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# Environmental sustainability of data centres: A need for a multi-impact and life cycle approach

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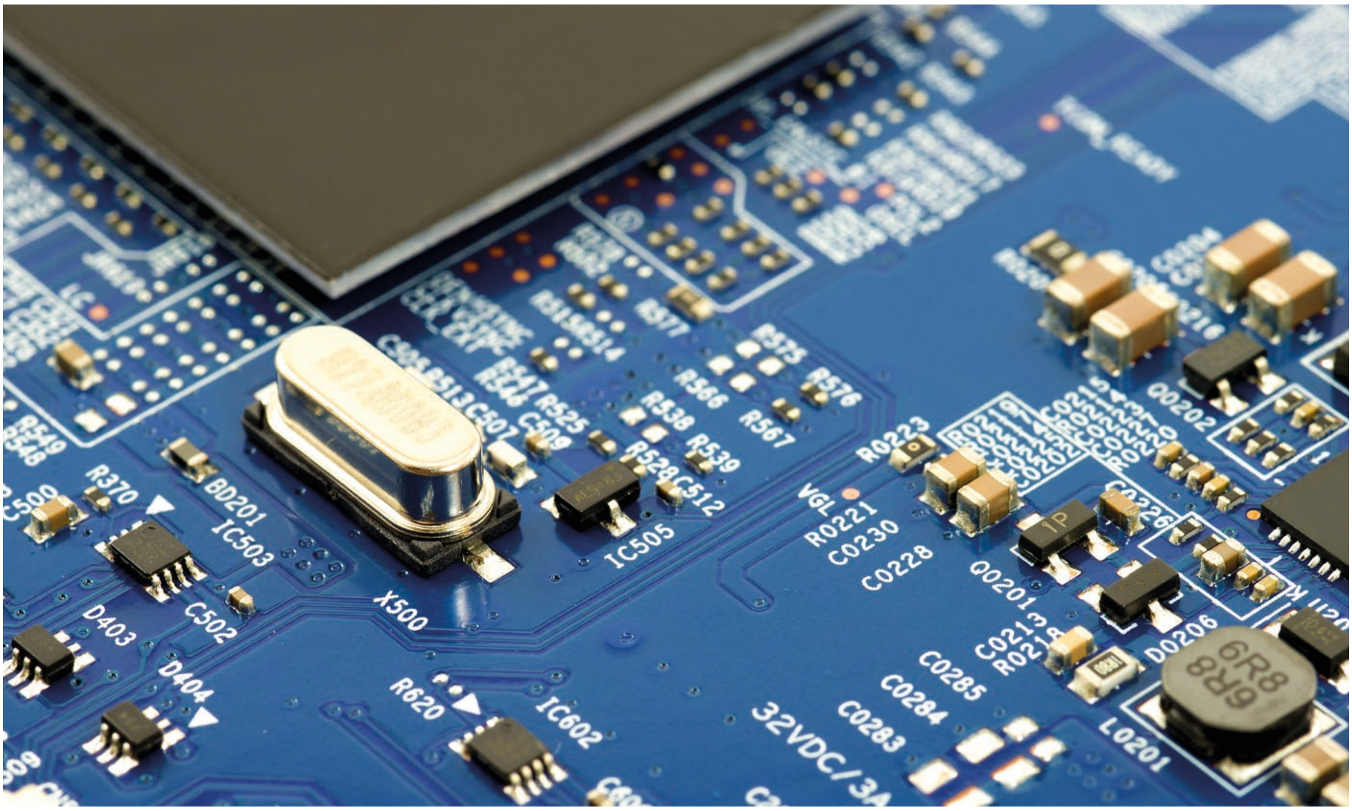
BRIEF 1

# Environmental sustainability of data centres: A need for a multi-impact and life cycle approach

## KEY MESSAGES

- The concerns over energy use of data centres and associated impacts on climate change have attracted efforts to reduce data centres' energy demand during operations.
- The focus on reducing climate change related impacts arising from data centres' operations can overlook relevant environmental impacts from other life cycle stages, including raw material extraction, equipment manufacturing, data centre construction, end of life of equipment and data centre buildings.
- To support the design of truly sustainable data centres, more comprehensive environmental sustainability assessments, encompassing the entire life cycle and factoring in a broad spectrum of environmental problems, are needed.
- This issue brief uses examples to showcase the substantial environmental impacts of data centres stemming from other life cycle stages than their operations and calls for the use of Life Cycle Assessment (LCA) to assess and address such impacts.




## 1. BACKGROUND: THE GROWING IMPORTANCE OF DATA CENTRES IN SOCIETY

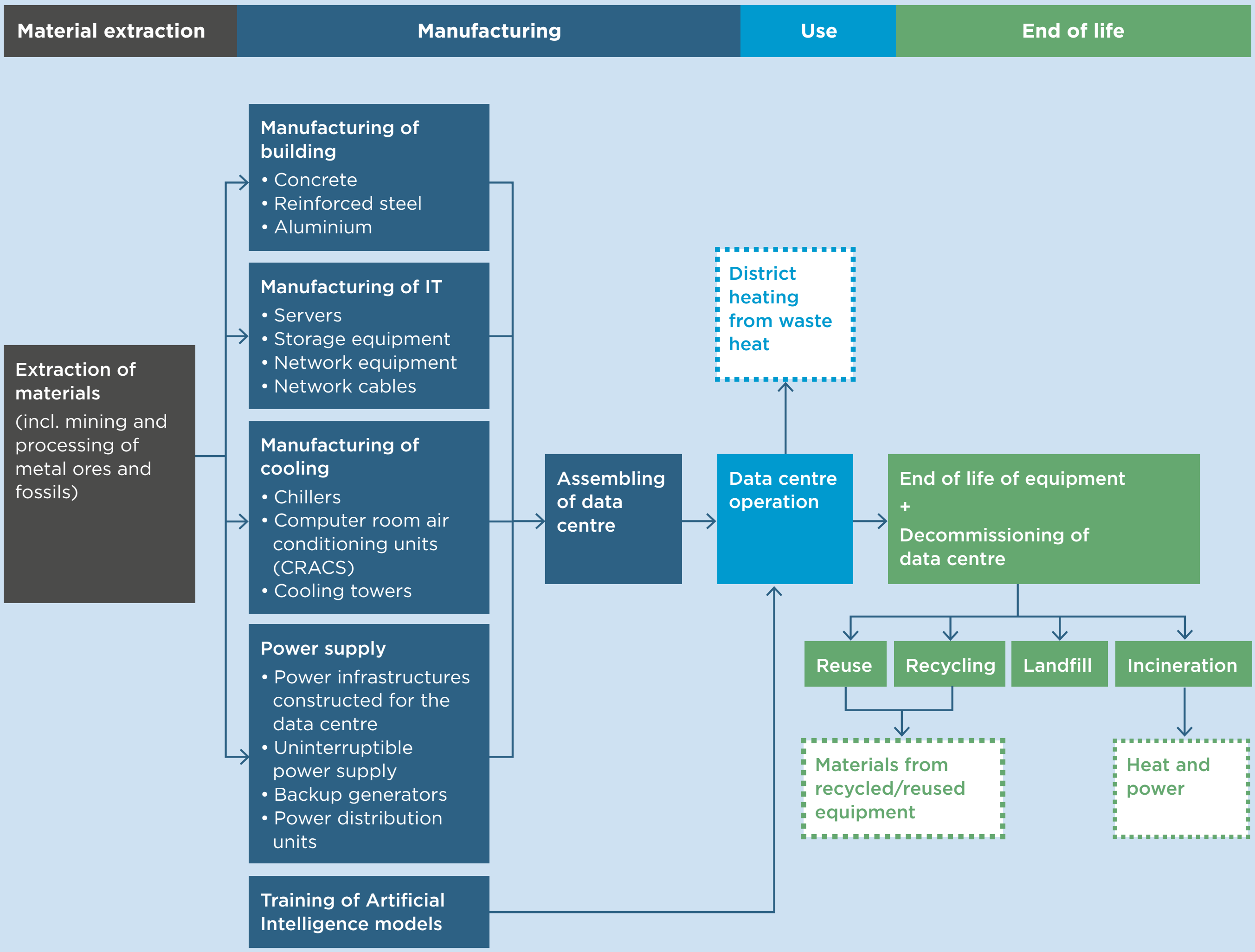
Over the past two decades, the reliance of societies on information and communication technologies (ICT) have grown exponentially. Internet traffic alone has moved from 60 PB in 1997 to 1.1 ZB in 2017 (i.e. with an increasing factor of 20,000)[i]. Taking an analogy with the human body, the main components of the ICTs include the data centres, which could be assimilated to their brain, while networks and the consumer devices could be regarded as the skeleton and arms of the ICTs. Data centres provide the key function of storing, safeguarding and processing data. Following the growth and diversification of ICTs, they have evolved from enterprise computing facilities, consisting of a few servers in a closet, to hyperscale systems of hundreds of thousands square metres providing the necessary support for the exponential growth of the internet, social media, and the successive generations of electronic devices growth.

Current estimates are that data centres use approximately 200 TWh of electricity annually, amounting to roughly 1% of global electricity demand. By 2030, it is projected that ICTs would represent more than 20% of the global electricity demand, with one third stemming from data centres alone[i]. The important role of data centres in future societies and their high energy demand call for urgent actions to address their environmental sustainability, including their contribution to climate change and potentially other environmental problems, like resource depletion. Such step is essential to anticipate and ensure an environmentally sustainable development of data centres in a long run.

## 2. EXISTING EFFORTS TO IMPROVE DATA CENTRE SUSTAINABILITY FOCUSING ON ENERGY USE DURING OPERATIONS

**Primary focus on electricity consumption.** The continuous (24/7) and high electricity demand of the equipment in data centres, and their resulting frequent contribution ramifications to climate change, has directed actions to mainly curbing energy consumption during the operations. Efforts have thus focused on improving energy efficiency, particularly addressing the high energy demand of three important components of the data centres: IT equipment, the cooling system, and the power delivery system[ii, iii]. Examples of such efforts include replacing chips and servers to gain operational efficiency, utilizing the heat from the servers for district heating, using air and water-based free cooling, shifting to hyperscale systems, cooling servers with isolating materials, and drawing on artificial intelligence for regulating the data centre's cooling system. Beyond energy efficiency, ICT giants, such as Google, Microsoft, and Facebook, have also started to increase the use of renewables to power their data centre operations.

**Figure 1. Simplified illustration of the life cycle of a data centre.**




The dotted boxes indicate recovery of materials and energy that substitute conventional means to providing them; for example waste heat produced by the data centres' operations can be captured and distributed to nearby customers, such as homes, offices, swimming pools or greenhouses and thus avoid the generation and distribution of heat from other sources like natural gas combustion. Note that supporting services taking place across the entire life cycle, like the necessary transport and energy supply are not displayed on the figure, although being an integral part of the system life cycle.

**The assessment and monitoring metrics used.** A number of metrics have been developed to quantitatively assess and keep track of the sustainability performance of data centres. Most of them focused on energy efficiency and renewable energy, including not only the IT system but also the energy source for cooling and power[iv]. A widely used metrics is the Power Usage Effectiveness (PUE), which measures the ratio between the power used by the IT equipment and the power delivered to the data centre. More recently, the ICT industry has started to look at other efficiency metrics beyond the sole problem of energy and use Carbon Usage Effectiveness (CUE) and Water Usage Effectiveness (WUE) to measure the carbon and water usage performance during the data centre operations, respectively[v].

**Limitations of past and current actions, and way forward.** The aforementioned measures and metrics, all relate to the operations of the data centres and adopt a narrow-sighted perspective, with the use of single-issue metrics, mainly focusing on energy requirements and, to a lesser extent, greenhouse gas emissions and water usage. Environmental sustainability however goes beyond those issues as it requires capturing damages to ecosystems, human health and natural resources from a large range of impacts, like toxicity exerted by chemicals releases to the environment. These past and current actions therefore overlook potentially important aspects pertaining to the sustainability of data centres, such as environmental problems that may stretch beyond the operations of the data centres and stem from the construc-

tion, transport and end-of-life of their different components. To encompass these and enable a comprehensive assessment of environmental sustainability, a life cycle and multi-impact perspective is required.

Such perspective can be provided by the ISO-standardized Life Cycle Assessment (LCA) methodology, which enables to quantify a large variety of environmental impacts[a] associated with products, technologies or systems taken in a life cycle perspective. The life cycle of a data centre includes all activities and processes from the necessary raw materials extraction, through the manufacturing of its components and its construction as well as the operations over its lifetime, up to its decommissioning and end-of-life involving disposal and possible materials and energy recovery. Figure 1 illustrates the simplified life cycle of a typical data centre.

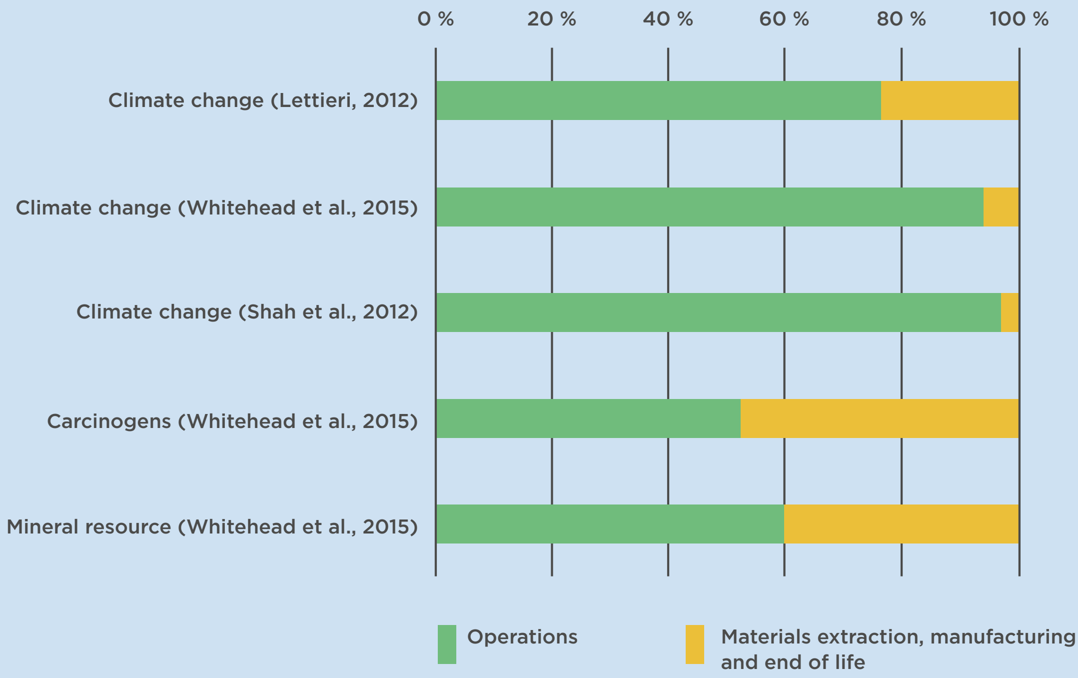
In recent years, the ISO 14044 standard requirements framing LCA conduct have served as a basis for the development of two guidance documents targeting applications to goods and services within the ICT sector: the Data Centre Life Cycle Assessment Guidelines developed by The Green Grid[vi], and the guidance document from the European Telecommunications Standards Institute (ETSI)[vii]. The EU Commission has flagged the use of LCA as optional and with medium priority in its currently-applicable Code of Conduct for Data Centre Energy Efficiency, which is focused on providing guidance for improving data centres' energy efficiency. The following section aims to evidence that such flagging could be strengthened and thus more comprehensive environmental sustainability assessments are needed.

## 3. LIFE CYCLE ASSESSMENT TO ENSURE A SYSTEMIC AND MULTI-IMPACT PERSPECTIVE

**Importance of the life cycle perspective.** The inclusion of the entire life cycle of data centres is essential to prevent environmental burden-shifting from one life cycle stage of the system to another or from one component to another. An example is the switch from fossils fuels to renewables sources like photovoltaics or wind turbines,

[a] *For example, climate change, resource depletion, ecotoxicity, eutrophication, water consumption, land use, human toxicity, ozone depletion, ionizing radiation, etc.*

**Figure 2. Life cycle contributions to selected environmental impacts associated with data centres.**




Notes: Lettieri (2012)[ix] has assessed a fictitious data centre with an average IT power of 1.3 MW located in Northern California. Whitehead et al. (2015)[x] have studied an existing data centre located in the UK with an average IT power of 13 MW. The data centre analysed by Shah et al. (2012)[xi] was a real-world production data centre of an insurance company with an average IT power of 1.8 MW.

where the reduction of environmental impacts during the operation of the system (no fuel combustion during generation of electricity) does not mean that this is the case over the entire life cycle, since the production and manufacturing of the photovoltaics panels and wind turbines may be associated with potentially large impacts, like chemical pollution and metal scarcity[viii].

Only a few LCA studies have been conducted on data centres, but their results demonstrate the relevance of adopting a life cycle approach covering multiple environmental impacts. In these studies, the operations of the data centre drive a number of environmental impacts, like climate change (see Figure 2), because of the high electricity demand from IT and cooling systems that is primarily met by combustion of fossil fuels. However, for some environmental problems, the impacts deriving from the pre- and post-operation stages of the data centre are as significant as the impacts stemming from the operations (see Figure 2). For example, the equipment in data centres require materials extraction, manufacturing and disposal of large amount of metals. These processes can lead to resource availability problems and potential metal pollution that may in turn cause significant toxicity damages to ecosystems and human health. Decisions, such as increasing the replacement frequency of servers to raise the energy efficiency during the operation of the data centres, thus lead to higher requirements in materials consumption and manufacturing efforts, and hence result in environmental burden-shifting from the operation stage to the other life cycle stages.

In general, the contribution of the operations stage to the environmental impacts should be considered with caution as a number of site-specific parameters may influence it. As hinted in one of the studies[ix], the composition of the electricity grid mix can have a strong influence on the life cycle environmental impacts of the data centres. In Figure 2, all three existing studies have been conducted in locations where the electricity grid mixes included large proportions of fossils fuels. However, one may anticipate very different distributions of environmental impacts between the operations stage and the other life cycle stages of data centres when the data centres are located in a country with a renewables-based grid mix, e.g. Norway or Iceland with virtually 100% renewable-based electricity generation. In their efforts to effectively reduce the contribution of data centres to environmental im-

pacts like climate change, stakeholders should thus consider carefully the type of energy sources supplying the electricity demand and sites selected to build data centres, in addition to focusing on energy efficiency gains.

**Importance of a multi-impact perspective.** Even in a setting where electricity demand would be met by renewable energy sources, a number of other environmental impacts would remain to be addressed, thus calling for covering all the potential problems when assessing environmental sustainability of data centres. As visible in Figure 2, the carcinogens-related impacts from the production of IT equipment, including the extraction of necessary materials, are an example of such environmental problem. As mentioned previously, mineral resource use is another important aspect to assess. Moreover, during the operation of data centres, significant amounts of water are necessary for cooling of the servers. The water use may cause availability problems in the local surroundings (shortages for ecosystems, human consumption and other competing sectors like agriculture), as well as potentially damages to ecosystems through thermal pollution as the water is released back to rivers at higher temperature. Various equipment of data centres contains many metal components and needs high metal inputs during the production stage. The exponential increase in the global data centre capacity can result in an increasing demand for specific metals and non-metal materials, including rare earth minerals, which are also key materials in other sectors (e.g. wind power sector) and may thus lead to availability issues. Efforts to address such material shortage can include improving materials efficiency during equipment manufacturing or enhancing material reuse and recycling at the end-of-life of the equipment. To test and identify these and other possible mitigation measures (e.g. integration of circular economy initiatives, eco-design measures, incentives towards renewable energy sourcing, etc.) and their far-reaching impacts, LCA should be used, thus providing support to policy and decision-makers to design long-term strategies for future sustainable data centres.

## 4. DISCUSSIONS AND RECOMMENDATIONS

**Data requirements.** Performing an LCA can require a significant amount of time and resources. To facilitate such assessments, LCA databases contain thousands of processes that can provide a useful starting point, and allow users to focus data collection on the key processes and iteratively improve the accuracy of the results. While publicly available databases do not yet seem to provide an adequate level of detail to model the life cycle of a data centre, databases, such as GaBi[xii] or Ecoinvent[xiii] databases that contain several processes relevant for the ICT industry, can be used. To keep pace with the fast growth of data centres and the rising concerns around their environmental impacts, it is expected that availability of relevant processes in LCA databases will keep improving.

**Considerations for developing countries.** While most data centres are located in North America and Europe, data centres' presence in developing countries is also increasing, although on a much smaller scale. Issues slowing down data centres' uptake in developing countries can be traced back to the shortage of skills to build and running their operation, and the lack of proper supporting infrastructures, including energy and water supply. Not only can the lack of reliable infrastructures hamper data centres' uptake. It can also come at the expenses of their sustainability. This could be the case, for example, in countries with a national grid heavily reliant on fossil fuels, issues related to high water stress levels, and weak electronic waste management systems. At the same time, in cases where specific infrastructures (for example, new power capacity) are built for the sole purpose of the data centres, the risk is to shift actions away from what is instead needed to satisfy local basic needs (for example, the lack of access to electricity). Nevertheless, the possibility for data centres to be a positive catalyst for improving infrastructures in a way that it benefits the sustainable development of local communities, should not be underestimated. Taking a holistic approach to social, environmental, and economic sustainability, and ensuring that best practices applied in developed countries is transferred and integrated in developing countries, is key to enable data centres to become sustainable, regardless of where they are built.

**Going beyond eco-efficiency.** History has shown that gains in technology efficiency are typically associated with a rising demand or use of that technology due to rebound effects, overall rendering a decreased effectiveness. Data centres seem to be on such a path, and foreseen gains in eco-efficiency alone are likely not to be able to counteract the increased use of data centres, characterised by their predicted increase in electricity consumption by a factor of 3-8 between 2019 and 2030 (assuming best-worst case scenarios in current energy projections)[xiv]. When assessing rapidly evolving technology systems such as data centres, one therefore needs to consider both perspectives of eco-efficiency and eco-effectiveness[xv]. LCA is a widely

used methodology to assess the former in its ability to differentiate which of several product or system alternatives is associated with the lowest environmental impacts. It does not yet address the latter.

To address eco-effectiveness, we must take a broad perspective to capture the dynamic interactions of data centres, or by extension the entire ICT sector, with other systems, including potential rebound effects. For example, the possible addition or displacement of electricity installation capacity as a consequence of growing ICT use (and energy demand) should be factored in. At the same time, we must additionally relate the global impacts of data centres to global boundaries or sustainability thresholds, which represent the maximum level of environmental impacts that we can afford in order to accommodate Earth's finite resources and not exceed Earth's carrying capacities or compromise Earth's life support systems. A number of scientific approaches have defined such thresholds, including the planetary boundary framework[xvi], the ecological footprint framework[xvii], or the definition of absolute sustainability targets like the one intended to keep the global average temperature below 1.5°C above pre-industrial levels (formalised by the Paris Agreement). Challenges currently remain to translate those at the level of data centres, where they can serve as benchmarks when assessing the global environmental footprint of data centres, and eventually help define what an environmentally sustainable data centre is and what would be needed to reach it.

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## ENDNOTES


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