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Information technology — Artificial intelligence — Environmental sustainability aspects of AI systems

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Foreword

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 42, *Artificial intelligence*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

Introduction

Unprecedentedly large and ever-growing deep learning models, large language models, natural language understanding networks and generative AI applications require vast data storage capacities, take weeks to train, are running continuously, require a lot of compute power as well as memory to load the models. And once completed they consume substantial amounts of network connectivity bandwidth in operation. Sixty per cent of IT industry carbon emissions come from the downstream use of products by customers.

The use of power intensive GPUs to run machine learning training (and non-AI uses such as crypto currency mining) has already been cited as contributing to increased carbon dioxide emissions.[1] Many machine learning packages have been modified to take advantage of the extensive parallelism available inside the average graphics processing unit. Often this resource intensity is used to exemplify environmental concerns with AI systems.

According to the World Economic Forum and experts in the field, AI has “the potential to accelerate environmental degradation, and is already doing so” [1,2]. In 2022, the OECD’s Policy Observatory [3] that provided input into basic framework for understanding, measuring and benchmarking domestic AI computing capacity by country and region, did not consider environmental sustainability in its charter [4].

The AI system life cycle does provide opportunities to consider and positively influence the environmental sustainability aspects of the system: for example, using and applying teacher–student models [5] in deep neural networks represents a trade-off between more learning and better inference performance when in production.

Improving in-operation product performance can, conversely, aid sustainability. Publications from the European Union,[6,7] the United States,[8-10] the United Nations [11,12] and other regional [13] and global think tanks [14] have called for better understanding and disclosure with regards to ICT’s environmental footprint and that of AI systems in particular.

Information technology — Artificial intelligence — Environmental sustainability aspects of AI systems

1 Scope

This document provides an overview of the environmental sustainability aspects (e.g. workload, resource and asset utilization, carbon impact, pollution, waste, transportation, location) of AI systems during their life cycle, and related potential metrics.

NOTE 1 This document does not identify opportunities on how AI, AI applications and AI systems can improve environmental, social or economic sustainability outcomes.

NOTE 2 This document can help other projects related to AI system environmental sustainability.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 22989:2022, *Information technology — Artificial intelligence — Artificial intelligence concepts and terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 22989 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
environmental sustainability
state in which the ecosystem and its functions are maintained for the present and future generations

[SOURCE: ISO 17889-1:2021, 3.1.1]

3.2
social responsibility
responsibility of an organization for the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that

— contributes to sustainable development, including health and the welfare of society;

— takes into account the expectations of stakeholders;

— is in compliance with applicable law and consistent with international norms of behaviour; and

— is integrated throughout the organization and practised in its relationships

Note 1 to entry: Activities include products, services and processes.

Note 2 to entry: Relationships refer to an organization's activities within its sphere of influence.

[SOURCE: ISO 26000:2010, 2.18]

3.3
life cycle
<product>consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal

[SOURCE: ISO 14040:2006, 3.1]

3.4
supply chain
<product> series of processes or activities involved in the production and distribution of a material or product through which it passes from the source

[SOURCE: ISO 22095:2020, 3.2.1, modified — Note 1 to entry has been removed.]

3.5
energy consumption
quantity of *energy* (3.9) applied

[SOURCE: ISO/IEC 13273-1:2015, 3.1.13, modified — Note 1 to entry has been removed.]

3.6
carbon footprint of a product
CFP
sum of greenhouse gas (GHG) emissions and GHG removals in a product system, expressed as carbon dioxide equivalents and based on a life cycle assessment using the single impact category of climate change

[SOURCE: ISO 22948:2020, 3.1.1, changed “CO_2” to “carbon dioxide”]

3.7
carbon intensity
carbon metric (3.16) expressed in relation to a specific reference unit related to the function of the AI system

Note 1 to entry: For the purposes of this document, the following terms are used as per their definitions in the following reference documents: function (ISO 15686-10:2010, 3.10) and building (ISO 6707-1:2004, 3.1.3).

Note 2 to entry: Examples of reference units may include per unit area, per person, per kilobyte, per unit output, and per GDP.

[SOURCE: ISO 16745-1:2017, 3.2, modified by changing “the function of the building” to “the function of the AI system”]

3.8
e-waste
electrical or electronic equipment which is *waste* (3.18), including all components, sub-assemblies and consumables which are part of the product at the time of discarding

Note 1 to entry: Electrical and electronic products include TVs, computers, laptops, handphones, printers, printed circuit boards, refrigerators, washing machines and audio and video systems.

Note 2 to entry: E-waste contains valuable renewable resources and certain toxic substances.

[SOURCE: ISO 24161:2022, 3.1.2.5, modified — “valuable resources” in Note 2 to entry has been changed to “valuable renewable resources”.]

3.9
energy
E
capacity of a system to produce external activity or to perform work

Note 1 to entry: Commonly the term energy is used for electricity, fuel, steam, heat, compressed air and other similar substances.

Note 2 to entry: Energy is commonly expressed as a scalar quantity.

Note 3 to entry: Work as used in this definition means external supplied or extracted energy to a system. In mechanical systems, forces in or against direction of movement; in thermal systems, heat supply or heat removal.

[SOURCE: ISO/IEC 13273-1:2015, 3.3.1, modified — Note 1 to entry has been updated: "media" has been replaced with "other similar substances".]

3.10
energy efficiency
E_f
ratio or other quantitative relationship between an output of performance, service, goods or *energy* (3.9), and an input of energy

EXAMPLE Efficiency conversion energy; energy required/energy used; output/input; theoretical energy used to operate/energy used to operate.

[SOURCE: ISO/IEC 13273-1:2015, 3.4.1, modified — Note 1 to entry has been deleted.]

3.11
energy efficiency improvement
increase in *energy efficiency* (3.10) as a result of technological, design, behavioural or economic changes

[SOURCE: ISO/IEC 13273-1:2015, 3.4.3]

3.12
inputs
material or product that enters an organization or part of an organization

[SOURCE: ISO 22095:2020, 3.2.2, modified — Notes to entry have been deleted.]

3.13
outputs
material or product that leaves an organization or part of an organization

[SOURCE: ISO 22095:2020, 3.2.3, modified — Notes to entry have been deleted.]

3.14
supply chain
set of organizations with a linked set of resources and processes, each of which acts as a customer, supplier or both to form successive supplier relationships established upon placement of a purchase order, agreement, or other formal sourcing agreement.

Note 1 to entry: A supply chain includes organizations involved in the provision of data, the design and development of AI systems or AI components or service providers involved in the development, operation, management and provision of AI services.

Note 2 to entry: The supply chain view is relative to the position of the customer.

[SOURCE: ISO/IEC 27036-1:2021, 3.10, modified —Note 1 to entry has been rewritten to be entirely AI-specific.]

3.15
chain of custody
process by which *inputs* (3.13) and *outputs* (3.13) and associated information are transferred, monitored and controlled as they move through each step in the relevant *supply chain* (3.14)

[SOURCE: ISO 22095:2020, 3.1.1]

3.16
carbon metric
sum of annual greenhouse gas emissions and removals, expressed as carbon dioxide equivalents, associated with the use stage of a building

Note 1 to entry: For the purposes of this document, the following terms are used as per their definitions in the following reference documents: greenhouse gas emissions (ISO 14064-1:2006, 2.5), and carbon dioxide equivalents (ISO 14064-1:2006, 2.19).

[SOURCE: ISO 16745-1:2017, 3.2, modified —changed "CO_2" to "carbon dioxide" and Note 1 to entry has been modified to remove non-AI system references.]

3.17
carbon-aware
attribute of software or hardware that adjusts its behavior (consumption of inputs, processing, or production of outputs) in response to the carbon intensity of the energy it consumes

[SOURCE: ISO/IEC 21031:2024, 2.2]

3.18
waste
substances or objects which the holder intends or is required to dispose of

Note 1 to entry: The definition is taken from the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (22 March 1989) but is not confined to hazardous waste.

[SOURCE: ISO 14044:2006, 3.35, modified — Note 1 to entry has been adapted.]

3.19
circular economy
economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development

Note 1 to entry: Resources can be considered concerning both stocks and flows.

Note 2 to entry: From a sustainable development perspective, the inflow of virgin resources is kept as low as possible, and the circular flow of resources is kept as closed as possible to minimize emissions and losses (waste) (of resources) from the economic system.

[SOURCE: ISO 59004:2024, 3.1.1]

4 Symbols and abbreviated terms

ASIC application specific integrated circuit

DSP digital signal processor

ESG environmental, social and governance

FPGA field programmable gate array

GHG greenhouse gas

GPU graphics processing unit

ICT information and communications technology

IoT internet of things

ITAD information technology asset disposition

ML machine learning

NLP natural language processing

NLU natural language understanding

NPU neural processing unit

PUE power usage effectiveness

SDG sustainable development goal

TPU tensor processing unit

WEEE waste electrical and electronic equipment

5 Purpose

5.1 General

Sustainability concerns are defined in ISO 14001.[15] Sustainability is often discussed in terms of three perspectives: economic, social and environmental[16]. The social perspective of AI systems is covered in ISO/IEC TR 24028[17] and ISO/IEC TR 24368[18].

Additionally, ISO/IEC TS 12791[19] and ISO/IEC 12792[20] take themes from ISO/IEC TR 24028[17] and ISO/IEC TR 24368[18].

Energy consumption is covered by several relevant International Standards such as ISO 50001.[21] As with ISO 14001 and ISO 26000, the AI specific environmental sustainability aspects are left unaddressed by ISO 51000. Additionally, experts[22] have identified AI characteristics that affect environmental sustainability[23] and the need to find a comparative measurement to determine AI systems' environmental impact.[24,25] ISO 14067 provides guidelines for the quantification of products' carbon footprint only.[26] ISO/IEC 21031:2024 enables quantification of carbon dioxide emissions emanating from an IT system's development and operation.[27]

ISO 14001 does not provide guidance that is suitable for AI systems. The organizational social responsibility guidance provided in ISO 26000[28] does not provide specific, relevant guidance for AI systems (nor is it certifiable).

ISO/IEC 42001:2023, B.5.5[29,30] references sustainability under "other information" and a brief section on power consumption of classification algorithms occurs in ISO/IEC TS 4213. However, as previously observed, no systematic inventory of environmental sustainability aspects specific to AI systems has been undertaken to date.

Sustainability concerns can furthermore be addressed by "circular" frameworks, such as cradle-to-cradle and circular economies, that:

— are based on elimination of waste by design;

— address social, environment and economic aspects across the life cycle of a business' operations; and,

— offer an effective alternative to cradle-to-grave approaches[31-33].

At the time of publication of this TR, the first standards in a new ISO circular economy International Standards series, being developed by TC 323, are completed or are in the process of being published. ISO 59004[31] provides a common vocabulary, principles and guidance for implementation. ISO 59010[34] details a method for organizations to transition value creation models and networks from a linear to a circular framework, while ISO 59020[35] details a method for measuring and assessing circularity performance. This can be applied to AI systems and include measuring and assessing the energy sources used (including the balance of renewable versus non-renewable sources of energy) throughout the life cycle of an AI system. This new series is not specific to AI systems but can be applied to them. AI systems have the potential to help in the transition to a circular economy[32].

This document is focused on environmental sustainability of AI systems. It supports ISO's and IEC’s commitments to helping governments, industry and other interested parties to develop and adopt standards that aids achieving the UN Sustainability Goals. Annex A maps each of the relevant clauses of this document against each of the UN Sustainability Development Goals[36].

5.2 The London Declaration

The London Declaration is a commitment by national standards bodies to ensure global standards will support climate action and advance international initiatives to achieve global climate goals. Its primary objective is to establish International Standards related to climate change and integrate climate-related language into existing International Standards. The agreement recognizes the urgent need for nations to come together to create, adopt and implement comprehensive measures that address the growing threat of climate change[37,38].

5.3 Existing International Standards

There are a number of International Standards that help adapting to climate change, quantify GHG emissions and promote the dissemination of good practices in environmental management.[39] This document seeks to aid this objective by categorizing environmental sustainability aspects of AI, identifying possible quantitative metrics to measure these aspects, as well as presenting actions AI stakeholders can take throughout the AI system life cycle to influence these impacts.

5.4 Environmental sustainability in the European Artificial Intelligence Act

The European Union regulation on artificial intelligence (the Artificial Intelligence Act) was adopted by the European Parliament on 13 March 2024, approved by the EU Council on 21 May 2024 and came into force on 1 August 2024, with provisions coming into operation gradually over the following 6 to 36 months.

The Artificial Intelligence Act is expected to affect organizations world-wide. This is known as “the Brussels effect”, the process whereby the EU’s market forces alone are enough to incentivize multinational companies to voluntarily abide by its regulations and encourage other countries to adopt similar laws of their own.

The purpose as stated in the Artificial Intelligence Act is “to promote the uptake of human centric and trustworthy AI and to ensure a high level of protection of health, safety, fundamental rights, democracy and rule of law and the environment from harmful effects of AI systems in the Union while supporting innovation and improving the functioning of the internal market”[40]. The regulation acknowledges certain AI systems can have an impact on the natural environment. Annex II contains a list of criminal offences includes environmental crime (e.g. a significant harm to the natural environment).

5.5 Enacted climate change legislation and market response

Various jurisdictions have enacted climate change legislation that commits them to reduce net GHGs and timeframes for achieving net zero GHG emissions.[41] They require organizations to adjust their operations accordingly. Whereas until recently ESG reporting was voluntary, mandatory, standardised sustainability reporting by corporations will increase significantly worldwide over the next few years[42,43,43].

For example, in response to investor, company and international policy maker demands by the G20, G7, International Organization of Securities Commissions (IOSCO) and the Financial Stability Board (FSB), the International Sustainability Standards Board (ISSB) was established as part of the International Financial Reporting Standards (IFRS) Foundation to provide decision-useful and comparable information, end the “alphabet soup” of voluntary initiatives and establish an efficient reporting landscape. The ISSB has a transparent, rigorous process to develop market-informed standards that provide a comprehensive global baseline of sustainability disclosures focused on the needs of investors and the financial markets.

The ISSB builds on the work of market-led investor-focused reporting initiatives — including: the Climate Disclosure Standards Board (CDSB); the Task Force on Climate-related Financial Disclosures (TCFD); the