Stakeholder Expectation Report

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SBSP Pre-Phase A System Study

Stakeholder Expectation Report

DRL: TN 1

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Change Records

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
01	19/05/2023	Issue 1	SBSP Team
02	04/08/2023	Updated §1.3 (Reference documents) Updated §2 (Stakeholder needs and requirements definition in response) and attached excel spreadsheet to Annex 1 in response to SKR RID **AGM-08** Updated §2.4 (SBSP User and Service Requirements) in response to SKR RID **AGM-01**, **AGM-02, AGM-03, AGM-04, AGM-05, AGM-06, AGM-07, SV-05** Updated §3.1 (Identified use-cases) in response to SKR RID **AGM-09** Updated §3.2 Figure 3-2, Figure 3-4, Figure 3-5, Figure 3-6 and Figure 3-7 Updated §3.3 (Reference use-case) both in response to SKR RID **AGM-09** and to implement ESA requests.	SBSP Team
03	20/12/2023	Removed Annex 1&2 and updated §1.4, §2.1, §2.3.1, §2.3.2 and §2.4 accordingly.	SBSP Team

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1 Introduction

The growth of the human population, industrialization of developing countries and rising living standards for the population are continuously increasing global energy demand, that in the next 30 years is forecast to double.

In the meantime most European countries have decided to phase out coal use in the power sector, some even by 2030 or by 2040 at the latest. Coal phase-out and current uncertainties over the supply of other types of fossil fuels (e.g., oil, natural gas) coupled with the phase-out of nuclear power plants in some countries would result in a significant decrease in baseload generation capacity. The increasing share of intermittent renewables alone cannot solve the growing demand from the electrification of modern economies. Their load profile is volatile due to their fluctuating and intermittent nature.

Following the above considerations we need to urgently investigate a variety of sustainable, affordable, secure and scalable energy sources in order to contribute to the collective objective to reach carbon neutrality by 2050 and fulfil the Paris Agreement.

SBSP system could largely contribute to the decarbonisation of the European energy sector in the upcoming decades, with the potential to turn solar power into a renewable baseload capacity. It has the potential to generate green electricity throughout the year with little interruption and without any direct greenhouse gas emissions.

Satellites in orbit are illuminated by the sun without being limited by constraints on ground (e.g. daylight/nightlight cycle and wheatear conditions) resulting with a solar intensity substantially greater than received on ground. Space Based Solar Power is the concept of collecting this abundant solar power in orbit, and beaming it securely on earth. Its main advantage over wind and terrestrial solar energy is the ability to deliver energy day and night throughout the year and in all weathers. It has good grid integration characteristics and is scalable, safe, resilient and secure.

1.1 Scope and purpose

This document summarizes the outcome of the stakeholders consultation meetings, organized by ESA on April 2023, with the objective to establish a consistent set of stakeholder needs and expectations for a prospective future SBSP service.

Here below a quick overview on the major aspects covered through this document:

- Definition of a set of stakeholder needs and requirements
- Definition of a set of use-cases and operational scenarios
- Selection of a reference commercial use-case for the SBSP service and system

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1.2 Applicable documents

Internal code / DRL	Reference	Issue	Title	Location of record
[AD1]			Orbit Analyses for Commercial-Scale Space-Based Solar Power Systems	
[AD2]			ESSB-HB-U-005 Space system Life Cycle Assessment (LCA) Guidelines iss.1.0	
[AD3]			ESA LCA Database	
[AD4]			ECSS-U-AS-10C Rev.1 – Adoption Notice of ISO 24113: Space systems – Space debris mitigation requirements (3 December 2019)	
[AD5]			Study Report(s) from ESA Future Launchers Preparatory Programme activity titled “euroPean Reusable and cOsT Effective heavy lIft transport investigation” (PROTEIN)	
[AD6]			ESA-TECSF-SOW-2022-003590 - Statement of Work Pre-Phase A System Study of a Commercial-Scale Space-Based Solar Power (SBSP) System for Terrestrial Needs	

1.3 Reference documents

Internal code / DRL	Reference	Issue	Title	Location of record
[RD1]			Final Deliverables from Frazer-Nash Consultancy for ESA-funded study titled “Cost-Benefit Analysis of Space-Based Solar Power Generation for Terrestrial Energy Needs” https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2a.html https://esamultimedia.esa.int/docs/technology/frazer-nash-consultancy-SBSP-cost-benefit-study-full-deliverables.zip	
[RD2]			Final Deliverables from Roland Berger for ESA-funded study titled “Cost-Benefit Analysis of Space-Based Solar Power Generation for Terrestrial Energy Needs” https://esamultimedia.esa.int/docs/technology/roland-berger-SBSP-cost-benefit-study-full-deliverables.zip	
[RD3]			SPS-ALPHA: The First Practical Solar Power Satellite via Arbitrarily Large Phased Array (A 2011-2012 NASA NIAC Phase 1 Project)	
[RD4]			Mankins, John C. "New Developments in Space Solar Power." NSS Space Settlement Journal (2017): 1-30.	
[RD5]			Space Solar Power: An Overview – John C. Mankins (Presentation at ISDC 2022)	

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Internal code / DRL	Reference	Issue	Title	Location of record
[RD6]			Cash, Ian. "CASSIOPeiA–A new paradigm for space solar power." Acta Astronautica 159 (2019): 170-178. https://doi.org/10.1016/j.actaastro.2019.03.063	
[RD7]			Cash, Ian. "CASSIOPeiA solar power satellite." 2017 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE). IEEE, 2017. 10.1109/WiSEE.2017.8124908	
[RD8]			UK Patent: GB2571383 - Solar concentrator: https://www.ipo.gov.uk/p-ipsum/Case/PublicationNumber/GB2571383	
[RD9]			UK Patent: GB2563574 - A phased array antenna and apparatus incorporating the same https://www.ipo.gov.uk/p-ipsum/Case/PublicationNumber/GB2563574	
[RD10]			CASSIOPEIA SPS: Advantages for Commercial Power, I Cash (Presentation at ISDC 2022)	
[RD11]			Space Solar Power development in China and MR-SPS, 4th SPS Symposium 2018, Kyoto, Japan https://www.sspss.jp/MR-SPS4.pdf	
[RD12]			Fraas, Lewis M. "Mirrors in space for low-cost terrestrial solar electric power at night." 2012 38th IEEE Photovoltaic Specialists Conference. IEEE, 2012.	
[RD13]			Fraas, Lewis M., Geoffrey A. Landis, and Arthur Palisoc. "Mirror satellites in polar orbit beaming sunlight to terrestrial solar fields at dawn and dusk." 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC). IEEE, 2013.	
[RD14]			Çelik, Onur, et al. "Enhancing terrestrial solar power using orbiting solar reflectors." Acta Astronautica 195 (2022): 276-286.	
[RD15]			Çelik, Onur, and Colin R. McInnes. "An analytical model for solar energy reflected from space with selected applications." Advances in Space Research 69.1 (2022): 647-663.	
[RD16]			ESSB-ST-U-004 ESA Re-entry Safety Requirements iss.1.0	
[RD17]			FNC 011337 53514R Space Based Solar Power End of Life Study Final Report (Frazer-Nash Consultancy) Issue 1	
[RD18]			FNC 011337 53615R Space Based Solar Power End of Life Study Summary Report (Frazer-Nash Consultancy) Issue 1	
[RD19]			Sala, Serenella, et al. "Global normalisation factors for the environmental footprint and life cycle assessment." Publications Office of the European Union: Luxembourg (2017): 1-16	
[RD 20]			NASA SP-2016-6105 Rev2 NASA Systems Engineering Handbook	

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1.4 Definitions and Acronyms

Acronym/Abbreviation	Definition
CAPEX	Capital Expediture
CASSIOPeiA	Constant Aperture, Solid-State, Integrated orbital Phased Array
DM	Digital Model
DOORS	Dynamic Object-Oriented Requirements System
DSO	Distribution System Operator
ESA	European Space Agency
GPS	Ground Power Station
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MBSE	Model Based Systems Engineering
MR-SPS	Multi-Rotary joints SPS
MW	Megawatt
MWp	Megawatt peak
NASA	National Aeronautics and Space Administration
NGO	Needs, Goals, and Objectives
PV	Photovoltaic
RF	Radio Frequency
SBSP	Space-Based Solar Power
S/C	Spacecraft
SPS	Solar Power Satellite
SPS-ALPHA	SPS by means of Arbitrarily Large Phased Array
TAS	Thales Alenia Space
TSO	Transmission System Operator
W	Watt

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2 Stakeholder needs and requirements definition

As stated in ISO/IEC/IEEE 15288:

[6.4.2.1] The purpose of the Stakeholder Needs and Requirements Definition process is to define the stakeholder requirements for a system that can provide the capabilities needed by users and other stakeholders in a defined environment

In the frame of the "Pre-Phase A System Study of a Commercial-Scale Space-Based Solar Power (SBSP) System for Terrestrial Needs" the following categories of stakeholders with a legitimate interest in the system have been involved by ESA:

- Energy Companies;
- ICT Companies;
- Grid Operators.

For each of the three categories listed above several stakeholders have been interviewed, under the Chatham House Rule[1], between April, 17 and April, 20. Those interviews, managed by our Consortium, were based on a set of questions prepared with the aim of establishing a consistent set of stakeholders needs and expectations of a prospective commercial SBSP system.

The elaboration of these interviews together with the identification of the stakeholder needs and requirements is presented in the following sections.

[1] The **Chatham House Rule** helps create a trusted environment to understand and resolve complex problems. Its guiding spirit is: share the information you receive, but do not reveal the identity of who said it. The Rule reads as follows: "When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed." Following this rule the stakeholders involved are not mentioned here nor in Annex 1.

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2.1 Stakeholder expectation statements

Based on the Stakeholders meeting interviews Q&A the following stakeholders expectation statements have been derived:

Topic	Stakeholders expectation statements
Approach to intermittent energy	The intermittent energy from renewables are counteracted with storage (e.g. batteries, green and blue hydrogen) and backup capacity (e.g. gas power plant). The big competition for SBSP is on the backup capacity because the gas power plants will have very low load factor and will be too expensive.
	To overcome intermittency the approach comprises: - improvement in the forecast - making the renewable energy controllable in terms of combination between storage and renewables.
SBSP for baseload power provision	SBSP can be seen as a source of baseload power, in a climate change World, as post nuclear considering that nuclear plants are powered down due to overheat, localisation, need of water. Moreover with SBSP no nuclear waste will be produced.
	Stakeholders are looking for baseload constant power. The baseload power availability fluctuation on ground shall be planned and the balance be maintained on a quarter of hour (15 minutes) basis. For deviations balancing power shall be payed to the grid operators.
Service interruption conditions to be respected	The interruption of service conditions depends on what kind of contracts we have with the customer. (e.g. home users vs big chemical industries). The interruption notification can vary from 10 minutes to one day.
SBSP in support of the generation of renewable energies	Baseload should be exploited more for distribution than for production of renewable energies. We can imagine the business case where the power plant is not cheap enough to produce electricity (price of electricity is negative) but it could be cheap enough to produce hydrogen. There will be also a big need in the future for water desalination which requires a lot of energy.
	We could see the thermal increase on ground (due to dissipation of the energy) as a benefit and use heat pumps systems for heating water, in particular during night.
Decentralized power for security and reliability reasons	For system security and reliability reasons decentralized power is considered better. The smaller the power plants the better.
SBSP for energy mix	Increasing the energy mix is perceived by all stakeholders as very positive and could allow to overcome power shortages
SBSP economic competitiveness	If we want to add additional power supply we will have to compete with other imported energy forms. We need to provide price comparison of SBSP power plants with respect to other power plants
	We consider the substitution of other sources that are less clean and less constant and secure as selling point.
Consumer behaviour and green solutions	The main changes observed in the consumer behaviour is seen in the mobility sector including electrical cars and heavy duty trucks for which there is a request for green solutions.
	People pay attention to energy consumption and are more and more interested in green solutions. The approach to green solutions vary between countries (Europe is very interested, India is not).
	Consumer behaviour is changing a lot due to higher energy prices. Consumer are currently considering decarbonisation.
Environmental Impact	The environmental sustainability is very important. Distribution System Operators (DSO) are pushing for sustainability considering that the process for producing panels is not very clean (the so called PV cycle). For that reason they are working on sustainable PV modules.
Space sector perception from energy sector	Space sector is perceived as highly reliable and as a source of solutions that could be commercialized on Earth, albeit expensive.
	The link between energy and space sectors is the use of satellites for geo-resources monitoring.
Power transmission and distribution	In case of RF transmission, the biggest question will be around the microwave effects on the environment. HSE (Health Security and Environment) part needs to be carefully taken into account.
	In case of RF transmission, the constraint on connection with the generator, including admissible transmission capacity, need to be taken into account.
	The following constraints exist for power transmission and distribution: - to find places and location where there is still place available for power plants - transportability - fishing for offshore power plant - high voltages vs low voltages
	In case of network congestion we can think to mitigate by connecting the steering antenna to several networks.
Energy market evolution	In the future what will change will be: - the added market capacity. Note than SBSP would be cheaper than gas power plants and could get similar remuneration; - an additional effort and strategies to decarbornisation goal especially via green hydrogen and also prospective nuclear power generation; - the electrification of transportation (car, trucks, airplanes); - the energy independence of Europe.
GPS installed power	In terms of installed power of a single GPS the suggestion is to not go beyond 1.5GWp. Above this limit the size of generators on ground need to be increased to cover possible energy gaps.
	The goal in installed power varies from stakeholders. The range is from 200MWp to 1-1.5GWp for a single GPS.
Low power GPS	Low power GPS(s) are definitely an option to make the system more flexible. The idea is to try to locate power plants in an area where we expect higher energy prices.

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Topic	Stakeholders expectation statements
	Moveable offshore GPS need connections and the related infrastructures. This can be useful if w e have large users in different locations but the cost w ould be quite large
GPS location and size	The most critical aspect on GPS location and size is the acceptance of the community.
	To put GPS(s) in Northern Europe could be a good choice especially in low population density areas (e.g. somew here in Sw eden, Finland, Norw ay w hich are seen also as more open to innovation).
	It w ould be important to compute the size of the rectantennas area for safety reasons
	If the GPS(s) is out of Europe they w ill be complex to manage and more risky. Also offshore GPS could be a problem in that sense
	It is suggested to place GPS(s) in Europe. Possible alternatives could be impractical considering for instance political instability. It w ill also difficult to compete w ith solar pow er plant based in Africa or Australia w here you have a lot of sun. Northern Europe w ould be the top candidate for the follow ing tw o reasons: 1) industrial residential demands that is in the order of GWs 2) reaction of governments faster in implementing enabling regulations.
	Land availability for GPS location in metropolitan areas can represent stumbling block
Double technology (PV+RF)	A double technology is considered a good idea but w e just need to keep in mind that in that case w e need bigger transformers and transmission lines. Moreover if it is offshore PV plant are not w orth it.
	On ground the use of existing solar plants need to be accepted by the people. A suggestion is to have an agile approach building small scale prototype on ground and demonstrate the effects on population (to probe acceptability).
	Grid/net w here rectantennas are placed can also be used to protect agriculture (so a double usage).
	One suggestion is to provide the costs of the SBSP solution and then add the price for a possible PV plant underneath.
On-shore vs off-shore GPS(s)	To start w ith an on-shore GPS solution is simpler. We could build an SBSP MWp plant prototype and subsequently scale-up the system or build a new bigger plant.
	The visual impact of on-shore GPS can be a concern. The use of offshore pow er plant can overcome this issue and also the security ones.
SBSP safety and security aspects	From a security perspective w e need a system that is inherently secure. You need to ensure the beam is only active w hen pointing in the right direction. Moreover w e should think about rockets that may target the pow er plants. We see cybersecurity and site security protections requirements.
SBSP system lifetime	The SBSP minimum lifetime should be 10 years, ideally in the range of 20-40 years.

Table 2-1 Stakeholder expectation statements

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2.2 Stakeholder Needs, Goals and Objectives (NGOs)

As stated in [RD 20]:

"[4.1.1.2.3] Needs, Goals, and Objectives (NGOs) provide a mechanism to ensure that everyone (implementer, customer, and other stakeholders) is in agreement at the beginning of a project in terms of defining the problem that needs to be solved and its scope. NGOs are not contractual requirements or designs."

From the stakeholder expectations captured in Table 2-1 the following Need has been derived:

Need Ref.	Need Description	Need Text
SBSP-SN-001	SBSP System characteristics	Stakeholders need a durable system providing baseload constant power taking into account safety, sustainability and security aspects

Table 2-2 Stakeholder Need

The following stakeholder goals have been derived from Table 2-2:

Goal Ref.	Need Ref.	Goal Description	Goal Text
SBSP-SG-001	SBSP-SN-001	Power delivery from space	The system shall collect solar power in space and deliver it to ground constantly or with predictable power fluctuation
SBSP-SG-002	SBSP-SN-001	Power control	The system shall be safe, sustainable and secure
SBSP-SG-003	SBSP-SN-001	System availability	The system commercial availability and operational lifetime shall be compatible with investment planning
SBSP-SG-004	SBSP-SN-001	System performance	The system shall be designed in order to satisfy the intended performance

Table 2-3 Stakeholder Goals

The following stakeholder objectives have been derived from Table 2-3:

Objective Ref.	Goal Ref.	Need Ref.	Objective Description	Objective Text
SBSP-SO-001	SBSP-SG-001	SBSP-SN-001	Fluctuation planning	The power availability fluctuation on ground shall be planned.
SBSP-SO-002	SBSP-SG-001	SBSP-SN-001	Service interruption	SBSP service interruptions shall be properly notified to transmission and distributions operators.
SBSP-SO-003	SBSP-SG-001	SBSP-SN-001	Insensitivity to time and weather	SBSP power provision shall be insensible to time of day and weather conditions.
SBSP-SO-004	SBSP-SG-001	SBSP-SN-001	Power delivery in EU	The SBSP system shall be capable to deliver power to a selected ground power station within Europe.
SBSP-SO-005	SBSP-SG-001	SBSP-SN-001	Space-based primary power	A minimum amount of primary power source shall be space-based.
SBSP-SO-006	SBSP-SG-002	SBSP-SN-001	Space Debris	The System shall be designed and constructed to ensure a safe decommissioning without generating debris.

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Objective Ref.	Goal Ref.	Need Ref.	Objective Description	Objective Text
SBSP-SO-007	SBSP-SG-003	SBSP-SN-001	Commercial approach	The System deployment and use shall be commercially driven.
SBSP-SO-008	SBSP-SG-003	SBSP-SN-001	Start of Operations	The System shall start its operations within a defined time.
SBSP-SO-009	SBSP-SG-003	SBSP-SN-001	Operational Lifetime	The System operational lifetime shall be compatible with investment planning.
SBSP-SO-010	SBSP-SG-004	SBSP-SN-001	GPS nameplate capacity	The GPS nameplate capacity (the maximum output that the generator can produce) threshold shall be defined.
SBSP-SO-011	SBSP-SG-004	SBSP-SN-001	Capacity factor	The SBSP system capacity factor (which measures how often a plant is running at maximum power) shall be defined.
SBSP-SO-012	SBSP-SG-004	SBSP-SN-001	Target Capability	A minimum target capability shall be provided by the SBSP plants during the whole operational lifetime.

Table 2-4 Stakeholder Objectives

2.3 Study assumptions and constraints

2.3.1 Assumptions

Based on the Stakeholders meeting interviews Q&A the following study assumptions have been derived:

- It is suggested to put the GPS inside Europe in order to avoid security, legal and commercial constraints. In particular Northern Europe could be a good choice especially in low population density areas (e.g. somewhere in Sweden, Finland, Norway which are seen also as more open to innovation).
- Stakeholders consider the substitution of other sources that are less clean (e.g. fossil fuels) and less constant and secure as selling point.

The proposed governance and funding model to be used for the realisation of the Commercial-scale SBSP system is reported in Figure 2-1.

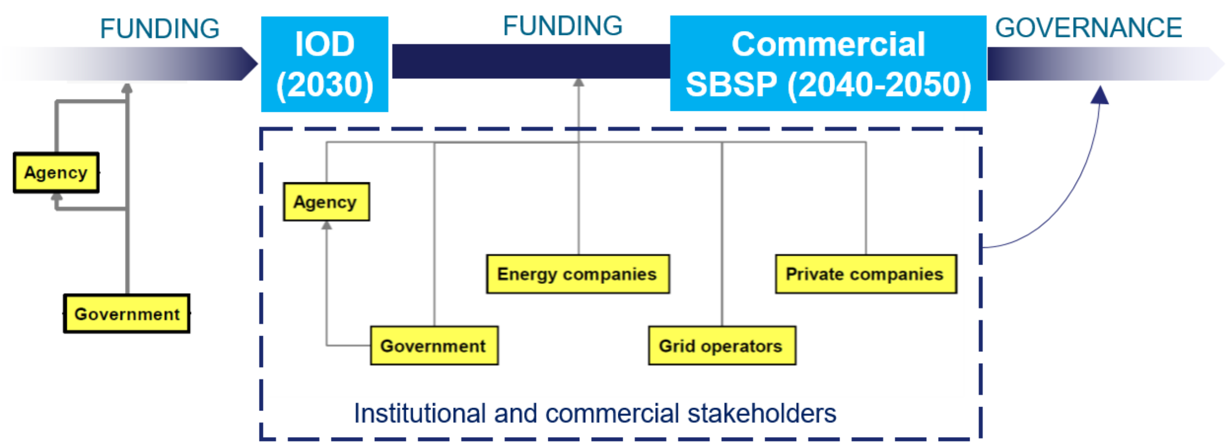

Figure 2-1 SBSP Governance and funding model

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2.3.2 Constraints

Based on the Stakeholders meeting interviews Q&A the following study constraints have been derived:

- Land availability for GPS location is considered critical. In metropolitan areas this can represent a stumbling block.
- Acceptance of the community for GPS location and size is considered critical.
- The power availability fluctuation on ground need to be minimized.
- For on-shore power plants the visual impact needs to be considered.
- For off-shore power plants the impact on fishing needs to be considered.
- Energy transportability constraints need to be taken into account.
- Power distribution constraints (high voltages vs low voltages) need to be taken into account.
- For moveable off-shore GPS the high costs of connections and infrastructures need to be taken into account.
- On ground the use of existing solar parks needs to be accepted by the people expecially if we are changing, with the double technology (PV+RF), the use of the power plant.
- For RF transmission the constraint on connection with the generator, including permissible transmission capacity, need to be taken into account.

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2.4 SBSP User and Service Requirements

From the stakeholder expectation statements and NGOs the following preliminary requirements have been derived:

Req. ID	ESA Req. (SoW Annex B)	Objective Ref.	Goal Ref.	Need Ref.	Req. Description	Req. Text	Req. Rationale
UR-REQ-0010	SBSP-SYS-001	SBSP-SO-007	SBSP-SG-003	SBSP-SN-001	Commercial Utilisation	The SBSP System shall provide electrical power (>= TBD watt) for commercial use in Europe.	This requirement is included to specify that the eventual deployment and use of SBSP at scale is foreseen to be commercially driven.
UR-REQ-0020	SBSP-SYS-002 (modified)	SBSP-SO-005	SBSP-SG-001	SBSP-SN-001	Space-Based Power Source	The SBSP System shall collect TBW watt of solar power in space for transfer to Ground Power Stations on Earth.	This requirement is included to specify that the primary power source for the SBSP System is intended to be space-based.
UR-REQ-0030	SBSP-SYS-003 (modified)	SBSP-SO-010	SBSP-SG-004	SBSP-SN-001	Nameplate Capacity	The nameplate capacity of each Ground Power Station in the SBSP System shall not exceed 1GWe.	The nameplate capacity is an important factor in determining the design and scale of SBSP systems.
UR-REQ-0040	SBSP-SYS-004	SBSP-SO-011	SBSP-SG-004	SBSP-SN-001	Capacity Factor	The SBSP System shall have a capacity factor of at least TBD % including planned and unplanned outages and degradation due to failed elements.	The nameplate capacity is an important factor in determining the design and scale of SBSP systems.
UR-REQ-0050	SBSP-SYS-005	SBSP-SO-008	SBSP-SG-003	SBSP-SN-001	Start of Commercial Operations	The SBSP System shall start commercial operations by 2035 (TBC).	This requirement is included to specify the need by date for the start of SBSP system power delivery. This is anticipated to drive the development schedule and technology selection for the first elements of the SBSP system.
UR-REQ-0060	SBSP-SYS-006	SBSP-SO-012	SBSP-SG-004	SBSP-SN-001	Target SBSP Capability	The combined capability of all Space Solar Power Plants operating in Europe shall generate up to 750TWh (TBC) per year of operations by 2050.	This requirement is included to capture the expected need for multiple SBSP Systems to be deployed. The design of the SBSP System will need to consider the need to scale up output through the deployment of multiple Space Solar Power Plants. This requirement is intended to prevent potential issues related to scalability and industrial capability from being neglected in the early design phase.
UR-REQ-0070	SBSP-SYS-007	SBSP-SO-009	SBSP-SG-003	SBSP-SN-001	System Lifetime	The SBSP system shall have a nominal operational lifetime of 30 years (TBC).	The system lifetime is an important factor in determining the design and scale of SBSP systems.

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Req. ID	ESA Req. (SoW Annex B)	Objective Ref.	Goal Ref.	Need Ref.	Req. Description	Req. Text	Req. Rationale
UR-REQ-0090	SBSP-SYS-008	SBSP-SO-006	SBSP-SG-002	SBSP-SN-001	Zero Space Debris	The end-of-life operations for the solar power satellite(s) in the SBSP system shall result in zero space debris.	The system must be designed and constructed to ensure that the solar power satellite(s) can be safely and effectively decommissioned at the end of lifetime operations without generating any debris that could pose a risk to other spacecraft or space activities.
UR-REQ-0110	N/A (new requirement)	SBSP-SO-003	SBSP-SG-001	SBSP-SN-001	Constant power provision	The SBSP system shall provide constant baseload power to the grid, within a TBD given tolerance range, regardless day time or weather conditions.	This requirement is included to guarantee a constant provision of power to the grid, regardless day time or weather conditions.
UR-REQ-0120	N/A (new requirement)	SBSP-SO-004	SBSP-SG-001	SBSP-SN-001	SBSP power delivery in EU	The SBSP system shall be capable to deliver 1GW (TBC) power to a selected ground power station within Europe.	This requirement is included to indicate that Europe will be the final user of the provided power.
UR-REQ-0150	N/A (new requirement)	SBSP-SO-001	SBSP-SG-001	SBSP-SN-001	SBSP fluctuation planning	The power availability fluctuation on ground shall be planned on a quarter of hour (15 minutes) basis.	This requirement is included to guarantee that possible power fluctuations need to be notified in due time to the transmission and distributions operators.
UR-REQ-0160	N/A (new requirement)	SBSP-SO-002	SBSP-SG-001	SBSP-SN-001	SBSP service interruptions	SBSP transmission and distributions operators shall be informed for service interruptions with a timeframe ranging from 10 minutes to one day (depending on the user contract).	This requirement is included to guarantee that any possible service interruption needs to be notified in due time to the transmission and distributions operators.

Table 2-5 SBSP requirements

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The Requirements Model has been implemented in DOORS and the requirements traceability is shown in Figure 2-2.

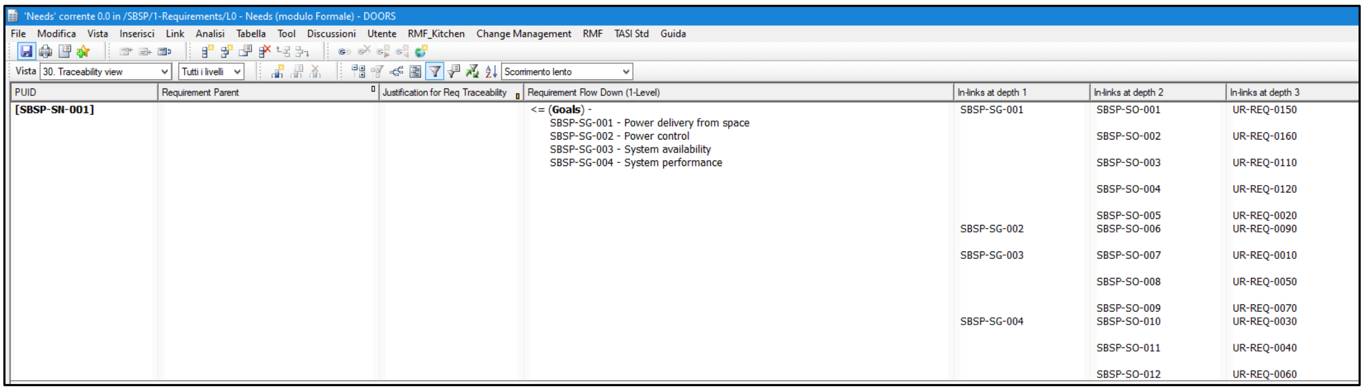

Figure 2-2 DOORS Traceability view

3 Use-cases & operational scenarios definition

This chapter is dealing with the identified use-cases envisioned to be valuable to prospective SBSP stakeholders, operational scenarios definition and reference use case definition.

3.1 Identified use-cases

As outcome of the discussion with the stakeholders the use-cases which are foreseen to be valuable have been broken down in the following two macro-categories:

- **On-Grid power use cases** (supplied power in the 0.5-1.5 GW range)
  - “Baseload” power to a single GPS – equivalent operation to a coal or nuclear powered power station. Can envisage situations where actually the GPS acts more like a peaking power plant, with excess capacity used to, say, create hydrogen locally when not needed. Main use case context for this is that a space power satellite provides power only to a single GPS all of the time.
  - Peaking “dispatchable” power provision (load balancing) – Power supplied to balance the provision of renewables with demand when the renewable generation is low (or demand is high). Like a gas or hydroplant (although noting that importance of these plants will increase with greater renewable capacity and lower baseload capacity). Power can then be distributed to multiple GPSs where it is needed (in different markets) rather than to just a single GPS, in the “Baseload” use case.

- **Off-Grid single use power supply** (supplied power in the 100-500 MW range). Should be noted that a grid level use case could also provide all these use cases, these are standalone applications where a local SBSP (non-grid connected) could be used.
  - Production of green hydrogen. Power is supplied to electrolyse water into green hydrogen. Can happen with a range of power levels and scales. Power doesn’t necessarily need to be continuous, so can be distributed between multiple sites from one space power satellite.

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- Water Desalination. Like hydrogen production, but used to drive a water desalination process. TBD if this needs to be continuous provision to one site, or can be “distributable”. Largest plants (Saudi Arabia) can use up to 2.5GW. Smaller plants such as those in Spain can use <100MW, so quite variable in needs.
- Data centres. ICT companies are looking for green baseload power on the grid they are supplied from. Power is used continuously, demand is very stable and security of supply is of very high importance, Redundant grid connections are used, so an SBSP system would need to provide 24/7 supply without interruption.

The Systems level implementation implications associated to the proposed use-cases are identified in Figure 3-1.

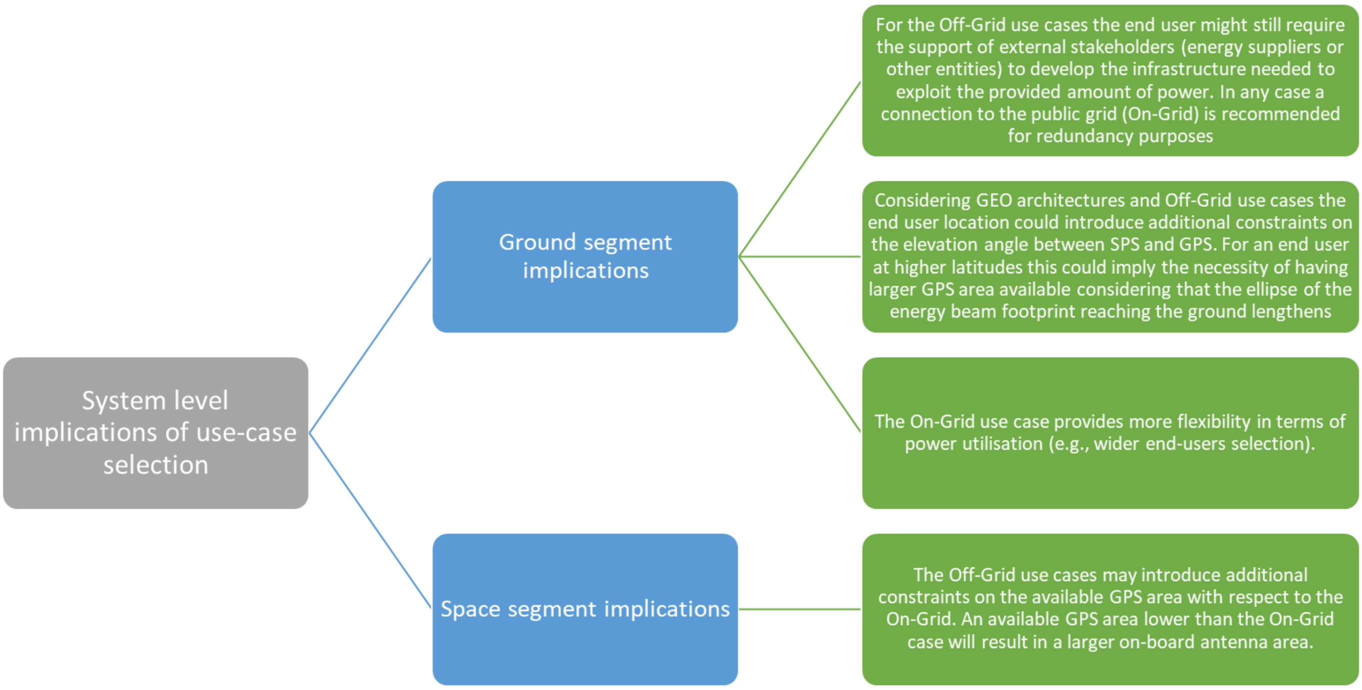

Figure 3-1 System level implications

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3.2 Operational scenarios

To better explain these two different uses cases we adopt a MBSE approach with models.

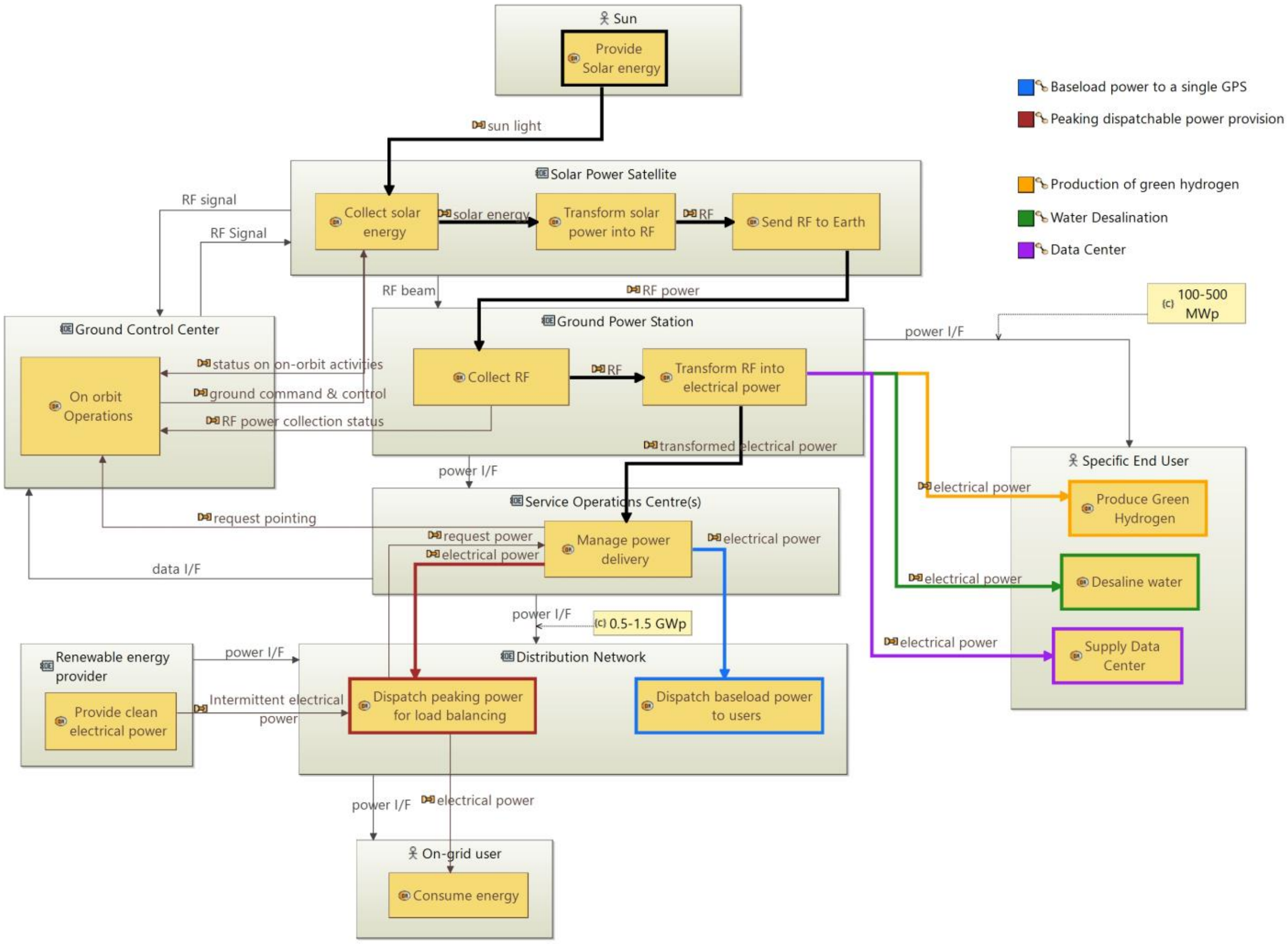

Figure 3-2 Operational Architecture

The diagram in Figure 3-2 is shows the Operational Architecture of the mission with five operational process associated to the two capabilities identified:

- On-Grid power supply, with the two process associated:
  - **Baseload power to a single GPS**, in which the baseload power provided by the Solar Power Satellite is directly distributed to the end users by the Network Distributor
  - **Peaking dispatchable power provision**, in which the baseload power is provided by rewable energies provider and SBSP supply power only when the renewable power is unavailable (e.g.no sunlight or no wind)
- Specific End User power supply, in which the Solar Based power is consumed by only one customer for a specific purpose, such as:
  - **Production of green hydrogen**

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- **Water desalination**
- **Data Center power provision**

The scenario of solar power generation is described in Figure 3-3 and does not change with the diffent use cases.

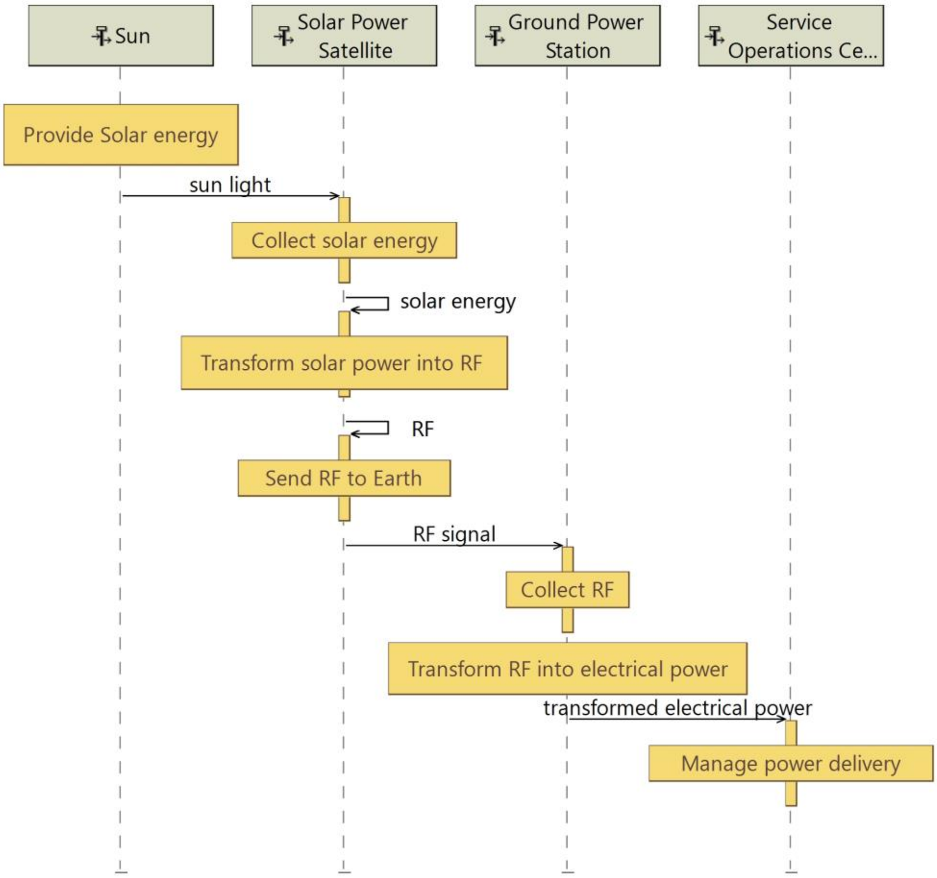

Figure 3-3 Operational Scenario (Solar Power Generation)

The scenario associated to the **SBSP baseload power** is provided in Figure 3-4.

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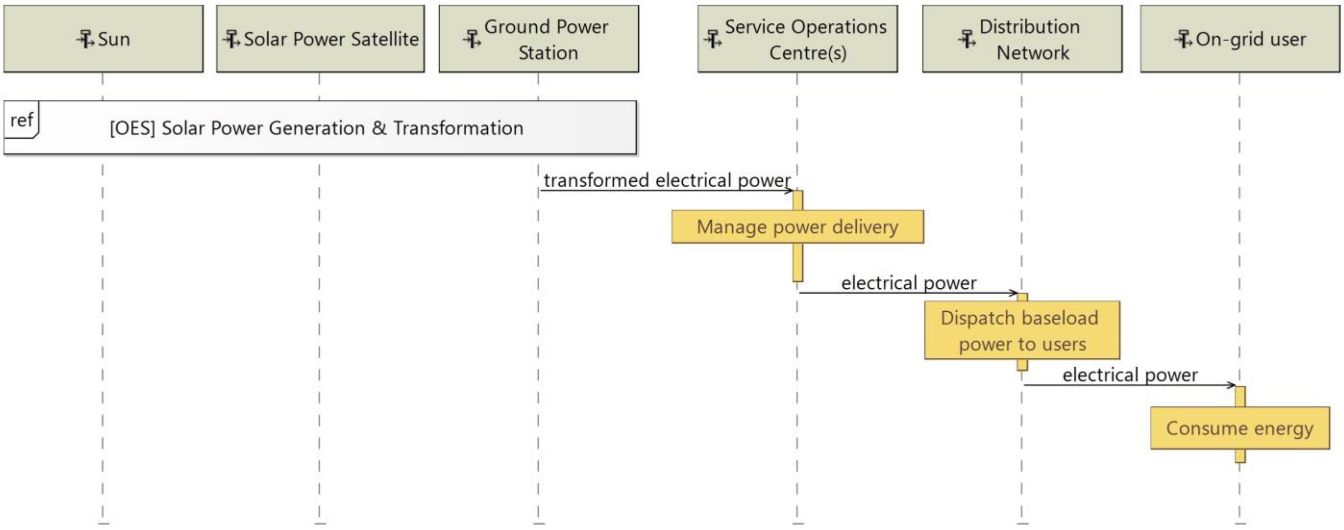

Figure 3-4 Operational Scenario (SBSP baseload power)

In Figure 3-5 the scenario in which SBSP is used to balance the power load when renewables sources are not available is shown.

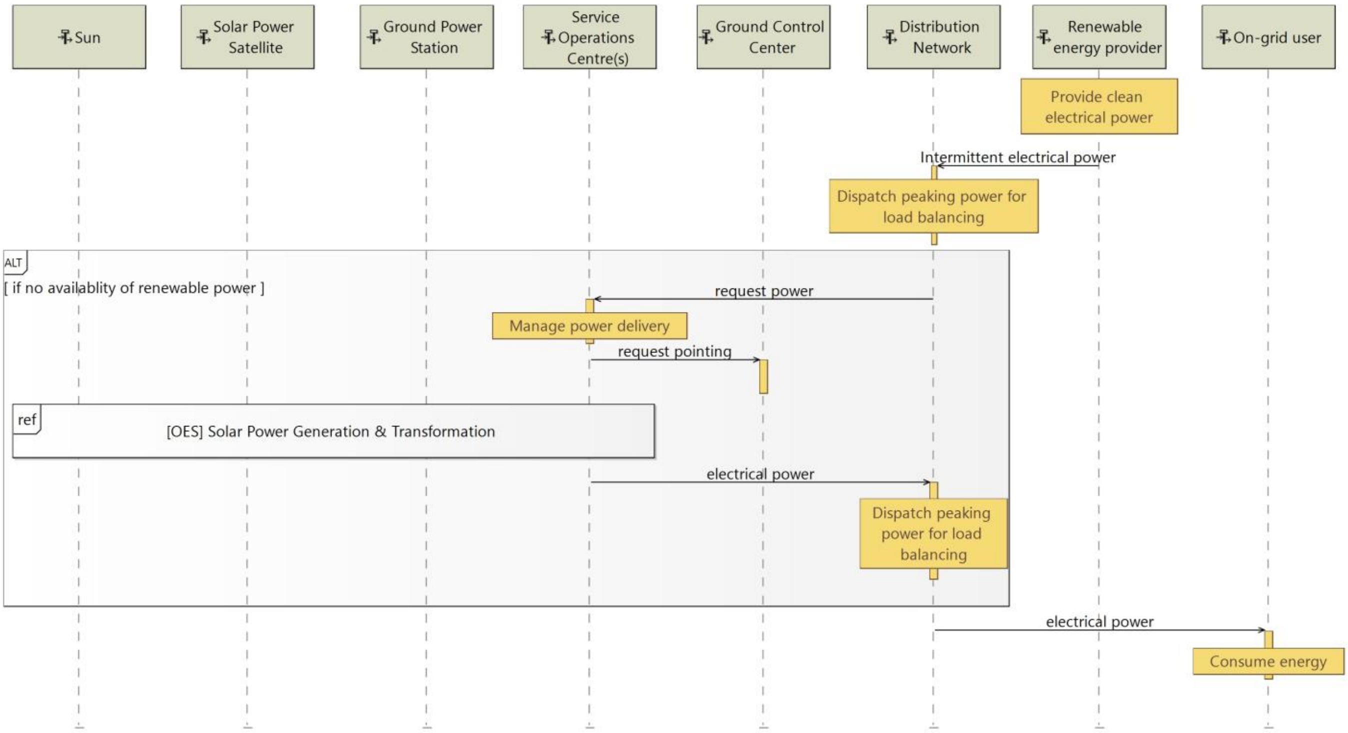

Figure 3-5 Operational Scenario (Power load balancing)

For the Specific End User use cases (Figure 3-6) , we have condensed all the three identifed end users in the same scenario, taking into account that the system can provide energy to only one user. Multiple consumers are not foreseen for the moment.

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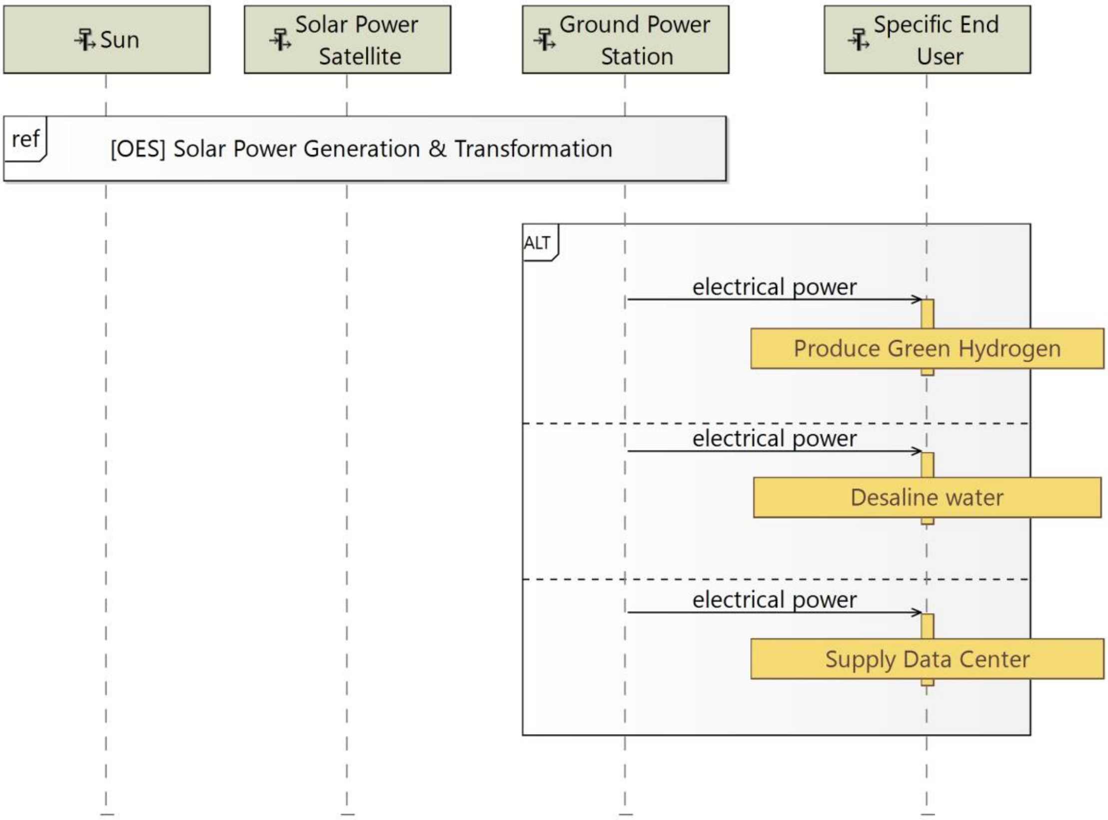

Figure 3-6 Operational Scenario (Specific End User)

In the last diagram, all the operational entities of SBSP are shown with the interfaces with the actors involved in all the use cases identified.

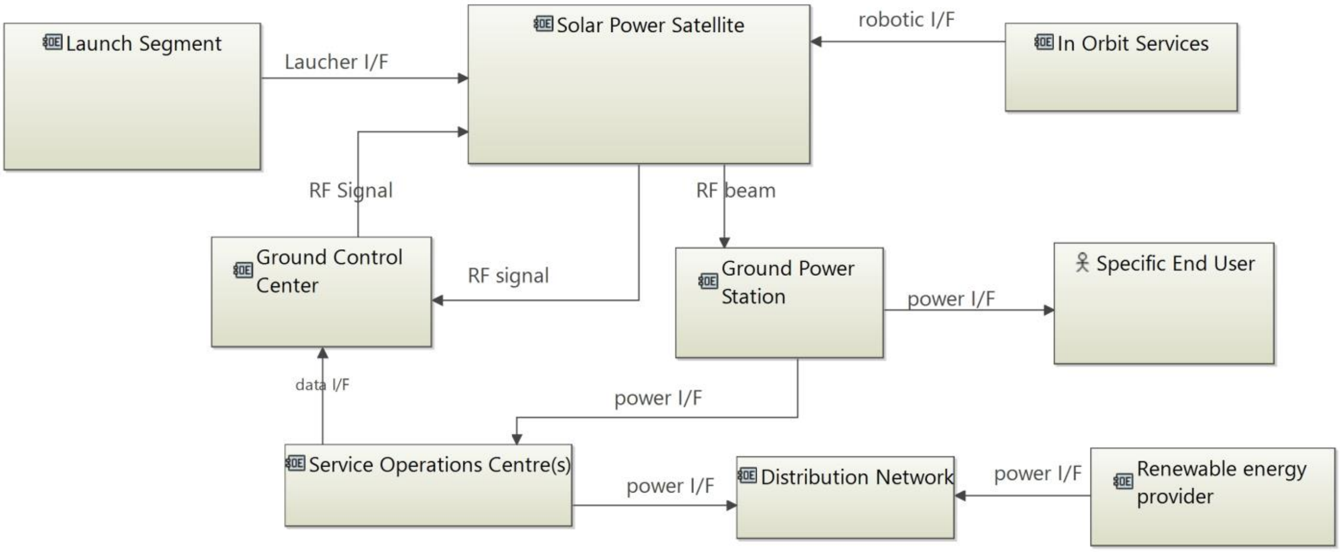

Figure 3-7 Operational Architecture

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3.3 Reference use-case

Based on the analyses of the stakeholder survey an *On-Grid power use case* has been considered more interesting to be pursued further as:

- responds to the needs of a larger community of users
- provides more flexibility in terms of utilisation
- it is less driven by specific application requirements (e.g. ICT, water desalinisation, etc…)

In terms of preferred GPS installed power the stakeholder interviews outcome are summarized in Figure 3-8.

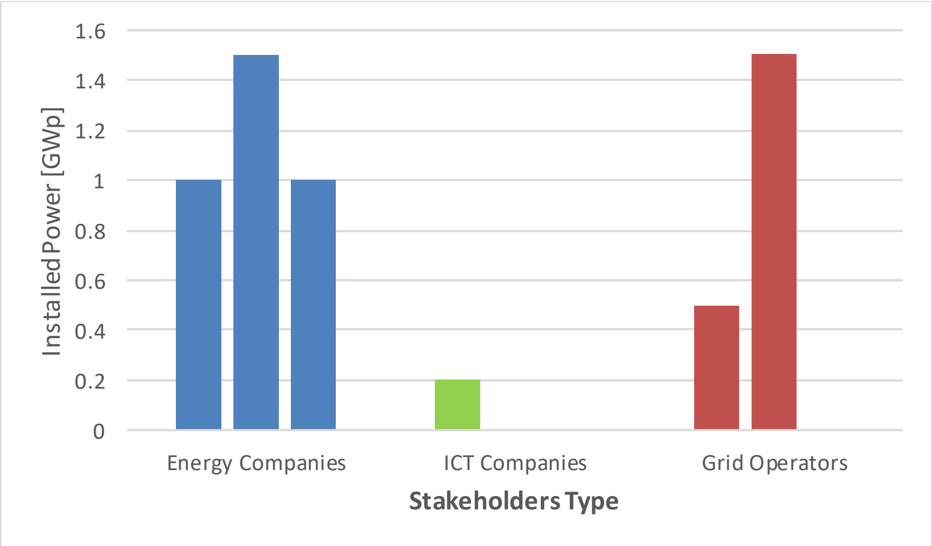

Figure 3-8 Preferred GPS Installed Power [GWp]

In particular the reference use case selected by the Consortium has the following characteristics:

Up to 1GW ± TBD % constant baseload power available 24/7 to be provided from one or several SPS to one GPS in Europe

The option to have one or several SPS(s) and either the on-shore or off-shore location of the GPS will be an outcome of the Architecture Selection Report trade-offs.

Considering a GPS capability of 8.76TWh per year of operation, to fulfill the requirement **UR-REQ-0060** asking for a target of 750 TWh (TBC) per year of operation by 2050, 86 SBSP systems will need to be deployed.

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