbit	R	SEN	11
3.2	Dissemination plan	3/4	CleanOrbit	R	SEN	14
4.2	Software Design Report	4	CleanOrbit	R	C-UE	19
4.3	Design and Production Report: Mechanical System	4	Universität Bremen	R	C-UE	21
4.4	Design and Production Report: Laser	4	CILAS	R	C-UE	21
4.5	Design and Production Report: Mirror	4	CILAS	R	C-UE	21
5	Procurement Guidelines	5	CleanOrbit	R	SEN	23
6.1	Prototype Proposal Selection and Manufacturing	6	CILAS	R	C-UE	23
4.6	Certification Report	1	CILAS	R	SEN	34
6.2	Prototype	6	CILAS	DEM	C-UE	35
2	Environmental Study	2	TU Delft	R	SEN	35
4.7	Maintenance Plan	4	CILAS	R	SEN	39
7	Testing Report	6	CleanOrbit	R	SEN	43

Table 10: List of milestones

Milestone (number)	Milestone name	Work package number	Due date (in month)	Means of Verification
M1	Project Feasibility Definition	1	4	The overall cost of the project is under the projected budget
M2	Tracking Data Legal Certification obtainment	1	8	The certifications needed to begin activity have been obtained.
M3	Laser Design and Production	4.2.2 6.3.1.2	24	The performance results of the laser have been computed.
M4	System Requirement Review (SRR)	6.2 6.4	32	The system performance ensures the requirements set originally.
M5	Preliminary Design Review (PDR)	6.2 6.4	36	The system design ensures reliable operation.
M6	Critical Design Review (CDR)	6.2 6.4 6.6	38	The system design ensures the critical requirements set originally.
M7	Test Readiness Review (TRR) and Technical Acceptance Review (TAR)	6.5	40	The system performance results are under the predicted ones prior to prototype testing.
M8	First Prototype Arrangement, Operational Test and Evaluation (OT&E)	7	41	The prototype operation is reliable and with performance results under the predicted ones.
M9	Stakeholders Feedback and Approval and Marketing Plan	1 3 4 7	44	The stakeholders validate the built model and approved its performance results. Furthermore the marketing plan is initiated since the system design is finished.
M10	Final Approval	1 2 3 4 5 6 7	46	Project members qualitatively assess the system obtained in order to begin activity.
M11	Service Launch	1 3 4 5	48	Monthly reports of the service performance and customers' feedback are used to assess the quality of the service.
M12	Maintenance Service Launch	1 4 5	48	Maintenance checklists are being implemented to ensure that the system runs under reliable and required conditions.

Critical risks mitigation

The project's correct implementation lies on the appropriate risk management and mitigation measures adoption in order to assure the achievement of the objectives. In this aspect, a list of the most critical risks for each work package of the project along with their mitigation measures is shown in Table 11.

Table 11: Critical risks for implementation.

Description of risk [(i): likelihood, (ii): severity]	**Work package(s) involved (number)**	**Proposed risk-mitigation measures**
B.1. Lack of accuracy in budget estimation [(i): High, (ii): Medium]	1	Mitigation - In order to reduce large deviations in budget due to possible modifications, the budget will be updated periodically according to the needs of the project. If any change is needed, this will be considered critical
B.3. Base material cost increase [(i): Medium, (ii): Medium]	1	Mitigation - Procurement dept. will be assigned to find possible funding sources in order to solve such cost increases. Budget dept. will have to update the budget accordingly.
B.4. Uneven / wrong cost distribution among departments [(i): Medium, (ii): Medium]	1	Mitigation - A budget update will have to be done after reassessing the economial needs of each department.
COM.2. Lack of external communication [(i): High, (ii): Medium]	1	Mitigation - Keep active the means of comunication with external members and create new ones if needed. HR dept. to perform possible feedback meetings with members.
COM.3. Lack of commitment of external members [(i): Medium, (ii): Medium]	1	Mitigation - Promote and enhance the means of comunication with external members in order to receive feedback and search for points of agreement and improvement. Business negotiations to be led by the Procurement dept.
D.2. Performance decrease in possible alternative design [(i): Medium, (ii): Medium]	4	Mitigation - A performance study of the alternative design will be carried out by the Simulations department and then the Testing department will validate the results. If poor performance is obtained with the model, send back the re-design task to the Design department.
HR.2. Mobbing, racism, sexual and/or physical abuse [(i): High, (ii): Medium]	1	Avoidance - When detecting any sign that could lead to unacceptable behaviours, take preventing measures by doing a meeting with the person in observation and take actions if needed. These kind of behaviours will be eradicated before even being produced, so they will be avoided.

Table 11 continued from previous page

Description of risk (indicate level of (i) likelihood, and (ii) severity: Low/Medium/High)	**Work package(s) No involved**	**Proposed risk-mitigation measures**
L.1. Supplier material shortage [(i): Medium, (ii): Medium]	5	Mitigation - Assign, in first instance, to the Procurement dept. the task of searching for new material suppliers. Assign, in second instance, to the Scheduling dept. the task of performing a schedule-impact study due to the material shortage. Assign, in last place, to the Budget dept. the task of updating the budget according to the new supplier's material.
L.3. Logistics cost increase [(i): High, (ii): Medium]	5	Mitigation - Procurement dept. will be assigned to find possible funding sources in order to solve such cost increases. Budget dept. will have to update the budget accordingly.
MF.2. Misunderstanding between design plans and fabrication [(i): Medium, (ii): High]	6	Mitigation - Assign a root cause analysis to the Quality dept. in order to track and solve this misunderstanding.
MKT.1. Miscalculation in market forecast for the product [(i): High, (ii): Low]	3	Mitigation - Study the economical and scheduling effects of having experienced errors in the market forecast by assigning it to the Budget and Scheduling depts. In addition, the Quality department will analyse the causes of this worse forecast.
MT.1. Careless maintenance, usage of damaging materials [(i): Medium, (ii): High]	4	Avoidance - The Quality dept. will make sure to have implemented manuals and high-standards to be followed in the maintenance process so this risk doesn't happen.
MT.2. Unexpected part damage [(i): High, (ii): Medium]	4	Mitigation - For each part, make a study of similarly working parts in similar machines, so as to have a list of possible failures.
P.2. Legal requirements change during project development [(i): High, (ii): Medium]	5	Mitigation - Negotiate with ESA & EU so as to have flexibility regarding the initial conditions given for the production and functioning of the deorbiter.
P.3. Unwanted information filtering [(i): Medium, (ii): Medium]	5	Mitigation - Before any information is sent via e-mail, it must pass, if possible, through a filter checking if the receiver is in a given list of accepted e-mail receivers. If not, a warning message will be sent, and the person who sent it must confirm that the receiver is the expected one.
Q.1. Lack of quality in deorbiter design [(i): Medium, (ii): High]	4	Mitigation - Through State of the Art and reverse engineering, every part must be designed so as to follow the quality requirements of the company, following the development of a quality management plan.
Q.3. Damaged manufactured parts because of incorrect transport to hub [(i): High, (ii): High]	4	Mitigation - Procurement must provide detailed explanaitions of how every single part should be transported so as not to be damaged, following recommendations given by the Design department.

Table 11 continued from previous page

Description of risk (indicate level of (i) likelihood, and (ii) severity: Low/Medium/High)	**Work package(s) No involved**	**Proposed risk-mitigation measures**
S.1. Supplier time delay [(i): High, (ii): Medium]	1	Mitigation - If possible, the materials to be supplied must be ordered in advance, and a fee depending on the delay must be agreed when signing the contracts.
S.2. Manufacturing delay [(i): High, (ii): Medium]	1	Mitigation - Similarly to S.1, the manufacturer must be prepared to build whatever parts are required in advance. A fee for delay must also be agreed.
SIM.2. Unexpected performance values in simulations [(i): High, (ii): Medium]	7	Mitigation - The simulations must accurately follow the parameters given by the design, so the preprocessing is the most important part of the simulation. Study how to accurately depict the reality (even if so means building a bigger model in simulations) is key to avoid unexpected results.
T.3. Parts non-compliant with test standards [(i): High, (ii): Medium]	7	Mitigation - By correctly defining the designed parts and having the manufacturing strictly follow the quality parameters given, the risk of said parts being non-compliant must be lower. Also, when designing, certain margins of safety must be imposed.
T.4. Non-matching results between simulations and testing [(i): High, (ii): Medium]	7	Mitigation - All machinery in the tests must be certified, and simulations must be verified before going into the testing phase. By combining these two factors, the differences caused by the result might be decreased.
T.5. Unsuccessful prototype verification & validation [(i): Medium, (ii): Medium]	7	Avoidance - Some activities within the project might not be following the quality standards set by the company. By performing an external audit, these can be found and corrected, if necessary.

Subcontracting costs summary

Table 12: Subcontracting costs' item.

RUAG		
	Cost (€)	**Description of tasks and justification**
Subcontracting	22.500	Electronics manufacturing. There are plenty of electronics needed for the laser that are common to other aerospace projects (power units, dividers, etc).
OHB Systems AG		
	Cost (€)	**Description of tasks and justification**
Subcontracting	60.000	Assembly with electronics. An specialized assembler is needed to assemble high precision electronics with laser.
Subcontracting	45.000	Laser assembly. A specialized assembler is needed for a high precision project, where mirror calibration is key for an optimal functioning.
AP Moller - Maersk		
	Cost (€)	**Description of tasks and justification**
Subcontracting	15.000	Prototype transportation. Each part of the laser system, manufactured in its corresponding factory, must be transported to the final destination where the laser is meant to operate.

3.2 Capacity of participants and consortium as a whole

In this subsection, an overall situation of the consortium is detailed. Firstly, a general introducton is presented, exposing how it does meet the project objectives, focusing on the expertise of each member. Next up, it is explained how members complement one another, showing each member's contribution to the project.

Starting with the consortium itself, as it has been detailed previously in other sections, is formed by three clearly differentiable profiles. On one hand, top notch universities from Europe are in charge of the design aspect of the project. From the mechanical aspect to the electrical one, going through optics, TU Delft, ISAE-SUPAERO and Universität Bremen implement their knowledge to produce a high quality design. Notice how each of them are multidisciplinary, with expertise to space related projects, a key quality for the consortium. In this group it is also included IAC, which provides the placement of the laser system and the tracking system in collaboration with DIGOS. On the other hand, the resultant participants of the consortium are several companies, each of them with expertise in key aspects of the project. Not only they provide manufacturing capability, but know-how in design which is really important feedback to the design-oriented members. Moreover, all companies are European based, which reduces any future incompatibility problems with the requirements and directly supports the European industry.

Table 13: Expertise of consortium members

Consortium member	**Expertise**
CleanOrbit	Management & Engineering
TU Delft	Optics design & Environmental Study
ISAE-SUPAERO	Laser design
Universität Bremen	Mechanical design
IAC	Debris tracking
DIGOS	Electronics design
CILAS	Laser & Mirror manufacturing

In table 13 is stated a summary of each company's field. However, it is not only the experience, but the interaction of the consortium members in order to succeed in a project like the one presented. Hence, figure 4 shows how each member interacts and complements witch each other:

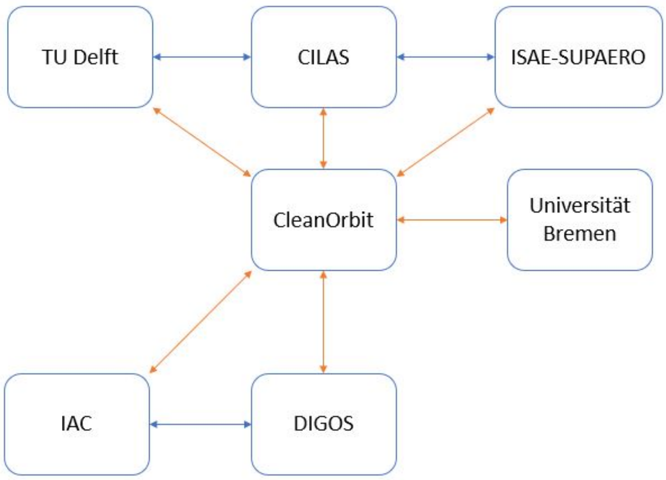

Figure 4: Consortium members interaction

Notice how *CleanOrbit* is the member coordinating all the consortium, assigning the project requirements to the design-focused members and the manufacturing guides and requirements to the companies involved. It is important to highlight two aspects, the first one being that the connecting arrow is bidirectional, meaning that an iterative process is pursued. Therefore, each consortium member is relevant to the final outcome. Secondly, there are members connected with a second link, meaning that their interaction is crucial for their function. For instance, the laser design (*ISAE-SUPAERO*) should be aligned with the capability of the manufacturer (*CILAS*).

Below is shown the resource allocation (in person-months) for each of the consortium members and each WP:

	WP 1	**WP 2**	**WP 3**	**WP 4**	**WP 5**	**WP 6**	**WP 7**	**Total**
CleanOrbit	76.75	15	23.50	50	12	60	171.75	**409**
TU Delft	-	22.75	-	41	-	-	-	**63.75**
CILAS	-	-	-	100	-	130	-	**230**
ISAE - SUPAERO	-	-	-	41.50	-	-	-	**41.50**
Universität Bremen	-	-	-	40.25	-	-	-	**40.25**
IAC	-	15	-	25.25	-	-	-	**40.25**
DIGOS	-	-	-	60.50	-	72	-	**132.50**
	76.75	**52.75**	**23.50**	**358.50**	**12**	**262**	**171.75**	**957.25**

Table 14: Resources allocated for each WP and consortium member

4 Budget for the proposal

Table 15: Budget for the proposal

No	Participant	Country	(A) Direct personnel costs	(B) Other direct costs	(C) Direct costs of subcontracting	(D) Contingency reserves (∼ 9%)	(E) Indirect costs	(H) Total estimated eligible costs (A+B+C+D+E)
1	DLR (Bremen)	DE	162.700 €	43.475 €	-	18.832,10 €	51.543,75 €	276.551 €
2	ISAE-SUPAERO	FR	162.700 €	43.475 €	-	18.832,10 €	51.543,75 €	276.551 €
3	TU DELFT	NL	162.700 €	43.475 €	-	18.832,10 €	51.543,75 €	276.551 €
4	IAC	ES	85.744 €	243.850 €	-	30.105,23 €	82.398,5 €	442.098 €
5	CleanOrbit / DIGOS	ES / DE	184.600 €	61.300 €	-	22.460,59 €	61.475 €	329.836 €
6	CILAS	FR	102.600 €	362.650 €	-	42.496,10 €	116.312,5 €	624.059 €
7	OHB System AG	DE	49.000 €	40.200 €	124.000 €	19.473,76 €	53.300 €	285.974 €
8	RUAG International	CH	49.000 €	40.200 €	106.000 €	17.829,64 €	48.800 €	261.830 €
9	Maersk	DK	49.000 €	29.600 €	90.300 €	15.427,39 €	42.225 €	226.552 €
TOTAL			1.008.044 €	908.225 €	320.300 €	204.289,00 €	559.142,25 €	**3.000.000 €**

Table 16: Other direct costs subsections

No	Participant	(B) Other direct costs		
		Travel and management	Equipment and material	Audits and other goods
1	DLR (Bremen)	12.825 €	25.650 €	5.000 €
2	ISAE-SUPAERO	12.825 €	25.650 €	5.000 €
3	TU DELFT	12.825 €	25.650 €	5.000 €
4	IAC	25.650 €	205.200 €	13.000 €
5	CleanOrbit / DIGOS	25.650 €	25.650 €	10.000 €
6	CILAS	25.650 €	324.000 €	13.000 €
7	OHB System AG	14.000 €	21.200 €	5.000 €
8	RUAG International	14.000 €	21.200 €	5.000 €
9	Maersk	14.000 €	10.600 €	5.000 €
		157.425 €	684.800 €	66.000 €

Table 17: Estimated income

(I) Reimbursement rate (%)	(J) Maximun EU contribution (HxI)	(K) Requested EU contribution
100	276.551 €	276.551 €
100	276.551 €	276.551 €
100	276.551 €	276.551 €
100	442.098 €	442.098 €
100	329.836 €	329.836 €
100	624.059 €	624.059 €
100	285.974 €	285.974 €
100	261.830 €	261.830 €
100	226.552 €	226.552 €
		3.000.000 €

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Appendix A Work Breakdown Structure (WBS)

n the next list, the different work packages and tasks related to the development of the project are presented.

1. Project Management
    - 1.1 Initial Deliverables
        - 1.1.1 Project Charter
            - 1.1.1.1 General scope, description and objectives
            - 1.1.1.2 Initial requirements and acceptance criteria
            - 1.1.1.3 High-level risks
            - 1.1.1.4 Deliverables and milestones
            - 1.1.1.5 Estimated budget
            - 1.1.1.6 Initial organisation
            - 1.1.1.7 Stakeholders identification
        - 1.1.2 Project Scope Statement
            - 1.1.2.1 Product Scope Description
            - 1.1.2.2 Deliverables
            - 1.1.2.3 Acceptance Criteria
            - 1.1.2.4 Exclusions
            - 1.1.2.5 Constraints
        - 1.1.3 H2020 Deliverable
            - 1.1.3.1 Call requirements identification
            - 1.1.3.2 Call documentation identification
            - 1.1.3.3 Information gathering
            - 1.1.3.4 Call proposal generation
    - 1.2 Schedule
        - 1.2.1 Organizational Breakdown Structure
            - 1.2.1.1 Departments identification
            - 1.2.1.2 Role identification
            - 1.2.1.3 Consortium relationship definition
            - 1.2.1.4 Stakeholders relationship definition
            - 1.2.1.5 External companies relationship definition
        - 1.2.2 Work Breakdown Structure
            - 1.2.2.1 Work Package identification
            - 1.2.2.2 Task identification
            - 1.2.2.3 Activities dependencies
            - 1.2.2.4 Network diagram
        - 1.2.3 Resources Breakdown Structure
            - 1.2.3.1 Resources identification
            - 1.2.3.2 Resources allocation
        - 1.2.4 Time Management
            - 1.2.4.1 Task duration estimation
            - 1.2.4.2 Gantt Diagram
    - 1.3 Finances
        - 1.3.1 Cost estimation
            - 1.3.1.1 Level of accuracy
            - 1.3.1.2 Activity cost method selection
            - 1.3.1.3 Activity cost computation
        - 1.3.2 Cost baseline
        - 1.3.3 Budget at completion
        - 1.3.4 Sources of funding identification
        - 1.3.5 Feasibility study
        - 1.3.6 Economic monitoring
    - 1.4 Risks
        - 1.4.1 Risks identification
        - 1.4.2 Risks assessment
            - 1.4.2.1 Probability computation
            - 1.4.2.2 Impact analysis
        - 1.4.3 Risk management plan
            - 1.4.3.1 Risk management strategies identification
            - 1.4.3.2 Risk management strategies execution
        - 1.4.4 Risks monitoring
    - 1.5 Legal
        - 1.5.1 Security
        - 1.5.2 Data privacy
        - 1.5.3 Environment
    - 1.6 Communication Management
        - 1.6.1 Internal (CO-LSDD)
            - 1.6.1.1 Communication procedures definition
            - 1.6.1.2 Contact points identification
            - 1.6.1.3 General information filtering
            - 1.6.1.4 Meetings planning
        - 1.6.2 Consortium
            - 1.6.2.1 Communication procedures definition
            - 1.6.2.2 Contact points identification
            - 1.6.2.3 General information filtering
            - 1.6.2.4 Meetings planning

- 1.6.3 Stakeholders
  - 1.6.3.1 Communication procedures definition
  - 1.6.3.2 Contact points identification
  - 1.6.3.3 Sensitive information filtering
  - 1.6.3.4 Meetings planning
- 1.6.4 External companies
  - 1.6.4.1 Communication procedures definition
  - 1.6.4.2 Contact points identification
  - 1.6.4.3 Sensitive information filtering
  - 1.6.4.4 Meetings planning
- 1.6.5 Monthly report
  - 1.6.5.1 Information gathering
  - 1.6.5.2 Main information identification
- 1.6.6 Biannual report
  - 1.6.6.1 Main information identification

2. Environmental Study
   - 2.1 Environmental policy
   - 2.2 Environmental impact
     - 2.2.1 Manufacturing environmental footprint
       - 2.2.1.1 Materials
       - 2.2.1.2 Industrial processes
       - 2.2.1.3 Waste management
     - 2.2.2 Operational environmental footprint
       - 2.2.2.1 Location ecology study
       - 2.2.2.2 Laser operation socio-economic study
       - 2.2.2.3 Facility maintenance
     - 2.2.3 Logistics footprint
   - 2.3 Report
   - 2.4 Nonconformance and corrective/preventive actions
   - 2.5 Training and awareness
   - 2.6 Monitoring and control of critical areas
3. Marketing
   - 3.1 Initial research
     - 3.1.1 Market evolution (past and present)
     - 3.1.2 Offer and demand analysis
     - 3.1.3 Market forecast
     - 3.1.4 SWOT analysis
     - 3.1.5 Business case
   - 3.2 Marketing actions
     - 3.2.1 Objectives definition
     - 3.2.2 Congress/Fairs attendance
     - 3.2.3 Media presence
     - 3.2.4 Social media management
     - 3.2.5 Space debris awareness campaigns
   - 3.3 Key performance indicators identification
   - 3.4 Success evaluation
4. Technical
   - 4.1 Research
     - 4.1.1 Research protocol
     - 4.1.2 State of the art review
     - 4.1.3 Quality assessment
     - 4.1.4 Reverse engineering
     - 4.1.5 Report
   - 4.2 Design
     - 4.2.1 Mechanical design
       - 4.2.1.1 Preliminary design
       - 4.2.1.2 Parts definition & list
       - 4.2.1.3 Basic part layout
       - 4.2.1.4 Mechanical assembly scheme
     - 4.2.2 Laser design
       - 4.2.2.1 High power laser diode design
       - 4.2.2.2 Wavelength stabilizer design
       - 4.2.2.3 Heavy duty power supply design
       - 4.2.2.4 Laser lens design
       - 4.2.2.5 Laser assembly scheme
     - 4.2.3 Mirror design
       - 4.2.3.1 Mirror shape design
       - 4.2.3.2 Mirror material selection
       - 4.2.3.3 Surface treatment & coating
       - 4.2.3.4 Mirror assembly scheme
     - 4.2.4 Software design
       - 4.2.4.1 Software planning
       - 4.2.4.2 Software analysis
       - 4.2.4.3 Implementation
       - 4.2.4.4 Testing & integration
   - 4.3 Quality management
     - 4.3.1 Quality standard definition
     - 4.3.2 Quality plan
     - 4.3.3 Quality review
     - 4.3.4 Quality standard evaluation
     - 4.3.5 Quality improvement
   - 4.4 Maintenance
     - 4.4.1 Plan

4.4.2 Checklist
4.4.3 Program
4.4.4 Periodic maintenance
4.4.4.1 Short-term maintenance
4.4.4.2 Long-term maintenance
4.5 Design certification
4.5.1 List of ISO norms for design
4.5.2 Non-ISO design certifications

5. Procurement
5.1 Definition of specifications
5.2 Procurement guide
5.2.1 Electronics procurement guide
5.2.2 Integration procurement guide
5.2.3 Logistics procurement guide

6. Prototype
6.1 Study of prototype providers
6.1.1 Quality standards for prototyping
6.1.2 Provider comparison
6.1.2.1 Prototype manufacturing proposal
6.1.2.2 Budget proposal
6.1.3 Provider selection
6.2 Prototype material selection
6.2.1 Viability analysis
6.2.2 Small-scale material analysis
6.2.3 Scalability analysis
6.3 Production
6.3.1 Manufacturing
6.3.1.1 Mechanical manufacturing
6.3.1.2 Laser manufacturing
6.3.1.3 Mirror manufacturing
6.3.2 Assembly with electronics
6.4 Prototype assembly
6.4.1 Mechanical assembly
6.4.2 Laser assembly
6.4.3 Mirror assembly
6.4.4 Prototype integration
6.5 Prototype testing
6.6 Root cause analysis

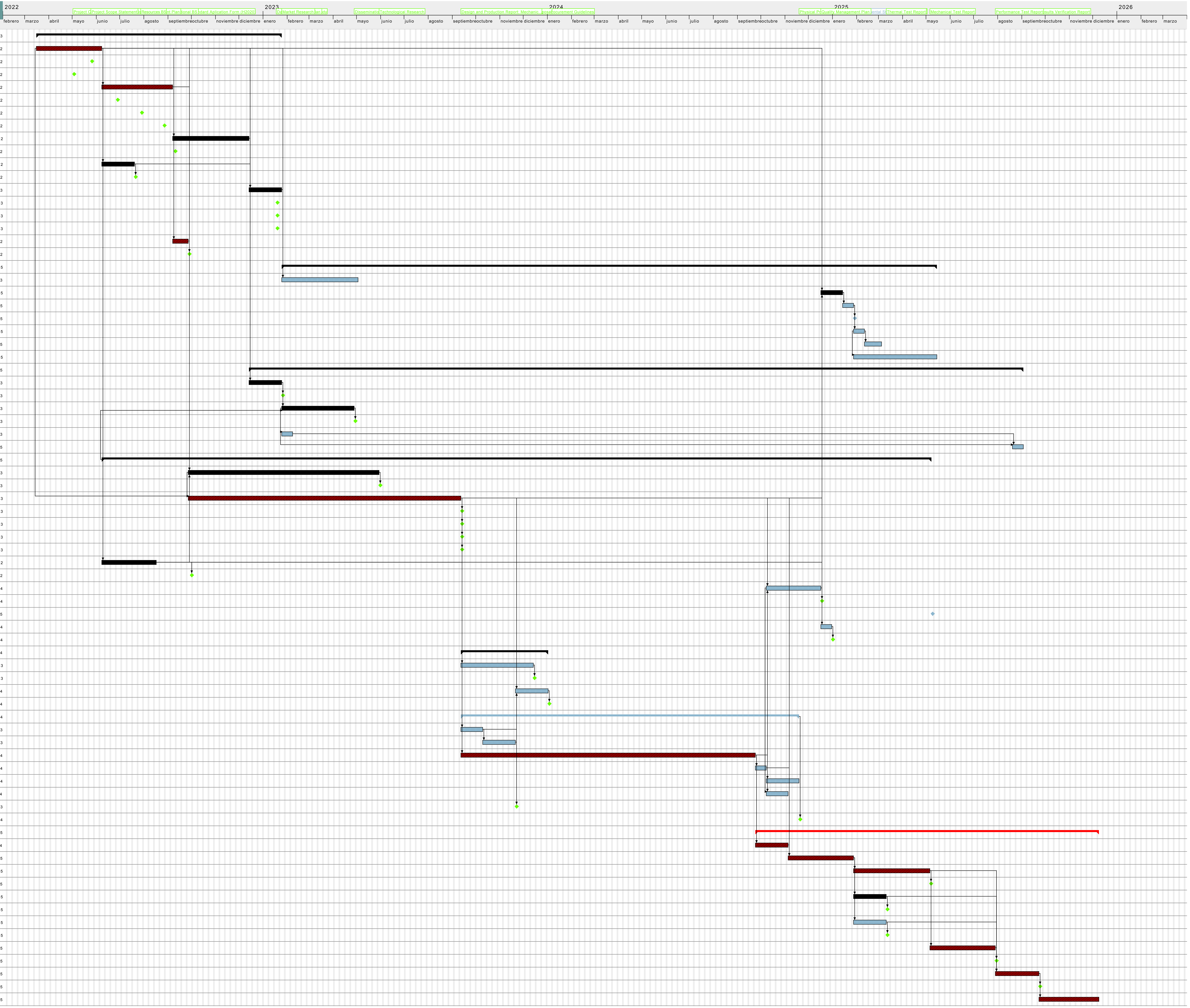
7. Testing
7.1 Test certification requirements
7.1.1 List of ISO norms
7.1.2 Non-ISO requirements
7.2 Test plan
7.2.1 Test procedures
7.2.2 Test reporting
7.3 Mechanical test
7.3.1 Stress test
7.3.2 Strain test
7.3.3 Frequency analysis
7.3.3.1 Sine vibration - Fixed frequency
7.3.3.2 Random vibration - Random frequency
7.3.3.3 Frequency spectrum diagram
7.4 Thermal test
7.4.1 Heat transfer analysis: Laser system
7.4.2 Heat transfer analysis: Electronics
7.4.3 Cooling systems
7.5 Software test
7.6 Performance test
7.6.1 Power output test
7.6.2 Wavelength oscillation test
7.6.3 Beam divergence test
7.6.4 Beam Parameter Product
7.6.5 Power loss test
7.7 Comparison to numerical results
7.8 Data adjusting & result verification

Appendix B Gantt and Network diagrams

In the next pages the schedule of the first level tasks (X.X) and main deliverables is provided in the form of Gantt Diagram. The critical path can be seen in red. In addition to this, different Network diagrams are also presented, one for each work package, with the dependencies between the tasks in the previous list.

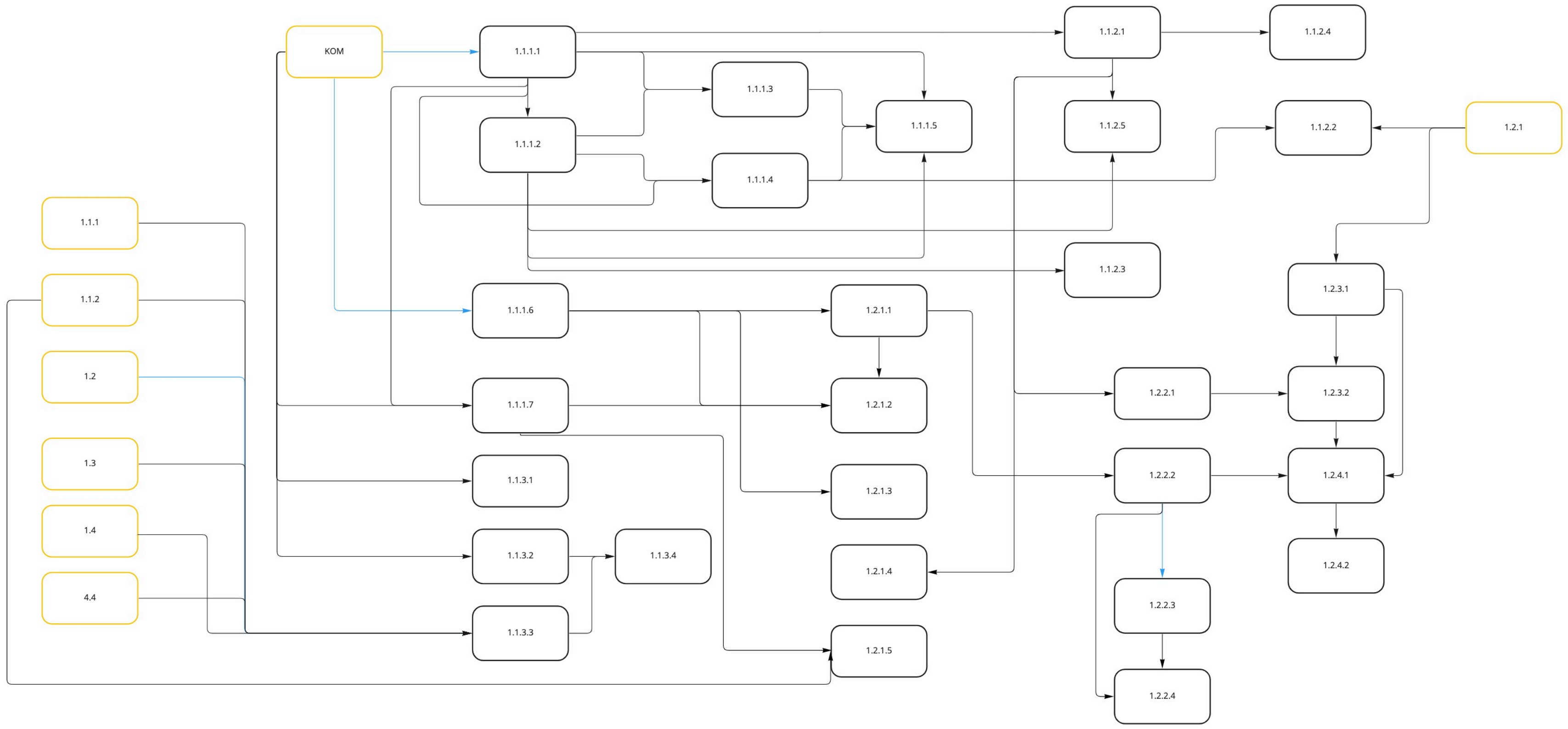
Diagrama de Gantt

Nombre	Fecha de inicio	Fecha de fin
1. Project Management	16/3/22	24/1/23
1.1. Initial Deliverables	16/3/22	7/6/22
Project Scope Statement	25/5/22	25/5/22
Project Charter	2/5/22	2/5/22
1.2. Schedule	8/6/22	6/9/22
Work Breakdown Structure	27/6/22	27/6/22
Resources BS	28/7/22	28/7/22
Organisational BS	26/8/22	26/8/22
1.3. Finances	7/9/22	13/12/22
Budget	9/9/22	9/9/22
1.4. Risks	8/6/22	19/7/22
Risks Management Plan	20/7/22	20/7/22
1.5. Legal	14/12/22	24/1/23
Security Regulations Study	18/1/23	18/1/23
Data Management Plan	18/1/23	18/1/23
Safety Environment Report	18/1/23	18/1/23
1.6. Communication Management	7/9/22	26/9/22
Communication Plan	27/9/22	27/9/22
2. Environmental Study	25/1/23	14/5/25
2.1. Environmental Policy	25/1/23	2/5/23
2.2. Environmental impact	17/12/24	13/1/25
2.3. Report	14/1/25	27/1/25
Environmental Study	28/1/25	28/1/25
2.4. Nonconformance and c...	28/1/25	10/2/25
2.5. Training and awareness	11/2/25	4/3/25
2.6. Monitoring and contr...	28/1/25	14/5/25
3. Marketing	14/12/22	2/9/25
3.1. Initial research	14/12/22	24/1/23
Market Research	25/1/23	25/1/23
3.2. Marketing actions	25/1/23	27/4/23
Dissemination Plan	28/4/23	28/4/23
3.3. Key performance indi...	25/1/23	7/2/23
3.4. Success evaluation	20/8/25	2/9/25
4. Technical	8/6/22	7/5/25
4.1. Research	27/9/22	29/5/23
Technological Research	30/5/23	30/5/23
4.2. Design	27/9/22	11/9/23
Software Design Report	12/9/23	12/9/23
Design and Production Rep...	12/9/23	12/9/23
Design and Production Rep...	12/9/23	12/9/23
Design and Production Rep...	12/9/23	12/9/23
4.3. Quality management	8/6/22	16/8/22
Standard Aplication Form (H2020)	30/9/22	30/9/22
4.4. Maintenance	8/10/24	16/12/24
Quality Management Plan	17/12/24	17/12/24
Mintenance Plan	8/5/25	8/5/25
4.5. Certification	17/12/24	30/12/24
Certification Report	31/12/24	31/12/24
5. Procurement	12/9/23	1/1/24
5.1. Definition of specifications	12/9/23	13/12/23
Technical Specifications Report	14/12/23	14/12/23
5.2. Procurement guide	21/11/23	1/1/24
Procurement Guidelines	2/1/24	2/1/24
6. Prototype	12/9/23	18/11/24
6.1. Study of prototype providers	12/9/23	9/10/23
6.2. Prototype material selection	10/10/23	20/11/23
6.3. Production	12/9/23	23/9/24
6.4. Prototype assembly	24/9/24	7/10/24
6.5. Prototype testing	8/10/24	18/11/24
6.6. Root cause analysis	8/10/24	4/11/24
Prototype Proposal	21/11/23	21/11/23
Physical Prototype	19/11/24	19/11/24
7. Testing	24/9/24	8/12/25
7.1. Test certification requirements	24/9/24	4/11/24
7.2. Test plan	5/11/24	27/1/25
7.3. Mechanical test	28/1/25	5/5/25
Mechanical Test Report	6/5/25	6/5/25
7.4. Thermal test	28/1/25	10/3/25
Thermal Test Report	11/3/25	11/3/25
7.5. Software test	28/1/25	10/3/25
Software Test Report	11/3/25	11/3/25
7.6. Performance test	6/5/25	28/7/25
Performance Test Report	29/7/25	29/7/25
7.7. Comparison to numerical results	29/7/25	22/9/25
Results Verification Report	23/9/25	23/9/25
7.8. Data adjusting & result verification	23/9/25	8/12/25

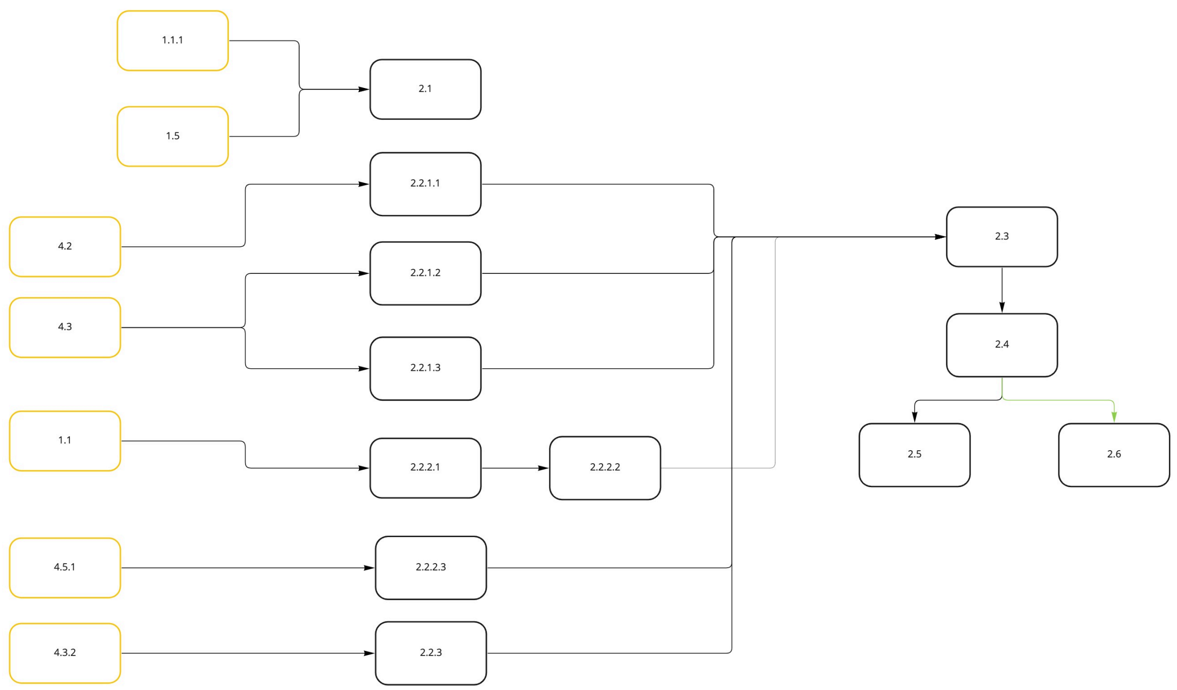


NETWORK DIAGRAMS

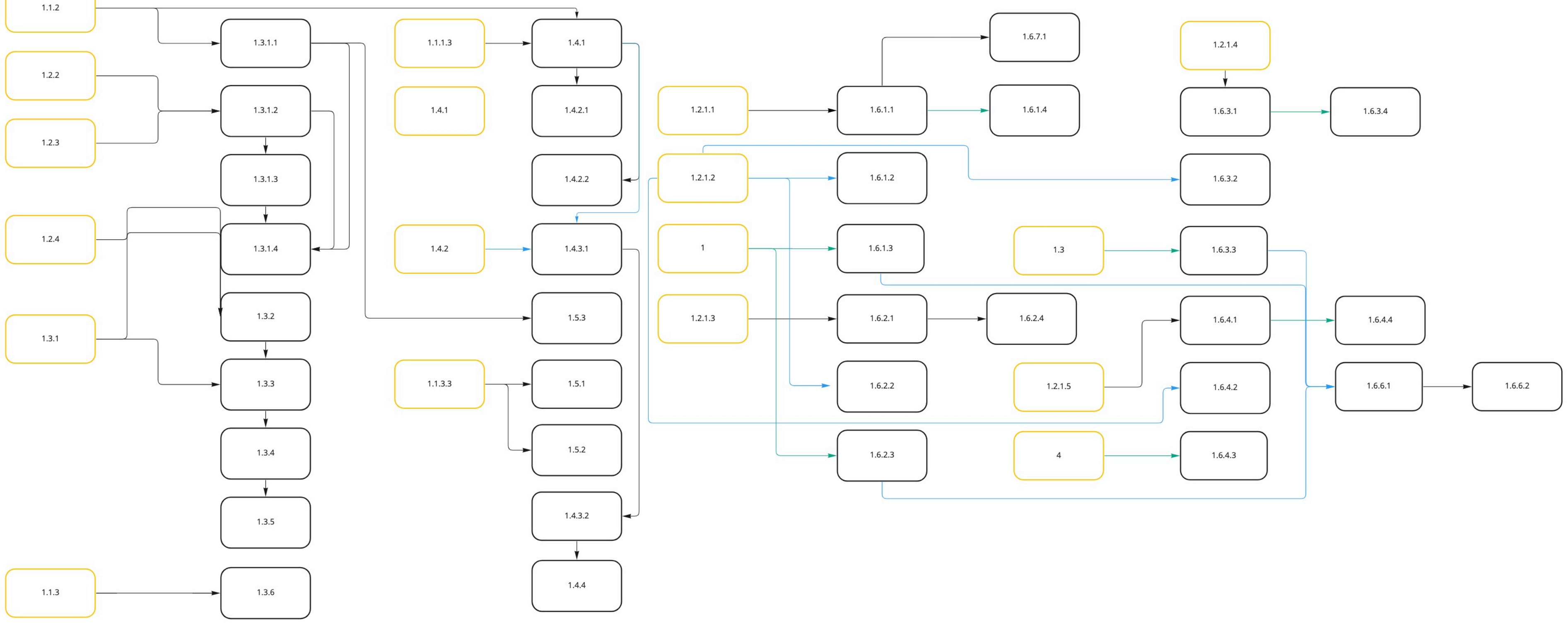
1. PROJECT MANAGEMENT (1.1 - 1.2)



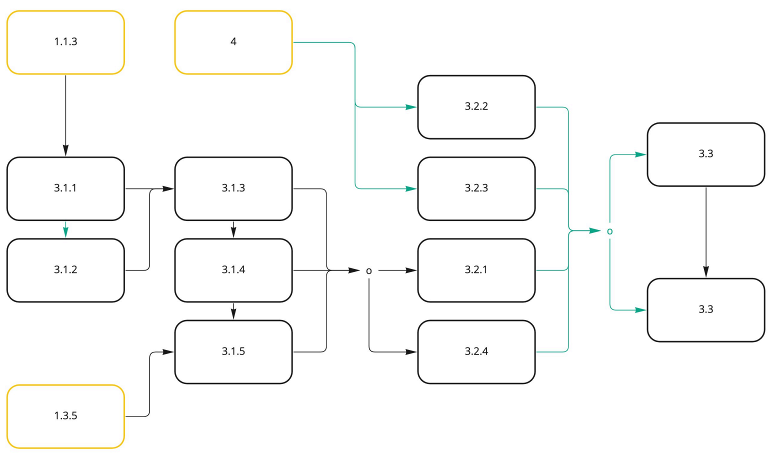
2. ENVIRONMENT



1. PROJECT MANAGEMENT (1.3 - 1.6)

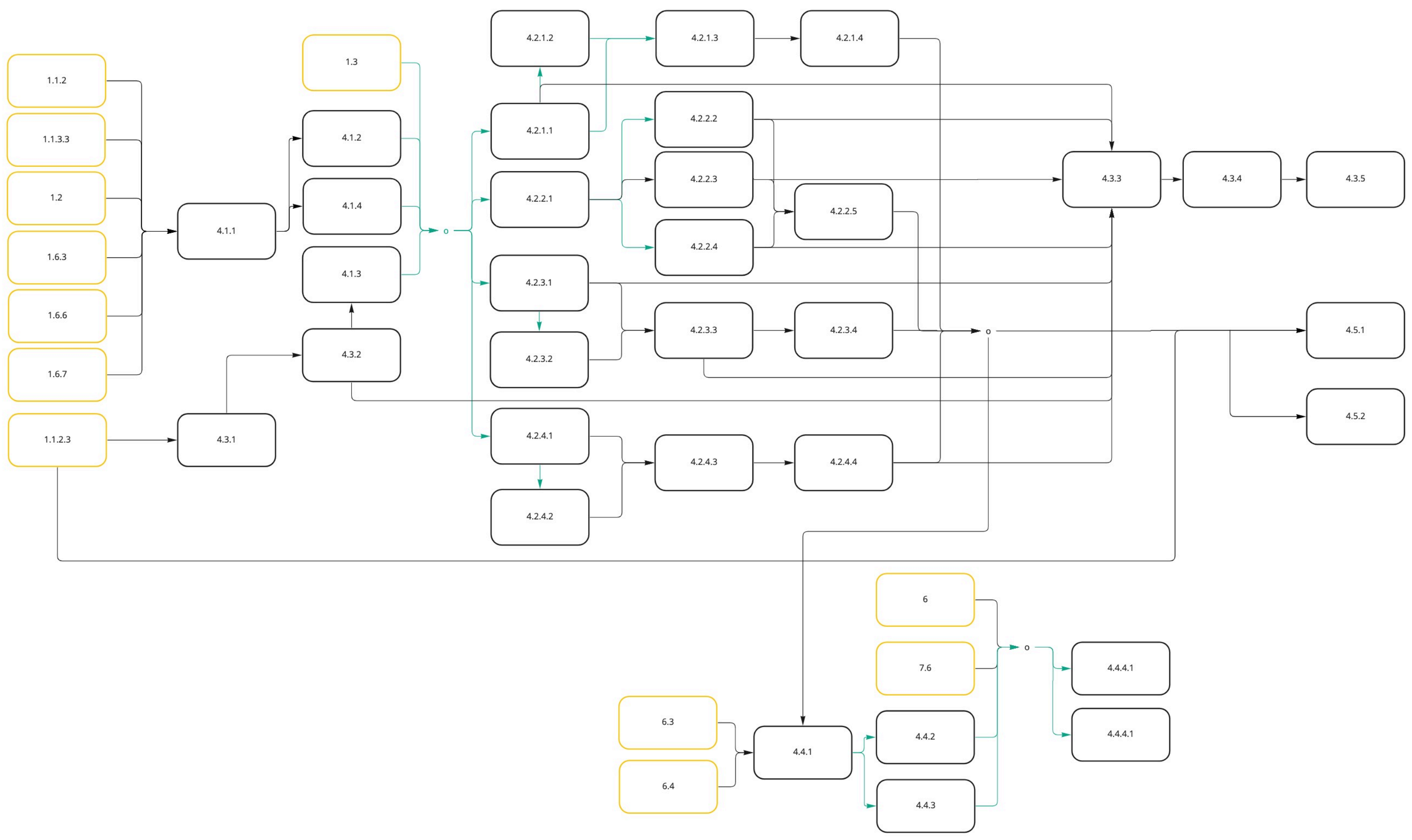


3. MARKETING

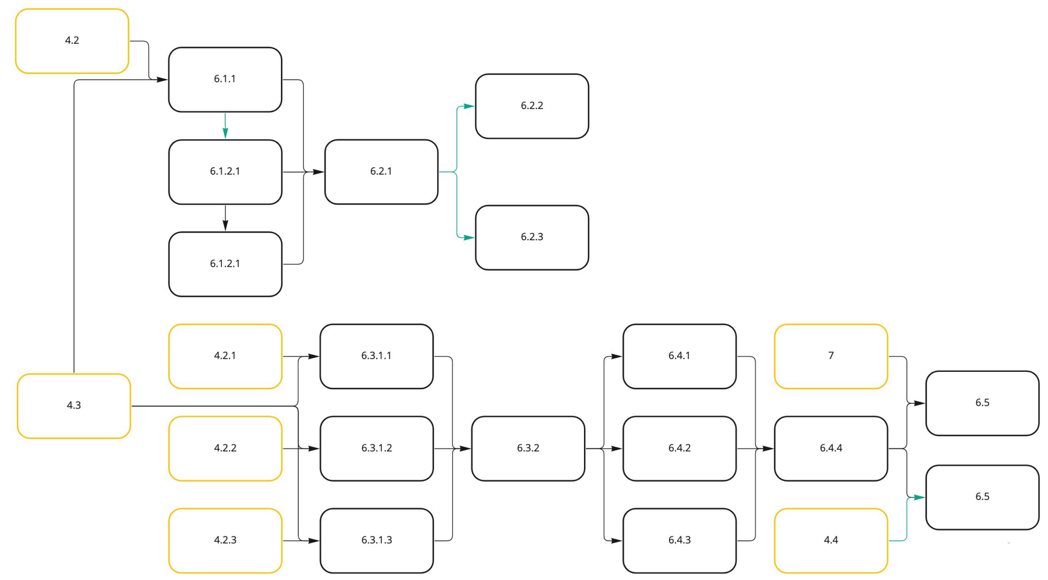


NETWORK DIAGRAMS

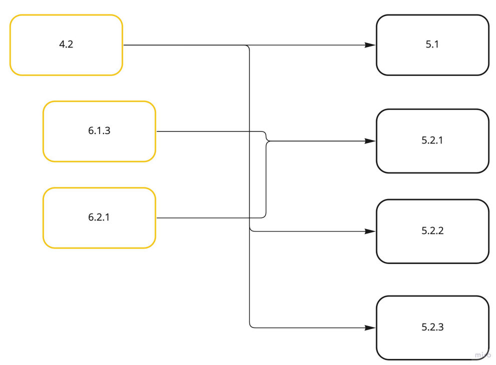
4. TECHNICAL



6. PROTOTYPE



5. PROCUREMENT



7. TESTING