Knowledge-based curriculum specifications to integrate environmental challenges in computing curricula

GDS CNRS EcoInfo

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1 Introduction

1.1 Objective

The objective of this document is to define a common knowledge reference framework on sustainable computing and ICT (Information and Communication Technologies) or, more precisely, on the impacts of computing and how to limit them.[1] This framework is dedicated to lecturers involved in plain computer science curricula or in programs involving courses in computer science.

Our goal is to address the following question:

> *What knowledge should any computer science education program provide to their students so as to make them tackle societal and environmental challenges in their professional life and as a citizen?*

This document therefore essentially focuses on the impacts of ICT, but more general elements such that environmental issues or economic context are nevertheless introduced because they are needed to understand the general context.

The objective of this document is to provide a list of useful notions and pointers, but is not intended to replace a lecture or a reference book.

1.2 Why should we develop these topics?

Some pressure for a change in the teachings now comes from the students themselves. Various calls, such as the student Manifesto for a wake-up call on the environment, encourage all actors in society – public authorities, businesses, individuals, associations – to play their role in the major transformation needed for a sustainable society. Students organizing for sustainability international was also created to ensure that all university graduates are given knowledge and competences about sustainability.

Yet, according to the Shift Project's 2018 Higher Education for Climate Report (in French), "the offer is largely insufficient, with only 11 % of [French Higher Education] programs currently addressing climate/energy issues in a mandatory way."

We believe that there currently exist too few teaching resources on the impacts of ICT. With this knowledge framework, we hope that we will contribute to their development.

1.3 Links with skills frameworks

We chose to tackle this problem from the point of view of knowledge. In other words, we chose to focus on the body of knowledge which seemed us essential in any computer science curriculum, and not on the elaboration of the program itself. We did not want to address curriculum implementation problems, nor the question of the skills, which seem to us highly dependent on the program objective. We nevertheless give in this paper some examples of skills that can be associated with each major theme. The interested reader can also rely on existing documents dedicated to the question of skills. In particular, the CGE and CPU's Guide to sustainability skills indicates 5 cross-cutting skills for courses related to sustainability: taking into account changes, exercising one's responsibility, a forward-looking vision that takes into account uncertainties, cooperation and the integration of systemic approaches. The European e-Competence Framework, which aims at listing the skills implemented in projects related to information and communication technologies (ICT), also includes a skill "Sustainable Development", which seeks to define the skills needed to implement an eco-responsible ICT policy in a company.

[1] The notion of "computing" is itself discussed later in this document

1.4 How to read this document

Embracing a very large scope of scientific domains is needed to adequately tackle environmental issues in ICT. The structure proposed in this document is only an option, that anyone can adapt to their specific needs.

Each field is structured as follows: first, an introduction sets the context of the field, then, some related notions are detailed, and finally, some pointers are given to investigate further. The pointers we provide are mostly references whose quality has been recognized, except in a few places where we only refer to a Wikipedia page which we leave to the reader to explore. In any case, these pointers are not meant to be exhaustive. For further reading, the EcoInfo website can also provide a lot of information, especially in the Resources pages, and on the page listing the courses addressing environmental aspects of ICT.

2 Context

This section describes the basic knowledge required to understand the role of digital technology in the anthropocene. The presentation goes from general (ecological issues) to more specific (digital sector).

This knowledge can be more deepened and possibly backed by tutorials or practical sessions depending on the knowledge and the speciality of the target audience. It is up to each student to master these themes according to his or her objectives.

2.1 Need for a sustainable development

To address ecological issues of our societies we first need to properly define what their environmental impacts are, and how they have been dealt with in the past.

2.1.1 Environmental issues

To realize why we crucially need an ecologically sustainable human development, one must first understand basic notions about ecology, and what is called the environment*.*

Concepts:

- Environmental impact
- Air indicators: climate change, greenhouse gases, acidification, tropospheric ozone formation, ozone layer depletion...
- Water indicators: ecotoxicity, water eutrophication, water consumption...
- Decrease in resources: primary energy consumption, depletion of non-renewable resources...
- Systemic aspects of environmental issues

References in English:

[1] S IPBES, J Díaz, ES Settele, ES Brondízio, N Hien, M Ngo, J Guèze, A Agard, P Arneth, KA Balvanera, et al. The global assessment report on biodiversity and ecosystem services—summary for policymakers. *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: Bonn, Germany*, 2019.

[2] IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, chapter IPCC, 2021: Summary for Policymakers. Cambridge University Press, 2021.

[3] Wikipedia page. Environnemental issues. https://en.wikipedia.org/wiki/Environmental_issues.

[4] Wikipedia page. Planetary boundaries. https://en.wikipedia.org/wiki/Planetary_boundaries.

References in French:

[1] Laurent Audouin, Emmanuelle Baudry, Céline A Bellard, Elsa Bonnaud, Laurent Bopp, Pascale Braconnot, Francois-Marie Breon, Raphael Brett, Thierry Brunelle, Jean-Christophe Bureau, François Chiron, Franck Courchamp, Charlotte da Cunha, Marc Delmotte, Nicolas Delpierre, Nathalie De Noblet Ducoudré, Catherine Even, Aude Farinetti, Nathalie Frascaria, Jeanne Gherardi, Pierre-Henri Gouyon, Christine Hatté, Frédéric Lantz, Catherine Larrère, Paul Leadley, Jane Lecomte, Yves Levi, Harold Levrel, Jean-Michel Lourtioz, Valérie Masson-Delmotte, Christian Mougin, Jean-Eudes Petit, Gilles Ramstein, Yorghos Remvikos, Franck Richecoeur, Guillaume Roux, Marielle Saunois, Jérôme Servonnat, Rémy Slama, Sophie Laval-Szopa, Cécile Tran Kiem, Jacques Treiner, Améline Vallet, and Jean-Paul Vanderlinden. *Enjeux de la transition écologique*. EDP Sciences, November 2021. URL: https://hal-universite-paris-saclay.archives-ouvertes.fr/hal-03461012, doi:10.1051/978-2-7598-2661-2.

[2] François Gemenne, Aleksandar Rankovic, Thomas Ansart, Benoît Martin, Patrice Mitrano, and Antoine Rio. *Atlas de l'Anthropocène*. Presses de Sciences Po, 2019.

[3] EcoInfo Pierre-Yves Longaretti. Enjeux environnementaux: Changements globaux, limites planétaires et risques d'effondrement. https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/ANF2019_EnjeuxEnvironnementaux-Autrans-PYL-1.pdf, 2019. URL: https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/ANF2019_EnjeuxEnvironnementaux-Autrans-PYL-1.pdf.

2.1.2 Awareness of these impacts

Awareness of environmental impacts is old and different notions and principles have been introduced to formalize them.

- The notion of sustainable development
- The (controversial) notions of ecological/energetic/environmental transitions
  - historical insights
- The concepts of planetary limits and anthropocene
- Main indicators: carbon footprint vs. national inventory
- Other indicators: ecological footprint, human development index...

References in English:

[1] Dennis Meadows, Donella Meadows, and Jorgen Randers. *The Limits to Growth: the 30-Year Update*. Yale University Press, 2004.

[2] Johan Rockström, Will Steffen, Kevin Noone, Åsa Persson, F Stuart Chapin III, Eric Lambin, Timothy M Lenton, Marten Scheffer, Carl Folke, Hans Joachim Schellnhuber, et al. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, 14(2), 2009.

[3] Will Steffen, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, and Cornelia Ludwig. The trajectory of the anthropocene: The great acceleration. *The Anthropocene Review*, 2(1):81–98, 2015. URL: https://doi.org/10.1177/2053019614564785, arXiv:https://doi.org/10.1177/2053019614564785, doi:10.1177/2053019614564785.

References in French:

[1] Fabrice Flipo. Les trois conceptions du développement durable. *Développement durable et territoires. Économie, géographie, politique, droit, sociologie*, 5(3), 2014.

[2] Florence Rodhain. Changer les mots à défaut de soigner les maux ? Critique du Développement Durable. *Revue Française de Gestion*, (176):pp.203–209, 2007. URL: https://hal.archives-ouvertes.fr/hal-00834024, doi:10.3166/RFG.176.203-209.

[3] UVED. Université virtuelle environnement et développement durable. https://www.uved.fr/.

2.2 Resources

Material – or primary resources – and energy are at the heart of digital infrastructures. Having a minimal knowledge of these concepts is thus crucial to understand environmental issues in ICT.

2.2.1 Primary resources

Digital infrastructures are built upon various primary resources, but the main concepts that need to be known are the same for all of them.

Concepts:

- The formation of mineral resources takes a very long time.
- Knowing about of stocks and resources is crucial to anticipate the risks of shortage.
- Extracting mineral resources requires energy. This energy evolves in time, depending on 1) technical progress 2) the concentration of minerals in the ground.
- The extraction processes cause various types of pollution.
- Primary resources come from all over the world, sometimes from conflict zones.
- Our ability to recycle mineral resources is limited.

References in English:

[1] S. Bringezu, A. Ramaswami, H. Schandl, M. O'Brien, R. Pelton, J. Acquatella, E. Ayuk, A. Chiu, R. Flanegin, J. Fry, S. Giljum, S. Hashimoto, S. Hellweg, K. Hosking, Y. Hu, M. Lenzen, M. Lieber, S. Lutter, A. Miatto, A. Singh Nagpure, M. Obersteiner, L. van Oers, S. Pfister, P. Pichler, A. Russell, L. Spini, H. Tanikawa, E. van der Voet, H. Weisz, J. West, A. Wiijkman, B. Zhu, and R Zivy. Assessing global resource use: A systems approach to resource efficiency and pollution reduction. Technical report, International Resource Panel, 2017. URL: https://www.resourcepanel.org/reports/assessing-global-resource-use.

[2] Wikipedia page. Mineral resource classification. https://en.wikipedia.org/wiki/Mineral_resource_classification.

References in French:

[1] Le portail français des ressources minérales non énergétiques. Technical report, Ministere de la transition écologique et solidaire, Ministère de l'économie et des finances, Ministère de l'enseignement supérieur, de la recherche, et de l'innovation.

[2] Philippe Bihouix and Benoît de Guillebon. *Quel futur pour les métaux ? Raréfaction des métaux : un nouveau défi pour la société.* EDP Sciences, 2010.

2.2.2 Energy

Energy is needed to build and operate digital infrastructures. Having a basic knowledge of how it is produced is therefore necessary to understand the environmental aspects of these infrastructures.

Various sources of energy *Information on the different types of energy and its production in different countries.*

Concepts:

- Primary energy, secondary energy, final energy, energy mix, energy vector.
- Efficiency, energy return rate, energy losses
- Energy independence of a country (and associated return rate)
- Energy in a given country: production, consumption
- Energy worldwide: production, consumption

References in English:

[1] International Energy Agency. https://www.iea.org/.

References in French:

[1] Julian Carrey. Sans pétrole et sans charbon - tome 1 : Techniques et énergies dans les sociétés préindustrielles, 2020. URL: https://sans-petrole-et-sans-charbon.fr/sans-charbon-et-sans-petrole-le-livre/sans-charbon-et-sans-petrole-le-livre-tome-1/.

[2] Cerema. Les chiffres clés de l'énergie – Édition 2018. http://reseaux-chaleur.cerema.fr/les-chiffres-cles-de-lenergie-edition-2018.

[3] Commissariat général au développement durable. Chiffres clés de l'énergie. https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2019-09/datalab-59-chiffres-cles-energie-edition-2019-septembre2019.pdf, 2019.

[4] Thierry Salomon, Marc Jedliczka, and Yves Marignac. *Le Manifeste négaWatt*. Actes Sud / Association négawatt, 2015.

Electricity *Electricity is a secondary energy source. It can be produced from a variety of primary energy sources and therefore generate various levels of pollution.*

Concepts:

- Differences in electricity production and consumption in a given country and worldwide
- Physical quantities: voltage, current, power, load and associated units; parallel between an electric circuit and a water circuit
- Electrical mix
- Indicator: carbon dioxide equivalent per kilogram (kgCO_2e / kWh)

References in English:

[1] International Energy Agency. https://www.iea.org/.

References in French:

[1] Ministère de la Transition Écologique. La production d'électricité. https://www.ecologique-solidaire.gouv.fr/production-delectricite.

[2] RTE. Toutes les données de l'électricité en temps réel - éco2mix. https://www.rte-france.com/eco2mix.

Energy transition *The energy transition is one of the most frequently mentioned tools for reducing GHG emissions.*

Concepts:

- Energy transition
- Energy transition scenarios
- Limits of energy transition scenarios

References in English:
(US)
[1] Trieu Mai, Debra Sandor, Ryan Wiser, and Thomas Schneider. Renewable electricity futures study. executive summary. Technical report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2012. URL: https://www.nrel.gov/docs/fy13osti/52409-ES.pdf.

[2] Sven Teske, Steve Sawyer, Oliver Schäfer, Thomas Pregger, Sonja Simon, and Tobias Naegler. energy [r]evolution - A sustainable world Energy outlook 2015. Technical report, greenpeace international, global wind energy Council and solarPowereurope, 2015. URL: https://wayback.archive-it.org/9650/20200416202821/http://p3-raw.greenpeace.org/international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf.

References in French:

[1] Ademe. Les scénarios énergie climat 2030-2050. https://www.ademe.fr/lademe/priorites-strategiques-missions-lademe/scenarios-2030-2050, 2019.

[2] Association négawatt. Scénario négawatt 2017-2050. https://negawatt.org/Scenario-negaWatt-2017-2050, 2017.

2.3 Global economic and production system

There is a very complex global international economic and productive system beyond the deployment and maintenance of digital infrastructures. We cannot fully grasp the ecological issues of digital technology without understanding that they are part of a global system.

Decoupling economy from environmental impacts *The possibility of having both global economic growth and environmental sustainability at the same time is widely debated. At best, in some countries, we observe a relative decoupling (the ecological intensity per unit of economic production decreases).*

Concepts:

- Absolute decoupling, relative decoupling
- Service economy
- Carbon leakage

References in English:

[1] European Environmental Bureau. Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability, 2019. URL: https://eeb.org/library/decoupling-debunked/.

[2] Gaël Giraud and Zeynep Kahraman. How Dependent is Growth from Primary Energy? The Dependency ratio of Energy in 33 Countries (1970-2011), December 2014. Documents de travail du Centre d'Economie de la Sorbonne 2014.97 - ISSN : 1955-611X. URL: https://halshs.archives-ouvertes.fr/halshs-01151590.

[3] E. Sanyé-Mengual, M. Secchi, S. Corrado, A. Beylot, and S. Sala. Assessing the decoupling of economic growth from environmental impacts in the european union: A consumption-based approach. *Journal of Cleaner Production*, 236:117535, 2019. URL: http://www.sciencedirect.com/science/article/pii/S0959652619323431, doi:https://doi.org/10.1016/j.jclepro.2019.07.010.

[4] James D. Ward, Paul C. Sutton, Adrian D. Werner, Robert Costanza, Steve H. Mohr, and Craig T. Simmons. Is Decoupling GDP Growth from Environmental Impact Possible? *PLOS ONE*, 11(10):1–14, 10 2016. URL: https://doi.org/10.1371/journal.pone.0164733, doi:10.1371/journal.pone.0164733.

Green growth *Green growth refers to a policy aiming at reconciling economic growth and sustainability by redirecting investments in economic sectors dedicated to the ecological transition. The digital sector is often strongly associated with this highly controversial concept.*

References in French:

[1] L. Chancel, D. Demailly, H. Waisman, and C. Guivarch. Une société post-croissance pour le xxie siècle - peut-on prospérer sans attendre le retour de la croissance ? 2013. URL: https://www.iddri.org/fr/publications-et-evenements/study/une-societe-post-croissance-pour-le-xxie-siecle-peut-prosperer.

References in English:

[1] OECD. Green growth and sustainable development. https://www.oecd.org/greengrowth/.

Some particularities of digital economy *Some peculiarities of the digital economy in the global production system play an important role on the environmental impacts of the sector.*

Concepts:

- Economy of attention
- Digital advertising: profiling, tracking, formats; screens in the public space
- Geopolitical issues of ICT: data, information manipulation
- Open-source and proprietary models of information

References in French:

[1] Yves Citton. *L'économie de l'attention. Nouvel horizon du capitalisme ?* La Découverte, 2014. URL: https://www.cairn.info/l-economie-de-l-attention--9782707178701.htm.

[2] Bruno Patino. *La civilisation du poisson rouge.* Grasset, 2019.

References in English:

[1] Jérémy Bonvoisin, Jahnavi Krishna Galla, and Sharon Prendeville. Design principles for do-it-yourself production. In Giampaolo Campana, Robert J. Howlett, Rossi Setchi, and Barbara Cimatti, editors, *Sustainable Design and Manufacturing 2017*, pages 77–86, Cham, 2017. Springer International Publishing.

[2] Robert J Gordon. Interpreting the "one big wave" in US long-term productivity growth. In *Productivity, technology and economic growth*, pages 19–65. Springer, 2000.

[3] Monique Sonego, Márcia Elisa Soares Echeveste, and Henrique Galvan Debarba. The role of modularity in sustainable design: A systematic review. *Journal of Cleaner Production*, 176:196 – 209, 2018. URL: http://www.sciencedirect.com/science/article/pii/S0959652617330561, doi:https://doi.org/10.1016/j.jclepro.2017.12.106.

2.4 The digital sector

Before discussing environmental impacts, it is useful to know the current situation of digital sector.

2.4.1 Evolution of the digital sector

What is a numerical device? How have devices evolved since the 1950s?

Concepts:

- Digital circuits and devices.
- Evolution of digital devices: from ENIAC in 1945 to the many devices of today; foresight reports (WSIS summit), current trends in the digital sector.

References in English:

[1] John F. Wakerly. *Digital Design: Principles and Practices (5th Edition).* Pearson, 2018.

References in French:

[1] Emmanuel Lazard and Pierre Mounier-Kuhn. *Histoire illustrée de l'informatique.* EDP Sciences, 2016.

2.4.2 Digital infrastructure

Today's ICT infrastructure can be divided in three main components: data centers, networks and user devices.

Data centers

- Definition of a data center (size, hardware, services...)
- Data center locations and owners

Network infrastructures

- Wired networks: Ethernet, ADSL, optical fiber....
- Wireless networks: 3G, 4G, 5G, LTE, Wi-Fi, satellite, Bluetooth...
- How networks work: routing, throughput, latency...
- Actors: access providers, deployment consortia, regulators, associations...

User devices

- Information and communication: phones, laptops, desktop computers, screens...
- Entertainment and multimedia: consoles, TV, printers, video projectors...

References in English:

[1] James Kurose and Keith Ross. *Computer Networking: A Top-Down Approach (7th Edition)*. Pearson, 2016.

[2] Larry Peterson and Bruce Davie. *Computer Networks : A Systems Approach (6th edition)*. Morgan Kaufmann, 2020.

2.4.3 Use

The digital infrastructure induces a wide range of uses through different mechanisms: communication, information, calculation, data production.

References in French:

[1] Stéphane Bortzmeyer. *Cyberstructure : Internet, un espace politique*. C & F Éditions, 2019. URL: https://cyberstructure.fr/.

[2] Dominique Cardon. *Culture numérique*. Presses de Sciences Po, 2019. URL: https://www.cairn.info/culture-numerique--9782724623659.htm.

3 Understanding: environmental impacts of ICT

The aim here is to present the different types of environmental impacts of ICT: what are the resources or phenomena on which ICT has a direct impact, and what are the systemic effects of ICT, i.e. how can the use of ICT have an impact on other sectors of society?

References in English:

[1] Frans Berkhout and Julia Hertin. Impacts of information and communication technologies on environmental sustainability: Speculations and evidence. *Report to the OECD, Brighton*, 21, 2001. URL: http://www.oecd.org/sti/inno/1897156.pdf.

References in French:

[1] Groupe EcoInfo. *Impacts écologiques des technologies de l'information et de la communication*. EDP sciences, 2012.

[2] Kevin Marquet, Jacques Combaz, and Francoise Berthoud. Introduction aux impacts environnementaux du numérique. In *1024, bulletin de la Société Informatique de France*, pages 85–97. April 2019. URL: https://hal.inria.fr/hal-02410129.

3.1 Direct Impacts

Manufacturing, transporting and energy consumption of devices are sources of resource consumption and various types of pollution. These so-called "direct" impacts are due to the physical existence of these devices.

Important concepts for this entire section:

- Technological perimeter (different studies may consider different devices)
- Uncertainties in the studies (see also calculation methodologies in section 4.1)

Types of impact *As seen in Section 2.1.1, environmental impacts can be diverse. This section details the different types of impacts attributable to ICT devices.*

Concepts :

- Greenhouse gas emissions
- Soil pollution (phtalates...) and water pollution
- Mineral resources: concentration in the subsoil; resource depletion; reserves; extraction energy; thermodynamic limits; evolution over time
- Comparison of the impact of ICT with other sectors

References in English:

[1] Critical raw materials. Technical report, European commission. URL: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en.

References in French:

[1] Le portail français des ressources minérales non énergétiques. Technical report, Ministere de la transition écologique et solidaire, Ministère de l'économie et des finances, Ministère de l'enseignement supérieur, de la recherche, et de l'innovation.

[2] Carbone 4. Sur les 5 dernières années, l'empreinte carbone des Français a stagné, 2013. URL: http://www.carbone4.com/sur-les-5-dernieres-annees-lempreinte-carbone-des-francais-a-stagne/.

[3] Frédéric Bordage, Lorraine de Montenay, and Olivier Vergeynst. Impacts environnementaux du numérique en france. Technical report, greenit, 2021. URL: https://www.greenit.fr/wp-content/uploads/2021/02/2021-01-iNum-etude-impacts-numerique-France-rapport-0.8.pdf.

[4] Liliane Dedryve. La consommation de métaux du numérique : un secteur loin d'être dématérialisé, 2020. URL: https://www.strategie.gouv.fr/publications/consommation-de-metaux-numerique-un-secteur-loin-detre-dematerialise.

[5] Gouvernement Français. Origine et décomposition par produit de l'empreinte carbone de la france en 2018, 2020. URL: https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2020-02/l-empreinte-carbone-des-francais-2-janvier2020.xls.

[6] Shift Project. Lean ICT – pour une sobriété numérique. Technical report, The Shift Project, 2018. URL: https://theshiftproject.org/article/pour-une-sobriete-numerique-rapport-shift/.

Impact by life cycle stage *Studying the impact by life cycle stage allows, among other things, to realize that the energy consumption for the use of devices is not at all the only important factor in the direct impacts.*

Concepts:

- Life cycle
- Particularity of ICT: impact of manufacturing
- Particularity of the end-of-life management: limited recycling, dedicated recycling channels

References in French:

[1] Ademe. Rapport annuel du registre des déchets d'équipements électriques et électroniques. données 2018. Technical report, 2018.

[2] Cornelis P. Balde, Vanessa Forti, Vanessa Gray, Ruediger Kuehr, and Paul Stegmann. *The Global E-waste Monitor 2017: Quantities, Flows and Resources*. United Nations University, International Telecommunication Union, and International Solid Waste Association, 2017. URL: https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx.

[3] Ecoinfo. *Les impacts écologiques des technologies de l'information et de la communication*. EDP Sciences, 2012.

References in English:

[1] Cornelis P. Balde, Vanessa Forti, Vanessa Gray, Ruediger Kuehr, and Paul Stegmann. *The Global E-waste Monitor 2017: Quantities, Flows and Resources*. United Nations University, International Telecommunication Union, and International Solid Waste Association, 2017. URL: https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx.

Impact by type of equipment (ICT infrastructure) *There are studies that quantify the impacts of each part of the ICT infrastructure (see Section 2.4.2).*

Concepts:

- Technological improvement (evolution over time of impacts)
- Rapid change (new uses, new devices, new technologies)
- Impact and specificities of each of the three main parts of ICT (see Section 2.4.2) :
  - Terminals: rapid replacement of devices, increasing personal equipment rate.
  - Data centers: building cooling is an important factor.
  - Networks: beware of the eqCO_2/GB transferred indicator, which may suggest that the impact of the transfer is always proportional to the amount of data transmitted.

References in French:

[1] Ademe. La face cachée du numérique. Technical report, 2019. URL: https://www.ademe.fr/sites/default/files/assets/documents/guide-pratique-face-cachee-numerique.pdf.

[2] Shift Project. Lean ICT – pour une sobriété numérique. Technical report, The Shift Project, 2018. URL: https://theshiftproject.org/article/pour-une-sobriete-numerique-rapport-shift/.

References in English:

[1] Anders S. G. Andrae and Tomas Edler. On Global Electricity Usage of Communication Technology: Trends to 2030. 6(1):117–157. URL: https://www.mdpi.com/2078-1547/6/1/117, doi:10.3390/challe6010117.

[2] Cisco. Cisco visual networking index: Forecast and trends, 2017–2022 white paper. Technical report, February 2019. Document ID:1551296909190103. URL: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html.

[3] Jens Malmodin and Dag Lundén. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. *Sustainability*, 10(9):3027, 2018. URL: https://www.mdpi.com/2071-1050/10/9/3027, doi:10.3390/su10093027.

Impact by type of use *The types of use of ICT technologies are extremely varied. It is necessary to study the environmental impact of each one to build sustainability.*

Concepts:

- End uses (consumers) vs. intermediaries (companies)
- "Information and communication" vs. "Entertainment and multimedia" uses

- Technological subdomain: AI, 5G, internet advertising, video etc.

References in French:

[1] EcoInfo. Impact environnemental de l'IA, 2019. URL: https://ecoinfo.cnrs.fr/2019/10/01/impact-environnemental-de-lia/.

[2] Shift Project. Lean ICT – pour une sobriété numérique. Technical report, The Shift Project, 2018. URL: https://theshiftproject.org/article/pour-une-sobriete-numerique-rapport-shift/.

References in English:

[1] Kerry Hinton. Technical report, Center for energy efficient telecommunications, Bell Labs, University of Melbourne, 2016.

[2] Jens Malmodin and Dag Lundén. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. *Sustainability*, 10(9):3027, 2018. URL: https://www.mdpi.com/2071-1050/10/9/3027, doi:10.3390/su10093027.

[3] M. Pärssinen, M. Kotila, R. Cuevas, A. Phansalkar, and J. Manner. Environmental impact assessment of online advertising. *Environmental Impact Assessment Review*, 73:177 – 200, 2018. URL: http://www.sciencedirect.com/science/article/pii/S0195925517303505, doi:https://doi.org/10.1016/j.eiar.2018.08.004.

3.2 Indirect socio-environmental effects

ICT has an impact on the environment not only because of manufacturing and energy consumption of devices: use of ICT transforms many sectors and these transformations have positive and negative effects from an ecological point of view.

Positive effects

Concepts:

- Substitution effects (example: paper replacement)
- Optimization effect (e.g., lights switched on when presence is detected)

References in English:

[1] Lorenz Hilty and Bernard Aebischer. *ICT Innovations for Sustainability*. Springer, 2015. URL: https://www.researchgate.net/publication/274075759_ICT_Innovations_for_Sustainability, doi:10.1007/978-3-319-09228-7.

[2] Arman Shehabi, Ben Walker, and Eric Masanet. The energy and greenhouse-gas implications of internet video streaming in the united states. *Environmental Research Letters*, 9(5):054007, may 2014. URL: https://doi.org/10.1088%2F1748-9326%2F9%2F5%2F054007, doi:10.1088/1748-9326/9/5/054007.

Negative effects

Concepts:

- Induction effects (e.g. on teleworking: over-equipment, increased heating, extra rooms)
- Rebound effects: when the improved efficiency of a technology leads to increased consumption. Rebound effect is an illustration of the famous *Jevons paradox*. Although the precise quantification of rebound effect is difficult and subject to much controversy, it has been observed in practice in many areas.
- Software and hardware planned obsolescence: technical, indirect, by incompatibility, psychological, ecological

References in French:

[1] Jacques Combaz. Introduction aux effets indirects et rebond des TIC, 2019. URL: https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/2019-09-26_ANF.pdf.

[2] Centre Européen de la consommation. L'obsolescence programmée ou les dérives de la société de consommation, 2013. URL: https://www.europe-consommateurs.eu/fileadmin/user_upload/eu-consommateurs/PDFs/publications/etudes_et_rapports/Etude-Obsolescence-Web.pdf.

[3] Serge Latouche. *Bon pour la casse*. Les liens qui libèrent, 2012.

[4] Mathias Rollot. *L'Obsolescence : ouvrir l'impossible*. MétisPresses, 2016. URL: http://journals.openedition.org/critiquedart/25686.

References in English:

[1] William Stanley Jevons. *The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines*. Macmillan London, 1866.

[2] Giles Slade. *Made to break*. Harvard University Press, 2007.

[3] Steven Sorrell. The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. Technical report, UK Energy Research Centre., 2007. URL: http://www.ukerc.ac.uk/asset/3B43125E-EEBD-4AB3-B06EA914C30F7B3E/.

[4] David Font Vivanco. Rethinking climate and energy policies: new perspectives on the rebound phenomenon. *Transport Reviews*, 37(6):810–813, 2017. URL: https://doi.org/10.1080/01441647.2017.1307878, doi:10.1080/01441647.2017.1307878.

Other effects to consider *Digital use leads to complex civilization changes, with ecological impacts that are difficult to apprehend.*

- Flow acceleration
- Delayed decision making due to information overload
- Increased complexity

References in French:

[1] Jacques Ellul. *Le bluff technologique (1988)*. Fayard/Pluriel, 2012.

[2] Hartmut Rosa. *Aliénation et accélération. Vers une théorie critique de la modernité tardive*. La Découverte.

[3] Hartmut Rosa. *Accélération*. La Découverte, 2010.

References in English:

[1] Will Steffen, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, and Cornelia Ludwig. The trajectory of the anthropocene: The great acceleration. *The Anthropocene Review*, 2(1):81–98, 2015. URL: https://doi.org/10.1177/2053019614564785, arXiv:https://doi.org/10.1177/2053019614564785, doi:10.1177/2053019614564785.

[2] Joseph Tainter. *The collapse of complex societies*. Cambridge university press, 1988.

3.3 Other types of impact: social, geopolitical...

Ecological impacts are often linked to other impacts, such as geopolitical ones.

Geopolitical aspects

Geopolitical aspects of rare-earth elements and rare metals for the ICT economy and the exploitation restricted to a few countries

References in French:

[1] Liliane Dedryve. La consommation de métaux du numérique : un secteur loin d'être dématérialisé, 2020. URL: https://www.strategie.gouv.fr/publications/consommation-de-metaux-numerique-un-secteur-loin-detre-dematerialise.

[2] Guillaume Pitron. *La guerre des métaux rares, La face cachée de la transition énergétique et numérique*. Les liens qui libèrent, 2018.

References in English:

[1] Critical raw materials. Technical report, European commission. URL: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en.

Impacts on health

ICT has impacts on health: sedentary lifestyle, addiction, developmental disorders, chronobiology...

References in French:

[1] Léo Favier (Arte). Dopamine. https://www.arte.tv/fr/videos/RC-017841/dopamine/, 2019.

References in English:

[1] Royal Society for Public Health. Social media and young people's mental health and wellbeing. https://www.rsph.org.uk/static/uploaded/d125b27c-0b62-41c5-a2c0155a8887cd01.pdf, 2017.

3.4 Evolution of ICT impacts

Beyond the impact of ICT at a given moment, it is necessary to understand the temporal dynamics of the sector in a context where a drastic reduction of ecological impacts is recommended by the IPCC.

Concepts:

- Development of the digital infrastructure: number of equipments, data volumes...
- Growing part of global GHG emissions
- Technical improvements: efficiency, intensity, Moore's law and Koomey's law, PUE, battery life, Landauer's principle etc.
- Predictions vs. projections. The projections made from the models should not be considered as predictions. They do not capture, far from it, all the complexity of socio-technical evolutions.
- Foresight scenarios for ICT: know and criticize prospective scenarios including a digital component: SMART 2020 and 2030 from GeSI, BIO Intelligence Service 2008, The Shift Project, Fing, Ademe, etc.

References in English:

[1] Cisco. Cisco visual networking index: Forecast and trends, 2017–2022 white paper. Technical report, February 2019. Document ID:1551296909190103. URL: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html.

[2] Charlotte Freitag, Mike Berners-Lee, Kelly Widdicks, Bran Knowles, Gordon S Blair, and Adrian Friday. The real climate and transformative impact of ict: A critique of estimates, trends, and regulations. *Patterns*, 2(9):100340, 2021.

[3] Jens Malmodin and Dag Lundén. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. *Sustainability*, 10(9):3027, 2018. URL: https://www.mdpi.com/2071-1050/10/9/3027, doi:10.3390/su10093027.

References in French:

[1] Shift Project. Lean ICT – pour une sobriété numérique. Technical report, The Shift Project, 2018. URL: https://theshiftproject.org/article/pour-une-sobriete-numerique-rapport-shift/.

Emerging technologies *Many new technologies, requiring ICT infrastructures, are being developed or deployed. The environmental impact is not currently taken into account in the processes that approve their deployment.*

Concepts:

- New technologies: AI, 5G autonomous vehicles, IoT
- Technical progress

References in French:

[1] Hugues Ferreboeuf. Faut-il faire la 5G ? https://jancovici.com/publications-et-co/articles-de-presse/faut-il-faire-la-5g/, 2020.

[2] Gauthier Roussilhe. La controverse de la 5G. https://gauthierroussilhe.com/fr/projects/controverse-de-la-5g, 2020.

References in English:

[1] Anne-Laure Ligozat, Julien Lefèvre, Aurélie Bugeau, and Jacques Combaz. Unraveling the hidden environmental impacts of AI solutions for environment, 2021. arXiv:2110.11822.

[2] Roy Schwartz, Jesse Dodge, Noah A Smith, and Oren Etzioni. Green AI. *arXiv preprint arXiv:1907.10597*, 2019. URL: https://arxiv.org/abs/1907.10597.

4 Taking action: measuring impacts

Show how to measure the impacts of digital technology, at different levels (digital service, establishment...), with different criteria (greenhouse gas emissions and others)...

4.1 Methodologies

As in any field, many methodologies can be used to measure, with various indicators (see Section **??***), the environmental impact of a digital device or service, each having its advantages and limitations.*

Concepts:

- Ecological indicators (cf. Section 2)
- Impact factor

Attributional Life Cycle Assessment (A-LCA)

> *(translated from Ademe) LCA identifies and quantifies the physical flows of materials and energy associated with human activities throughout the life cycle of products. It evaluates the potential impacts and interprets the results obtained according to its initial objectives.*

References in French:

[1] Ademe. Qu'est-ce que l'acv ? https://www.ademe.fr/expertises/consommer-autrement/passer-a-laction/dossier/lanalyse-cycle-vie/quest-lacv.

Consequential Life Cycle Assessment (C-LCA)

> *(translated from French Wikipédia) LCA-C also includes processes indirectly affected by the implementation of the life cycle of the studied product or by its change.*

References in English:

[1] LCA Consultants. Consequential lca, why and when? https://consequential-lca.org/clca/why-and-when/.

Carbon footprint *A greenhouse gas emissions assessment is a diagnosis of the greenhouse gas emissions of a legal entity (company, organization, etc.) over one year. It aims at identifying and leveraging actions for reducing these emissions. It can also be carried out for an information system, for example. In France, the term "Bilan Carbone" designates a set of "method + tool + emission factors + associated documentation" distributed by ADEME, which has made it a registered trademark.*

Other methodologies

- Carbon cost
- Environmental impact assessment
- Multi regional input output analysis (MRIO)

References in French:

[1] Pierre André, Georges Lanmafankpotin, Jean-Pierre Revéret, and Samuel Yonkeu. *L'évaluation des impacts sur l'environnement: Processus, acteurs et pratique pour un développement durable. (4e édition).* Presses inter Polytechnique, 2020.

[2] de l'Énergie et de la Mer Ministère de l'Environnement. Méthode pour la réalisation des bilans d'émissions de gaz à effet de serre conformément à l'article l. 229-25 du code de l'environnement. version 4., 2016. URL: https://www.ecologie.gouv.fr/sites/default/files/Guide%20m%C3%A9thodologique%20sp%C3%A9cifique%20pour%20les%20collectivit%C3%A9s%20pour%20la%20r%C3%A9alisation%20du%20bilan%20d%E2%80%99%C3%A9missions%20de%20GES.pdf.

References in English:

[1] ADEME. Resource centre for greenhouse gas accounting. URL: https://www.bilans-ges.ademe.fr/en/accueil/contenu/index/page/emisions_factor_categories/siGras/0.

[2] Wikipedia page. Environmental impact assessment. https://en.wikipedia.org/wiki/Environmental_impact_assessment.

[3] Decun Wu and Jinping Liu. Multi-regional input-output (mrio) study of the provincial ecological footprints and domestic embodied footprints traded among china's 30 provinces. *Sustainability*, 8(12), 2016. URL: https://www.mdpi.com/2071-1050/8/12/1345.

4.2 Tools and indicators for measuring electrical consumption

From consumption measurements, it is possible to draw a diagnosis.

Concepts:

- A measuring instrument, or tool, allows observing and measuring (quantify a physical quantity) a quantity coming from a sensor.
- A measuring instrument and tool can be a software or a hardware
- An indicator provides information based on measurements. It gives meaning to measurements, according to an objective.
- Diagnosis: qualitative aspect of measures and indicators

Indicators

- PUE (*Power Usage Effectiveness*)
- Electrical quantities, carbon equivalent (cf. 2.2.2)

Power measurement tools

- PDUs, power meters, ammeters
- Parameters of these tools: sampling frequency, precision, multi-socket, remotely operable

References in French:

[1] Amélie Bohas, Francoise Berthoud, and Gabrielle Feltin. Normes numériques et Green IT, 2019. URL: https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/ANF2019_Normes-num%C3%A9riques_GabrielleFeltin.pdf.

[2] Laurent Lefevre. Impact du numérique: focus sur les consommations en phase d'usage. https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/ANF_2019_Autrans_EcoInfo_Laurent_Lefevre_diffuse.pdf, 2019.

Sofware tools

- PowerAPI
- Intel Power Gadget
- Mac Power Meter, software / wattmeter comparison (under development)

References in English:

[1] Intel power gadget. https://software.intel.com/content/www/us/en/develop/articles/intel-power-gadget.html.

[2] Mac power meter. https://gitlab.inria.fr/guenneba/mac-power-meter/-/tree/master.

[3] Powerapi. https://pypi.org/project/powerapi/.

Online measuring tools *Several online tools can be used to measure the impact of a webpage and possibly to carry out a diagnosis. Be aware that the methodology is not always the same and that some tools are criticized for their imprecision.*

- Carbonalyser: a browser extension calculating the carbon emitted during the use time of the browser.
- Ecometer: measures the environmental impact of a website
- Ecoindex : measures the environmental impact of a website

References in English:

[1] Github de l'extension carbonalyser. https://github.com/carbonalyser/Carbonalyser.

[2] Site web ecoindex. http://www.ecoindex.fr/.

[3] Site web ecometer. http://www.ecometer.org/.

Information on supercomputers TOP 500 is a project evaluating the 500 biggest supercomputers in terms of performances on numerical analysis benchmarks. Since 2007, a Green 500 ranking also exist to evaluate energetic efficiency. These data are available on Top500.org.

5 Taking action: towards sustainable ICT

In this section, several aspects of sustainable ICT are presented: first, how to apply environmental criteria to ICT (Green IT) and second, how ICT can contribute to sustainable development (IT for Green).

Concepts:

- Green IT, IT for Green (and IT for Good), sustainable ICT...
- eco-conception (hardware and software)

References in English:

[1] Bordage, Frédéric and Chaussat, Jean-Christophe. Du Green IT au numérique responsable, Lexique des termes de référence. Technical report, ClubGreenIT, 2018. URL: https://club.greenit.fr/doc/2018-05-ClubGreenIT-lexique-numerique_responsable-v1.8.3.pdf.

5.1 Less impacting ICT services

In this section, we present methods and tools to implement a more environmentally friendly ICT, in various ways (impact assessment, optimization of solutions, implementation methods). We also discuss the implementation of these good practices by various standards and labels.

Sustainable ICT strategy *A sustainable ICT strategy integrates environmental factors into decisions, both internally and externally (suppliers, subcontractors...).*

- Sustainable IT strategy, for example by involving IT departments in decision-making
- Transition management
- Training, education and communication
- Engagement with partners, suppliers... towards sustainable solutions and services

References in French:

[1] Institut du Numérique Responsable. *Le petit livre bleu - Référentiel Green IT*. 2020. URL: https://institutnr.org/wp-content/uploads/2020/06/2020-v3-65-bonnes-pratiques-greenit.pdf.

[2] INRA et Agreenium. Transition numérique et pratiques de recherche et d'enseignement supérieur en agronomie, environnement, alimentation, sciences vétérinaires à l'horizon 2040, 2019. URL: https://www.inrae.fr/sites/default/files/pdf/prospective-transition-numerique-dans-l-esr-rapport-pdf-1_0.pdf.

Building sustainable digital solutions and services *Internally, apply an eco-conception approach when developping digital solutions and services in order to fight obsolescence.*

Concepts:

- infrastructure
  - Share resources
  - Increase equipments lifetime (repair, reuse) and good end-of-life management (recycling)
- Applications:
  - before: analysis of real needs (digital or not, low tech? which functionalities are essential?); choice of languages, libraries, platforms, data format...
  - during: code analysis, performance measurement...
  - after: standby systems, user awareness, sustainable update management...

References in English:

[1] Peter Henderson, Jieru Hu, Joshua Romoff, Emma Brunskill, Dan Jurafsky, and Joelle Pineau. Towards the systematic reporting of the energy and carbon footprints of machine learning, 2020. arXiv:2002.05651.

[2] Shift Project. Implementing digital sufficiency. Technical report, The Shift Project, 2021. URL: https://theshiftproject.org/en/article/implementing-digital-sufficiency/.

References in French:

[1] CIGREF. Du Green IT au Green by IT, Exemples d'application dans les Grandes Entreprises. https://www.cigref.fr/wp/wp-content/uploads/2017/01/CIGREF-Du-Green-IT-au-Green-by-IT-2017.pdf, 2017.

About low tech:

References in French:

[1] Low tech : face au tout-numérique, se réapproprier les technologies. https://www.ritimo.org/Low-tech-face-au-tout-numerique-se-reapproprier-les-technologies-8264, 2020.

[2] Gauthier Roussilhe. Guide de conversion numérique au low tech. http://gauthierroussilhe.com/fr/posts/convert-low-tech, 2019.

Example of comparison of programming languages, always to be taken with care :

References in English:

[1] Rui Pereira, Marco Couto, Francisco Ribeiro, Rui Rua, Jácome Cunha, João Paulo Fernandes, and João Saraiva. Energy efficiency across programming languages: how do energy, time, and memory relate? In *Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering*, pages 256–267, 2017.

5.2 ICT standards and labels

There are currently very few legally binding measures on eco-conception, but regulations are tending to grow.

The paper below proposes a thematic vision with, for each Green IT issue (life cycle analysis, eco-design, labels, waste electrical and electronic equipment, digital infrastructure), a review of standards, legislation, regulations, when they exist:

References in French:

[1] Amélie Bohas, Francoise Berthoud, Gabrielle Feltin, et al. Norme numérique et green IT. *Normaliser le numérique ?*, page 22, 2019.

ISO standards *Currently there are no standards to certify environmentally responsible ICT, but some standards may apply partly to it.*

Standards 140xy concern environmental management. They are not specific to digital technology but it is mentioned as a possible field of application, for example via software. Standards ISO 14040 et 14044 concern life cycle assessments. ISO 14006 et ISO 14062 are about eco-conception in general. Ecolabels are also specified by standards ISO 14020-25, with different levels of requirement.

An example of application of standard ISO 14001 at IBM, with energy savings and reprocessing of equipment in end of life:

References in French:

[1] ISO. IBM s´appuie sur ISO 14001 pour le développement durable. https://www.iso.org/fr/news/2015/11/Ref2015.html, 2015.

Regarding datacenters, a certain number of standards (ISO/IEC 30134-n) on indicators such as PUE or REF (renewable energy factor) exist.

Finally, we can mention the standard ISO 25010 for software quality.

References in English:

[1] ISO. ISO 25010. https://latavernedutesteur.fr/tag/iso-25010/.

Labels/certifications Differences between labels and certifications depend mostly on the existence of a third party that grants the certification or not. We distinguish:

- Official ecolabels, certified by the ISO 14024 standard: Blue Angel (for digital equipment, created in 1978), European Ecolabel, TCO (Swedish ecolabel for equipement), Energy Star, Cygne Blanc (sustainable conception of products)
- Environmental self-declarations that fall under standard ISO 14021: Criteria are defined by the groups of interest that create them. Examples: EPEAT (23 mandatory criteria and optional ones), ECMA.

We can also note a certain number of French initiatives:

- The Greencode label [1] is dedicated to eco-conception of websites. It provides a certification for the eco-design of websites. It gives a 2-years certification.
- The certification proposed by the collective "Conception Numérique Responsable" [2] is granted to developers based on a MCQ.
- The Numérique Responsable label, launched in June 2019, is for organizations.

Among the players who carry out certifications, there are very generalist companies (Bureau Veritas), others specialized in digital sobriety (Greenspector) or even groups from public research (EcoInfo for datacenters).

Regulations

- The management of WEEE is partly in line with the international framework defined by the Basel Convention (1989) that aims at reducing more generally the movement of hazardous waste.
  At the European level, the directive 2012/19/UE for the treatment of WEEE and the regulation CE 660/2014 onshipments of waste.
- For the use of hazardous substances in electrical and electronic equipment, the European directives RoHS 1 (2002) et RoHS 2 (2017) allow the compliance of the regulation REACH (2006).
- The directive EuP (Energy using Products from 2005 and 2009), on electrical consumption.
- The French and European legislation on planned obsolescence. Directive 2006/66/EC on the non removability of the batteries.
- In terms of responsible sourcing of minerals from conflict zones: part XV of the law Dodd-Franck (USA, 2010), Regulation UE 2017/821 (Tin, Tantalum, Tungsten) binding from 2021.

[1] https://label.greencodelab.org/ [2] https://collectif.greenit.fr/certification.html

References in French:

[1] Amélie Bohas. *Vers une analyse de la relation systèmes d'information, développement durable et responsabilité sociale d'entreprise : l'adoption et l'évaluation du Green IT*. PhD thesis, Lyon 3, 2013. Thèse de doctorat dirigée par Bouzidi, Laïd et Chappoz, Yves Sciences de gestion. URL: http://www.theses.fr/2013LYO30076.

[2] Amélie Bohas, Francoise Berthoud, and Gabrielle Feltin. Normes numériques et Green IT, 2019. URL: https://ecoinfo.cnrs.fr/wp-content/uploads/2019/10/ANF2019_Normes-num%C3%A9riques_GabrielleFeltin.pdf.

[3] EcoInfo. Les normes de la communication environnementale. URL: https://ecoinfo.cnrs.fr/2012/08/09/les-normes-de-la-communication-environnementale/.

[4] EcoInfo. Pages sur les aspects législatifs. URL: https://ecoinfo.cnrs.fr/category/les-thematiques/aspects-legislatifs/.

[5] Romuald Priol. Le numérique responsable, Normes, labels, certifications et outils, 2020. URL: https://ecoinfo.cnrs.fr/wp-content/uploads/2020/04/INSA_2020_Le-numerique-responsable_normes.pdf.

5.3 ICT at the service of ecology

ICT can be put at the service of ecology, for example by simulating global warming to better understand it. This part discusses principles, strengths and weaknesses of IT for Green.

5.3.1 Toools for better understanding the world

A better understanding of the world is part of the classic scientific approach with hypotheses, modeling, simulations, which lead to predictions and then possible decision-making, as in 5.3.3

Different application domains of digital science can lead to ecological advances:s :

- Modeling several environmental phenomena to understand them
- Simulation of these phenomena
- Modeling and simulating in order to make forecasts or even predictions

References in English:

[1] Climate Change AI initiative. URL: https://www.climatechange.ai.

[2] David Rolnick, Priya L Donti, Lynn H Kaack, Kelly Kochanski, Alexandre Lacoste, Kris Sankaran, Andrew Slavin Ross, Nikola Milojevic-Dupont, Natasha Jaques, Anna Waldman-Brown, et al. Tackling climate change with machine learning. *arXiv preprint arXiv:1906.05433*, 2019.

[3] Ricardo Vinuesa, Hossein Azizpour, Iolanda Leite, Madeline Balaam, Virginia Dignum, Sami Domisch, Anna Felländer, Simone Daniela Langhans, Max Tegmark, and Francesco Fuso Nerini. The role of artificial intelligence in achieving the sustainable development goals. *Nature communications*, 11(1):1–10, 2020.

5.3.2 Tools to travel less

We give a special attention to digital tools for travelling less, given the weight of transport in environemental impacts.

In particular, visio-conference can limit travels.

References in English:

[1] Nelson N Gichora, Segun A Fatumo, Mtakai V Ngara, Noura Chelbat, Kavisha Ramdayal, Kenneth B Opap, Geoffrey H Siwo, Marion O Adebiyi, Amina El Gonnouni, Denis Zofou, et al. Ten simple rules for organizing a virtual conference—anywhere. *PLoS computational biology*, 6(2), 2010.

[2] Ken Hiltner. A nearly carbon-neutral conference model, 2016. URL: http://hiltner.english.ucsb.edu/index.php/ncnc-guide/.

5.3.3 Tools to better manage resources

Often, hopes placed in digital technologies for reducing environemental impacts are related to a better management of resources which would be possible with some automatic processing. A basic example is to only switch on lights when someones passes by.

- Improving power grids
- Improving vehicle efficiency
- Smart building, better waste sorting, optimization of people and goods flows, etc.

Same references as in 5.3.1.

5.3.4 Tools for better sharing

A whole part of the digital economy targets collaboration and sharing between people. Some people hope that this fringe of the economy will have a ripple effect on the ecological transition. Other fears that no digital device will be able to meet the environmental challenges.

- Collaborative economy (platforms of exchange of goods, services...).
- Digital devices and applications " encapacitating " (allowing people to communicate, collaborate, etc., e.g. conferences held entirely remotely [1]).
- Blockchain economics: some cryptocurrencies would have less impact than fiat currencies, the transparency provided in the supply chain domain could lead to gains through optimization
- Third place: fab-lab, digital inclusion houses.

5.3.5 Socio-environmental benefits of digital devices: food for thought

Despite the often highlighted potential of digital technology to move towards a sustainable world, the effects are small or not visible, which gives food for thought.

- Digital sobriety does not appear clearly and the contribution of digital technology is not visible because of complex indirect effects 3.2.
- We have known for a long time about the planetary ecosystem. Producing knowledge is not anymore a rationale for inventing, deploying services and infrastructures, without asking ourselves what is their environemental impact and if the means allocated for these would not be more useful elsewhere.
- Producing goods and digital services for the general public has an impact. We could imagine that inventions in the digital domain only serves causes that make ecological sense. But it is of course not that simple. The general public finances innovation, and innovation serves the economic competition between countries. How to innovate without selling to the general public? What impact on economic competition?

References in French:

[1] Matthieu Amiech. Peut-on s'opposer à l'informatisation du monde ?, 2020. URL: https://www.terrestres.org/2020/06/01/peut-on-sopposer-a-linformatisation-du-monde/.

[1] http://hiltner.english.ucsb.edu/index.php/ncnc-guide/

5.4 Why and how can organizations integrate ICT impacts?

All organizations are a priori included in their diversity (organizational-diversity, Graham & Gibson): companies, associations, communities, etc., even if some points may be specific to certain types of organizations.

Concepts:

- Adoption theories of Green IT
- Types of pressure: coercive (regulations, legislation, incentive mechanisms), mimetic (pressure from competitors), normative (NGOs, professional associations), environmental context
- Maturity of Green IT
- Sustainability objectives

References in French:

[1] Amélie Bohas. *Vers une analyse de la relation systèmes d'information, développement durable et responsabilité sociale d'entreprise : l'adoption et l'évaluation du Green IT.* PhD thesis, Lyon 3, 2013. Thèse de doctorat dirigée par Bouzidi, Laïd et Chappoz, Yves Sciences de gestion. URL: http://www.theses.fr/2013LYO30076.

6 Some actors of sustanainable ICT

Many actors are nowadays interested in the impacts of ICT or related fields. They have different points of view, different methods, different types of discourse and ways of working.

6.1 Sustainable development, transitions, energy...

Actors not necessarily working only in the digital domain

- International Energy Agency: international organization within the framework of the OECD
  - with works such as Digitalization and Energy
- Greenpeace: non-governmental organization to protect the environment and promote peace
  - many articles on digital, such as the reports Clicking Clean
- World Wildlife Fund (WWF): international non-governmental organization dedicated to environmental protection and sustainable development
  - worked on studies on responsible digital technology with the Green IT Club
- Agence de la transition écologique (ADEME): many resources
  - in particular, in French, La face cachée du numérique
- French Ministry of Ecological Transition: information and figures for France
- The Shift Project: think tank association working for a carbon-free economy
  - workstream on sustainable ICT
- Institut du Développement Durable et des Relations Internationales (Institute for Sustainable Development and International Relations), think tank, author of Livre blanc numérique et environnement

6.2 Responsible digital

Several organizations work specifically on digital issues.

- GreenIT.fr: community of "responsible digital" actors
- Institut du Numérique Responsable : think & do tank about digital responsibility
- Association pour la Fondation d'un Internet Nouvelle Génération (Fing) : think & do tank for digital transformations
- and EcoInfo CNRS group of higher education and research members for a responsible digital environment
  - in particular a non exhaustive list of training courses dealing with the environmental aspects of IT has been created.

6.3 Students associations and networks

The student and engineering networks have also become aware of the issues and are active.

- Réseau Étudiant pour une Société Écologique et Solidaire (RESES): network of French student organizations working for sustainable universities.
  - some initiatives on ICT services, for example the « Responsible ICT on Campus » sheet in association with Ecosia
- Student Manifesto for an ecological awakening: to " encourage all actors in society - public authorities, companies, individuals and associations - to play their part in this big transformation and to lead the necessary changes towards a finally sustainable society "
  - Teaching platform, with many resources
- Ingénieurs engagés (Committed Engineers)
  - Change formations group, and discord discussions on digital
- Ingénieurs sans frontières (Engineers Without Borders)
  - projects « Change curricula » et « Training the Citizen Engineer »

7 Examples of skills

We list below some examples of skills that can be associated with the knowledge presented. These competencies are obviously to be adapted according to the targeted curriculum.

- Understand ICT impacts
- Perform an energy mix calculation for different countries
- Compare different energy transition scenarios
- Describe the strengths and weaknesses of an energy transition scenario and its impact on the digital sector
- Perform an attributional life cycle analysis of a device
- Perform an attributional life cycle analysis of a digital services
- Identify the consumption factors on a web page, in a software...

- Compare the instantaneous consumption of different digital devices
- Compare the consumption of several digital services
- Determine the direct and indirect impacts of a technology
- ...

8 Conclusion

We hope you found this document useful and we welcome any comments or encouragement you may have. Please let us know if you used this document!

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