AI-BASED MEASUREMENTS: A SUSTAINABLE PERSPECTIVE

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Outline

1. **Introduction**
   - Background on sustainability
   - Sustainability of ICT
   - The role of AI in achieving sustainability
2. **Proposal**
   - A method for measuring the sustainability of AI
3. **Case study & Experimental results**
   - Impact Assessment
   - Strategies to improve sustainability
4. **Conclusions**

1. Background on sustainability

What is Sustainability?

- Being *sustainable*: ensuring present needs without compromising those of future generations

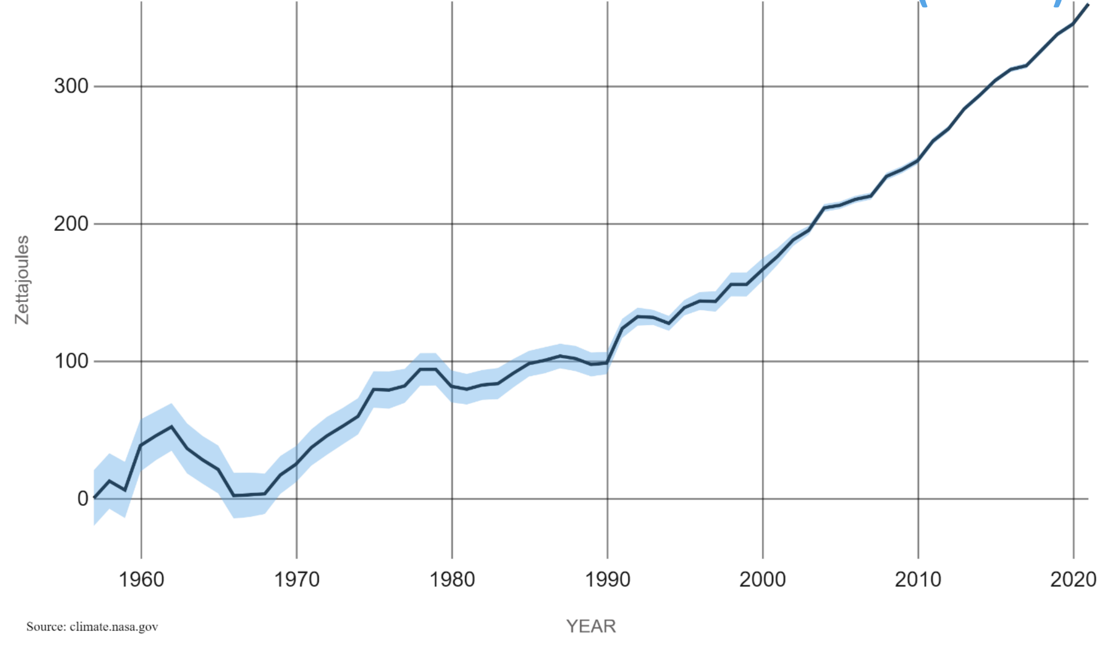
1. Background on sustainability
What is Sustainability?

- The *United Nations* outlines the 2030 Agenda with the 17 *GOALS* for sustainable development

1. Background on sustainability
Environmental sustainability

- The *environment* is experiencing adverse effects because of the imprudent utilization of resources
- An unprecedented shift in the climate is occurring, altering the equilibrium of our planet

OCEAN HEAT CONTENT CHANGES SINCE 1955 (NOAA)



1. Background on sustainability
Environmental sustainability

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13 CLIMATE ACTION

➨ Sustainable development goal no. 13: **Climate Action**

"Take urgent action to combat climate change and its impacts"

1. Sustainability of ICT

Green by ICT & Green of ICT

Information and Communication Technologies (ICTs) have two effects on sustainability:

Green by ICT

ICTs represent an important *resource* for the battle against climate change for:

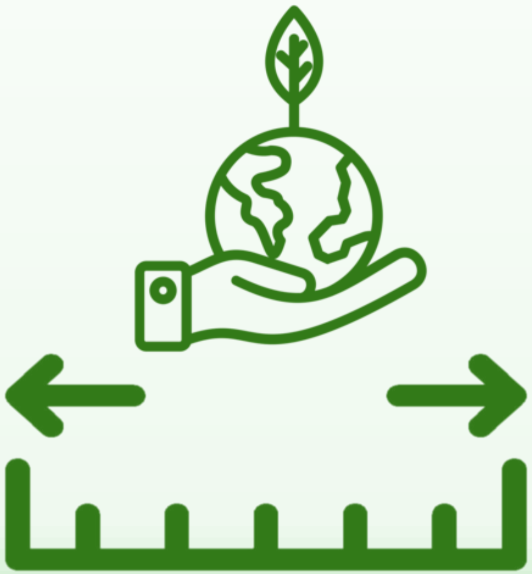
- energy-efficiency
- low-carbon production

Green of ICT

ICTs have an *impact* themselves that must be assessed by evaluating:

- energy consumption
- e-waste

How to measure the sustainability of ICTs?



1. Sustainability of ICT
Standards and Recommendations

Standard International Organization for Standardization (ISO) 14000 family

- ISO 14064-67: *Carbon Footprint*
- ISO 14040-44: *Life-Cycle Assessment*

International Telecommunication Union (ITU) Recommendation

- ITU-T L1400: *Environmental Impact Assessment of ICT Systems*

Carbon Footprint: This quantity is the amount of greenhouse gas emitted in the observation time interval (expressed in kg $\mathbf{CO_{2,eq}}$)

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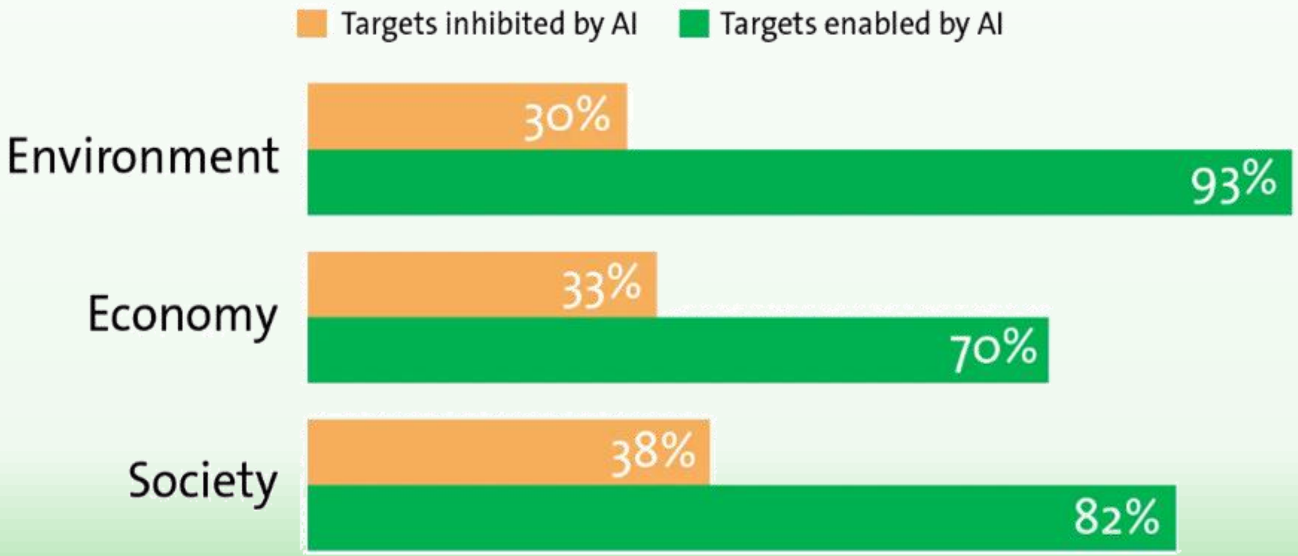
Life-Cycle Assessment (LCA): This method enables the assessment of the Carbon Footprint of an ICT system throughout its entire life cycle, from the design and production stages through to its use and eventual disposal.

1. The role of AI in achieving sustainability

AI duality

AI, considered a *key ICT innovation*, has a double role in achieving sustainability:

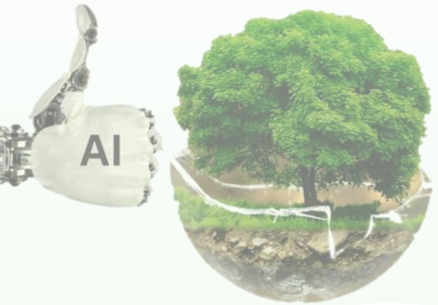
SUSTAINABLE DEVELOPMENT GOALS



Vinuesa, Ricardo, et al. "The role of artificial intelligence in achieving the Sustainable Development Goals." Nature communications 11.1 (2020): 1-10.

1. The role of AI in achieving sustainability

Green by AI & Green of AI



Green by AI

- Support & preservation of ecosystem
- Sustainable energy and agriculture systems
- Resource & waste management
- Climate modeling & prediction
- Natural disaster prediction

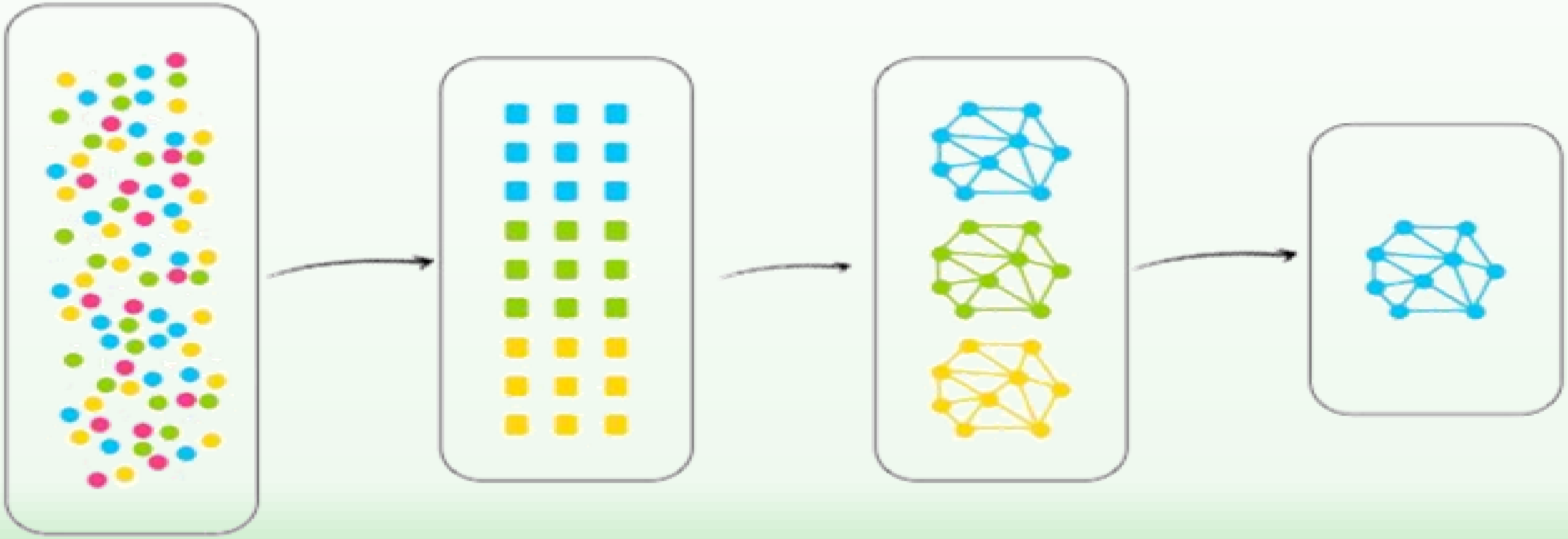
Green of AI

- Data processing demands
- Large-scale computing infrastructures
- Significant computational power
- Cloud service providers
- Electronic waste of data centers

1. The role of AI in achieving sustainability

How to measure the sustainability of AI?

Let us consider a typical *AI pipeline*, employed in AI-based measurements:

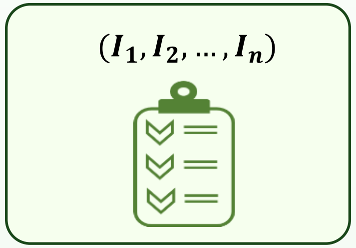


1. *Data Collection*
2. *Data Preprocessing*
3. *Model Training & Validation*
4. *Model Testing & Deployment*

2. Proposal

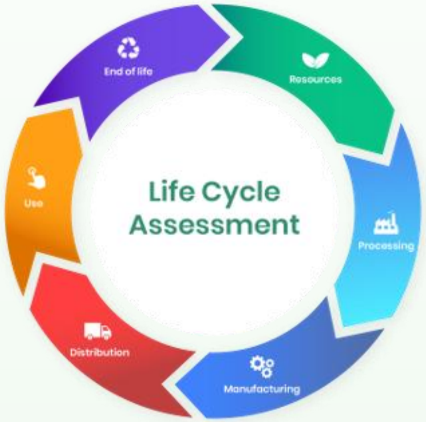
A method for measuring the sustainability of AI

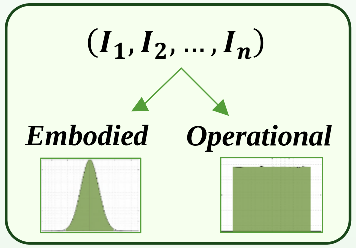
In line with ISO standards and ITU recommendations:



Checklist of the items characterizing each stage of the AI pipeline:

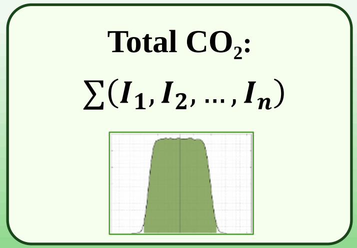
- Hardware components
- Software applications





Modeling of the items (PDF Assignment):

- *Embodied contributions* (manufacturing, transport, packaging, disposal)
- *Operational contributions* (energy consumption of the items)

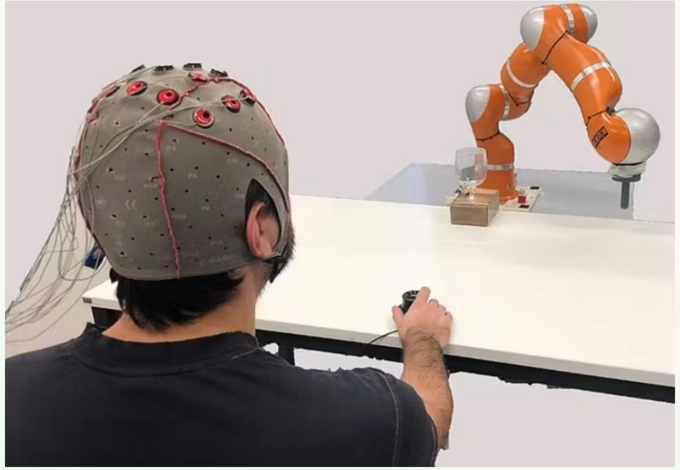


Aggregation of the contributions (PDF Propagation):

- The impacts of each stage of the pipeline are aggregated: the resulting PDFs represent the *Carbon Footprint* of the specific pipeline stage
- The contributions are aggregated to have the total output Carbon Footprint

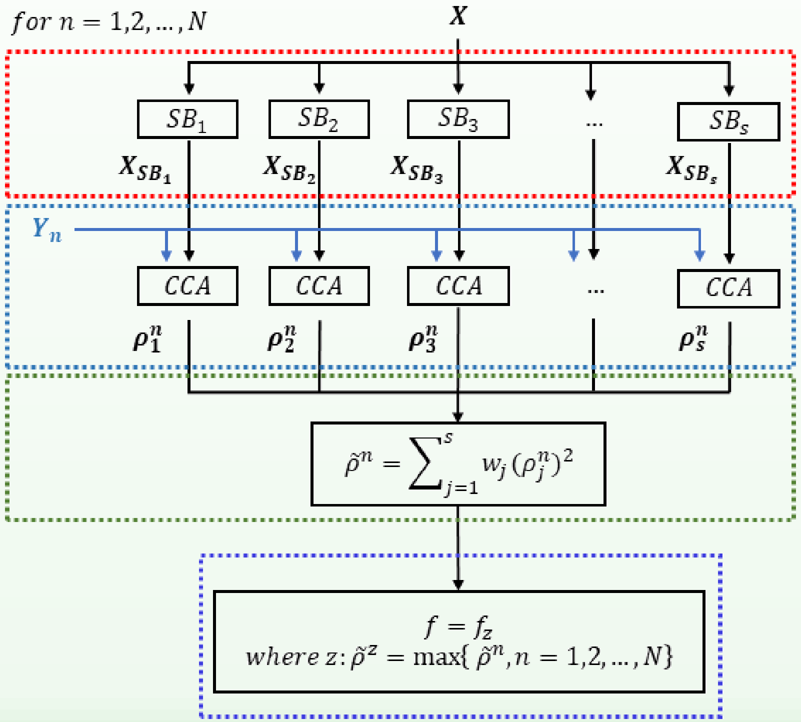
3. Case study
SVEP-based BCIs

Impact assessment of a scenario involving wearable *Brain-Computer Interfaces* (BCIs) that use *Steady-State Visually Evoked Potentials* (SSVEPs):



- This non-invasive technology relies on *electroencephalography* (EEG) to monitor brain activity, capturing brain responses to visual stimuli
- SVEP-based BCIs present visual stimuli in the user's field of view via *augmented reality* (AR)

3. Case study
AI-based algorithm



AI-algorithm: Filter-Bank Canonical Correlation Analysis

Validation: Leave-One-Subject-Out Cross Validation

Hyperparameters: Grid Search (2160 combinations)

Classification Accuracy: evaluated at 99 % confidence level, assuming normal probability distribution

This approach is suitable for two potential case studies: (1) ***downloading training data*** from online repositories and (2) ***conducting an experimental campaign*** to collect new data

3. Experimental results
Checklist

Case study (1): Downloading training data

Utilizing online repositories containing pre-existing datasets: *data were retrieved from a public dataset benchmark containing Visually Evoked Potentials acquired from 35 subjects*[1]

Dataset download
- Laptop
- Modem
- Server

→ **Data preprocessing**
- Laptop
- Software

→ **Model training & validation**
- Laptop
- Software

→ **Model Testing & Deployment**
- Laptop
- Software

[1]Wang, Yijun, et al. "A benchmark dataset for SSVEP-based brain–computer interfaces." IEEE Transactions on Neural Systems and Rehabilitation Engineering 25.10 (2016): 1746-1752.

3. Experimental results

Checklist

Case study (2): Acquiring and uploading training data

Conducting an experimental campaign and subsequently uploading the collected data

Dataset acquisition & upload
- AR Head-Mounted Display
- EEG Headset
- Laptop
- Modem
- Server
- Software

Data preprocessing
- Laptop
- Software

Model training & validation
- Laptop
- Software

Model Testing & Deployment
- Laptop
- Software

3. Experimental results
Checklist

Case study (1):

- Hardware: Lenovo Thinkpad T15g laptop
- Software: MATLAB

Case study (2):

- Hardware:
  - g.tec UNICORN Hybrid Black EEG headset
  - Microsoft Hololens 2 head-mounted display
  - Lenovo Thinkpad T15g laptop
- Software: MATLAB

3. Experimental results
Embodied contributions

Embodied impacts are associated to the entire *life cycle* of the item: production, transport, packaging, and disposal

- *Modeling of items through OpenLCA* (open-source software for LCA): it enables access to free and commercial databases to assess environmental impacts
- The incomplete knowledge of all the internal components of the items led to the derivation of a *probability density function (PDF)* associated with the impact of each item

openLca

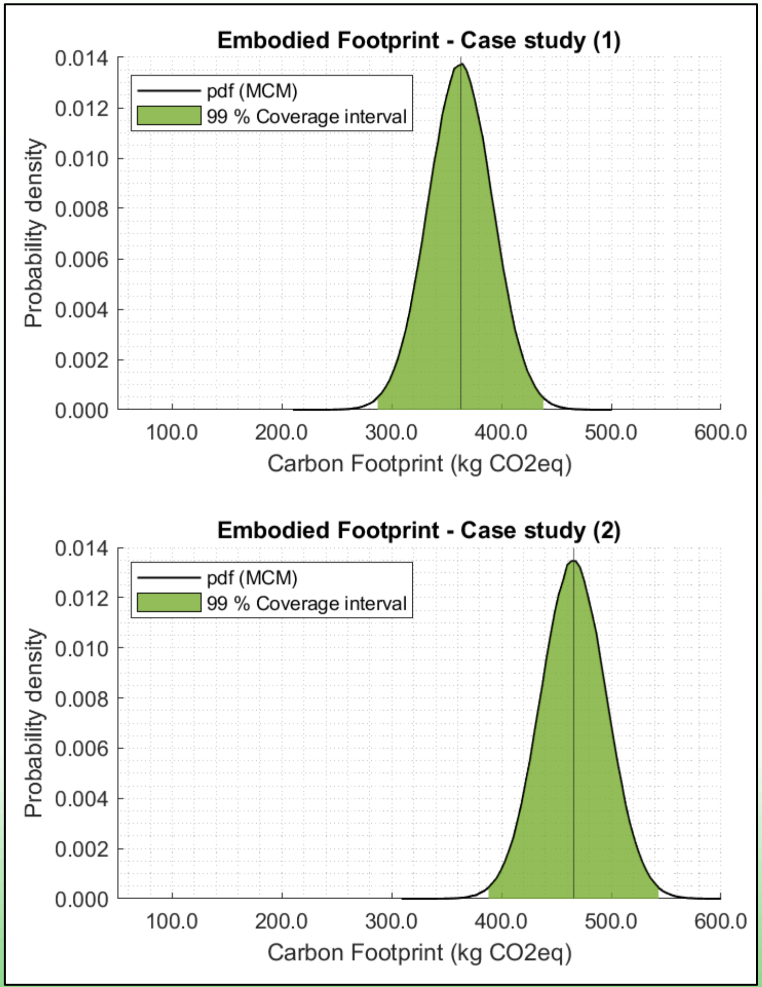
3. Experimental results
Embodied contributions

PDFs were aggregated using *Monte Carlo simulations*: results are shown with the *99 % coverage interval* for the output PDFs

Items Case Study (1)	$CO_{2,eq}$ [kg]
Laptop	246.66÷393.34
Modem	32.13÷52.91
TOTAL IMPACT	**287.58÷437.57**

Items Case Study (2)	$CO_{2,eq}$ [kg]
Hololens 2	94.03÷98.98
g.tec UNICORN EEG headset	5.02÷7.99
Laptop	246.66÷393.34
Modem	32.13÷52.91
TOTAL IMPACT*	**389.13÷541.81**

*Note: The server is external, and the impact of Matlab is zero



3. Experimental results
Operational contributions

Operational impacts are related to the use of the system over *time*, particularly its energy consumption:

- The *energy consumption* of each item was determined based on *power data* obtained from datasheets

- The *carbon-related values* were obtained through a conversion factor derived from Nowtricity, based on historical data in Italy from 2023

EXECUTION TIME PER AI PIPELINE STAGE FOR BOTH CASE STUDIES

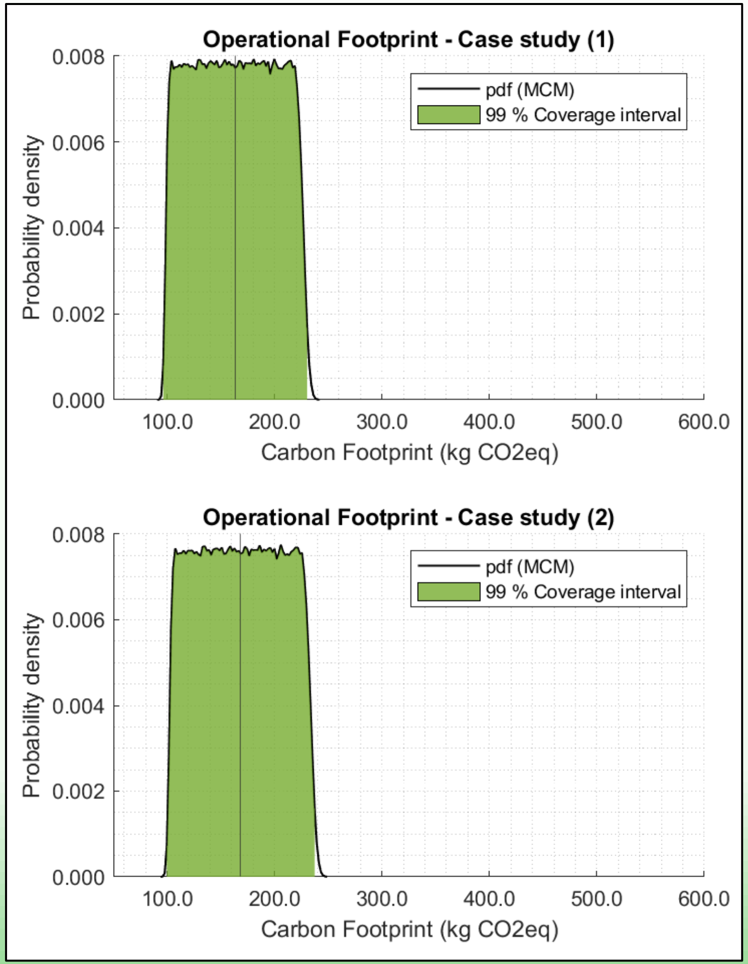
AI pipeline stage	**Case study (1):** *Data Download*	**Case study (2):** *Data acquisition* (a) *Data Upload* (b)
Data collection	0.4 h	(a) 112 h (b) 1.4 h
Data preprocessing	8 h	8 h
Model training & validation	336 h	336 h
Model Testing & deployment	24 h	24 h

3. Experimental results
Operational contributions

Operational impacts for each stage of the pipeline expressed with 99 % coverage interval:

AI pipeline stage	**Case study (1):** *Operational Footprint* kg [CO_2,eq]	**Case study (2):** *Operational Footprint* kg [CO_2,eq]
Data collection	90.79÷213.94	87.35÷207.08
Data preprocessing	0.23÷0.47	0.23÷0.47
Model training & validation	9.74÷19.90	9.74÷19.90
Model Testing & deployment	0.69÷1.42	0.69÷1.42

The results highlight that *data collection* has the highest impact, followed by *model training*

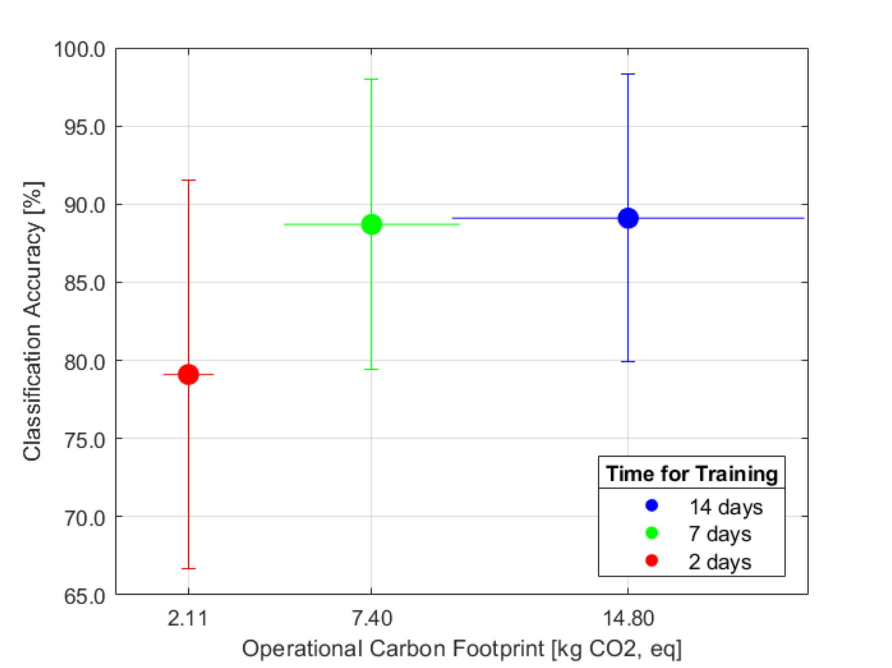


3. Strategies to improve sustainability
How to reduce the Carbon Footprint?

- Strategies to reduce environmental impact include *reducing dataset size* or *shortening model training time*
- It is crucial to evaluate *trade-offs* between sustainability and performance: the model training was performed at three different times

Times	Operational Footprint kg [CO_2,eq]	Accuracy [%]
14 days	9.75÷19.91	79.90÷98.30
7 days	4.87÷9.95	79.40÷98.00
2 days	1.39÷2.84	66.70÷91.50

The intermediate duration offers performance comparable to 14 days while reducing environmental impact



4. Conclusions

➨Information and Communication Technologies (ICTs), in particular *Artificial intelligence* (AI), have a two-fold effect on environment:

- They offer fundamental tools for developing more sustainable processes and products (*Green by ICT*)
- The very use of ICTs has its own environmental impact (*Green of ICT*)

➨A methodology for measuring the environmental impact of AI pipelines is proposed in line with ISO standards and ITU recommendation

➨ Through a case study on EEG data processing, the methodology introduced is employed to measure the *Carbon Footprint of each stage of the AI pipeline*

➨In future, the focus will be on trade-offs between performance and sustainability: there is **the need to include Sustainability as a decision parameter when designing an AI pipeline**

Thank you for the attention

To explore: