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. 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 EcolInfo 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:


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:


References in French:


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:


References in French:


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:

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$_2$e / kWh)

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
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:


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:


References in English:

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:


References in English:


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:


References in French:


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:


2.4.3 Use

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

References in French:


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:


References in French:


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 (phthalates...) 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:

References in French:

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
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.

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
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)

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
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:


References in English:


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
Impacts on health

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

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.
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

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.
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:

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:

References in English:


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

Software tools

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

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

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:

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:

Building sustainable digital solutions and services Internally, apply an eco-conception approach when developing 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:


References in French:


About low tech:

References in French:


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

References in English:


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:


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:

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:

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 equipment), 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.


- The directive EuP (Energy using Products from 2005 and 2009), on electrical consumption.


- 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.

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 Tools 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:

- 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:


### 5.3.2 Tools to travel less

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

In particular, visio-conference can limit travels.

References in English:


5.3.3 Tools to better manage resources

Often, hopes placed in digital technologies for reducing environmental 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 someone 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).
- 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.
- 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 environmental 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 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:


6 Some actors of sustainable 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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