Environmental Impacts of AI : the Lifecycle of AI-based Services

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ARCEP Project

ARCEP's Question

What is the Environmental Impact of AI ?

3 Objectives

1. Assess the current state of knowledge on the direct and indirect environmental impacts—both positive and negative—across all stages of AI development and deployment.
2. Develop an algorithm to run in Python regularly that returns the most recent and influential papers on the topic (ie. an algo that webscraps the most relevant articles on googlescholar).
3. Develop an algorithm to run in Python that handles the most recent new articles

Methods

Life Cycle Assessment (LCA) is a standardized approach to evaluate the full environmental impact of AI systems.

Scope of Analysis :

- **Direct lifecycle stages :** raw material extraction, production, transport, operation, and end-of-life.
- **Indirect impacts :** rebound effects and systemic environmental consequences.
- **Positive contributions :** energy efficiency, renewable integration, sustainable practices.

Data Sources : Peer-reviewed literature and institutional reports. used to quantify or estimate impacts at each phase.

1. The Project
2. Our Objectives
3. Methods
4. **Literature Review Plan**
5. Tool Development

Literature Review Plan (1/2)

1. **Introduction**
2. **Direct Negative Environmental Impacts of AI**
    1. Production
    2. Transportation
    3. Operation Phase
    4. End-of-Life of Equipment
3. **Indirect Negative Environmental Impacts of AI**
    1. Material Rebound Effects
    2. Economic Rebound Effects
    3. Societal Rebound Effects

Literature Review Plan (2/2)

4. **Positive Environmental Contributions of AI**
   1. Energy Efficiency in Buildings and Industrial Processes
   2. Renewable Energy Integration
   3. Sustainable and Precision Agriculture
   4. Intelligent Waste Management
   5. Environmental Monitoring and Biodiversity Conservation
5. **Future Considerations and Mitigation Strategies**
   1. Regulatory Frameworks
   2. Transparency Mechanisms
   3. Insights from Behavioral Sciences
   4. Emerging Sustainable Trends
6. **Conclusion**

1. Introduction

AI and Life Cycle Assessment (LCA)

1. AI's rapid expansion has hidden environmental costs—**from rare earth mining to energy-intensive data centers**—often overlooked in public discourse.
2. Life Cycle Assessment (LCA) allows for a **comprehensive evaluation** of AI ’ s footprint : production, transport, operation, and end-of-life.
3. The review covers **direct impacts** (Section 2), **indirect rebound effects** (Section 3), **positive applications** (Section 4), and **frugal AI strategies** (Section 5).

2. Direct Environmental Impacts

Production (Extraction and Assembly of Materials, Hardware)

1. The production of AI computing hardware requires **raw materials** such as cobalt, lithium, palladium, and rare earth elements.
2. Semiconductor and **chip fabrication** contribute significantly to carbon emissions due to high energy consumption.
3. The manufacturing process generates substantial **pollution and electronic waste**.

2. Direct Environmental Impacts

Transportation

1. Long-distance transport from REE mines (China, Brazil, Australia) to fabs (East Asia, U.S., Europe).
2. Fossil fuel-powered shipping & trucking : high GHG emissions.
3. AI hardware transport $<$ 5% of total AI system emissions
4. Sustainable transport needed to reduce AI’ s carbon footprint.

2. Direct Environmental Impacts

Operation Phase : Energy Consumption, Efficiency, and Water Use

1. AI training and inference require **massive energy**, with carbon emissions depending on hardware generation and electricity source (e.g., TPU v4 vs. v6e shows 3 times efficiency gain).
2. **Model type and deployment strategy** matter : GenAI agents can consume 4600 times more energy per inference than traditional NLP models ; energy use varies across cloud regions.
3. Data centers also consume large volumes of **water for cooling**, often underreported ; Water Usage Effectiveness (WUE) and cooling strategies are now key sustainability indicators (OECD, 2022 ; Desroches et al., 2025).

2. Direct Environmental Impacts

End-of-Life : Emissions and Management Challenges

1. End-of-life (EoL) emissions—**from dismantling, transport, recycling, disposal**—are part of embodied emissions, contributing a small but non-negligible share (e.g., TPU v6e : 692 kgCO_2e over 6 years).
2. Attribution is complex : many emissions from **auxiliary devices and reverse logistics** are excluded ; Google's Zero Waste strategy offsets up to 4% via material recovery, but results vary.
3. OECD (2022) notes **poor data and metrics on AI-specific e-waste** ; recommends digital product passports, circular design, and policy coordination to address regulatory gaps.

3. Indirect Environmental Impacts

Dual effects of AI on environment

1. Growing area of research with **inter-disciplinarily efforts** (life cycle analysis, behavioral science, sociology, anthropology)
2. Much harder to identify than direct impacts, **more qualitative** for part of the indirect impacts (requiring user studies, interviews, ect).

3. A. Negative Indirect Environmental Impacts

Gains can be offset by "**rebound effects**" that cancel out positive sustainability impacts (Paul et al., 2019)

1. **Material rebound effects :** Substitution impacts $\Rightarrow$ new phones, fridges, etc. incorporating AI
2. **Economic rebound effects :** "Jevons Paradox" $\Rightarrow$ improved efficiency of a product leads to an increase in its consumption Ex : Hardware efficiency improves, but more GPUs used each year (Giampietro and Mayumi, 2018)
3. **Societal rebound effects :** Time rebound $\Rightarrow$ AI saves time (e.g. using Google Maps saves time spent in traffic), but this leads to another additional activity negative for the environment (shopping, travelling, etc.).

4. Positive Environmental Contributions of AI

AI can support sustainability goals by optimizing complex systems and enabling data-driven decision-making.

Energy Efficiency in Buildings and Industrial Processes

1. AI models **predict energy consumption** using historical data and contextual variables (e.g., temperature, occupancy, humidity).
2. Especially useful for **retrofitting and managing existing buildings**, where physical system modeling is less practical.
3. In industry and logistics, AI improves **demand forecasting and supply chain efficiency**, reducing overproduction and transport emissions.

4. Positive Environmental Contributions of AI

Renewable Energy Integration

1. AI **forecasts energy output** from variable sources like wind and solar to stabilize and optimize grid operations.
2. Enhances **real-time system management**, helping utilities adapt to fluctuations in renewable energy supply.
3. In wind energy, AI enables **predictive maintenance and performance tuning**, increasing output and reducing downtime (Dörterler et al., 2024).

4. Positive Environmental Contributions of AI

Sustainable Agriculture

1. AI analyzes **weather, soil, and crop data** to guide irrigation, fertilization, and pest management with high precision.
2. Enables **precision agriculture**, reducing pesticide and fertilizer use, and minimizing water waste.
3. Deep learning models perform **robustly in diverse field conditions**, supporting tasks like fruit counting and leaf classification (Kamilaris Prenafeta-Boldú, 2018).

4. Positive Environmental Contributions of AI

Waste Management

1. AI enables **automated waste sorting, volume forecasting, and route optimization**, improving recycling efficiency.
2. Applications include **smart bins, sorting robots, and predictive models** to streamline waste logistics.
3. AI integration reduces transport distances by 36.8%, costs by 13.35%, and time by 28.22%, while boosting sorting accuracy up to 99.95% (Fang et al., 2023).

4. Positive Environmental Contributions of AI

Environmental Monitoring and Conservation

1. AI processes **satellite and sensor data** to detect pollution, deforestation, biodiversity loss, and to support early warning systems for wildfires and floods.

2. Tools like WWF's Forest Foresight and AI-enhanced drones enable **early detection of illegal logging, wildlife diseases, and ecosystem changes**.

3. In marine conservation, AI identifies fish species, detects illegal fishing (e.g., via OceanMind), and **supports sustainable fishing practices**.

5.Future Considerations and Mitigation Strategies

1. **Transparency :** using a common framework to examine the environmental impacts of AI systems : more data collection from national agencies, intergovernmental organizations, and private sector actors + used of consistent indicators (OECD, 2022)
2. **Regulation :** laws and taxes can reduce resource use by incentivising the use of more efficient tools and system
3. **Behavioural insights** : nudge consumers towards more frugal consumption of AI applications (OECD, 2017).

5.Future Considerations and Mitigation Strategies

Transparency : Toward Measurable and Accountable AI Footprints

1. OECD (2022) emphasizes **transparency as essential for environmental equity**, calling for open access to AI compute data and lifecycle benchmarks.
2. Lack of harmonized metrics hinders comparability ; OECD and Hacker (2023) advocate for **mandatory reporting of emissions and energy use**, tied to SDG-aligned KPIs.
3. Hacker (2023) highlights tensions with GDPR' s "right to erasure" and calls for **legal reforms to balance privacy rights with environmental traceability**.

5.Future Considerations and Mitigation Strategies

Emerging Sustainable Trends

1. Researchers are advancing **algorithmic efficiency** through pruning, Bayesian optimization, and energy-aware hardware strategies (e.g., DVFS, efficient GPUs).
2. Cloud providers using **renewable energy sources** offer lower-carbon options for training and deployment.
3. Tech firms explore **innovative infrastructures**, like submerged or geothermal-powered data centers, to reduce cooling-related emissions (e.g., Microsoft's Project Natick).

6.Conclusion

Balancing AI's Environmental Burden and Promise

1. AI is both an **environmental burden and a potential enabler** of sustainability, depending on how it is designed and deployed.
2. While direct impacts are increasingly quantifiable, **indirect effects remain complex**, tied to systemic and behavioral changes.
3. A sustainable AI future requires **regulation, transparency, and behavioral shifts** to align innovation with planetary boundaries.

Automated Academic Literature Search Method

- Automated search performed on **Google Scholar**.
- Articles scrapped and sorted by
    - Overlap between query terms and article titles (Score of revelance),
    - Citation count,
    - Publication year.
- Abstracts scraped and cleaned using **Selenium**.
- **Final results exported as a downloadable Excel table**.

```
# ==========================================================================================================
# CONFIGURATION
# ==========================================================================================================

QUERY = "Environmental Impacts Artificial Intelligence"
# Number of articles to fetch from Google Scholar before filtering
NUM_FETCH = 15
# Minimum publication year to consider an article valid
MIN_YEAR = 2020
# Number of valid articles to select for export
NUM_SELECT = 10
```

Figure 1 – Configuration Section of the Google Scholar Algorithm

	A	B	C	D	E	F	G
1	Title	Author(s)	Year	Citations	Relevance Score	Full Abstract	URL
2	Toward artificial intelligence and mach	T Ibn-Mohamme	2023	22	4	The application of functi	https://link.springer.com/article/10.1557/S43579-023-00480-W
3	Implementing artificial intelligence te	A Koyamparamba	2022	50	4	Nowadays, product desig	https://www.mdpi.com/2071-1050/14/6/3699
4	Optimizing waste management strateg	R Alsabt, W Alkha	2024	16	3	Applying artificial intellig	https://www.sciencedirect.com/science/article/pii/S27729125240003C
5	Application of artificial intelligence in	N Kumari, S Pand	2023	25	3	The artificial intelligence	https://www.sciencedirect.com/science/article/pii/B97803239971400C
6	Role of artificial intelligence in enviro	MA Habila, M Ou	2023	22	3	Climate change has beco	https://www.sciencedirect.com/science/article/pii/B97803239971400C
7	Using artificial intelligence and data fu	Y Himeur, B Rima	2022	158	3	Analyzing satellite image	https://www.sciencedirect.com/science/article/pii/S15662535220057
8	Towards sustainable artificial intellige	A Pachot, C Patis	2022	27	3	Artificial Intelligence (AI	https://arxiv.org/abs/2212.11738
9	Artificial intelligence solutions for env	A Curmally, BW S	2022	14	3	This chapter has two obj	https://www.elgaronline.com/edcollchap/book/9781800379633/book-
10	Artificial intelligence-based solutions	L Chen, Z Chen, Y	2023	205	2	Climate change is a majo	https://link.springer.com/article/10.1007/s10311-023-01617-y
11	Unraveling the hidden environmental	AL Ligozat, J Lefe	2022	105	2	In the past ten years, art	https://www.mdpi.com/2071-1050/14/9/5172
12							
13							
14							

Figure 2 – Output of Google Scholar Algoritm

Automated News Literature Search Method

- Automated news search performed with **News API**.
- Full Text Extraction : Uses **newspaper3k**.
- **Keywords** : "AI environmental impact" (EN) "impact environnemental de l'IA" (FR)
- Sorting : Newest to oldest (publishedAt) and removes inaccessible or short articles
- **Results**
  - Extract Date, Language, Title, Source, Link, Text.
  - Final results exported as a downloadable csv file.

```python
# NewsAPI key (replace with your own key)
API_KEY = "0b248e558e354c2e88b4fc4bee466ead"

# Search queries for articles (English & French)
QUERY_EN = "AI environmental impact"
QUERY_FR = "impact environnemental de l'IA"

# Languages to fetch articles in
LANGUAGES = {"en": QUERY_EN, "fr": QUERY_FR}

# Number of articles to fetch per query
PAGE_SIZE = 60

# Sorting criteria for articles (most recent first)
SORT_BY = "publishedAt"

# Minimum article text length to be considered valid
MIN_TEXT_LENGTH = 100

# Output file for saving the results
OUTPUT_FILENAME = "ai_environmental_impact_articles_FULLTEXT.csv"
```

Figure 3 – Configuration Section of the NEWS API Algorithm

	Title	Source	Raw.Date	Parsed.Date	Link	Language	Full.Article.T
1	Predicting the Unpredictable: The AI Outlook	Acm.org	2025-03-20T18:24:47Z	2025-03-20 18:24:47+00:00	http://cacm.acm.org/news/predicting-the-unpredict...	en	The history
2	Machine healing	Harvard School of Engineering and Applied Sciences	2025-03-20T18:08:41Z	2025-03-20 18:08:41+00:00	https://news.harvard.edu/gazette/story/2025/03/ho...	en	When Adam
3	Digital Product Passport (DPP) Market Forecast to Rea...	GlobeNewswire	2025-03-20T15:39:00Z	2025-03-20 15:39:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Dublin, Marc
4	Investments, action plans, and the shifting AI landscape	TechRadar	2025-03-20T15:02:28Z	2025-03-20 15:02:28+00:00	https://www.techradar.com/pro/investments-action-...	en	The UK rece
5	Radware Named as a Strong Performer in Analyst Rep...	GlobeNewswire	2025-03-20T15:00:00Z	2025-03-20 15:00:00+00:00	https://www.globenewswire.com/news-release/2025...	en	MAHWAH, N
6	Asia-Pacific's Precision Weeding Market to Quadruple ...	GlobeNewswire	2025-03-20T14:57:00Z	2025-03-20 14:57:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Dublin, Marc
7	Contractors Insurance Alert: Construction Defect Law...	Carriermanagement.com	2025-03-20T14:48:40Z	2025-03-20 14:48:40+00:00	https://www.carriermanagement.com/news/2025/03...	en	A new repor
8	E-Invoicing Market to Quadruple in Size by 2033, Rea...	GlobeNewswire	2025-03-20T14:36:00Z	2025-03-20 14:36:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Dublin, Marc
9	Green Technology & Sustainability Market Report 202...	GlobeNewswire	2025-03-20T14:17:00Z	2025-03-20 14:17:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Dublin, Marc
10	Sidetrade sets new ESG benchmarks with elevated Eth...	GlobeNewswire	2025-03-20T14:13:00Z	2025-03-20 14:13:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Sidetrade, th
11	Sidetrade franchit un cap en ESG avec des notations e...	GlobeNewswire	2025-03-20T14:13:00Z	2025-03-20 14:13:00+00:00	https://www.globenewswire.com/news-release/2025...	fr	Sidetrade, le
12	Uncovering water conservation patterns in semi-arid ...	Plos.org	2025-03-20T14:00:00Z	2025-03-20 14:00:00+00:00	https://journals.plos.org/plosone/article?id=10.1371...	en	Under the in
13	Lawn Vacuum Rental Market Trends, Demand, and Bu...	GlobeNewswire	2025-03-20T13:50:00Z	2025-03-20 13:50:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Luton, Bedfo
14	Syntactic Foam Market to Reach $241.6 Million, Globa...	GlobeNewswire	2025-03-20T13:39:00Z	2025-03-20 13:39:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Wilmington
15	The Market for Windows Handheld Devices 2025-203...	GlobeNewswire	2025-03-20T13:17:00Z	2025-03-20 13:17:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Dublin, Marc
16	Inspection and Maintenance Robots Market to Hit USD...	GlobeNewswire	2025-03-20T13:15:00Z	2025-03-20 13:15:00+00:00	https://www.globenewswire.com/news-release/2025...	en	Austin, Marc
17	Hoteliers could see 12% increase on room rates by sel...	Hospitality Net	2025-03-20T12:47:42Z	2025-03-20 12:47:42+00:00	https://www.hospitalitynet.org/news/4126338.html	en	New researc
18	How to Use AI to Reduce Household Waste	CNET	2025-03-20T12:33:03Z	2025-03-20 12:33:03+00:00	https://www.cnet.com/tech/services-and-software/h...	en	Most people
19	EPRI, NVIDIA and Collaborators Launch Open Power AI...	Nvidia.com	2025-03-20T12:00:41Z	2025-03-20 12:00:41+00:00	https://blogs.nvidia.com/?p=78880	en	Global conso
20	Hostelworld sees 'lower than expected' revenue with ...	Independent.ie	2025-03-20T11:57:19Z	2025-03-20 11:57:19+00:00	https://www.independent.ie/business/hostelworld-s...	en	Man pulling
21	Global Industrial Air Compressor Market to Reach US...	GlobeNewswire	2025-03-20T11:30:00Z	2025-03-20 11:30:00+00:00	https://www.globenewswire.com/news-release/2025...	en	NEWARK, De
22	IREN Restatement of Previously Issued Financial State...	GlobeNewswire	2025-03-20T10:50:00Z	2025-03-20 10:50:00+00:00	https://www.globenewswire.com/news-release/2025...	en	SYDNEY, Ma
23	What HP's Amplify announcements mean for UK partn...	ComputerWeekly.com	2025-03-20T10:45:00Z	2025-03-20 10:45:00+00:00	https://www.computerweekly.com/microscope/news...	en	The spotligh
24	Impact Plus explains how to make digital ad campaig...	Music Ally	2025-03-20T09:25:40Z	2025-03-20 09:25:40+00:00	http://musically.com/2025/03/20/impact-plus-expl...	en	From AI pro
25	Skeptical Science New Research for Week #12 2025	Skepticalscience.com	2025-03-20T06:36:20Z	2025-03-20 06:36:20+00:00	https://skepticalscience.com/new_research_2025_12...	en	Skeptical Sci
26	SLM series - Qodea: A jumpstart for multi-model AI s...	ComputerWeekly.com	2025-03-20T05:22:54Z	2025-03-20 05:22:54+00:00	https://www.computerweekly.com/blog/CW-Develop...	en	This is a gue
27	Google and NVIDIA Team Up to Solve Real-World Pro...	Csharp.com	2025-03-20T00:00:00Z	2025-03-20 00:00:00+00:00	https://www.csharp.com/news/google-and-nvidia-t...	en	Google and

Figure 4 – Output of the NEWS API Algorithm