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Empowering Users toward Environmentally Sustainable Digital Practices: From Web-Based to Generative AI Interactions

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Context and Motivation

01

The Hidden Footprint of AI

Rising Energy Demand

Digital technologies contribute 2-4% of global carbon emissions.

By 2030, this is projected to surge to 13% due to AI growth.

The Inference Challenge

Unlike traditional ML, GenAI energy costs are dominated by inference.

A single Gemini prompt costs 0.24 Wh (0.03 gCO2e).

User Awareness Gap

End users remain largely unaware of emissions associated with everyday online interactions. The environmental cost of Generative AI remains "hidden" behind clean interfaces.

- Lack of transparent reporting
- Misaligned utility perceptions
- Need for in-context feedback

Methodological Journey

Monitoring

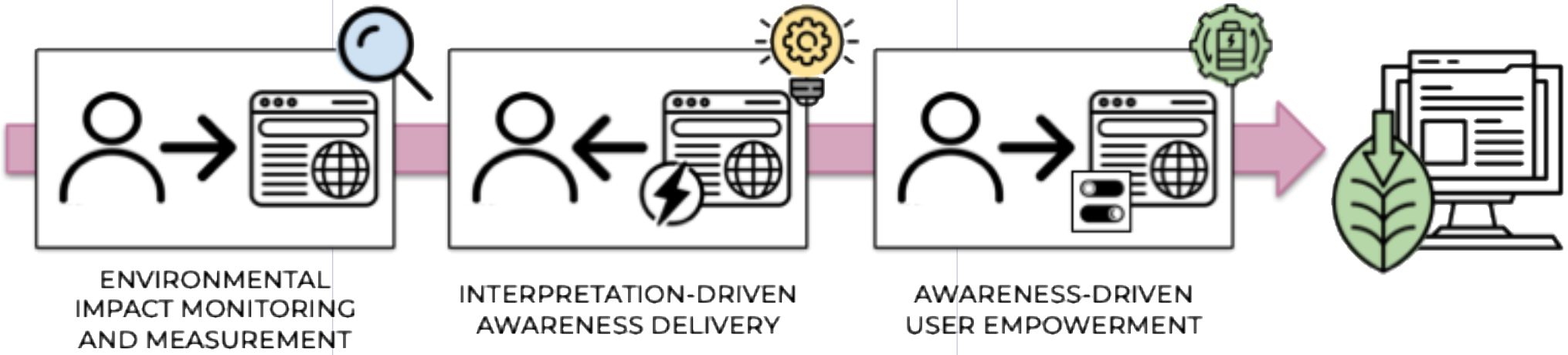
Identifying metrics to capture the cost of web interactions and AI prompts

Interpretation

Translating raw data into relatable real-world equivalents

Empowerment

Enabling users to take direct action via behavioral changes.



Research Questions

RQ1

- What is the **effectiveness of Carbon Tracker tools** in creating **sustainability awareness** when using web and AI systems?

RQ2

- What is the **user experience and usability** of Carbon Tracker tools?

Carbon Tracker

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What's a Carbon Tracker?

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- An app, website, plugin, agent, or system that measures and monitors greenhouse gas emissions associated with any human activities
- We look into digital interactions (specifically, information seeking tasks)

- Individuals use them to understand and reduce their carbon footprint
- Companies use them for sustainability reporting and emissions management.

Carbon Footprint Tracking Strategy

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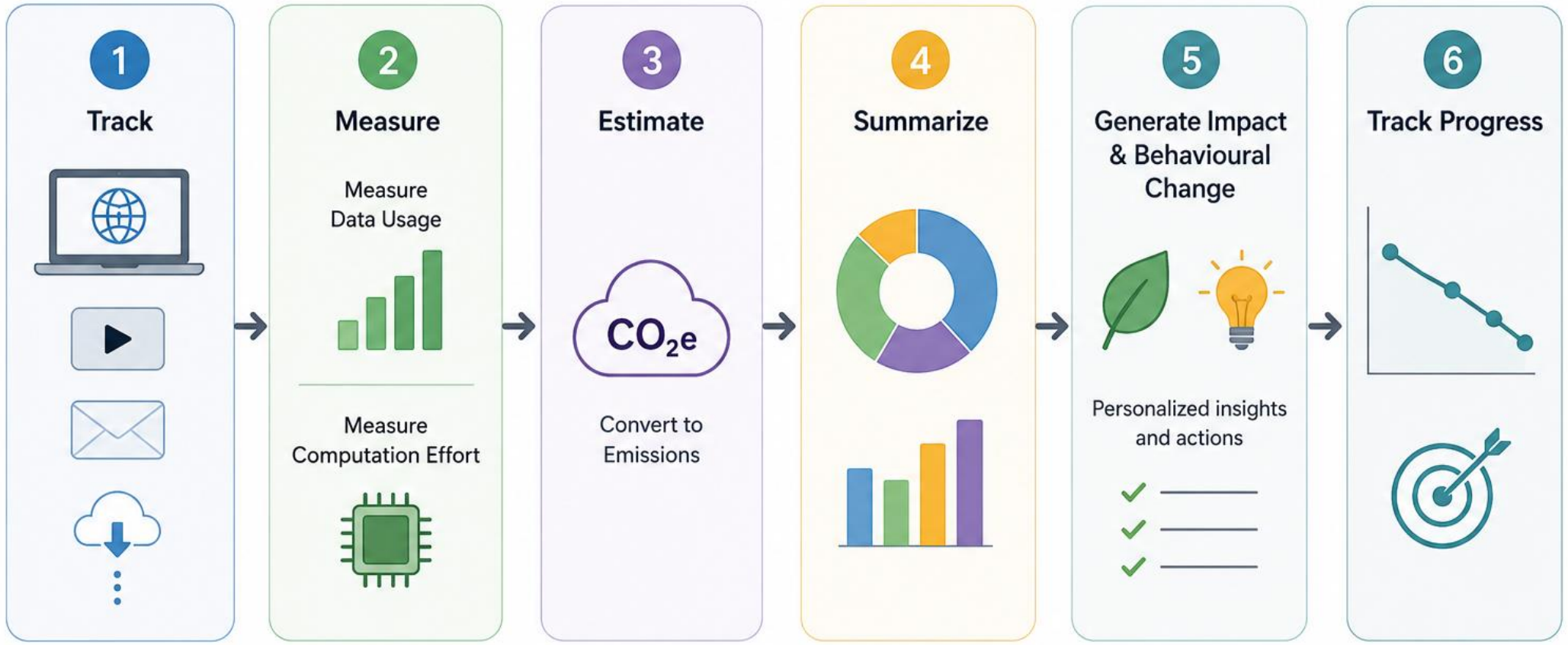
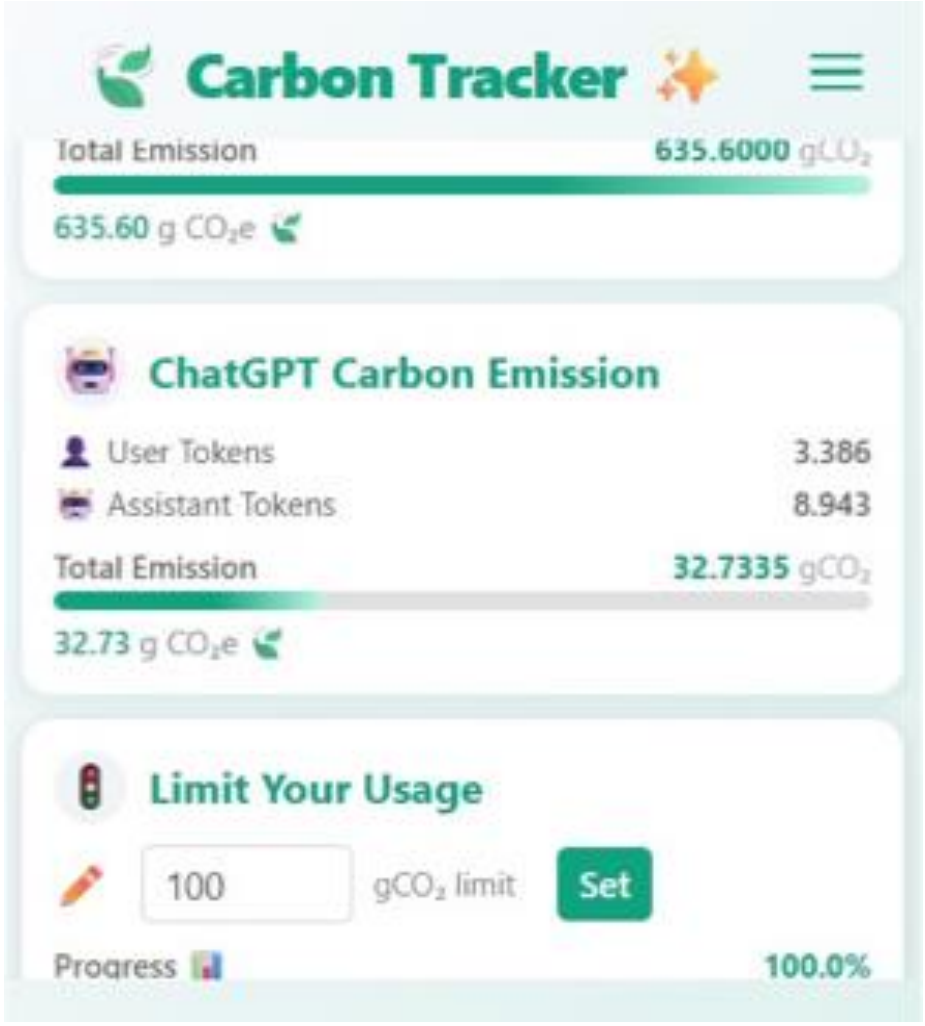


Our Carbon Tracker

Developed as a Chrome extension to monitor traditional browsing and ChatGPT activity in real-time.

Built with React/TypeScript, providing a persistent but non-intrusive dashboard for sustainability metrics.

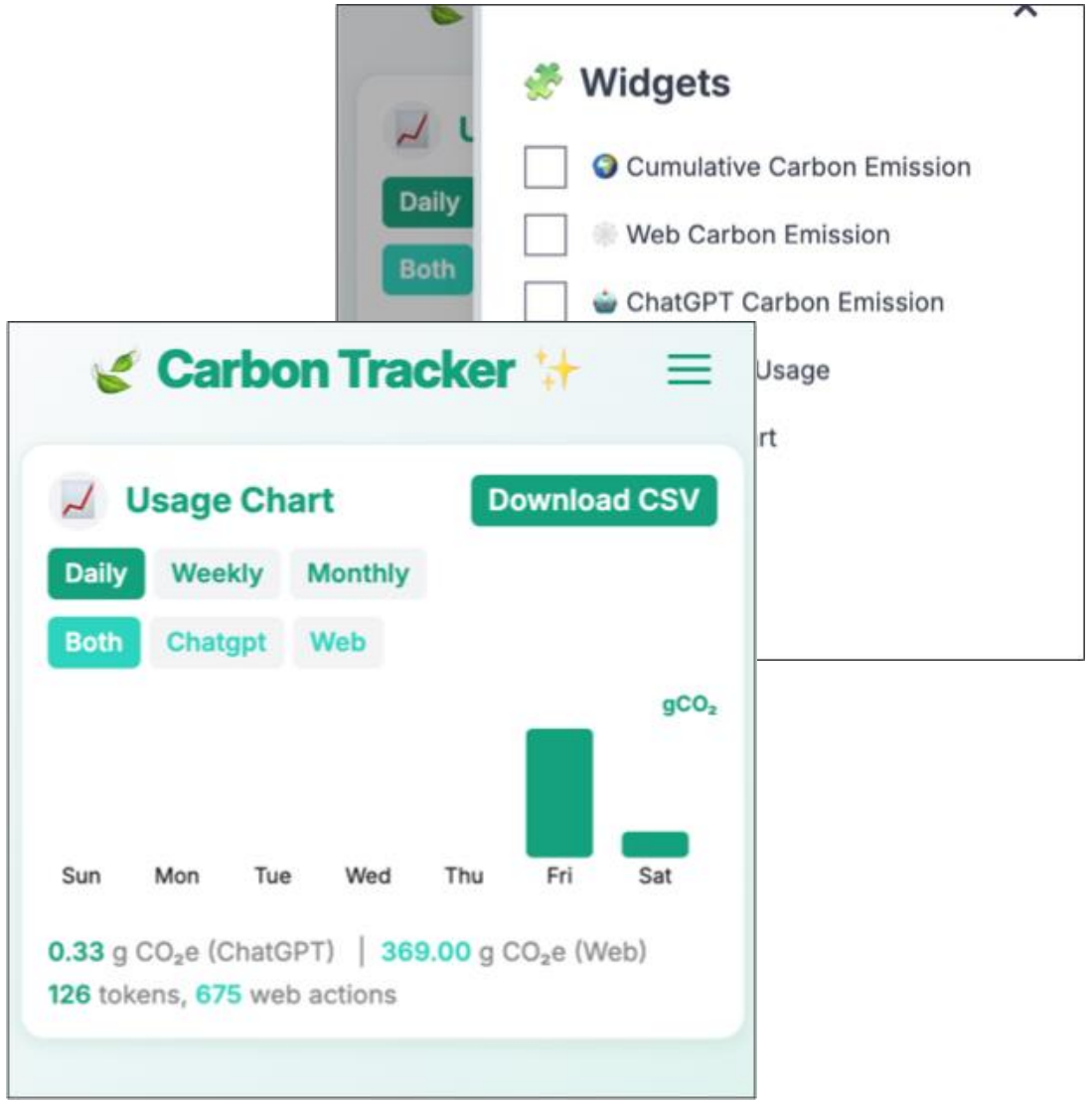


Extension

A Chrome Extension that opens a pop-up where different widgets can be added/removed based on personal or experimental preference.

The **widgets:**

- **Web Carbon Emissions:** view of carbon emissions produced by visiting pages on the browser
- **ChatGPT Carbon Emissions:** a view of carbon emissions produced by ChatGPT
- **Cumulative Carbon Emissions:** sum of both
- **Limit Your Usage:** sets a limit of gCO2 and shows progress bar
- **Usage Analytics:** a bar chart representing the gCO2 emissions, at different granularity level

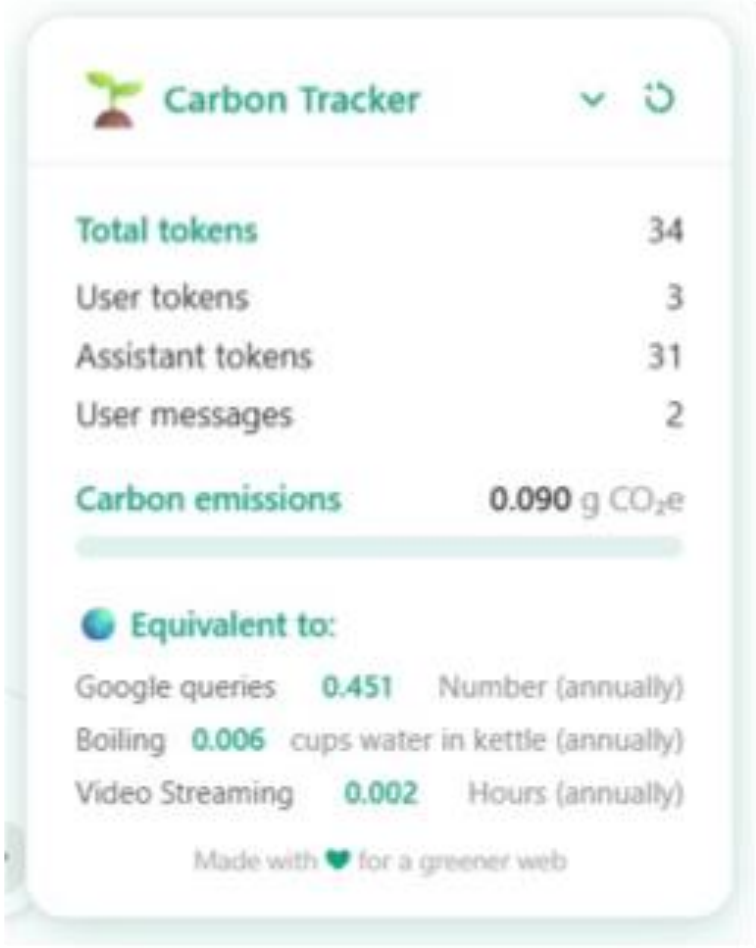


Floating Window

A small pop-up that appears at the bottom of the ChatGPT
interface, showing the analytics of usage of that particular conversation.

It also shows the number of input and output tokens and the equivalence of current usage to other daily life tasks

(e.g., the number of cups of water boiled in a kettle every day for a year, number of video streaming watched in a year.



Empirical Evaluation

03

Back to our Research Questions

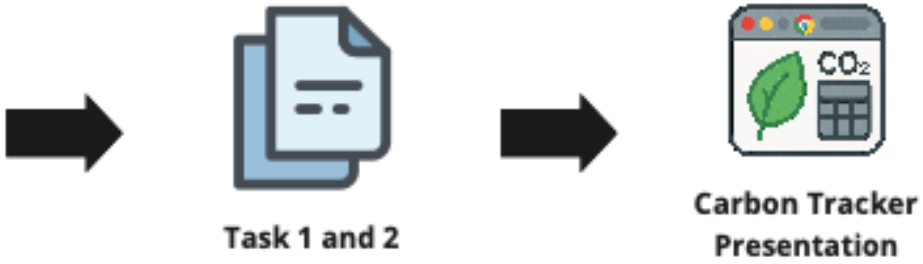
RQ1

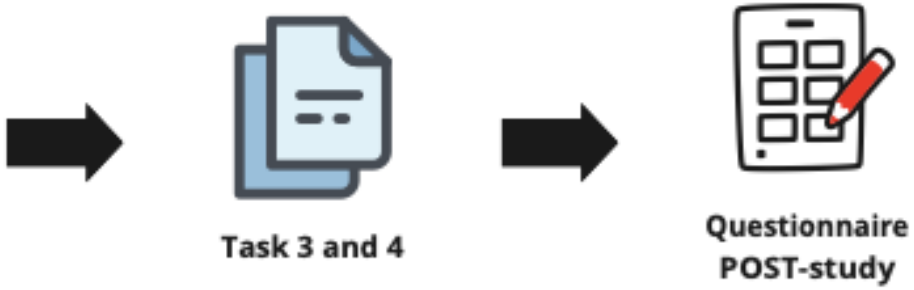
- What is the **effectiveness of Carbon Tracker tools** in creating **sustainability awareness** when using web and AI systems?

RQ2

- What is the **user experience and usability** of Carbon Tracker tools?

Experimental Setup and Process





Experimental Session Plan

Two tasks performed by subjects:

- writing a newsletter to announce an event
- summarising a presentation.

They were then introduced to Carbon Tracker,

Two more tasks executed with the tool installed on their browser:

- replying to an email (written in a language different from their native language)
- writing a document aiming to promote a staff week

The tasks were deliberately framed around participants' working contexts

➔ foster ecological validity and minimise the Hawthorne effect (altered behaviour as a result of being

After the evaluation: assessments of UX experience and environmental attitudes.

Research Variables on Sustainability

Self-efficacy (SE): participants' confidence and capacity to adopt sustainable behaviours

Action Effectiveness (AE): participants' assessments of the effectiveness of their own efforts towards sustainability

New Ecological Paradigm: participants' agreement with eco-friendly values (relationship between humanity and nature)

Metric	*SE*	*AE*	*NEP*
Pre AVG	4.233	5.800	5.507
Pre SD	0.738	0.958	0.430
Post AVG	4.767	5.300	5.580
Post SD	0.704	1.674	0.622
Shapiro-Wilk W	0.919	0.902	0.883
Shapiro-Wilk p	0.350	0.229	0.143

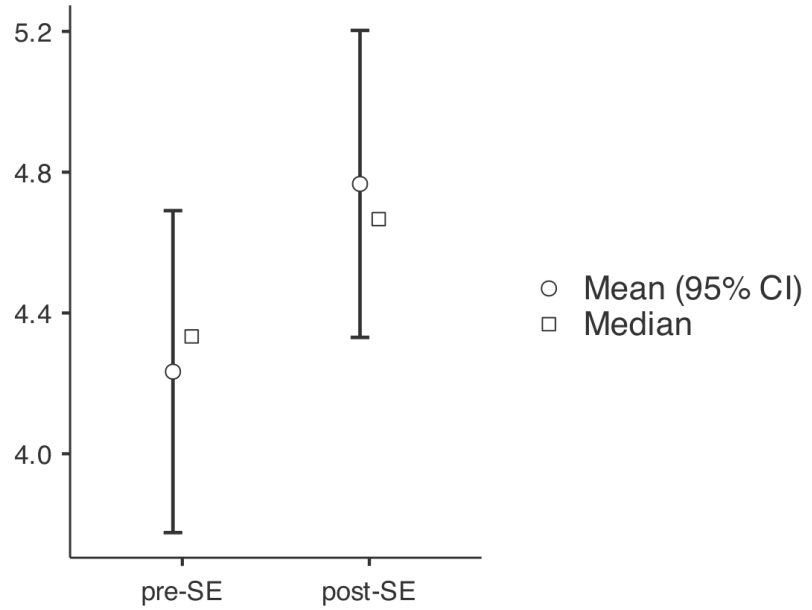
Results

To check statistical significance, we use the **Paired Samples t-Test**.

- significant main effect for self-efficacy,
- no significant difference between pre- and post- results of AE and NEP.

			Statistic	df	p
pre-SE	post-SE	Student's t	-2.331	9.000	0.045
		Wilcoxon W	8.000		0.052
PRE-AE	POST-AE	Student's t	1.449	9.000	0.181
		Wilcoxon W	27.500		0.207
PRE-NEP	POST-NEP	Student's t	-0.729	9.000	0.485
		Wilcoxon W	20.000		0.492

Note. $H_a\ \mu_{Measure1-Measure2} \neq 0$



Research Variables for Usability

User Experience Questionnaire (UEQ) gathers feedback regarding the User Experience (UX) of the digital tool

System Usability Scale (SUS) used to get participants' perceptions of the system usability

	Variable	AVG	SD
UEQ	obstructive vs. supportive	6.100	0.994
	complicated vs. easy	6.200	1.317
	inefficient vs. efficient	6.300	0.949
	confusing vs. clear	5.600	1.430
	boring vs. exciting	5.800	1.398
	not interesting vs. interesting	6.200	1.135
	conventional vs. inventive	5.600	1.776
	usual vs. leading edge	5.100	1.663
SUS	SUS	75.571	12.444

Results

To check statistical significance, we use the Paired Samples t-Test.

- significant main effect for self-efficacy,
- no significant difference between pre- and post- results of AE and NEP.

Discussion & Limitations

The Awareness Shock
A major gap between users' perceived digital footprint and their actual footprint, particularly regarding the **high energy overhead of generative AI**

Power of Metaphors
Translating abstract **CO_2 grams into relatable daily actions** (e.g., boiling a kettle) successfully triggers user reflection

Behavioral Change
The **statistically significant increase in self-efficacy** ($p = 0.045$) proves that **real-time, in-context transparency** empowers users to adopt greener habits

Limitations
The pilot evaluation relied on a small sample size.
Carbon metrics for AI are currently based on industry averages rather than real-time server grid fluctuations

Conclusion & Future Work

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Core Takeaway
Digital sustainability is no longer just a backend data center challenge; it requires **empowering end-users with transparency** at the interface level.

Validated Approach
The Carbon Tracker extension successfully bridges the **gap between complex energy telemetry and actionable user awareness** without disrupting the browsing experience.

Next Step – Active Mitigation
Shifting the tool from passive monitoring to **proactive intervention** by directly suggesting green alternatives (e.g., prompt caching or lighter model alternatives).

Long-Term Vision
Scaling the framework to support **broader organizational deployment** and contributing to open-standard digital footprint benchmarks.

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Thanks!

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