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# Remote Sensing Data for Life Cycle Assessment

Project proposal

PWRG 2

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## Project proposal

The aim of this university assignment is to create a project proposal to demonstrate ability to get an overview of a research field, summarize the findings, identify a gap in the existing knowledge, define a research question, and outline a project plan to address it.

The chosen research field is the use of remote sensing, in particular satellite data, for life cycle assessments (LCAs). In the first part of the scientific publication, an introduction to the topic aimed at readers who are not familiar with LCA or Earth Observation with satellites will be provided. After that, a literature review of the current state of the art in employing satellite data for LCA will be performed, and an overview of relevant tools and dataset will be provided. The outcomes of the literature study and the data and tools review will be the identification of a research or data/tooling gap. A research question will be defined based on these insights. A proposed research project aimed at addressing the research question will then be developed and described in detail. The final part of the publication will present a project plan for conducting the suggested research.

Grading consists of the following parts: Scientific Publication: 50%, Supporting Material 15%, Oral Presentation 25%, Work Process / Project Management: 10%

## 1 Introduction

Life Cycle Assessment (LCA) as defined in (International Organization for Standardization, 2006a) and (International Organization for Standardization, 2006b) is a standardized tool used to evaluate the environmental impacts associated with every stage of a product or service's life, from raw material extraction through production, use, and disposal. Central to the accuracy and usefulness of an LCA is the availability and quality of the underlying data. Without robust and representative data, the conclusions drawn from an LCA risk being misleading or incomplete.

Remote sensing, particularly through satellites, provides vast amounts of data. Satellites offer a unique, large-scale perspective for continuous observation of the Earth's surface and atmosphere. They collect data that can be directly or indirectly used to assess land cover, vegetation health, surface temperatures, atmospheric gases, and ocean characteristics. All of these are essential for understanding environmental trends and changes over time. Satellite derived data supports a wide range of applications, from climate modeling and disaster response to agricultural planning.

The focus of this work is to explore if and how observational satellite data can be integrated into LCA to enhance the accuracy of environmental impact evaluations in various stages, especially in the inventory and modeling phases, where accurate, detailed, and geographically specific information is essential. While remote sensing supplies the observational data, LCA offers the framework for quantifying and interpreting environmental impacts.

## 2 Overview: Satellite data for earth observation

The focus of this work is on satellites that provide observational data of the Earth for environmental monitoring. The many other existing use cases for satellites in communication, broadcasting, navigation, and for military purposes will not be discussed.

There are several different types of methods to sense the data: optical, thermal, and radar based as summarized in Table 1. Optical methods detect sunlight reflected by clouds, land, and oceans, e.g., for red and blue visible light reflectance. Near-infrared (NIR) and infrared (IR) is invisible to the human eye. NIR is strongly reflected by vegetation, and absorbed by water. Therefore, NIR based methods make land cover, plant health, and boundaries between land and water easy to detect. IR detects thermal radiation, i.e. heat, emitted from the Earth and atmosphere at day and night. This is useful for observation of temperature and moisture or dryness as well as atmospheric gaseous water vapor. Synthetic Aperture Radar (SAR) is an active method that works at night and through clouds (unlike the other methods). It detects surface structure and moisture.

Table 1

| Method | Key feature | Works at night | Cloud penetrating |
|---|---|---|---|
| Optical (incl. Near-Infrared, NIR) | Reflects sunlight | No | No |
| Thermal Infrared (IR) | Detects heat | Yes | No |
| Synthetic Aperture Radar (SAR) | Uses radar | Yes | Yes |

At a high level, satellites can be categorized based on their orbital types, which determine their position and altitude, and consequently coverage and purpose:

1. Low Earth Orbit (LEO) satellites orbit at altitudes between 160 and 2.000 kilometers. They are known for their high resolution data. A subset of them, polar orbits, pass over the Earth's poles and provide global coverage as the planet rotates beneath them. Another subset is sun-synchronous orbits, which maintain a consistent position relative to the sun, allowing satellites to observe the Earth under similar lighting conditions with each pass.

2. Medium Earth Orbit (MEO) satellites operate at altitudes ranging above 2.000 and below 35.000 kilometers. They are typically used for navigation services such as devised based on Assisted Global Navigation Satellite Systems as defined in (3rd Generation Partnership Project (3GPP), 2019), which rely on acquiring and decoding satellite signals to determine their position.

3. Geostationary Earth Orbit (GEO) satellites are located above the equator at 35.786 kilometers, which matches the Earth's rotation period, to provide continuous

observation of a fixed region of the Earth. They are known for providing low resolution data with high update frequency. The data provided is often used for weather and broad climate monitoring.

Each of these orbital satellite types serves different purposes. The satellite orbital types most common for earth observation are LEO and GEO satellites. In the following, an overview of available public domain and commercial observational satellite data of these types that could potentially be relevant for LCA is provided.

### 2.1 Geostationary Earth Orbit (GEO) satellites

Observational Geostationary Earth Orbit satellites provide continuous, real-time monitoring of atmospheric conditions, cloud cover, sea surface temperatures, and solar radiation over large fixed regions. They have lower spatial resolution compared to LEO satellites, but this is being compensated by providing high temporal resolution. Table 2 provides an overview of the existing GEO satellites, their operators, the regions covered, the type of access and, if relevant, the license that the data is available under.

Table 2

| Satellite / Series | Operator / Agency | Region Covered | Licensing |
|---|---|---|---|
| GOES series (GOES-16, GOES-17, GOES-18) | NOAA (USA) | Americas | Most data available under NOAA's data policy |
| Meteosat (MSG and MTG series) | EUMETSAT (Europe) | Europe, Africa, Atlantic Ocean | Open access under EUMETSAT's data policy |
| Himawari series (8 and 9) | JMA (Japan) | Asia-Pacific region | Open access for research and public use |
| INSAT/GSAT series (INSAT-3D, INSAT-3DR) | ISRO (India) | Indian subcontinent | Limited public access |
| Fengyun series (FY-2, FY-4) | CMA (China) | Asia-Pacific region | Restricted access for partners |
| Electro-L series | Russian Space Agency | Russia, Europe, parts of Asia | Limited public access |

The three satellite series where data that is accessible under open licenses offer data delivery frequencies between 5 and 15 minutes for full images. They provide similar imaging capabilities: 16 spectral ranges of wavelengths, called bands or channels, collected by the satellite sensor as discrete portions of the electromagnetic spectrum. Each series provides comparable numbers of optical, near-infrared and infrared channels.

They support rapid scan modes for their regions of focus with data delivery frequencies between 30 seconds and 5 minutes. These are used for detecting fast-changing weather and environmental events such as storms, tornadoes, wildfires and volcanic eruptions, and for short-term weather forecasting (called now-casting).

To summarize, GEO satellites for Earth observation are most helpful for high-frequency monitoring of large-scale land and ocean processes.

### 2.2 Low Earth Orbit (LEO) satellites

Far more LEO satellites for Earth observation than GEO satellites exist: around 35 GEO satellites compared to around 1000 LEO satellites. Table 3 provides a non-exhaustive listing of the most relevant providers together with the resolution and revisit frequency of the data provided. Note that some providers have more than one satellite on offer. In these cases only the one with the highest resolution and revisit frequency is listed. The newest satellites are Biomass from ESA for forest biomass and carbon content monitoring, and FireSat and OroraTech for wildfire detection. The (*) sign indicates future plans.

Table 3

| Satellite / provider | Access | Resolution | Revisit Frequency |
|---|---|---|---|
| Landsat 8 & 9 | open | 15 – 30 m multispectral | 8 days (combined) |
| Sentinel-1 (A & B/C) | open | 5 – 20 m SAR | 6 days (combined) |
| Sentinel-2 (A, B & C) | open | 10 – 60 m multispectral | 5 days (combined) |
| MODIS (Terra, Aqua) | open | 250 m – 1 km multispectral | Daily |
| Biomass | open (*) | 10 m P-band SAR | Up to 16 orbits/day |
| Planet Labs | commercial | 3 – 5 m optical | Daily |
| Maxar WorldView | commercial | 30 – 50 cm optical | Up to 15 orbits/day |
| Airbus | commercial | 30 cm optical | 1–3 days |
| Iceye | commercial | 0.5 m SAR | Daily to sub-daily |
| Capella Space | commercial | 0.5 m SAR | Daily to sub-daily |
| GHGSat | commercial | 25 m | Variable |
| FireSat | commercial | 5 m thermal IR | 30 minutes (*) |
| OroraTech | commercial | Variable thermal IR | 30 minutes (*) |

To summarize, LEO satellites play a crucial role in Earth observation, particularly for high-resolution and frequent monitoring. The revisit frequency is primarily determined by the size of the satellite constellation. Larger constellations, such as those with over 100 satellites, can achieve revisit frequencies approaching those of geostationary systems. While a few public providers offer open-access data, many different commercial options are on the market.

## 3 Literature study: Satellite data for LCA

Use cases: forest, water (?), contrails (??)

https://scholar.google.com/scholar?hl=en&as_sdt=0,5&qsp=2&q=forest+loss+life+cycle+assessment&qst=b

Amazon often full with clouds, gets exploited by loggers

Dieser Schweizer Bauer hat ein Wassersystem für die Zukunft gebaut https://www.tagesanzeiger.ch/katzhof-richenthal-der-klimaresistenteste-hof-der-schweiz-526267449775

Which aggregation levels are in use

(2014) Assessing biodiversity loss due to land use with Life Cycle Assessment: are we there yet? https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.12709 LCA mainly introduces biodiversity as an endpoint category modeled as a loss in species richness due to the conversion and use of land over time and space. The functional and population effects on biodiversity are mostly absent due to the emphasis on species accumulation with limited geographic and taxonomical reach. Current land-use modeling activities that use biodiversity indicators tend to oversimplify the real dynamics and complexity of the interactions of species among each other and with their habitats.

Quantifying the Environmental Impacts of Manufacturing Low Earth Orbit (LEO) Satellite Constellations https://www.mdpi.com/2071-1050/16/21/9431

Existing estimates for environmental impact of satellites

International Journal of Applied Earth Observation and Geoinformation

Zhao et al. (2022) conduct a literature study of scientific article that reference EO satellite missions and find that their number is exponentially growing and that most of the work is based on the freely available data. TBD Worldview mentioned

Contrail Cirrus Climate Impact: From Radiative Forcing to Surface Temperature Change https://journals.ametsoc.org/view/journals/clim/38/8/JCLI-D-24-0245.1.pdf

Evidence for climate change in the satellite cloud record https://www.nature.com/articles/nature18273 Clouds play a huge role in Earth's temperature by both reflecting sunlight back into space (a cooling effect) and trapping heat from the ground (a warming effect). How clouds will change due to global warming has been one of the biggest questions in climate science. Climate models and real-world observations didn't agree on how clouds have changed in recent decades. This is largely because the satellites used to monitor clouds were built for short-term weather forecasting, not for tracking subtle, long-term climate changes. The data from these older systems needed to be carefully corrected to be reliable. This study successfully corrected several independent satellite records from the 1980s to the 2000s. After correction, the data revealed large-scale cloud changes that match the predictions made by climate models. Both the real-world data and the computer models show the same patterns: Storm tracks are moving away from the equator and towards the poles. Subtropical dry zones are expanding. The highest cloud tops are getting even higher. The main causes for these changes are rising greenhouse gas concentrations and the planet warming up after the cooling effects of past volcanic eruptions. This research shows that the cloud changes long predicted by climate models are actually happening now.

Earth's long-term climate stabilized by clouds https://www.nature.com/articles/s41561-021-00691-7?fromPaywallRec=true Billions of years ago, the Sun was much dimmer than it is today.Logically, Earth should have been a frozen ice ball, but evidence shows it had liquid water. This mystery is called the "faint young Sun problem." For a long time, scientists thought the solution was a much stronger greenhouse effect. The idea was that early Earth's atmosphere was filled with extra greenhouse gases (like $CO_2$), which trapped the Sun's faint heat and kept the planet warm enough for liquid water. This study suggests a different key factor: clouds. Researchers used climate models to look back in time. They found that with a dimmer sun and more $CO_2$, early Earth had far fewer low-level clouds than it does today. Fewer clouds meant less sunlight was reflected away from the planet's surface. Think of it like a dark t-shirt absorbing more sunlight than a white one. By absorbing more of the Sun's faint energy, the planet stayed warm. This cloud effect was incredibly powerful, providing about 40% of the warming needed to solve the problem.

## 4 Tools and datasets

GlobalBuildingAtlas: https://github.com/zhu-xlab/GlobalBuildingAtlas?tab=readme-ov-file

Neumann et al. (2025) Forest stuff PhD student: https://github.com/SherryJYC

Remote sensing agriculture: Bruno Basso https://scholar.google.com/citations?user=EItklH0AAAAJ&hl=en

Agriculture: The Cropland Data Layer (CDL) is a dataset provided by the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) that provides information about crop types across the United States.

## 5 Project proposal

Ideas:

- Use ESA Biomass satellite for LCA for forest loss
- ML for LCA?
- Modelling with Python?

# 6 Project plan

## References


3rd Generation Partnership Project (3GPP). (2019). *3GPP TS 36.355 V15.3.0 - LTE Positioning Protocol A (LPPa)*. 3GPP.

International Organization for Standardization. (2006a). *ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework*. International Organization for Standardization.

International Organization for Standardization. (2006b). *ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines*. International Organization for Standardization.

Neumann, M., Raichuk, A., Stanimirova, R., Sims, M., Carter, S., Goldman, E., Rey, M., Jiang, Y., Anderson, K., Poklukar, P., et al. (2025). *Natural forests of the world-a 2020 baseline for deforestation and degradation monitoring*.

Zhao, Q., Yu, L., Du, Z., Peng, D., Hao, P., Zhang, Y., and Gong, P. (2022). An overview of the applications of earth observation satellite data: Impacts and future trends. *Remote Sensing*, *14*(8), 1863.