

Module 6

Sustainability and Societal Impact of AI Technologies



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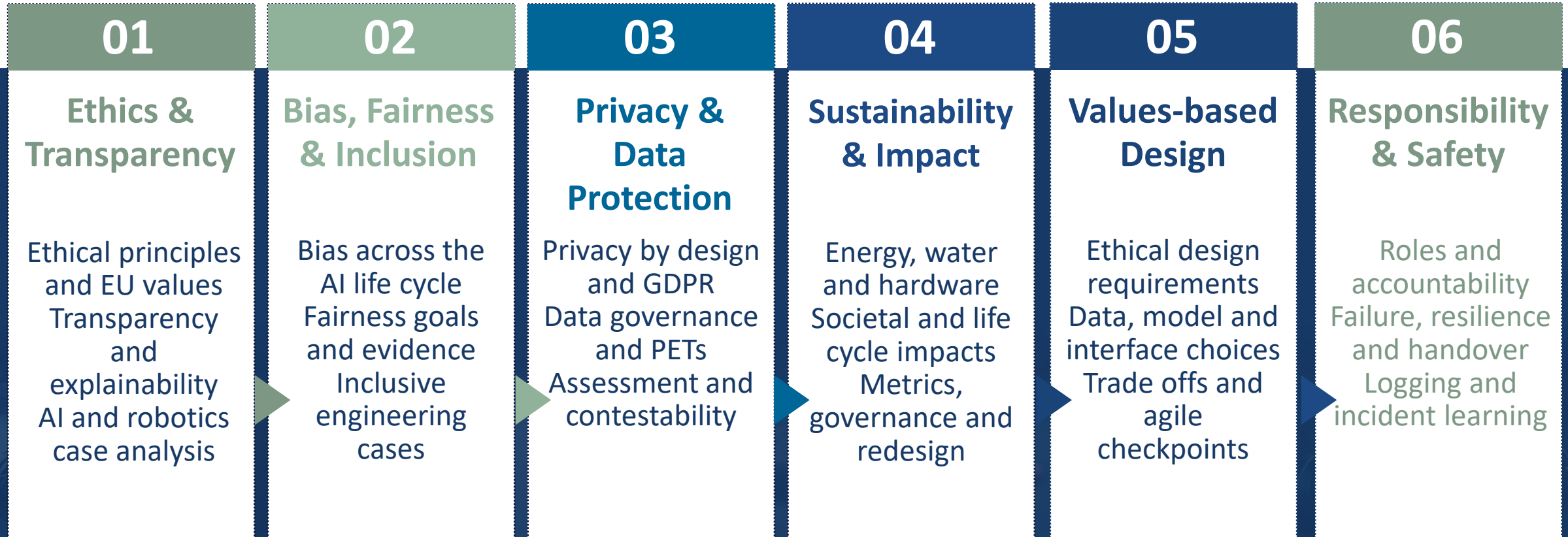


Ethical Engineer

www.ethicalengineer.eu

Ethical Engineer course at a glance

Core content and learner output for each module. Module 6 is highlighted in green.



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Sustainable AI

Engineering for long term impact

This module examines AI as a physical and socio technical system. Learners connect purpose, data, models, infrastructure, operation and retirement with environmental, social, economic and technical evidence. The module develops practical skills for measurement, redesign, governance and long term engineering decisions.

Learning Outcome

By the end of the module, learners will be able to:

1. Define a system boundary and functional unit for a sustainability assessment.
2. Map environmental, social, economic and technical impacts across the AI life cycle.
3. Estimate energy, emissions, water and hardware impacts with stated assumptions.
4. Compare engineering options using mandatory thresholds, evidence quality and uncertainty.
5. Produce a sustainability plan with safeguards, owners, metrics and review triggers.



01

SYSTEMS PERSPECTIVE



The background of the slide features a dark blue field with abstract, glowing blue and white geometric shapes and lines, suggesting a high-tech or digital environment. In the bottom left corner, there is a close-up of a robotic arm or sensor tip, rendered in a light blue/white color, pointing towards the center of the frame.

Ai Is A Physical And Socio Technical System

AI services depend on data collection, human labour, networks, processors, data centres, electricity, water, minerals and organisational decisions. These dependencies create impacts before deployment, during operation and after retirement.

A sustainability assessment therefore covers the complete system, including purpose, alternatives, affected people, infrastructure, maintenance and end of life. It also states what is excluded and why.

The engineering question is whether the system produces a justified benefit within defined environmental and social limits.

Sustainability Requires Systems Thinking

Sustainable AI engineering requires systems thinking across purpose, design, infrastructure, measurement and governance.

Begin with the need and a non AI alternative. Define the functional unit, such as one verified prediction or one supported engineering decision. Select a baseline. Measure impacts in the relevant locations and time periods. Compare feasible options.

Record uncertainty, transferred impacts and the conditions that require redesign, restricted use or retirement.

Definition Of Sustainable Ai

Sustainable AI means designing, developing, deploying, operating and retiring AI systems so that a legitimate long term benefit is delivered within defined environmental, social, economic and technical limits.

The assessment uses a clear boundary, functional unit, baseline, evidence sources and review period. It considers direct impacts, supply chain impacts, distribution of benefits and burdens, rebound effects and uncertainty.

Sustainability is an engineering requirement with owners and acceptance criteria.

Four Connected Sustainability Dimensions

Environmental

Energy, greenhouse gas emissions, water, land, materials, pollution and electronic waste across the life cycle.

Social

Rights, safety, fairness, accessibility, labour conditions, participation, community effects and remedy.

Economic & Technical

Affordability, resilience, maintainability, supplier dependence, skills, reliability, security and compliance.

Map Impacts Across The Ai Life Cycle

○ Purpose and alternatives

Define the need, functional unit, baseline and non AI option.

- DATA AND MODEL
- Record collection, labelling, storage, training, evaluation and reuse.

○ Infrastructure and deployment

Include hardware manufacture, networks, data centres, edge devices and integration.

Map Impacts Across The Ai Life Cycle

- **Operation and change**

Measure inference, monitoring, maintenance, updates, user behaviour and rebound.

- **Retirement**

Plan data deletion, model withdrawal, hardware reuse, repair, recycling and evidence retention.

02

INTRODUCTION TO SUSTAINABLE AI

Sustainable AI

Discussion Prompt

- What benefit justifies this AI system?
- Which environmental and social impacts could occur across its life cycle?
- Which evidence would support the claim?
- Could a simpler digital, mechanical or organisational solution meet the need?

Sustainable AI

Two Directions of Impact.

Sustainability of AI

Measure and reduce the energy, emissions, water, material, labour and societal impacts created by the system.

AI for Sustainability

Evaluate whether an AI application produces additional environmental or social benefit compared with a credible baseline.

Both directions require boundaries, evidence, safeguards and monitoring for rebound effects.

Potential Harms Across The Life Cycle

Area	How AI Can Harm Sustainability	Example
Energy Use	Training and operating large models consume huge amounts of electricity and water.	Data centres for LLMs (Large Language Model) draw megawatts of power.
E-Waste	Rapid hardware cycles and specialized AI chips increase electronic waste.	GPUs/TPUs become obsolete within 2–3 years.
Bias & Inequity	Unfair or opaque algorithms can reinforce social inequality.	Biased credit scoring or hiring tools.
Overconsumption	AI-optimized advertising drives unsustainable consumption patterns.	Recommender systems promoting fast fashion.
Resource Extraction	Mining rare minerals for chips damages ecosystems.	Lithium and cobalt extraction for servers.

Potential Benefits With Evidence

Area	How AI Can Harm Sustainability	Example
Climate Modelling	AI improves prediction of weather, wildfires, and carbon cycles.	DeepMind's GraphCast for faster weather forecasting.
Energy Efficiency	AI optimizes building energy use and industrial systems.	Google AI reduced data centre cooling energy by 40%.
Sustainable Agriculture	Precision agriculture minimizes fertilizer and water waste.	Drone-based crop analysis for irrigation control.
Circular Economy	AI aids material tracking, recycling, and waste sorting.	Vision AI identifies recyclables in sorting plants.
Environmental Monitoring	Satellite AI tracks deforestation, pollution, and biodiversity loss.	AI models detect illegal fishing and forest clearing.

Application Domains And Evidence Questions

Domain	AI Helps	AI Harms
Computer Science	Model compression, green software, edge AI	Energy-hungry model training, data hoarding
Engineering	Smart grids, energy optimization	Overreliance on automation, loss of resilience
Business / Economics	Sustainable supply chain forecasting	Manipulative marketing, planned obsolescence
Health Sciences	AI diagnostics reduce waste and delay	Privacy violations, bias in health data
Environmental Science	Automated conservation monitoring	High-cost sensors and cloud compute demands

03

ENVIRONMENTAL IMPACTS AND EVIDENCE



The background of the slide features a dark blue gradient with abstract, glowing blue and yellow geometric shapes and lines, suggesting a high-tech or artificial intelligence theme. A robotic arm is visible in the bottom left corner.

The Footprint Extends Across The Life Cycle

AI systems rely on physical infrastructure that consumes energy, water and materials. Impacts arise from data acquisition, hardware manufacture, model development, deployment, inference, networking, storage, maintenance and retirement.

Define the boundary before calculating a footprint. State the functional unit, baseline, geography, time period, allocation method, electricity factors, hardware assumptions and data quality.

A result without these details is difficult to interpret or compare.

Energy And Greenhouse Gas Emissions

Training, fine tuning, inference, data processing and storage all use electricity. The significance depends on workload, hardware, utilisation, location, time and electricity supply.

Report the baseline, functional unit, measured or estimated kilowatt hours, hardware type, duration, utilisation, data centre allocation and emissions factor. Separate development from operation and identify uncertainty.

Reduce demand through sufficiency, smaller models, reuse, efficient software, right sized hardware, scheduling and verified low carbon supply.

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Water Use And Local Context

- Water impacts include direct water used for cooling and indirect water associated with electricity and equipment production. The result varies by technology, climate, season, electricity mix and local water stress.
- Report location, period, water source, cooling method, withdrawals or consumption, allocation and uncertainty. Avoid applying one global figure to every system.
- Consider demand reduction, suitable cooling, recycled water, heat management and scheduling, while protecting local community and ecosystem needs.

Hardware, Materials And Electronic Waste

Processors, servers, storage, networks and edge devices create embodied impacts through mining, refining, manufacture, transport and disposal. Social risks can also occur in extraction and supply chains.

Record equipment type, useful life, allocation to the workload, repairability, upgrade path, supplier evidence and end of life route. Include premature replacement caused by software or procurement choices.

Prefer longer use, high utilisation, modular repair, reuse, refurbishment and verified recovery of materials.

Cloud And Data Centre Evidence

Operational Impacts

- Measure workload electricity, allocation, utilisation, location and time. Data centre indicators such as power usage effectiveness and water usage effectiveness provide context and do not replace workload measurement.
- The EU reporting regulation applies to covered data centre operators. Use the current scope and reporting rules.

Embodied And System Impacts

- Include servers, accelerators, storage, networks, cooling equipment, building systems and replacement cycles. Ask suppliers for methods, boundaries and allocation assumptions.
- Use JRC good practice guidance for energy management, cooling, reuse and monitoring.

[Sources] Ethical Engineer approved KA220-HED application, WP3 Teaching and Learning (OER Development), pp. 61-70.

AI For The Environment Requires Additionality

- AI can support grid operation, environmental monitoring, precision agriculture, buildings, transport and industrial optimisation.
- A credible claim compares the AI system with a realistic baseline, includes the footprint of the AI service, tests accuracy and failure consequences, identifies who benefits or carries risk and monitors rebound.
- Continue only when the measured net benefit remains meaningful in the operating context.

ENVIRONMENTAL EVIDENCE SUMMARY

Use the table as an evidence checklist. Add the system boundary, functional unit, baseline, method, data source, uncertainty, owner and review trigger for every material impact.

Impact Area	Environmental Cost	Sustainable Solution
Energy Use	High power demand for training/inference	Renewable energy, efficient models
Water Use	Cooling data centres	Water recycling, smart scheduling
Hardware	Mining rare materials	Ethical sourcing, longer life cycles
Carbon Emissions	Fossil-based energy	Carbon offsets, green data centres
E-Waste	Toxic materials	Circular economy, recycling programs

04

SUSTAINABLE ENGINEERING PRACTICES



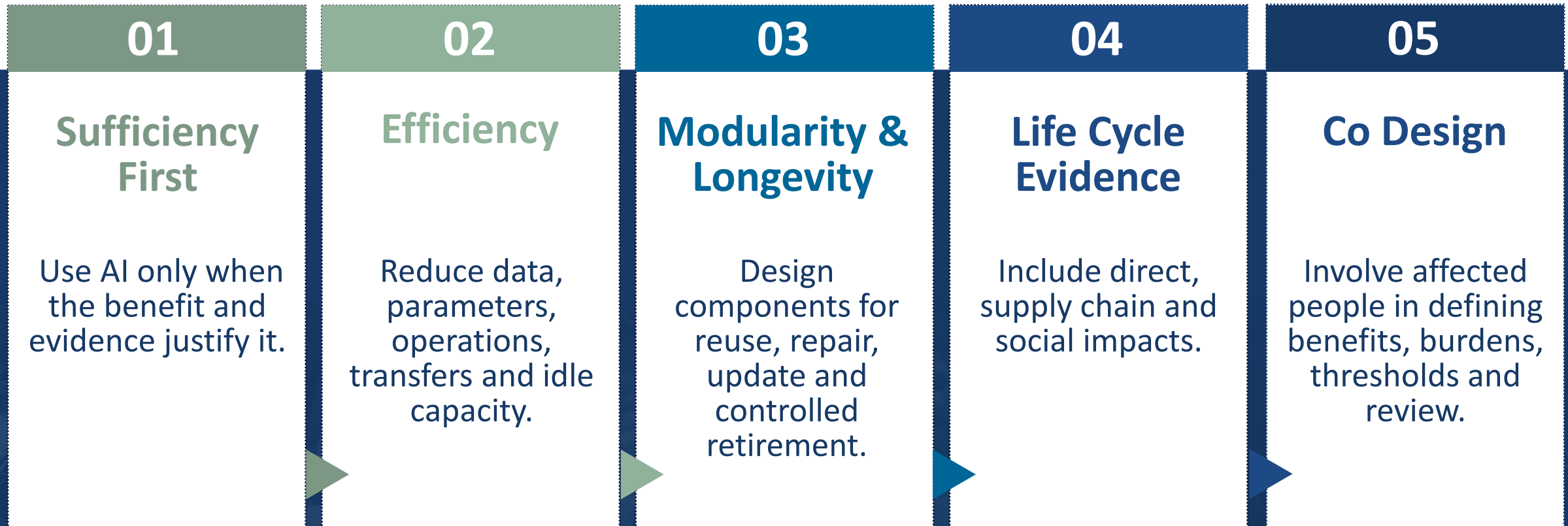
Sustainable Engineering For Ai

Sustainable engineering for AI defines the purpose and constraints, selects the least resource intensive feasible approach, measures material impacts and keeps evidence connected with design, procurement, operation and retirement.

It combines sufficiency, efficiency, resilience, maintainability, circularity, stakeholder participation and responsible AI requirements.

The output is a traceable decision with a baseline, acceptance criteria, safeguards, owners and review conditions.

Sustainable Design Principles





Efficient Hardware And Infrastructure

- Match the workload to hardware that meets performance, reliability and energy requirements. Improve utilisation through right sizing, scheduling and shared capacity.
- Evaluate cloud, edge and local options using operational and embodied impacts, latency, privacy, resilience, repair and network demand.
- For facilities, examine metering, cooling, airflow, temperature ranges, renewable supply, water context and heat reuse. Request supplier evidence for boundaries and allocation.

Algorithmic And Software Efficiency

- Begin with a simple baseline. Reuse a suitable model before training a new one. Consider smaller architectures, feature reduction, pruning, quantisation, sparse computation, distillation, batching, caching and early exit.
- Measure quality and resource use with the same functional unit and operating conditions. Test subgroup performance, robustness, latency and maintenance effects.
- Report compute and energy alongside performance so that efficiency claims can be reviewed.

Circular Ai Systems

Reuse

Use existing data, models, components and infrastructure when purpose, provenance, rights and performance remain suitable.

Repair And Upgrade

Design hardware and software for modular maintenance, secure updates and long service life.

Retire Responsibly

Withdraw unsafe or unnecessary models, delete data securely, retain decision evidence and route hardware to verified reuse, refurbishment or recycling. Avoid transferring obsolete equipment to contexts without safe support.

Metrics Become Engineering Controls

For each material impact, define:

1. Functional unit and baseline.
2. Boundary, location and measurement period.
3. Energy, emissions, water, material and service quality measures.
4. Data source, allocation method and uncertainty.
5. Owner, acceptance threshold and review frequency.
6. Action when evidence crosses a trigger.

Use the Software Carbon Intensity specification where it fits the system. Keep environmental evidence connected with safety, rights and service outcomes.

Systems Thinking And Long-Term Accountability

- A sustainable engineering mindset connects every technical choice with material, environmental, social and operational consequences.
- Work with domain experts, affected communities, facilities teams, procurement, suppliers and maintainers. State assumptions and uncertainty. Preserve evidence that challenges the preferred option.
- Define stop conditions. Reopen the assessment after changes to purpose, data, model, hardware, supplier, scale, population, location or law.

Sustainable Engineering Practices

Use the summary table to connect each practice with a requirement, measure, evidence source, owner, acceptance threshold and life cycle review point.

Engineering Focus	Sustainability Challenge	Mitigation Strategy
Algorithm Design	High computational demand	Use efficient models and transfer learning
Hardware & Infra	Energy and cooling use	Renewable energy, efficient cooling
Software Lifecycle	Frequent retraining	Modular updates, reusability
Materials	Rare earth mining	Recycling, ethical sourcing
Governance	Lack of metrics	Track CO ₂ , energy, and water use

05

GOVERNANCE AND ETHICS IN SUSTAINABLE AI

Governance & Ethics

Sustainability evidence belongs inside engineering governance. It influences purpose, requirements, architecture, procurement, release, monitoring, incident response and retirement.

Governance should identify who defines the boundary, approves methods, owns data quality, challenges claims, accepts residual impacts and can restrict or stop the system.

Environmental goals remain connected with rights, safety, fairness, accessibility, labour conditions and community effects.



What Is Sustainability Governance?

Sustainability governance is the system of decision rights, processes, evidence, controls and accountability used to define acceptable impacts across the AI life cycle.

It connects legal and professional duties with engineering requirements, measurement, stakeholder participation, procurement, release authority, monitoring, remedy and retirement.

Governance & Ethics

Core Goals

Confirm a legitimate purpose and credible baseline.

- Set mandatory legal, rights, safety and environmental thresholds.
- Require evidence for benefits and material impacts.
- Allocate decision, measurement and stop authority.

Enable independent challenge, stakeholder participation and remedy.

Review the system after material change or new evidence.

Governance & Ethics

Transparency

Methods, boundaries, data sources, assumptions and limits.

- Accountability
- Named owners for decisions, evidence, controls and remedy.
- Fairness and Participation

Distribution of benefits and burdens, including affected communities and workers.

Safety And Resilience

Failure controls, fallback, monitoring and incident learning.

Sustainability

Ethical Foundations And Current Duties

Ethical Principle	AI Relevance	Sustainability Link
Beneficence	AI should do good for individuals and society.	Optimize for long-term wellbeing, not short-term gain.
Non-maleficence	Avoid causing harm or risk.	Prevent negative environmental and social externalities.
Justice	Ensure fair access and outcomes.	Equitable access to sustainable technologies.
Autonomy	Respect user control and consent.	Transparency in AI decisions.
Responsibility	Engineers and organizations are accountable.	Report sustainability metrics and impacts.



Completed Sustainability Record: Ai Chiller Control

DECISION REVISE:

Pilot AI supported chiller control for one data hall. Keep rule based fallback and operator stop authority.

FUNCTIONAL UNIT:

One hour of cooling that maintains the approved thermal envelope.

BASELINE:

Existing control under matched weather and workload.



Completed Sustainability Record: Ai Chiller Control

EVIDENCE:

Metered cooling electricity, water, server inlet temperature, alarms and operator interventions.

THRESHOLDS:

Thermal safety and service reliability remain mandatory. Water use cannot increase in the local stress period.

REVIEW:

Facilities lead reviews weekly. Stop after threshold breach, sensor fault or unexplained control action.

Governance Tools And Evidence

LIFE CYCLE ASSESSMENT

Define boundary, functional unit, inventory, impact method and interpretation.

SOFTWARE CARBON INTENSITY

Measure operational energy and embodied emissions per functional unit where suitable.

IMPACT AND RIGHTS ASSESSMENT

Connect affected people, risks, safeguards, evidence and remedy.

PROCUREMENT AND REPORTING

Request supplier methods, allocation, energy, water, materials, repair and incident evidence.

MODEL AND SYSTEM RECORDS

Document purpose, components, evaluation, limits, sustainability evidence and change history.

Risks In Sustainability Claims

Greenwashing

Claims lack a boundary, baseline, method or verification.

Omitted Impacts

Development, data, networks, embodied hardware, water, labour or retirement remain outside the calculation.

Weak Factors

Average electricity or water data conceal location and time.

Impact Transfer

Efficiency in one component increases risk or resource use elsewhere.

Risks In Sustainability Claims

Rebound

Lower cost increases total demand.

Limited Participation

People carrying the burden lack influence, evidence or remedy.

Procurement Review Questions

1. What functional unit and baseline support the supplier claim?
2. Which energy, water and material impacts are measured, estimated or excluded?
3. Where and when were the factors collected?
4. How are shared infrastructure and embodied hardware allocated?
5. What supports renewable electricity claims?
6. Which data, models and logs are retained?
7. Can hardware and software be repaired, upgraded and transferred?
8. Which incidents, threshold breaches and audit evidence must be disclosed?

Future Priorities For Sustainable Ai

Priorities For Engineering Practice

- Audited and interoperable measurement.
- Energy and power benchmarks connected with service quality.
- Efficient inference and workload aware scheduling.
- Longer hardware life, repair and circular procurement.
- Location and time aware electricity and water decisions.
- Evidence for distributional and community effects.
- Clear review triggers for scale, model, hardware and supplier changes.

Education should connect these priorities with real design decisions and field evidence.

Sustainability Assessment Rubric

Use the table to review purpose, boundary, functional unit, baseline, methods, environmental evidence, social evidence, options, thresholds, owners, uncertainty and review triggers.

Governance Focus	Practical Action	Example
Transparency	Publish model cards, dataset factsheets	Google's Model Cards
Accountability	Assign responsibility for each lifecycle stage	Responsible AI Leads
Fairness	Bias audits, fairness testing	IBM AI Fairness 360 Toolkit
Environmental Responsibility	Track CO ₂ , water, materials	Green AI reporting tools
Global Cooperation	Align regulations and ethics	OECD / UNESCO frameworks

Managing Trade Offs

Apply mandatory legal, rights, safety and environmental thresholds first. Then compare feasible options.

Accuracy And Energy

Use the lowest resource option that meets the defined service threshold.

Latency And Throughput

Batching can improve utilisation while affecting response time.

Edge And Cloud

Compare energy, network demand, embodied hardware, privacy, resilience and maintenance.

Privacy And Compute

Test the full system effect of privacy techniques.
Record evidence quality, affected stakeholders and the trigger that reopens the decision.

Risks And Pitfalls

- **Greenwashing**
Claims without a baseline, boundary or measurement.
- **Hidden Costs**
Data, storage, transfer, hardware, water, labour and retirement are omitted.
- **Narrow Optimisation**
A local efficiency gain weakens safety, fairness, privacy, resilience or maintainability.

Risks And Pitfalls

- **Uncertain Data**
Estimates appear precise while factors and allocation remain weak.
- **Scale And Rebound**
Demand grows after efficiency improves.
- **Social Impact**
Benefits and burdens are distributed without participation or remedy.

Alignment And Standards

Life Cycle Methods

Use ISO 14040 and 14044 principles for goal, scope, inventory, impact assessment and interpretation.

Software And Ai Measurement

Use the Software Carbon Intensity specification and SCI for AI where suitable. MLCommons Power supports workload power benchmarking.

Alignment And Standards

EU Context

Apply current EU data centre reporting rules, JRC good practice and the current AI Act according to scope and role.

Ethics And Societal Impact

Use OECD and UNESCO principles with stakeholder evidence and domain standards. Record the version, scope and reason for every framework used.

06

SYNTHESIS AND REFERENCES



Final Remarks

Sustainable AI engineering begins with a justified need, a clear boundary and a credible baseline. It measures environmental and social impacts across the life cycle and uses the evidence to change design, procurement, operation and retirement.

A strong decision selects the least resource intensive feasible option, protects mandatory rights and safety thresholds, states uncertainty and names the people who own evidence, controls and review.

Stewardship means maintaining benefit within defined limits and acting when the evidence changes.

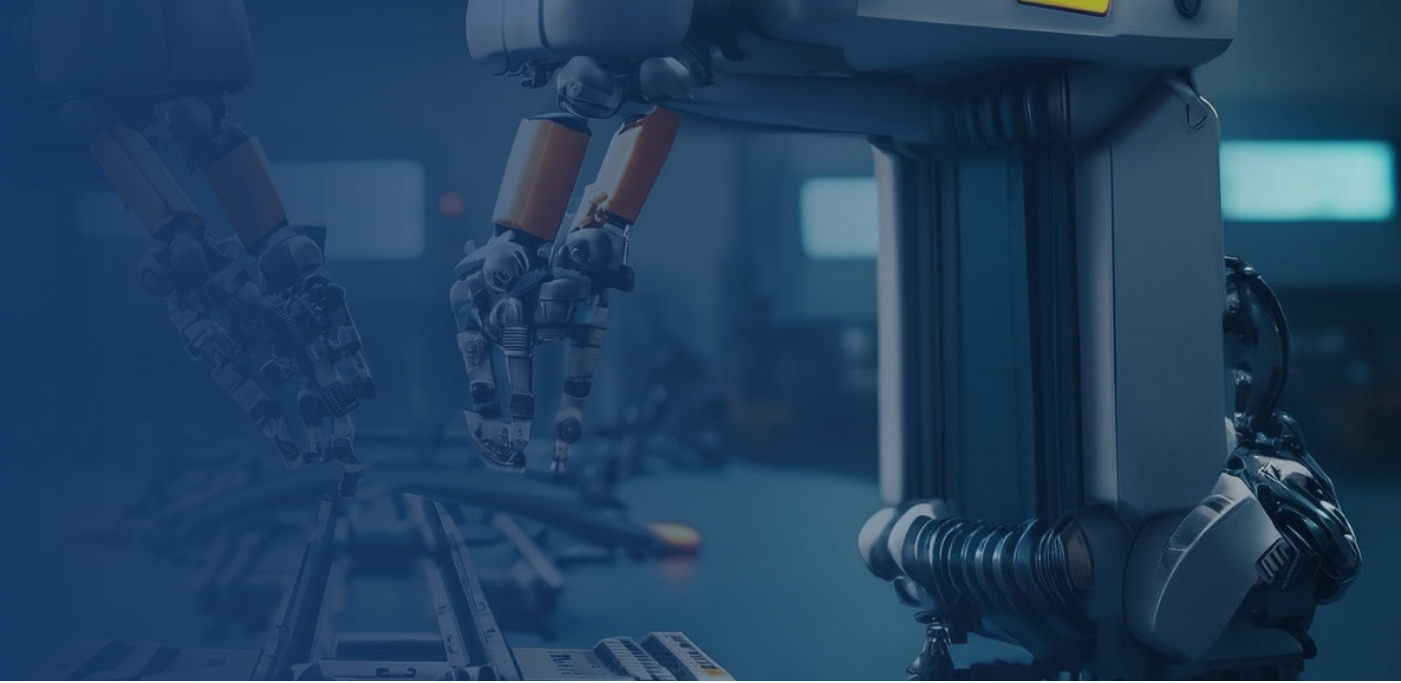
Core References & Further Reading

- International Energy Agency. [Energy and AI](#).
- [ISO 14040](#). Life cycle assessment principles and framework.
- Green Software Foundation. [Software Carbon Intensity](#) specification and SCI for AI.
- European Commission Joint Research Centre. [Data Centre Code of Conduct](#) and 2025 best practices.
- European Union. [Current AI Act](#) and data centre reporting regulation.
- OECD. [AI Principles](#) and measurement of environmental impacts of AI.
- UNESCO. [Recommendation on the Ethics of Artificial Intelligence](#) and AI for Environment toolkit.
- MLCommons. [Power benchmarking](#).
- Schwartz and colleagues. [Green AI](#).
- [Ethical Engineer project resources](#) and case bank.

Direct links appear in the speaker notes.

07

ACTIVITY AND TEAM DESIGN CHALLENGE



Applied Activity

Choose an AI system from your field:

Define the need, functional unit, boundary and baseline.

1. Identify energy, emissions, water, material and social impacts.
2. Separate measured data, estimates and omissions.
3. Compare a current design, an efficient design and a non AI option.
4. Apply mandatory thresholds and recommend GO, REVISE or STOP.
5. State the owner, uncertainty and review trigger.

Output:

One page assessment and a two minute engineering defence.

Team Project 1: Redesign An Ai Pipeline

Team Project 1

Redesign an AI data analytics pipeline using the Ethical Engineer project case. Map data collection, processing, model, infrastructure, operation and retirement. Define a functional unit and baseline. Estimate the material impacts with stated assumptions. Compare at least two redesign options and a non AI alternative.

Deliverables

Five slide presentation

- One page sustainability plan
- Evidence table with sources and uncertainty
- GO, REVISE or STOP decision

Team Project 2: Sustainable Ai System

Challenge

Design an AI system for a real engineering problem. Show the intended social or environmental value and how the system's own impacts will be managed.

Include

- Stakeholders and life cycle impacts
- Resource indicators
- Fairness, privacy, labour and accessibility
- Governance, targets and review points

Deliverables

Six slide proposal and two page dossier.

Teamwork And Presentations

Learning Outcome Check

Before finishing, confirm that you can:

1. Define a boundary, functional unit and baseline.
2. Map impacts across the AI life cycle.
3. Estimate energy, emissions, water and hardware impacts with assumptions.
4. Compare options using thresholds, evidence quality and uncertainty.
5. Produce a sustainability plan with safeguards, owners and review triggers.

Evidence:

Life cycle map, calculation record, option comparison and sustainability decision.

A green tree with dense foliage is positioned at the top center of the image. Below it, a dark blue rectangular box contains the title and text. At the bottom, a robotic hand with blue and silver segments is visible, holding a glowing sphere that features a circuit-like pattern. The background is a deep blue with some blurred light effects.

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Thank You

You have completed **Module 6**



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