KOMPASS

ARTIFICIAL INTELLIGENCE AND SUSTAINABILITY

Topic sheet

Artificial Intelligence and sustainability

This fact sheet examines the impact of artificial intelligence (AI) on the environment. It provides **an overview** of sustainability in relation to AI.

The factsheet is aimed at teachers in primary and secondary education and provides **background information** to help them address the topic in their own teaching.

What does AI have to do with sustainability?

The use of AI offers numerous opportunities and possibilities to help people in various fields, such as medicine, education or sustainability. For instance, there is hope that AI and algorithms can help save energy, make resource consumption more efficient, facilitate a transition towards renewable energy and sustainable mobility, or warn of extreme weather events. On the other hand, the use of AI requires a large amount of water, electricity and raw materials, and thus emits a **vast amount of CO_2**. In this sense, AI can help in some cases and make situations worse in others. The question is therefore not whether humans should or can use it, but rather how they use AI (sustainably) and for what purpose.

Sustainability

There are various definitions and interpretations of the term *'sustainability'* or 'sustainable *development*'. In this fact sheet, it refers to respecting both the needs and resources of the present and those of the future. The guiding principle is **not to restrict or jeopardise** the opportunities of future generations through the depletion or misuse of resources by the current generation.
Sustainability generally encompasses various dimensions: economic, social and environmental aspects, which must be considered equally in order to preserve resources in the long term.
In short: it is about the responsible management of the Earth's economic, social and environmental resources, for both present and future generations, so that they can lead a life worth living.

AI and the social and environmental aspects of sustainability

The use of AI and AI systems influences the social and environmental aspects of sustainability. These are described in more detail below.

1. Raw materials

AI relies on high-performance hardware, which is usually operated in large data centres. Such data centres are operated by companies such as *Google*, *Amazon*, *OpenAI, Microsoft* as well as other providers worldwide. At the same time, it is technically possible to run smaller AI models on local hardware, for example on one's own computer. However, particularly powerful systems are run in specialised server farms due to the high computational demands.

These servers consist of microchips, circuit boards, cooling systems and emergency power infrastructures. A wide variety of mineral raw materials is required to manufacture such a server. **Silicon** forms the basis of modern

semiconductor chips, regardless of whether they are used for AI or not. The silicon required is extracted from **quartz sand** and processed in energy- and technology-intensive processes into thin, mostly circular discs (known as *wafers*), onto which billions of transistors are then integrated. Modern AI applications require particularly powerful **semiconductor chips**, the production of which relies on highly complex global supply chains. As digital infrastructure and data centres expand, so too does the demand for high-performance semiconductors.

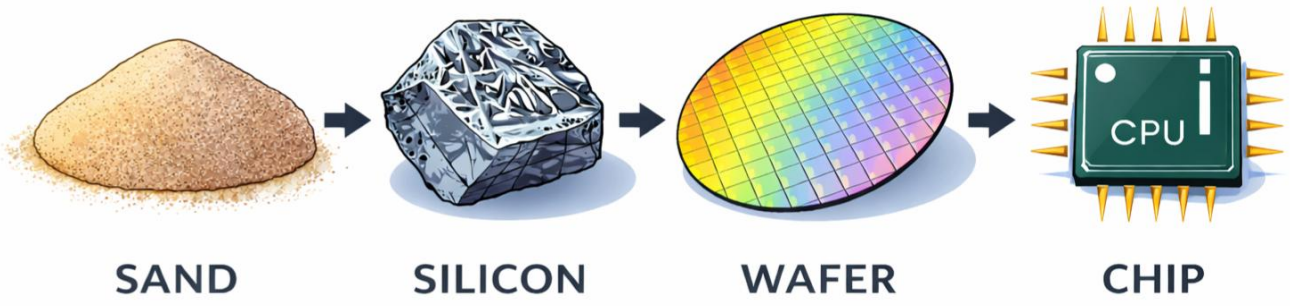

Figure 1: Graphic based on: https://componentbyozdisan.com/en/what-is-a-wafer/, revised using AI

Copper plays a crucial role in data centre infrastructure. It is used for power lines, data cables, transformers and printed circuit boards. Data centres contain kilometres of cabling, and as cloud and AI infrastructures expand, so too does the demand for copper. Data centres are therefore, along with demand from renewable energy transition efforts, grid expansions and electromobility an additional driver of rising global copper demand. The *World Bank's 2020 report* on *'Minerals for Climate* Action' emphasises that demand for metals such as copper is increasing significantly in the wake of global digitalisation and electrification.

Battery storage systems are required to secure the power supply for data centres (see *2. Electricity consumption*). These often contain **lithium**, **cobalt** and **nickel**. The extraction of these metals is sometimes associated with social and environmental problems, particularly in small-scale mining. The *World Bank Report 2020* points out that the rising demand for digital and electrical technologies is further increasing pressure on these raw materials markets.

In addition to electronic components, data centres require large quantities of **steel** and **aluminium** for building structures, server racks and enclosures. The production of these materials is resource- and emission-intensive. Consequently, the construction of the physical infrastructure alone contributes significantly to the resource consumption of digital technologies.

Another problem is the short lifespan of IT hardware. High-performance processors and servers are often replaced after just a few years in order to keep pace with technological progress. According to the *'Global E-Waste Monitor 2024'*, a United Nations report, the global volume of electronic waste is rising steadily, whilst only a fraction of it is recycled properly. This results in the loss of valuable raw materials and causes additional environmental impact.

2. Energy consumption

The energy consumption (or power consumption) of AI systems can be divided into two phases:

- Training
  When training an AI model, large amounts of data are processed. The model uses the data to learn specific patterns, probabilities, etc. This phase usually takes place only once. It is energy-intensive, as it can run for several weeks to months for large models. For GPT-4, energy consumption is estimated at approximately 50 GWh (gigawatt hours). The country of Luxembourg has an estimated daily consumption of 16 GWh (according to www.worlddata.info). This means that Luxembourg could have been supplied with electricity for over three days in the time it took to train GPT-4.
- Usage
  When the model is used – a process also known as inference – it generates an output based on the data it has been trained on, ideally matching the prompt. This typically consumes very little energy, approximately 0.34 Wh (watt-hours)[1]. However, approximately 2.5 billion queries are made to ChatGPT alone every day. This results in a daily consumption of 850 MWh (megawatt-hours) and an annual consumption of approximately 310 GWh. A wind turbine generates approximately 10 GWh per year. Consequently, 31 wind turbines are required for inference with ChatGPT alone. These figures are, however, estimates.

Overall, it is evident that, despite what appears at first glance to be low energy consumption per individual query, AI systems make a significant contribution to global electricity consumption due to their enormous scale of use and the energy-intensive training process, and can therefore also have an impact on the environment and climate.

3. Water consumption

Data centres consume large quantities of water, both directly for cooling the servers and indirectly through the manufacturing of semiconductors and the generation of electricity required to operate the facilities. However, actual water consumption depends heavily on the cooling technology used, the local climate and the energy source.

Recent studies estimate the global water consumption of data centres at approximately 560 billion litres per year, a figure that could rise to around 1,200 billion litres by 2030 if the expansion of AI and cloud infrastructures continues to increase. [2]

A large proportion of this water consumption does not occur directly in the data centres, but indirectly through electricity generation. Depending on the electricity mix, water is used, for example, to cool power stations or in energy production.

The manufacturing of modern semiconductor chips is also water-intensive. So-called *ultrapure water* (water that is virtually free of impurities) is required for cleaning the *wafers* (see *1. Raw materials*), and this is produced through complex processes. Large semiconductor factories can therefore consume several million litres of water every day.

In view of increasing water scarcity due to climate change, there is discussion about building new data centres in water-rich regions or in areas with cool climatic conditions. At the same time, companies and research institutions

[1] https://medium.com/illumination/how-much-energy-exactly-does-chatgpt-use-0a0bdf2e4cd4
[2] https://www.danfoss.com/en/about-danfoss/news/cf/urgent-action-needed-on-water-sector-s-rising-energy-consumption

are working on new technologies to reduce water consumption. These include air-based cooling systems, closed water circuits or liquid cooling directly at the processors, which can be more efficient than traditional cooling towers.

AI and the economic and social aspects of sustainability

However, sustainability does not focus solely on the environmental consequences of resource consumption, but also keeps the economic and social dimensions in mind.

Currently, the AI world is dominated primarily by US companies, such as *OpenAI*, or Chinese firms, such as *DeepSeek*. Major tech conglomerates are investing billions in these technologies to secure market share in this sector.

But what does it mean when private companies increasingly operate such AI systems? Questions arise regarding state sovereignty, economic prosperity, national security and critical infrastructure (such as water, electricity or transport) and how AI can influence or jeopardise all these aspects.

The European AI Act from 2025, therefore categorises AI use cases into risk levels and sets out the associated obligations (e.g. transparency) within the EU. Such a regulation is important because it demonstrates that, if not properly controlled and used thoughtfully, AI systems can promote discrimination, create international conflicts and thus undermine trust and significantly limit the technology's potential. This, in turn, can have negative consequences for the economic well-being of an individual, a society or a nation.

Is sustainable AI possible in practice?

The previous sections have explained the link between sustainability and AI, as well as the potential negative impacts on the environment.

This raises the question of whether sustainable AI is possible in practice. This question is explored below.

More sustainable AI systems in practice

There are ways to design AI systems to be more resource-efficient, such as:

- **Open-source approaches:** Models can be reused and do not need to be redeveloped for every application. Pre-trained models can be adapted for different use cases, which is significantly more environmentally friendly than constantly training AI models from scratch.
- **Data-minimalist approaches**: To reduce energy consumption during the training and deployment of AI, the aim is to work with the smallest possible datasets. The goal is to solve tasks efficiently and effectively with minimal data usage.
  However, unnecessarily large amounts of data are often used – particularly in industry, where vast amounts of data are available. Beyond a certain point, however, further training yields only minor improvements, yet consumes significantly more energy and contradicts the data-minimalist approach.
- **Small Language Models (SLMs):** *SLM's* are smaller language models that require significantly less computing power, memory and energy than large AI models (LLMs – Large Language Models). They can be sufficiently powerful for many specialised tasks and can sometimes be run directly on local devices, thereby reducing energy consumption and data transmission.

- **Policy measures**: In its AI Act, the EU has taken initial steps to mitigate the environmental impact of AI production. Developers are required to document the resource consumption of high-risk AI systems in order to reduce their energy and raw material requirements throughout their lifecycle.

Personal sustainable use of AI

It is not only large tech companies or operators of AI systems that influence resource consumption. Everyone can try to make their own use of AI sustainable.

- Only use AI when it makes sense: use AI technology with care, purpose and reason. It is important to ask why AI is being used or why a task is being outsourced to AI, and what the intended outcome of the results is.
    - **Prioritise non-AI technologies:** A simple search query via search engines (such as *Google*, *Bing* or *Ecosia*) usually serves the purpose just as well. It is not always necessary to consult a Large Language Model (LLM) for every query. If, for example, you are asking about the weather or want to find out the birthday of a famous person, a simple search query is sufficient.
    - **Limit the generation of media**: Before creating an image, graphic or video using AI, it is important to ask yourself whether you could find the image through a simple image search (such as a photo of an animal) or create it yourself using a tool (such as a simple graphic or diagram). Much media already exists and does not need to be created from scratch.
- **Formulate good prompts:** Prompts should be clear and specific, as it is better to create one detailed prompt than several shorter ones. Furthermore, some tasks or questions can be included in a single prompt rather than being asked individually each time (more details on this in the factsheet 'AI and Prompting').
- **Use SLMs and local models:** Where possible, download, install and use smaller local models on local hardware (e.g. on your own computer), as they are generally sufficient for a wide range of tasks. Open-source models can be downloaded via certain platforms and run on local devices.
- **Handle data responsibly**: LLMs learn from all the data fed into them, such as every prompt and every piece of information we provide. It is important to handle personal data responsibly and not to input everything into the AI systems.
- **Ask your neighbour first:** Some questions can be easily clarified by asking another person, such as fellow students, work colleagues, parents or neighbours. This not only stimulates our own and our peers' cognitive abilities but also promotes social skills.

Resources for teaching

There are several ways to address the topic of sustainable development and sustainability in the context of AI in the classroom. Below is a small selection of resources on this topic:

- The *SustAIn* project is a collaborative initiative between *AlgorithmWatch*, theInstitute for Ecological Economy Research (IÖW) and the DAI (*Distributed Artificial Intelligence)* Laboratory at TU Berlin (Technical University of Berlin). The second issue of the *SustAIn* magazine highlights instances where AI is not

sustainable and explores what better solutions might look like: https://edulink.lu/yf8q

- The University of Luxembourg offers a comic series entitled *"LUX:plorations – A Universe of Research"*, available in five languages. In the third volume, the comic "Watt ass lass? D'Chronike vum Smart Grid" (pp. 15–18) focuses on the smart grid: https://edulink.lu/gn02
- With the *"AI Footprints Estimator for Students"* tool from *Wayfinder Learning Lab*, pupils can examine the energy consumption of their own AI usage by comparing different AI tools. As these are complex calculations, errors can creep in. In addition to the calculations for their *AI footprint*, the site also offers lesson plans and further background research: https://edulink.lu/e7tl
  The calculator and lesson plans are also available via the *VittaScience* tool, which is provided via the KI Kompass: https://ki-kompass.lu/tool/vittascience/
- The French Ministry of Culture has created the *Compar:IA* comparison tool, which allows tools and datasets to be compared. Any prompt is submitted to two selected tools, and the CO_2 and electricity consumption of the two are then compared. https://edulink.lu/numo
- Greenpeace Germany has produced teaching materials on the topic of sustainable development, focusing on AI and climatel. The materials are aimed at *secondary school* learners. https://edulink.lu/cohu

Note: Teachers should check the resources to see if they are suitable for the respective class and context and adapt their use if necessary.

To implement or adapt the teaching ideas presented, the tools provided on the KI Kompass website should preferably be used.

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