Computing and Environment [work-in-progress]

https://network23.org/theb/computing-and-environment/
brentc@riseup.net

Overview

This is an ongoing study of environmental issues around computing. It starts with theoretical background, with an aim towards practice and application. While clearly large-scale change is paramount, this focus is at a 'mid' level, such as a small organisation or group. Some individual and local actions are drafted in Appendix: General advice.

It begins with some premises. Firstly, the understanding that digital computing has a very material basis. Further, with a holistic, socio-technical view of technology, the possibility of a simple technofix is rejected. The problem of greenwashing and criticisms of compensatory measures such as offsetting should be noted. In the terms of targets, it is argued that stronger 'net zero' and beyond goals that call for real reduction and broad application are necessary. These premises are subject to debate, but with good evidence, so a call to challenge views.

It is useful to determine some terminology. Emissions are typically expressed as 'carbon equivalent' emissions (CO_2e), and divided into 'scopes'. Scope 1 refers to direct organisation emissions, such as in manufacturing, while Scopes 2 and 3 include emissions in the wider value chain of suppliers and customers. For many modern organisations (such as a digital agency), their major emissions are in the Scope 3 region. Impacts can be categorised as 'first order', concerning hardware lifecycles, 'second order', relating to use of ICT, and 'third-order' wider effects, which include 'rebound effects', where efficiency gains are counteracted by increased consumption.

Taking a view as a provider of computing services, environmental concerns can be analysed in terms of hardware, hosting and software.

The 'embodied carbon' in hardware production, shipping and disposal greatly overshadows the impact of its use. The extraction of raw materials and 'rare earth metals' for hardware is particularly problematic. These are also major social justice and colonial issues around the extraction, manufacture and disposal of hardware. A key action here is to extend the lifetime use of computing equipment to avoid new procurement.

Hosting, including data centres and 'cloud computing', have significant material environmental impacts, for example requiring hardware, power, air conditioning and resources such as water for cooling. Key actions are to use 'greener' services, while being wary of greenwashing, but most importantly to reduce usage.

While hardware and hosting are major factors, it is necessary to consider software as a driver of hardware and hosting requirements. Software design and implementation need to be optimised for sustainability. Some points are in Appendix: Software and systems considerations. Sustainable 'design patterns' may be useful.

Therefore a key action is to reduce usage across hardware, hosting and software.

There are complications. As a basic example, while a desktop computer uses more energy than a laptop, laptops have a lower lifespan and need replacing more often. 'Thin' computing using cloud services may reduce the impact of personal computing devices, but shifts the impact to data centres.

There can also be conflicting considerations- environmental measures may need to be balanced against requirements such as maintenance, performance and security, and wider social issues such as digital divides and inequalities should be considered.

There are emerging standards and guidance. These range from strategic to implementation and assessment, with various tools available, for example to assess website sustainability. See: Standards, guidance and tools.

For further development, strategic and policy work would be best done in collaboration with existing initiatives, such as the W3C Sustainable Web Design Community Group or Mozilla Projects/Sustainability/Research. Providers of web services and applications should develop sustainability assessments for their products, and provide low-impact solutions. Critical and alternative perspectives, such as permacomputing, computingwithinlimits.org or Trans*Feminist Counter Cloud Action Plan and others may be inspiring.

Some links and reading

- Greenwood, T. and ChatGPT (2023). *An interview with AI on the social and environmental impacts of AI.* Available at: https://www.wholegraindigital.com/blog/social-environmental-impacts-of-ai/
- Monserrate, S. G. (2022) 'The Cloud Is Material: On the Environmental Impacts of Computation and Data Storage', *MIT Case Studies in Social and Ethical Responsibilities of Computing*, Winter 2022. Available at: https://mit-serc.pubpub.org/pub/the-cloud-is-material/release/1
- Reading group: Environment and tech - https://docs.google.com/document/d/1o_9jqN-xMXvFTIeVXbWoib5D7HTSA1cHmBd0IlvG8NE/edit#heading=h.row59kb9mtuz
- See also: Systems thinking.

Part 1: Background

Premises

- Digital computing has a material basis, with environmental impacts- "a digitalized economy also accelerates the fossil economy" (Rosol et al., 2018)
- There is a significant and growing environmental impact of ICT…
- These environmental issues have social justice issues- advantaged groups disproportionately benefit from computing while marginalised groups are disproportionately harmed (Grantham Research Institute, 2022; …)
- The environmental impact of computing is complex: "intricate, interwoven and currently often indeterminable" (Stonham, 2022d)
- Action is needed across scopes (see below) but Scope 3 is significant (GreenHouse Gas Protocol, 2011; Stonham, 2022d)
- Greenwashing is a problem (cf. European Commission, 2021)

- Technofixes are almost certainly illusory (cf. Arvesen, 2011)
- The use of computing to address environmental issues is complicated: "Digital technologies can contribute to mitigation of climate change.. [but] .. counterbalanced by growth in demand for goods and services due to the use of digital devices..[and].. involves trade-offs. Digital technology supports decarbonisation only if appropriately governed (high confidence)" (IPCC, 2022, B.4.3; see also Rosol et al., 2018).
- There is also not an economic fix- 'green capitalism' is not a solution (Buller, 2023). Offsetting is not a robust solution- consider e.g. Corrigan (2006)
- There is still cost to renewable or 'green' energy (for example, "windmills break" - Thoughtworks, 2021).
- Action is needed at macro, societal level (e.g. big corporations [and rich individuals?]) more than micro (individual) level (Frick, 2023a; cf. Bugeau, 2023).
    - Larger scale progress needed includes the development of sustainable and circular supply chains for IT equipment. It is possible to fully recycle computing equipment, although challenges include separating materials and working with hazardous materials (Greenwood and ChatGPT, 2023).
    - Macro changes need to consider a move away from big tech models (Ferreboeuf, 2023).

Scopes

- Scope 1: Direct emissions from owned or controlled sources, e.g. manufacturing industries, gas?
- Scope 2: Indirect emissions, e.g. purchased electricity.
- Scope 3: Further indirect emissions in the value chain, including by suppliers and customer use of services and products

(B Lab, 2021; GreenHouse Gas Protocol, 2004)

Uncertainty calculation can be included, for example if using data from secondary sources (as in dxw, 2022b).

See also: Impacts.

Impacts

The environmental effects of ICT are complex but may be usefully categorised as follows (Bergmark, 2022; ITU, 2014):

- First order effects: The footprint of the ICT hardware, including, from production to disposal.
- Second order effects: Effects related to the use of ICT. These may be negative, or positive ("*enabling effects*").
- Other ['third-order'?] effects: Wider effects associated with the technology. This especially includes "*rebound effects*", where efficiency gains are counteracted by increased consumption. These may be *direct* (improved accessibility of ICT leads to greater use) or *indirect* (efficiency gains in ICT free resources for other activities).

See also: Scopes.

Targets

- Neutral: any CO2 or GHG (Greenhouse Gases) released from a company's activities are balanced by an equivalent amount being removed. Includes offsetting and focuses on Scope 1 and 2.
- Net zero: An activity releases net-zero carbon emissions into the atmosphere. Avoids offsetting and covers scope 1, 2 and 3.
- Negative (or 'climate positive'): Goes beyond net-zero by removing additional GHG from the atmosphere.

(Carbon Trust, 2023; planA, 2022)

Computing

- Digital carbon footprints and environmental impacts are significant. For example, the internet CO_2e emissions are estimated at 6% and 12% of the global totals (Stonham, 2022d)
- Computing systems considered end-to-end cover client devices (including end-user computers as well IoT, for example), network equipment and data centre equipment (servers and storage) (BSI, 2016)
- Computer systems have four life cycle (LCA) phases (Gupta et al., 2021):
  - Production and manufacturing, including sourcing raw materials
  - Transport / shipping
  - Use
  - End-of-life (e-waste or recycling)
- Considering an individual device such as an end-user desktop or laptop computer, the 'embodied carbon' in its production, shipping and disposal significantly outweighs the carbon emitted from operational use over its lifetime (Gupta et al., 2021; University of Edinburgh / Hart, 2016)
- The sourcing and extraction of raw materials is particularly nasty
- This is fueled by "upgrade culture" and "planned obsolescence" (Isaac Computer Science, no date)
- There are trade-offs, for example:
  - Digital technologies may offer environmental advantages relative to alternatives, such as online communication compared to physical travel (Stonham, 2022b)
  - Cloud computing can reduce the need for powerful personal computing devices (Stonham, 2022c)
- There are possible positive applications of computing for the environment, for example improved information about natural issues, energy monitoring and transport coordination (Isaac Computer Science, no date)
- There are also difficulties in measuring impacts. Bugeau (2023) identifies implicit hypotheticals (e.g. electricity impact differs across countries), the varying proportionality between usage and impact (there is residual waste, for example network infrastructure is always on), the paradox of efficiency indicators: efficiency appears to increase with usage, but this hides the absolute impacts increase, also

leading to individualization at the expense of collective, systemic action. Network nodes and routes also get complex.

Other considerations

There may be complex interactions amongst environmentally positive computing and the following:

- Cost
- Effective maintenance and support of equipment (cf. Dawson, 2023)
- Resilience and performance
- Security, compliance, safety (Stonham, 2022d)
- Accessibility, responsiveness (cf. Dawson, 2023)
- Digital ethics, privacy, digital divides and inequalities
- Wider impacts, for example social exploitation around computer manufacture and social impacts of data centres
- There is “[business] value to doing the right thing” (Thoughtworks, 2021)

Critique

- RTE (2022)
- Webinar on climate sceptic networks in Germany - Alexander Ruser - Universitetet i Agder - https://uia.pameldingssystem.no/networks-climate-scepticism-germany
- Understanding and responding to the backlash against climate policy in the UK - https://www.youtube.com/watch?v=VBeBJskGeqM
- Google. 2020. “24/7 by 2030: Realizing a Carbon-Free Future.” Mountain View, California: Google. https://www.gstatic.com/gumdrop/sustainability/247-carbon-free-energy.pdf
- https://titipi.org/wiki/index.php/Counter_Cloud_Action_Plan

Conclusions

- Limit procurement of computer hardware- increase computing lifespans
- Limit usage
- Optimise software for reducing usage and environmental impact
- Move away from big tech? (https://theshiftproject.org/en/home/)

“How we source, procure and dispose of our technology assets is the first area to address, an important part of this being how to use equipment for longer.”
(Stonham. 2022d)

Further work

- W3C Sustainable Web Design Community Group - https://www.w3.org/community/sustyweb/

- Mozilla Projects/Sustainability/Research - https://wiki.mozilla.org/Projects/Sustainability/Research
- Study course opportunities are listed at https://www.w3.org/community/sustyweb/wiki/References#Courses
- Reading group: environment and tech - https://docs.google.com/document/d/1o_9jqN-xMXvFTleVXbWoib5D7HTSA1cHmBd0IlvG8NE/edit#heading=h.row59kb9mtuz
- Pattern Sphere (PS) - http://labs.publicsphereproject.org/ps/

Part 2: Practice

Process

Cf. ISO 50001: Energy management:

- Develop a policy for more efficient use of energy
- Fix targets and objectives to meet the policy
- Use data to better understand and make decisions about energy use
- Measure the results
- Review how well the policy works, and
- Continually improve energy management.

Key considerations

- Leadership and governance (aka Stonham, 2022b?)
- Awareness raising:
  - Improving “carbon literacy” and countering perceptions that the digital is immaterial and free from environmental impact (Stonham, 2022b)
  - Raising critical thinking about the possibility of technofixes

Standards, guidance and tools

Strategy

- ITU L.1471 : Guidance and criteria for information and communication technology organizations on setting Net Zero targets and strategies - https://www.itu.int/rec/T-REC-L.1471

Implementation

- Green Handbook for Community Tech Practitioners (Green Web Foundation, 2023)
- Microsoft Green Design Principles - https://wxcteam.microsoft.com/download/Microsoft-Green-Design-Principles.pdf
- Design Declares Toolkit - https://designdeclares.com | https://driftime.notion.site/Design-Declares-Toolkit-dcb18f2911394d52a711d8cf4e9f15b8
- https://www.gesi.org/research/ict-sector-guidance-built-on-the-ghg-protocol-product-life-cycle-accounting-and-reporting-standard [$]

- GeSI ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard - https://ghgprotocol.org/sites/default/files/GHGP-ICTSG%20-%20ALL%20Chapters.pdf
- IEEE 1680.1-2018: Standard for Environmental and Social Responsibility Assessment of Computers and Displays (IEEE, 2018) and IEEE 1680.1a-2020 amendments (IEEE, 2020)
- NSF/ANSI 426 - 2019: Environmental Leadership and Corporate Social Responsibility Assessment of Servers (NSF/ANSI, 2019)
- Corporate Digital Responsibility Self-Assessment Tool - https://corporatedigitalresponsibility.net/cdr-self-assessment
- W3C Sustainable Web Design Community Group - https://www.w3.org/community/sustyweb/ - https://www.w3.org/community/sustyweb/wiki/Main_Page
    - Sustainable Hosting & Infrastructure Guidelines [in development, requires login]
    - Sustainable Web Development Guidelines [in development, requires login]
- ETSI ES 203 199 - Methodology for environmental LCA of ICT goods, networks and services - https://www.etsi.org/deliver/etsi_es/203100_203199/203199/01.03.01_60/es_203199v010301p.pdf
- Institute for Sustainable IT (2021) Handbook Of Sustainable Design Of Digital Services - https://gr491.isit-europe.org/en/
- ITU L.1410 : Methodology for environmental life cycle assessments of information and communication technology goods, networks and services - https://www.itu.int/rec/T-REC-L.1410

Assessment

- SAT-S (Self Assessment Tool - Services) - https://ictfootprint.eu/en/self-assessment-tool
- Software Carbon Intensity (SCI) Specification - greensoftware.foundation
- http://aremythirdpartiesgreen.com/
- https://sustainablewebdesign.org/calculating-digital-emissions/
- https://www.websitecarbon.com/
- https://digitalbeacon.co/
- https://ecograder.com/ (from Mightybytes)

Other tools

- PowerAPI - http://powerapi.org/
- Carbon Aware SDK - https://github.com/Green-Software-Foundation/carbon-aware-sdk

Hardware

- Procurement guidance: See EC (no date)

- Organisation strategies can include (Stonham, 2022d):
    - Longer equipment lifetimes
    - 'Thin' computing with cloud services [noting cloud environmental issues]
    - Refurbishment and remanufacturing
- These procurement strategies need to be balanced against other considerations, specifically (Stonham, 2022d):
    - Maintenance and support requires standardisation and reliability of equipment
    - Security concerns around supplier support lifetimes
    - See also: Other considerations above
- Resources:
    - WorldWatchers.org - product-level carbon analysis
    - Co2analysis.com

Hosting

- Procurement guidance: See EC (no date)
- Web Services (AWS) Customer Carbon Footprint tool
- https://www.cloudcarbonfootprint.org/ (Open Source Cloud Carbon Emissions Measurement and Analysis Tool)
- Be cautious of greenwash
- 'Hyper-redundancy' - 99.9n% targets require over-provisioning
- Turn off cloud services when possible (Stonham, 2022d)
- https://greenpixie.com/ ?

Software and systems

- Energy intensive computational processes
    - Monserrate (2022) highlights machine learning and cryptocurrency mining
- Simon, T., Rust, P., Rouvoy, R. and Penhoat, J. (2023): Environmental Impact of Software Life Cycle
- Energy efficient of programming languages and design patterns (Thoughtworks, 2021)
    - With consideration of compiler optimisation (Thoughtworks, 2021)
    - With consideration of maintainability of code (Thoughtworks, 2021)
    - With consideration of complexity and performance (e.g. thread management) (Thoughtworks, 2021)
    - I.e. First, second and third-order effects (cf. Rebecca Parsons, Thoughtworks, 2021)
- Sustainable design patterns (Schuler et al., 2022)
- See: Appendix: Software and systems considerations

Part 3: Application

Low impact website

"The carbon footprint of a website can be

reduced through many ways, some easier than others. They include, reducing the number of images and videos, avoiding auto-play videos, optimising source code, reducing the number of database lookups that are required to build the page, using static pages instead of dynamic content, and switching to a hosting provider that runs on green energy and has a robust procurement and e-waste policy.
Website compression is another technique that is often used, but it requires additional energy to compress and decompress, so instead of compression, reducing code and streamlining how that code is delivered and rendered by the devices is more impactful."
Stonham, 2022d, p. 40)

References and links

- https://www.websitecarbon.com/
- https://512kb.club/
- Quirk, K. (2021) *How To Build A Jekyll Site Using Simple.css.* Available at: https://kevquirk.com/how-to-build-jekyll-site-simple-css/
- https://blog.mro.name/2019/05/wp-to-hugo-making-of/
- https://solar.lowtechmagazine.com/
- Mobile devices are good at hardware measurement (Thoughtworks, 2021)
- See also: Standards, guidance and tools, e.g. W3C Web Development

Appendices

Appendix: Terminology

- Anthropocene: The current era where human action has a major planetary effect, featuring industrialisation, nuclear energy and digitalisation (Rosol et al., 2018)
- Carbon equivalent emissions (CO_2e): A measurement of various greenhouse gas emissions expressed as their equivalent in carbon emissions, including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and fluorinated gases
- Carbon removal: Practices and technologies to remove carbon from the atmosphere, in contrast to carbon reduction (Stonham, 2022d). Also known as Carbon dioxide removal (CDR), greenhouse gas removal (GGR) or negative emissions
- Effects (or Impacts): ICT impacts may be seen as first order (equipment-related) or second-order (use-related), and higher-order effects, specifically 'rebound effects', referring to where efficiency gains lead to increased consumption (See Impacts and Bergmark, 2022; ITU, 2014).

- ‘Embodied’ or ‘embedded’ carbon: The carbon impact of a computing device in its manufacture, transport and disposal, as distinct from its operational use (Hussain, no date; cf. Stonham, 2022a; Gupta et al., 2021)
- Life-cycle analyses (LCAs): Phases in a computing system lifetime, including production/manufacturing, transport, use, and end-of-life processing (Gupta et al., 2021)
- Power Usage Effectiveness (PUE): Ratio of the total amount of energy used by a computer data centre facility to the energy delivered to computing equipment. Lower is better (Open University, 2023).
- Scopes: Emissions may be divided into Scope 1, 2 or 3. Scope 1 are direct emissions from organisation activities, while Scopes 2 and 3 focus on emissions upstream or downstream in supply and customer lines (See Scopes and B Lab, 2021; GreenHouse Gas Protocol, 2004).
- Small energy consumption: energy required to power smaller electrical equipment such as computers, monitors, smart phone chargers, printers, vending machines (Stonham. 2022d)
- Water Usage Effectiveness (WUE): Similarly to PUE, the ratio of water consumption to the energy delivered to computing equipment (Open University, 2023).

Appendix: General advice

At the individual and local level.
Consider trade-offs and wider requirements, e.g. security, backup, data protection, etc.

- Switch off
- Laptops vs desktops …
- Set IT equipment defaults for energy efficiency and power saving (Stonham, 2022b)
- Use dark mode (Stonham, 2022d)
- Address ‘small energy’ issues (the energy required by smaller electrical equipment, charging devices and standby modes that accumulates) (Stonham, 2022b)
- Avoid unnecessary cloud storage- stored data is often not used, but still has environmental impacts, so consider local storage (Stonham, 2022b)
- Review and delete unneeded data (Stonham, 2022b)
- [TBC] Consider using local applications rather than cloud services?
- Use local media if available rather than streaming over the internet (cf. Bugeau, 2023)
- Prefer using lower bandwidth communications- chat and audio use less resources than video (Stonham, 2022d).
- Digital cleanups (e.g. https://www.digitalcleanupday.org/)
- Switch routers off if possible (Bugeau, 2023) [this requires further research]
- Avoid unnecessary emailing (Stonham. 2022d)
- Reduce email signatures, especially images (Stonham. 2022d)
- Prefer wifi over mobile networking (Stonham. 2022d)
- Use Linux?
- Try low resource computing (e.g. https://100r.co/site/uxn.html)

Appendix: Software and systems considerations

Area	Recommendations	References
Energy efficiency of programming languages	Consider, balanced against development needs	(Thoughtworks, 2021)
Energy efficiency of design patterns	Consider, balanced against development needs	(Thoughtworks, 2021)
Energy intensive computational processes	Avoid, optimise and apply carbon-aware patterns	(Monserrate 2022)
Caching and edge computing	Use appropriately and effectively	(Thoughtworks, 2021)
Workflows (Continuous Integration, testing, etc.)	Optimise and avoid bloat (build and test only as necessary)	(Thoughtworks, 2021)
Data management: data deletion	Implement data deletion steps of data management policies	(Stonham, 2022b)
Data storage and database design	Avoid unnecessary storage, especially in the cloud Optimise database structure and use	(Stonham, 2022b, 2022d)
Third-party add-ons	Avoid or reduce third-party requests (such as analytics and digital marketing)	(Frick, 2023b)

Appendix: Organisations, links and events

What a waste: surplus art, theory and tékhnē - https://www.nsuweb.org/study-circles/circle-2-cybioses-life-in-the-future-imperfect/

https://www.sustainablecomputing.eu

18 March - https://www.digitalcleanupday.org/

https://pad.riseup.net/p/transfeministdigitaldepletionstrike-keep

https://pro.europeana.eu/page/climate-action-community

https://environmentalmusicprize.com/

https://gsha2023.sciencesconf.org/

https://titipi.org/wiki/index.php/Counter_Cloud_Action_Plan

Counter Cloud Action Day - https://hub.vvvvvvaria.org/rosa/8m/

https://permacomputing.net/

https://degrowth.info/

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