Erasmus+

GreenDiLT

Towards improved digital practices in higher education institutions

This study has been initiated in the frame of the Erasmus+ project

Green Digital Learning and Teaching

ARTS ET MÉTIERS ParisTech

École des Ponts ParisTech

AgroParisTech

POLITECNICO DI MILANO

TU Delft

Co-funded by the European union

Co-funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

Authors

Saïda MRAIHI
Direction Générale Adjointe à la Formation, Arts et Métiers Technologies, Paris, France - saida.mraihi@ensam.eu

Valérie CAMEL
UMR SayFood, Université Paris-Saclay, INRAE, AgroParisTech, Palaiseau, France – valerie.camel@agroparistech.fr

Gilles BUISSON
Direction de l'Enseignement, École Nationale des Ponts et Chaussées, Champs-sur-Marne, France - gilles.buisson@enpc.fr

Elisa AMODEO
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy - elisa.amodeo@polimi.it

Marta PINZONE
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy - marta.pinzone@polimi.it

Collaboration

Léopold BOYART, Nina LEPANNETIER: Arts et Métiers (France)
Léonore MONTAIGNE: AgroParisTech (France)
Nela KAPELAN, René TAMBOER: TU Delft (Netherlands)

Funding

This work was co-funded by the European Union under the Erasmus+ programme Key Action 2 "Partnership for cooperation".

Rights and Permissions

This work is available under the Creative Commons Attribution – NonCommercial - NoDerivatives 4.0 International (CC BY-NC-ND 4.0) license. You are free to copy and redistribute the material in any medium or format under the license terms as indicate below.

Attribution— You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. Please cite the work as follows: "Mraihi S., Camel V., Buisson G., Amodeo E. and Pinzone M. (2026) Towards improved digital practices in higher education institutions. White book of the Erasmus+ GreenDiLT project. License: Creative Commons Attribution – NonCommercial - NoDerivatives CC BY-NC-ND 4.0".

NonCommercial —You may not use the material for commercial purposes.

NoDerivatives — If you remix, transform, or build upon the material, you may not distribute the modified material.

No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

GreenDiLT Co-funded by the European Union

Table of content

LIST OF ABBREVIATIONS **3**

1. INTRODUCTION **4**

2. THE GREENDILT PROJECT **4**

2.1. AIM OF THE PROJECT 4
2.2. THE PARTNERS' CONSORTIUM 5
2.3. ORGANIZATION 6

3. INVENTORY OF DIGITAL PRACTICES **7**

3.1. METHODOLOGY FOR ASSESSING DIGITAL PRACTICES 7
3.2. CURRENT DIGITAL PRACTICES 8
3.3. DISCUSSION 11

4. ASSESSING THE IMPACT OF THE DIGITAL PRACTICES **14**

4.1. CHOICE OF THE METHODOLOGY BASED ON BIBLIOGRAPHY 14
4.2. METHODOLOGY ADOPTED 15
4.3. RESULTS AND DISCUSSION 17
4.4. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS 22

5. TOWARDS IMPROVED DIGITAL PRACTICES **22**

5.1. THE GREENDILT ONLINE TRAINING MODULES 23
5.2. GREENDILT ACADEMY: THE BOARD GAME 24
5.3. KEY CONCEPTS FOR GRASPING ENVIRONMENTAL IMPACTS 26
5.4. KEY INSIGHT OF THE TRAINING 27
5.5. AMBASSADOR NETWORK 28

6. CONCLUSIONS **29**

REFERENCES **30**

APPENDICES **31**

APPENDIX 1 – GREENDILT CONSORTIUM COMMUNICATIONS 32
APPENDIX 2– DETAILS OF LCA METHODOLOGY FOR ASSESSMENT 33

GreenDiLT Co-funded by the European Union

List of abbreviations

GAI	Generative artificial intelligence
GWP	Global warming potential
IT	Information technology
ICT	Information and communication technology
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LES	Levels of environmental sustainability
LMS	Learning management system
MOOC	Massive open online course
SPOC	Small private online course
VET	Vocational education training
WP	Work package

GreenDiLT Co-funded by the European Union

1. Introduction

Digital technology is currently used in higher education institutions, being often considered as a vector of progress. In the past decade, teaching and learning practices have moved to usages that limit printing and paper documents, with a view of reducing damages to the environment in line with a sustainability trend in the higher education. Exchanging and storing resources on virtual clouds is also becoming more and more frequent in educational communities. In the meantime, the introduction of learning management system (such as Moodle) along with the development of several digital tools easily accessible (with education licenses frequently proposed for free) has open new opportunities for teaching and learning. In addition, the Covid-19 pandemic accelerated the transformation of these practices, by rending more accessible distance activities due to the rapid development of accessible tools for visioconference. By way of consequence this has expanded the diversity of practices with teaching, learning and working activities that may now operate face-to-face or remotely, being either synchronous or asynchronous.

The education community (teachers, learners and support staff) has adapted its practices to this digital (r)evolution and the plethora offer of digital tools. Higher education institutions have also operated internal transformation to adapt their digital systems in order to face the evolving needs, and to manage the digital tools, skills and equipment of their employees. This is still in progress with the emergence of generative artificial intelligence (GAI) more recently.

The explosion of all these usages and digital resources is questioning considering the concerns related to climate changes and depletion of resources. Practices developed empirically without questioning these issues, and digital technology has long been considered as virtual, whereas it has a real environmental and social impact throughout its life cycle (extraction of raw resources, manufacturing, end-of-life management). So, there is an urgent need to get an inventory of the current practices in order to assess their environmental impact. That way, recommendations should be given to help stakeholders adopting responsible digital practices, and training might be considered to support them in this transformation. This question has considerable importance as well, due to the fact that higher education community has an educational responsibility towards its learners who are the actors of tomorrow. Changing practices at the level of the educator's or student's profession should lead to transformations at the larger societal level, and contribute to a general awareness on the topics.

The GreenDiLT's stakeholders could support higher education institutions embark on a path in line with the principles of digital sobriety and the Green IT movement. Previous example of the GIVE (Green IT for VET providers) project, that addressed the vocational education and training (VET) community, shows that improved practices are possible to better balance between benefits and drawbacks of digital technology (GIVE, 2023).

Main results are described in this report, with a view of dissemination for improving digital practices in higher education institutions. Additional information may be found in communications of the GreenDiLT consortium as indicated in **Appendix 1** at the end of this report.

2. The GreenDiLT project

2.1. Aim of the project

Funded by the key action 2 of the Erasmus+ programme, GreenDiLT is a partnership for cooperation. Starting in October 2023, with an initial duration of 24 months, the total duration of the GreenDiLT project was at final 33 months (from 2 October 2023 to 1 July 2026).

The aim of this project was to rethink the use of digital technology in training. Its final objective was to support the educational stakeholders (teachers, students, support staffs) towards a sustainable use of digital technology for learning and teaching through awareness and training actions. It intended to assess the environmental impact of existing digital teaching and learning practices, and to provide useful and concrete recommendations that should help stakeholders to improve their daily practices.

2.2. The partners' consortium

The GreenDiLT consortium was a partnership bringing together five European higher education institutions as illustrated in **Figure 1**: Arts et Métiers Institute of Technology (ENSAM) – France, National Institute of Technology for Life, Food and Environmental Sciences (AgroParisTech) – France, École Nationale des Ponts et Chaussées (ENPC) – France, Politecnico di Milano (POLIMI) – Italy, Delft University of Technology (TU Delft) – Netherlands. Arts et Métiers was the leading institution and coordinator of this project.



Figure 1: the GreenDiLT consortium.

This consortium was composed of recognized universities with extensive experience in the creation of educational content as well as in European projects.

- Arts et Métiers (France) has a large experience in integrating digital technology as a tool to support learning by conducting several digitization projects, such as digital twins and massive open online courses (MOOCs), and of coordinating European projects aiming to disseminate more sustainable practices;
- TU Delft (Netherlands) has extensive experience in new advanced digital tools and pedagogical innovations;
- POLIMI (Italy) has in-depth experience in external communication and awareness-raising in sustainability issues, including but not limited to the youth.
- AgroParisTech (France) holds expertise in training and accompanying professors and university staff in the topics of sustainability;
- ENPC (France) has years of experience in creating online pedagogical content, such as learning paths and modules.

These five higher education institutions have all placed sustainability at the heart of their engineering curriculum. In addition, the involvement of each partner in several national and European networks and partnerships with other countries outside Europe will make possible to disseminate good practices and initiate virtuous joint actions on a larger scale than the GreenDiLT consortium.

2.3. Organization

The project was structured into five work packages (WP) as illustrated in **Figure 2**: project management (leader: Arts et Métiers), inventory of current practices (leader: Arts et Métiers), environmental impact assessment (leader: POLIMI), training (leader: ENPC), and dissemination (leader: AgroParisTech). Each institution was actively contributor to all work packages.

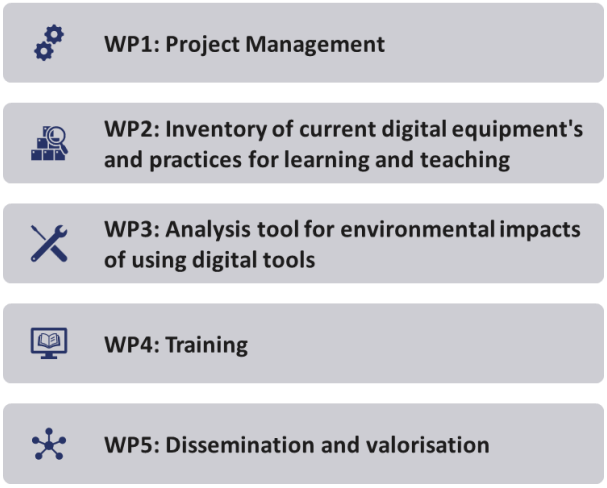


Figure 2: the GreenDiLT organization in five work packages.

The deliverables of some work packages were resources for other work packages. Hence, we started by conducting an inventory (WP2), based on a survey designed to collect information helpful for building teaching and learning scenarios that will serve as the basis for assessing their environmental impact in WP3. Later on, the process developed for assessing environmental impacts of digital practices using a life-cycle analysis (WP3) was inspiring for designing the training resources. Once these training resources were created (WP4), they were tested for further implementation thanks to the ambassador network created in WP5, and all our results were disseminated to ensure concrete changes on the ground. At the end, as illustrated in **Figure 3**, our final aim was to develop a toolkit that will help the stakeholders of our higher education communities to measure, train, support and ultimately improve digital learning and teaching practices.

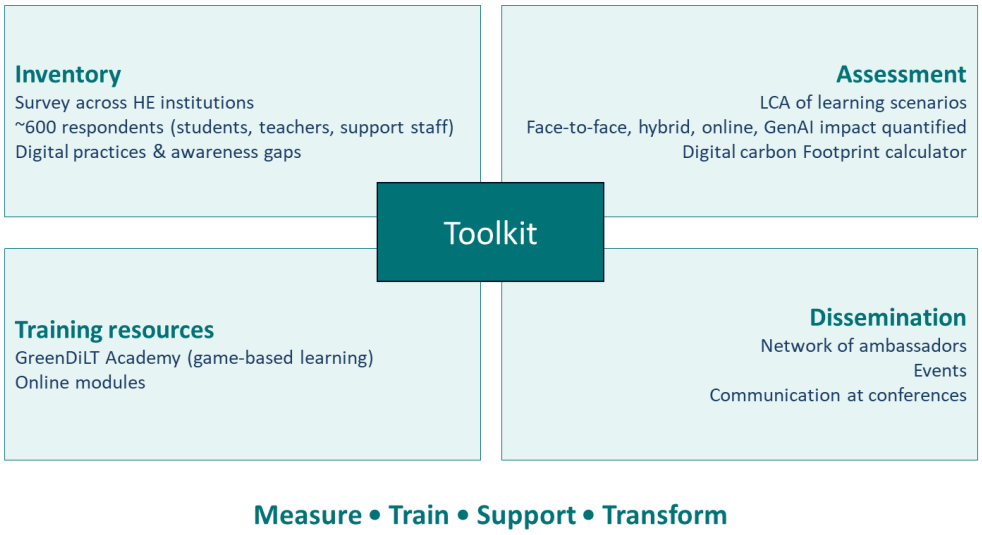


Figure 3: The overall GreenDiLT approach.

GreenDiLT Co-funded by the European Union

3. Inventory of digital practices

GreenDiLT first objective was to establish a baseline understanding of current digital practices within the five partner institutions involved in the project. Thus, a study was undergone to explore how educational stakeholders (students, teachers, and support staff) use digital equipment and services in their daily activities, while also examining their awareness, knowledge, and actions related to reducing the environmental impact of their digital practices.

3.1. Methodology for assessing digital practices

3.1.1. Digital survey

To conduct our study, we designed and created an online survey that examined different dimensions:

- Digital equipment practices, including the types of devices used, equipment renewal periods, purchasing practices, and end-of-life management;
- Digital resources and services, focusing on the resources used, content-sharing practices, and duration of use across different educational and professional contexts;
- Sustainability-related dimensions, including environmental awareness, training, self-assessed competencies, individual actions, and perceptions of institutional initiatives.

To reflect a range of different usage contexts, the survey included several user scenarios based on the participants' profiles. For teachers and students, these scenarios covered face-to-face teaching and learning situations (large groups, small groups, lab sessions), hybrid and distance modalities. For support staff, they were questioned about office and remote work situations.

Three versions of the questionnaire were developed—one for students, one for teachers, and one for support staff— in three different languages: English, French, and Italian. Although the core structure remained similar across versions, several questions were adapted to reflect profile-specific practices as illustrated in **Figure 4**.

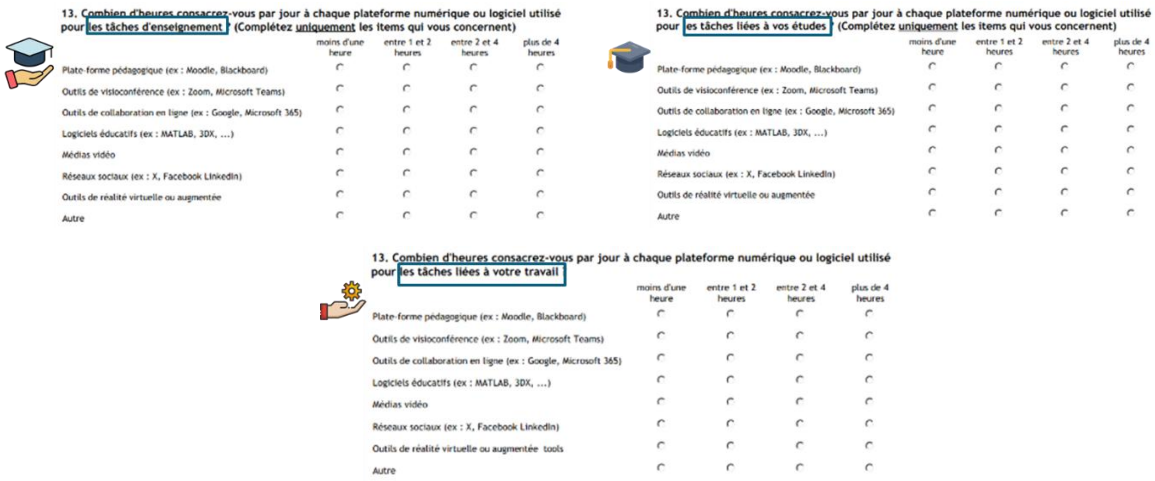


Figure 4: Extract of the GreenDiLT online survey (French version) showing how the same question was adapted to the respondent profile: teacher, student or support staff.

In total, the survey contained 32 questions, most of which were closed-ended. The open-ended questions focused on actions taken at the individual and institutional levels to reduce the environmental impact of digital technology use.

GreenDiLT Co-funded by the European Union

3.1.2. Dataset and treatment

Data collection took place between March and May 2024. The survey was distributed within each institution through institutional mailing lists, and participation was voluntary and anonymous, with no compensation nor retribution in return.

A robust dataset was obtained from 665 respondents across partner universities, which include Arts et Métiers, ENPC, AgroParisTech, POLIMI, TU Delft [1] as well as a few other institutions (39 answers) as illustrated in **Figure 5**. At the consortium scale students represent the largest respondent group (379 answers), followed by support staff (151 answers) and teachers (96 answers).

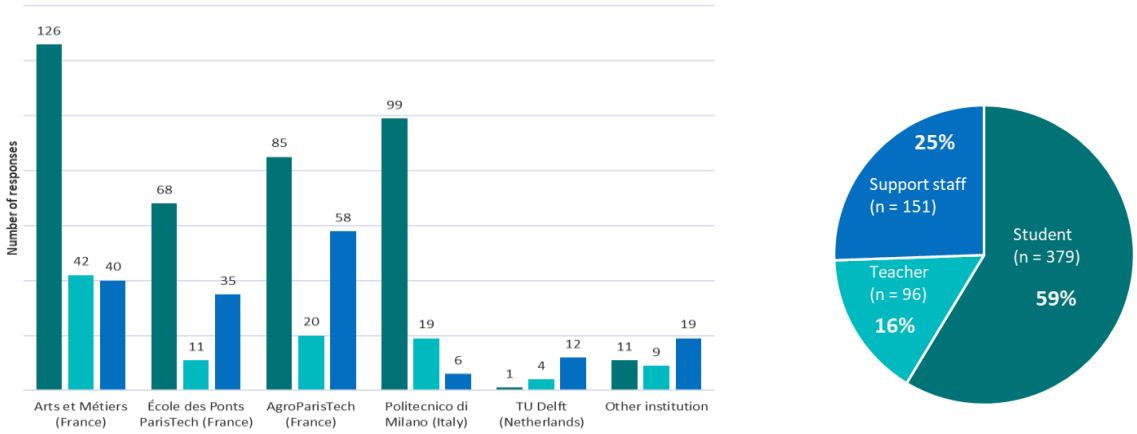


Figure 5: Number of respondents to our survey classified by institutions and profiles (students, teachers, and supports staff), and respective proportions of the three respondent profiles among the GreenDiLT partners.

The gender and demographic distribution were the following:

- Gender distribution: The sample consists of 41.7% women, 57.5% men, and 0.7% identifying as other.
- Age distribution: Reflecting the high proportion of students, the majority of respondents were between 20 and 30 years old (59.8%). Minorities were found in the under-20 category (2.6%) and over-60 category (2.8%). The remaining respondents were distributed uniformly between 11.1% (ages 30–40), 11.7% (ages 40–50) and 12.0% (ages 50–60).

After cleaning the dataset (i.e. removing partial answers), low-response categories (one respondent per profile and institution, or categories representing less than 5% of responses) were excluded to improve data reliability.

We have chosen to present the results in the white paper in aggregate form, without distinguishing between the partners. In fact, the results among the partners are quite similar.

3.2. Current digital practices

3.2.1. Equipment usage patterns

The results indicate widespread use of digital devices across all profiles, with clear similarities between institutions and usage contexts.

[1] Due to the limited sample size from TU Delft (17 respondents) compared to the French and Italian cohorts, the percentages for the Netherlands should be interpreted with caution and as localized trends rather than statistically representative generalization.

GreenDiLT Co-funded by the European Union



Teachers primarily use laptops, projectors, and display screens during face-to-face teaching activities, while students primarily use laptops and smartphones. In labs, laptops remain essential, although equipment use becomes more specialized depending on disciplinary needs.



Support staff report slightly different habits, characterized by greater use of double-screen configurations, headphones, networked printers, and smartphones. These practices appear closely linked to administrative tasks, remote collaboration, and hybrid work environments—for example, the use of professional applications on personal smartphones.

The survey also highlights the persistence of practices carried over from the post-pandemic period, particularly the intensive use of laptops, multiple screens, and videoconferencing tools.

3.2.2. Equipment replacement practices

Equipment replacement cycles reveal a significant impact of institutional policies, particularly for staff members (teachers and support staff) whose equipment is provided by their institution.



For teachers and support staff, most equipment replacement cycles exceed five years, suggesting that institutions are implementing strategies to extend the lifespan of equipment. However, a notable 26% teachers report renew their laptops every four years, likely due to research activities requiring more powerful hardware.



Students exhibit different patterns, as they generally purchase their own devices. Smartphones are replaced more frequently—typically every three to four years—while laptops are kept significantly longer, often beyond five years.

A notable finding was the limited knowledge among respondents regarding institutional equipment replacement policies. A significant proportion of support staff state they "Do not know" what the institutional renewal policy is, suggesting that institutional digital sustainability strategies are not always visible or well communicated.

3.2.3. Resources and services

Regardless of the institution or the participants' profiles, digital practices related to resources and services present a highly convergence.



Office documents, online resources, multimedia content, cloud services, and institutional platforms are widely used by all groups. Engineering software plays an important role in laboratories, reflecting the disciplinary requirements of engineering education. The use of immersive technologies such as virtual reality and augmented reality remains limited across all institutions, suggesting that these technologies have not yet become part of standard teaching practices.

In terms of content sharing, email and institutional cloud platforms have emerged as the dominant channels for all profiles. Learning management systems (LMS) play a central role for teachers and indirectly influence student practices, as students' use of LMS depends largely on teachers' pedagogical preferences.

These results suggest that institutional digital ecosystems have a strong influence on digital behaviors and serve as important levers for promoting more sustainable practices.

3.2.4. Knowledge and training

One of the strongest findings of our survey relates to the limited level of respondents' knowledge regarding sustainable digital practices. Across all participant profiles, most respondents reported having received no training related to sustainable digital practices in higher education. At the same time, they expressed a clear demand for a training opportunity.

An impressive 89% of respondents have never received training related to digital sustainability. However, there is a clear desire to learn, as 42% of them expressed a strong interest in this type of training. The country-level distributions were remarkably similar: 88% untrained in France (44% interested), 95% untrained in Italy (43% interested), and 95% untrained in the Netherlands (21% interested). Disparities were noted among professional profiles. Administrative and technical staff were completely absent from training initiatives on sustainability. For all other categories, including teachers and students, there was very little access to training.

Due to this lack of training, 31% of respondents reported having absolutely no knowledge, and 46% reported having limited knowledge on sustainable digital practices in higher education. Only a tiny minority (3% globally) claimed to have good knowledge, with IT staff scoring the highest (22% reported having good knowledge).

To address these gaps, respondents explicitly requested training resources on:



The environmental impact of daily digital tasks and specific sources of emissions linked to digital technologies



Circular economy concepts and sustainable data management



The design of eco-friendly products and concrete ecological practices adapted to teaching and learning practices.

3.2.5. Awareness of existing actions

There was a strong individual commitment to limiting the environmental impact of digital technology: 76% of respondents declared they were actively making personal efforts to reduce their digital environmental footprint. This proactive attitude was widespread: 84% in the Netherlands, 79% in Italy, and 76% in France. However, disparities emerged when analyzing roles: administrative staff and technical support staff reported making lowest effort (34% and 50%), followed by teachers (30%). Importantly, 91% of respondents declared themselves willing to change their digital habits if they were provided with adequate institutional resources and actionable advices.

Nearly half of the respondents in France (46%) and the Netherlands (53%) had no knowledge of what their university was doing regarding digital sustainability. In Italy, this lack of knowledge was accompanied by high interest, as 70% stated they did not know but would like to know what their institution implements. Where institutional actions were recognized, they were largely dominated by a single measure: limiting printing (heavily cited in France under "paperless" policies). Other initiatives,

GreenDiLT Co-funded by the European Union

such as implementing automated energy-saving modes, promoting renewable energy sources, or optimizing hardware recycling, remained not well known to respondents.

3.3. Discussion

3.3.1. General trends of digital practices

Our data show that students mainly use a laptop and their smartphone for their work (both in and out of the classroom); in some schools, tablets are also used by a number of them. This data highlights a trend observed over several years, namely the use of mobile devices to supplement learning outside the classroom (Ricardo-Barreto et al., 2020), bearing in mind that these devices are also increasingly used in the classroom. Laptops are very widespread amongst teachers, and their use now far exceeds that of desktop computers, whereas until very recently, the use of these two types of equipment by teachers was comparable (Ricardo-Barreto et al., 2020); the practice of remote working and distance learning since the Covid-19 pandemic may be a contributing factor, as may the policy of some of the schools surveyed to no longer purchase desktop computers. In face-to-face teaching, there is also widespread use of video projectors, as had already been observed in other schools (Ricardo-Barreto et al., 2020), whilst in distance learning, the use of headphones is common. The use of a second screen is observed among some teachers (both in and out of the classroom) as well as a printer (either a local or network printer) during the preparation phase.

In terms of environmental impact, in addition to the energy consumption of digital equipment, the use of resources during its production and its disposal at the end of its life are two key factors (Filho et al., 2024). Our results show that a significant proportion of teaching staff purchase refurbished or second-hand equipment, particularly laptops. It is interesting to note that this proportion is twice as high amongst students, probably for economic and/or environmental reasons. Overall, support staff appear to be less well informed about the purchasing and end-of-life conditions of the equipment they use, compared with students and teaching staff.

When it comes to digital resources, text files, spreadsheets and presentations remain the most commonly used in the classroom (whether face-to-face or remotely), closely followed by resources such as videos, animations, images and audio files, and then by links to online resources. Virtual reality remains a marginal practice amongst our respondents. In practical classes, the rate of use of engineering software is significantly higher, which makes sense as this software is often used to facilitate the running of these classes. These resources are still mainly shared between teachers by email and via a LMS, and to a lesser extent via the cloud. It is interesting to note that the use of the cloud is more widespread amongst support staff than amongst teachers.

3.3.2. Application of the Triple-S Framework to digital practices in education

To analyze data related to equipment and usage, we have adopted **the Triple-S framework**. Originally developed in the field of water resources, it has been recently adapted to the context of educational technology, with several criteria proposed and an interesting application to digital resources (Moro et al. 2023). We found relevant and innovative to use this theoretical framework in order to analyze digital practices related to learning and teaching in higher education institutions in terms of **Scalability, Sustainability and Serviceability**. That way we could examine not only patterns of use but also the long-term sustainability and maintainability of digital equipment and services.

We analyzed the characteristics and opportunities offered by the different equipment used based on different criteria addressing the Scalability, Sustainability and Serviceability. As illustrated in **Figure 6**,

shared equipment (such as printers, projectors) generally offers greater scalability because it can serve a large number of users. In contrast, personal devices raise concerns regarding repairability, software obsolescence, and individual support, which limit their sustainability and serviceability. Devices such smartphone, tablets, and laptops score low on repairability due to the presence of integrated components and a heavy reliance on support contracts provided by external service providers, which often leads to the generation of electronic waste rather than the local repair of equipment.

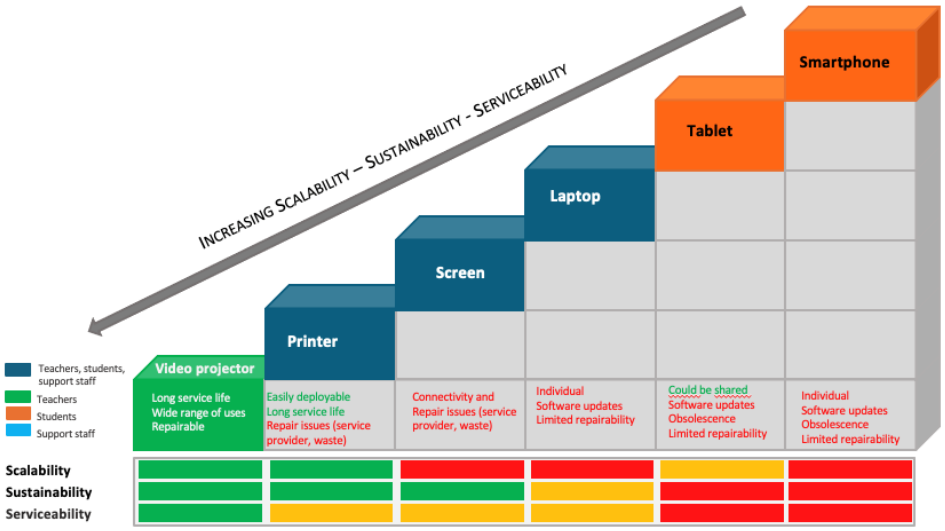


Figure 6: Comparative evaluation of equipment based on their scalability, sustainability, serviceability.

Regarding digital services, office documents, online resources, and LMS platforms tend to perform well in terms of scalability (see **Figure 7**), as they are widely deployable and accessible. In contrast, videoconferencing systems, cloud storage, specialized software, and immersive technologies raise sustainability concerns due to infrastructure requirements, storage needs, and energy consumption. Their level of serviceability is also limited because they require dedicated licenses and equipment.

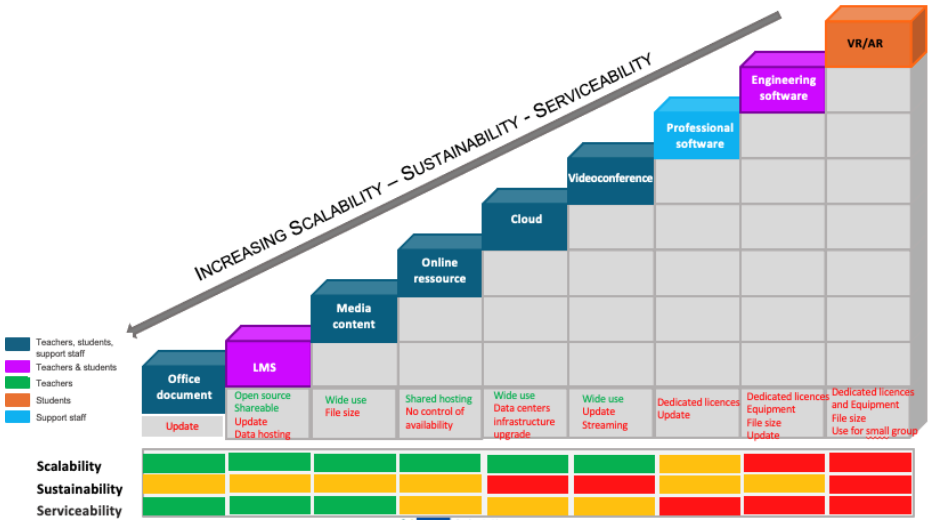


Figure 7: Comparative evaluation of resources and services based on their scalability, sustainability, serviceability.

The analysis also highlights the importance of institutional choices. Decisions regarding software ecosystems, equipment procurement, hosting infrastructure, and platform selection significantly influence the environmental impact of digital practices.

GreenDiLT Co-funded by the European Union

Finally, the application of the Triple-S framework to digital equipment and resources was found valuable. It provided additional insight into the sustainability challenges associated with digital practices, and it should help higher education institutions to address a checklist of criteria to take into account before promoting digital practices within their community.

3.3.3. Identification of good practices at the individual or institutional level

The open-ended responses collected from our survey allowed us to categorize good practices at the individual level into three main categories as detailed in **Table 1**.

Table 1: Classification of individual good practices mentioned by our respondents.

Hardware & Equipment 	• Turning off equipment: Systematically powering down devices at night or during long breaks rather than leaving them on standby • Extending device lifespan: Maximizing usage duration, performing repairs, and upgrading components (e.g., adding RAM) • Unplugging devices and removing chargers
Daily Digital Practices 	• Eco-mode: Activating power-saving modes on devices. • Brightness management: Lowering screen brightness to save battery and increase hardware longevity • Efficient email management: Cleaning up inboxes, deleting large attachments, and substituting attachments with download links
Internet & Cloud Usage 	• Reducing cloud storage: Localizing data storage on internal servers or hard drives, and actively cleaning up cloud spaces. • Network optimization: Preferring Wi-Fi or Ethernet connections over mobile data (3G/4G/5G).

Based on the feedback and suggestions gathered from stakeholders, we have also identified three categories of recommendations for institutions in order to improve practices within their community as indicated in **Table 2**.

Table 2: Recommendations for institutions to improve digital practices.

Train stakeholders	• Focused training: Implement mandatory training modules on eco-friendly digital practices, specifically including administrative and support staff • Awareness campaigns: Design sustainable institutional campaigns focused on the hidden impacts of technology (e.g., the manufacturing phase versus data storage) • Co-development workshops: Organize collaborative workshops to share best practices in IT equipment management and carbon footprint reduction
Best practices easy to implement	• Automated power-off: Deploy centralized IT policies that automatically shut down computers, monitors, and audiovisual equipment during non-business hours and at night • Purchasing and lifespan: Prioritize the purchase of energy-efficient devices that are easily repairable or refurbished and commit to extending the lifespan of equipment beyond standard replacement cycles
Sustainable actions	• Eco-friendly email policies: Institutionalize guidelines promoting responsible use of email (limiting attachments, cleaning up archives) • Data cleanup days: Organize dedicated institutional days allowing staff and students to clean up cloud storage spaces and shared drives, in order to limit unnecessary server load • Optimizing paper use: Promote balanced strategies for paper use, for example by encouraging the use of reusable physical documents when digital distribution leads to high energy consumption or cognitive fatigue

GreenDiLT Co-funded by the European Union

4. Assessing the impact of the digital practices

4.1. Choice of the methodology based on bibliography

4.1.1. Why assess the environmental impact of educational models?

Over the last decade, the increasing adoption of online, hybrid, and blended learning models has profoundly transformed higher education systems worldwide. While numerous studies have assessed the environmental impacts of universities and higher education institutions, only a limited number have systematically compared the environmental performance of different teaching modalities using standardized assessment methodologies.

As digital technologies become increasingly embedded in educational processes, understanding the environmental implications of alternative teaching models is essential for supporting evidence-based sustainability strategies within higher education institutions.

4.1.2. Overview of assessment approaches

The literature identifies three main approaches for assessing the environmental impacts of educational activities as indicated in **Table 3** (Sarti, 2025).

Table 3: The three main approaches reported in the literature for assessing the environmental impacts of educational activities.

Approach	Main characteristics	Strengths	Limitations
GHG Protocol	Carbon accounting based on scope 1, 2, and 3 emissions	Standardized reporting framework	Limited life-cycle perspective
Ad-hoc Models	Survey- and statistics-based assessments	Easy implementation and customization	Limited comparability across studies
Life Cycle Assessment	ISO 14040-compliant life-cycle approach	Comprehensive, systematic, and replicable	Data-intensive and methodologically complex

The literature review shows that only approximately 25% of the studies employ Life Cycle Assessment. Moreover, the few comparative studies available (e.g., Lopes Silva et al., 2021; Giusti et al., 2023) provide valuable insights but are often limited to specific courses, departments, or institutional contexts.

4.1.3. Rationale for adopting life cycle assessment

Life Cycle Assessment (LCA) was selected as the most suitable methodology because it (Sarti, 2025):

- represents the most established framework for comparative environmental assessments;
- considers the full life cycles of products and processes, and it can integrate both physical and digital infrastructures, transportation, energy consumption, ICT devices, and digital platforms within a single analytical framework;
- enables the development of a replicable model applicable across different educational institutions.

The literature consistently identifies transportation, energy consumption and ICT infrastructure as the most relevant variables influencing the environmental performance of educational systems. Consequently, these elements were incorporated into the assessment framework developed in this study.

4.2. Methodology adopted

All details are given in **Appendix 2** at the end of this report. Main features are gathered below.

4.2.1. Goal and scope

The objective of this study is to compare the environmental impacts associated with different teaching modalities using empirical data collected from the Department of Management Engineering at Politecnico di Milano. The assessment was conducted following the ISO 14040 and ISO 14044 standards for Life Cycle Assessment.

4.2.2. Functional unit

The functional unit has been defined as: “One student attending 10 hours of lectures and performing 15 hours of independent study activities”.
This functional unit (overall 25 hours per student corresponding to around 1 ECTS credit) enables a direct comparison among alternative educational delivery models while ensuring consistency across scenarios.

4.2.3. System boundaries

The study adopts a **cradle-to-gate** approach, that includes the following processes:

- production and use of ICT devices;
- university facilities and infrastructure;
- household energy consumption;
- data transmission and digital services;
- student and staff commuting;
- educational platforms, streaming, and recording systems.

In the meantime, several processes were excluded in this approach:

- end-of-life treatment of waste and in particular of electronic devices;
- construction of university buildings;
- institutional activities not directly related to teaching and learning;
- other processes not mentioned in the previous list (e.g. food consumption).

4.2.4. Educational scenarios

Seven educational scenarios were assessed, built based on the data collected from our survey presented initially in this document. They are detailed in **Table 4**.

Given the growing adoption of AI-supported learning tools, the study also includes an exploratory assessment of the environmental impacts associated with the use of Generative Artificial Intelligence in educational activities (additional scenario).

The analysis considers the energy consumption and digital infrastructure required to process interactions with large language models and AI-based learning systems.

The **Figure 8** gathers the scenarios 1 to 3 considered in this study, and the additional scenarios integrating GAI.

Table 4: Educational scenarios considered in this work.

 **Scenario 1 – Fully face-to-face** All teaching activities are delivered in person.	 **Scenario 2 – Hybrid** (75% in-person + 25% streaming/recording) This scenario combines predominantly on-campus teaching with partial remote participation.	 **Scenario 3 – Fully online synchronous** All lectures are delivered through live-streaming platforms.	 **Scenario 4 – Hybrid with streaming** In-person teaching combined with synchronous remote participation.
 **Scenario 5 – Hybrid with recorded content** In-person teaching combined with asynchronous access to recorded lectures.	 **Scenario 6 – Blended learning** A structured combination of face-to-face and online learning activities.	 **Scenario 7 – Fully online asynchronous** All teaching activities are delivered through recorded educational content.	 **Additional scenario – Generative AI**

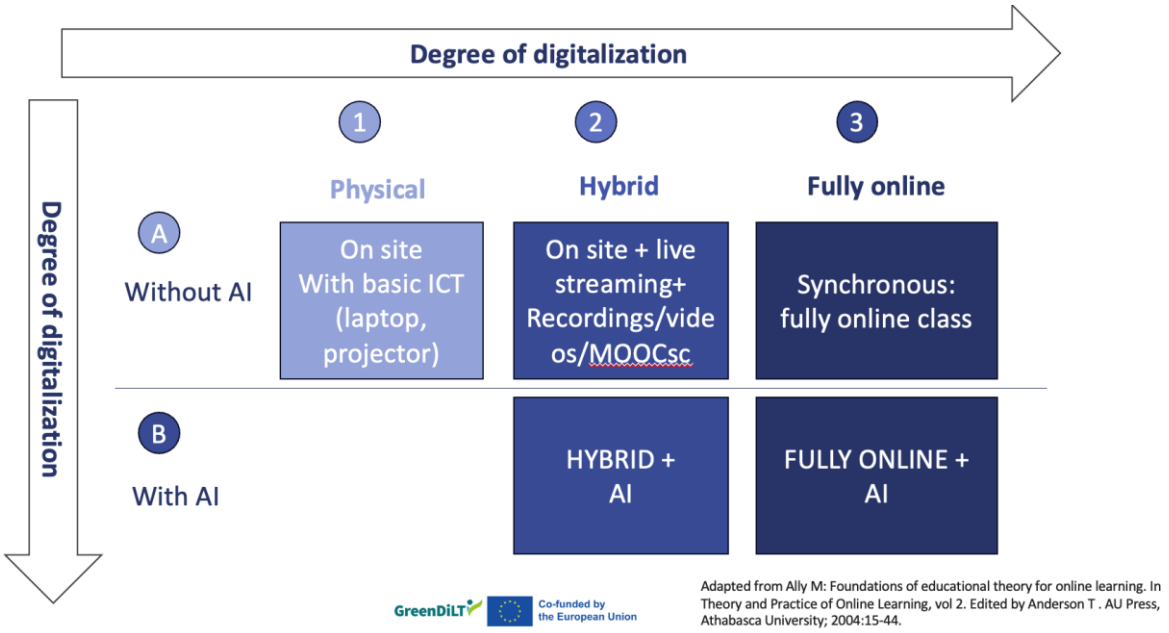


Figure 8: Main assessed scenarios with different degrees of digitalization.

4.3. Results and discussion

4.3.1. Scenarios' comparison at POLIMI

The results reveal substantial differences among educational models as shown in **Table 5** (Sarti, 2025). The fully online scenario reduces greenhouse gas emissions by approximately 65% compared with conventional face-to-face teaching.

These findings confirm that educational digitalization can generate significant environmental benefits, particularly when transportation requirements are reduced.

Table 5: Carbon footprint of the educational scenarios assessed through LCA at POLIMI.

Scenario		Details	Total Emissions (kg CO_2 eq per student)	Reduction vs. Face-to-face
1		Fully face-to-face	17.0	–
2		Hybrid (75% in-person + 25% online)	14.3	- 16%
6		Blended learning	11.2	- 34%
3		Fully online synchronous	5.87	- 65%
7		Fully online asynchronous	5.75	- 66%

4.3.2. Main environmental hotspots

Transportation

Transportation represents the dominant environmental hotspot in traditional educational settings. Approximately 85.2% of total emissions in the face-to-face scenario are attributable to student commuting as illustrated by total emissions given in **Table 6**. This result is consistent with previous international studies identifying mobility as the primary contributor to the carbon footprint of higher education activities.

Energy Consumption

While online learning substantially reduces transportation-related emissions, it shifts part of the environmental burden to domestic energy consumption. The analysis indicates a **+77% higher household energy consumption** compared with the face-to-face scenario. This highlights the importance of considering rebound effects and indirect energy consumption when evaluating digital learning models.

ICT Infrastructure

Although ICT-related impacts remain lower than transportation impacts, their relative contribution increases significantly as educational models become more digitalized. Digital devices, network infrastructure, cloud services, and data transmission therefore become increasingly relevant environmental considerations in hybrid and online learning environments.

GreenDiLT Co-funded by the European Union

Table 6: Carbon footprint of the face-to-face and hybrid educational scenarios assessed with or without transportation at POLIMI.

Scenario		Details	Total emissions (kg CO_2 eq per student)
1		Face-to-face	17.00
1bis		Face-to-face (excluding transportation)	2.51
2		Hybrid (75% in-person, 25% streaming and recording)	14.30
2bis		Hybrid (75% in-person, 25% streaming and recording) – excluding transportation	3.43

4.3.3. Environmental impact of generative AI

One of the most relevant findings concerns the environmental implications of Generative Artificial Intelligence. So, scenarios 2 and 3 have been implemented to include the use of GAI as additional scenarios to assess.

As shown in **Table 7**, the study estimates **0.4 kg CO_2 eq for 125 AI queries** which corresponds to approximately twice the impact associated with 10 hours of live-streaming educational activities.

Table 7: Carbon footprint of the face-to-face and hybrid educational scenarios assessed with or without GAI at POLIMI.

Scenario		Details	Total emissions (kg CO_2 eq per student)
2		Hybrid (75% in-person, 25% streaming and recording)	14.30
2-GAI		Hybrid (75% in-person, 25% streaming and recording) – including GAI	14.70
3		Fully online synchronous (live streaming)	5.87
3-GAI		Fully online synchronous (live streaming) – including GAI	6.27

Although still exploratory, this result highlights the need for greater awareness regarding the environmental footprint of AI-supported learning tools and suggests that future educational sustainability assessments should explicitly account for AI-related impacts.

GreenDiLT Co-funded by the European Union

4.3.4. Scenarios' comparison at other institutions

The results obtained by POLIMI were compared with the results of other GreenDiLT partner institutions, namely ENPC, AgroParisTech and Arts & Métiers (ENSAM) (Riffiod & Montfort, 2026). The partner institutions, using the survey questionnaire data and bibliographic resources, through the LCA method, assessed and quantified the environmental impacts of different educational strategies at the, ranging from fully on-site learning to fully remote lessons.

Data obtained as presented in **Table 8** and **Figure 9**.

Table 8: Global warming potential comparison across GreenDiLT partner institutions.

Institution	Campus	Scenario 1 on-site (kg CO_2 eq/FU)	Scenario 2 remote (kg CO_2 eq/FU)	S1/S2 ratio
POLIMI	Bovisa	17.00	5.87	2.90
ENPC	Champs-sur-Marne	7.077	4.369	1.62
AgroParisTech	Palaiseau	14.20	4.48	3.17
ENSAM	Chambéry	22.70	2.87	7.91

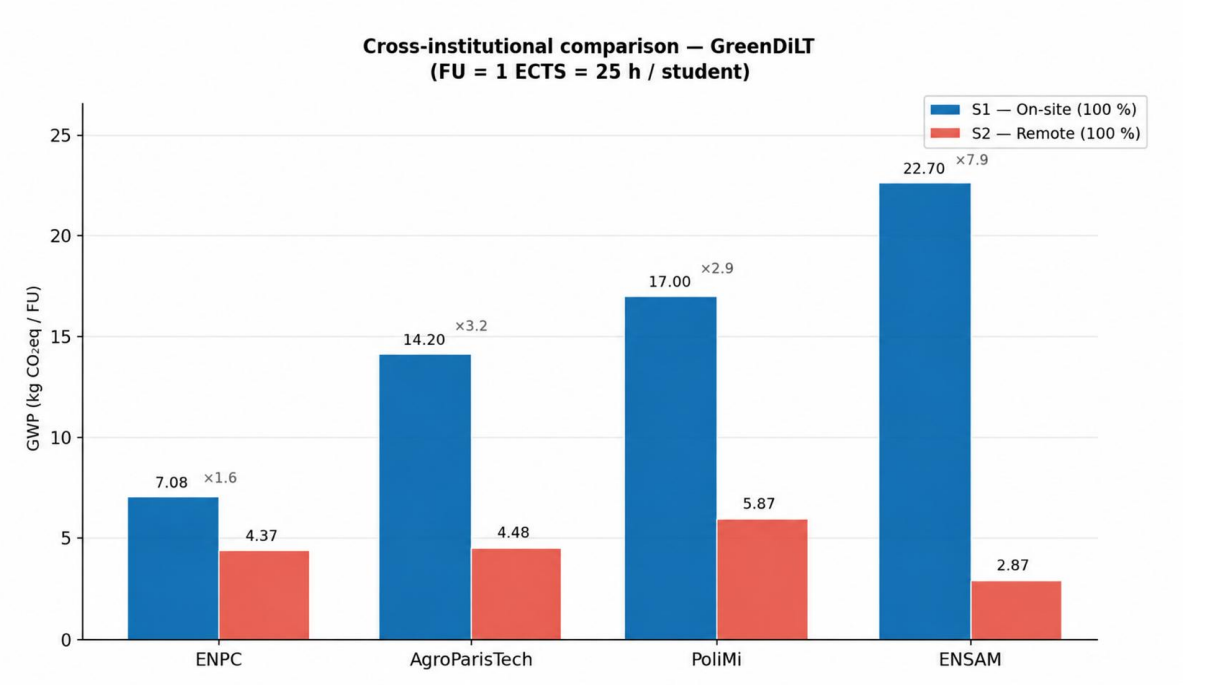


Figure 9: Global warming potential per FU for each institution and scenario. The remote modality is preferable across the consortium. ENPC has the lowest S1/S2 ratio (1.62), reflecting its uniquely low transport footprint.

With 7.077 kg CO_2 eq, ENPC produces the smallest on-site carbon footprint of all four institutions, 2 times lower than AgroParisTech (14.20), 2.4 times lower than POLIMI (17.00) and 3.2 times lower than ENSAM (22.70). This exceptional performance is driven by the modal structure of student commuting: 74.3% of students walk to campus, a figure that is structurally impossible at institutions with dispersed urban or peri-urban student populations. Besides, the French nuclear-dominated electricity mix further suppresses campus energy emissions relative to Italy (≈52 vs. ≈230 g CO_2 eq/kWh in 2023), giving ENPC an additional advantage in the campus energy sub-process. In this specific case the relative

GreenDiLT Co-funded by the European Union

benefit of switching to remote learning is smallest at ENPC, even though the conclusion is the same: remote is preferable from the point of view of environmental impact.

The comparison of the remote learning scenario (S2) was further performed across partner institutions as indicated in **Table 9**.

Table 9: Domestic energy vs. ICT contribution across institutions for remote scenario (S2).

Institution	Total S2 (kg CO_2 eq/FU)	Domestic energy (kg CO_2 eq/FU)	Share (%)	ICT + Streaming (kg CO_2 eq/FU)
POLIMI	5.870	4.510	76.8%	0.719
ENPC	4.369	2.221	50.8%	2.018
AgroParisTech	4.480	2.603	58.1%	1.887
ENSAM	5.580	–	–	–

This comparison highlights notable differences in the contribution of domestic energy consumption and ICT-related activities. Total S2 impacts range from 4.369 kg CO_2 eq/FU for ENPC to 5.870 kg CO_2 eq/FU for POLIMI. Domestic energy use represents the largest share of impacts in all cases, accounting for approximately 51% of total emissions at ENPC, 58% at AgroParisTech, and as much as 77% at POLIMI. Conversely, the contribution of ICT equipment and streaming activities is relatively stable in absolute terms for ENPC and AgroParisTech (around 1.9–2.0 kg CO_2 eq/FU), but substantially lower for POLIMI (0.719 kg CO_2 eq/FU). These results indicate that the environmental performance of remote education is strongly influenced by local electricity consumption patterns and household energy requirements, while ICT-related emissions, although significant, play a secondary role in determining overall impacts. The particularly high share of domestic energy observed for POLIMI suggests that household electricity use is the dominant hotspot in the remote learning scenario.

The GAI contribution (0.89% of S1 and 1.44% of S2 at ENPC) is now non-negligible under the updated electricity mix assumption. It remains considerably lower than POLIMI's estimate of 6.34% in S2, which uses the Italian grid mix (≈230 g CO_2 eq/kWh). This contrast illustrates the decisive role of the data-center electricity mix.

4.3.5. Implications for sustainable education

The findings suggest that no single educational model can be considered universally optimal. Rather, environmental performance depends on how educational systems are designed and managed (Pinzone et al., 2026; Sarti, 2025).

For conventional face-to-face education, the most effective mitigation strategies involve reducing transportation-related emissions through:

- incentives for public transportation use;
- promotion of cycling, bike-sharing, and car-sharing schemes;
- flexible attendance policies allowing remote participation when appropriate;
- compact timetables that reduce commuting frequency;
- intensive teaching weeks and block scheduling approaches;
- prioritization of on-campus attendance for high-value activities such as laboratories, workshops, and practical sessions.

Stable and predictable academic schedules can further reduce unnecessary travel by enabling more efficient mobility planning.

GreenDiLT Co-funded by the European Union

For online and hybrid education, sustainability efforts should focus on improving energy efficiency in home learning environments. Universities can support students by promoting energy-efficient devices, responsible energy consumption practices, and awareness of the environmental implications of digital technologies.

The growing adoption of Generative AI also requires dedicated sustainability strategies. Educational institutions should encourage responsible AI use, support efficient digital infrastructures, and prioritize low-carbon data centers powered by renewable energy sources.

Overall, sustainable educational planning should seek a balance between educational effectiveness, accessibility, social value, and environmental performance.

4.3.6. Implications for sustainable educational planning

The results of this study suggest that environmental considerations should be systematically integrated into educational planning and decision-making processes within higher education institutions (Pinzone et al., 2026).

For conventional face-to-face education, transportation emerged as the dominant environmental hotspot, accounting for the largest share of total emissions. Consequently, the most effective mitigation strategies are those aimed at reducing mobility-related impacts. These include incentives for the use of public transportation, the promotion of car-sharing and bike-sharing schemes, and the adoption of flexible attendance policies that allow remote participation when physical presence is not strictly required.

Organizational measures can further contribute to emission reductions. Compact timetables, which concentrate teaching activities within fewer days per week, can decrease the frequency of student commuting. Similarly, intensive teaching weeks or block scheduling approaches can reduce the repetition of travel over extended periods. Limiting mandatory on-campus attendance to activities with high educational added value—such as laboratory sessions, workshops, and practical exercises—while providing greater flexibility for lecture-based activities may further reduce transportation demand, particularly for students living far from campus. In addition, stable and predictable academic schedules can support more efficient travel planning and minimize unnecessary journeys caused by timetable changes.

The analysis also highlights that the environmental benefits of online education are accompanied by a shift in impacts from transportation systems to domestic energy consumption and digital infrastructures. Therefore, universities should complement digitalization strategies with initiatives aimed at improving energy efficiency in home learning environments. Practical recommendations may include guidance on the use of energy-efficient devices, optimization of screen settings, and responsible management of heating, cooling, and lighting systems during remote study activities.

Another emerging issue concerns the environmental footprint of digital technologies themselves. While ICT-related impacts remain lower than transportation impacts in most scenarios, their relative importance increases significantly as educational models become more digitalized. Particular attention should be paid to the growing adoption of GAI tools. Although GAI can enhance learning experiences and educational effectiveness, its increasing use may generate non-negligible environmental burdens associated with data processing and computing infrastructure. To maximize benefits while limiting environmental impacts, higher education institutions should promote responsible GAI use, encourage efficient prompting practices, and support the adoption of low-carbon digital infrastructures, renewable-energy-powered data centers, and optimized GAI models.

Overall, the findings indicate that sustainable educational strategies should not be framed as a simple choice between face-to-face and online learning. Rather, they should aim to identify balanced educational configurations capable of combining pedagogical effectiveness, social value, and environmental performance.

4.4. Limitations and future research directions

Despite providing one of the first comprehensive Life Cycle Assessment comparisons of multiple educational scenarios characterized by different levels of digitalization, several limitations should be acknowledged (Pinzone et al., 2026).

First, the analysis was constrained by the availability of primary data. Updated information on mobility patterns, detailed distinctions among transportation modes, and precise estimates of domestic energy consumption were not always available. Similarly, actual device usage times during teaching and self-study activities could only be estimated, and the analysis did not include a complete cradle-to-grave assessment of digital devices.

Second, the study focuses exclusively on environmental performance and does not consider social and educational dimensions. Previous research suggests that online and hybrid learning may influence student engagement, learning outcomes, social interaction, and well-being. Future studies should therefore adopt a more holistic sustainability perspective by integrating environmental, social, and educational indicators.

Further research is also needed to better understand the environmental implications of rapidly evolving digital technologies, including GAI, whose contribution to educational emissions is expected to grow in the coming years. Expanding the analysis to include the full life cycle of digital devices and alternative end-of-life scenarios would provide an even more comprehensive understanding of the sustainability implications of digitally enhanced education.

5. Towards improved digital practices

As detailed in section 3., data collected from our respondents have clearly shown a lack of knowledge related to responsible digital practices and the importance of assessing the environmental impacts of digital usages. In addition, most of our respondents were willing to be trained about these issues, in order to be informed and prone to improve their digital practices.

Consequently, we have conceived three ways of training our higher education community, that are complementary:



Digital resources, available on Moodle platform under the license Creative Commons Attribution – NonCommercial - NoDerivatives 4.0 International (CC BY-NC-ND 4.0)



A board game, with material available under digital format for free printing under the license Creative Commons Attribution – NonCommercial - NoDerivatives 4.0 International (CC BY-NC-ND 4.0)



An ambassadors' network, created by the GreenDiLT project partners, with explaining sheet and feedback freely available on demand.

These training modalities are detailed below.

5.1. The GreenDiLT online training modules

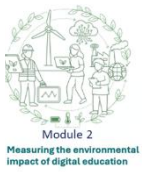
The first way we chose to train our community relies on a set of open digital resources, brought together in a Small Private Online Course (SPOC) and shared freely on the Moodle platform of each partner under the Creative Commons CC BY-NC-ND 4.0 license. The idea grew out of the benchmark we ran at the start of the work package: sustainability is already well covered across the consortium, but the specific question of digital practices in teaching and learning was rarely addressed, which convinced us that a dedicated course was needed.

We built the SPOC so that anyone can follow it without prior knowledge of environmental science or life cycle assessment — teachers, student, support staff, managers in charge of digital strategy, and more generally anyone in a university who wants to understand the subject.

The course is made of three short interactive modules as illustrated in **Figure 10**. They follow a simple thread — define, measure, then limit — each lasting about one to two hours:



The **first module, 'defining',** helps learners picture what the digital world of a university is really made of and reads it through the LES model (Levels of Environmental Sustainability), which separates impacts into three levels: (i) the direct effects tied to manufacturing and using equipment, (ii) the indirect effects that follow from our behaviours, and (iii) the systemic effects that depend on institutional choices



The **second module, 'measuring',** introduces LCA in a simplified form, following its main steps — setting the goal and the functional unit, drawing up the inventory, assessing the impacts and interpreting the results — and puts real orders of magnitude on them through the GreenDiLT case study carried out at POLIMI



The **third module, 'limiting',** distinguishes two complementary paths, digital efficiency (doing the same with less) and digital sobriety (questioning the need itself), and organises concrete actions around the 5R logic — refuse, reduce, reuse, repair, recycle — while showing the levers a university can pull at its own level.

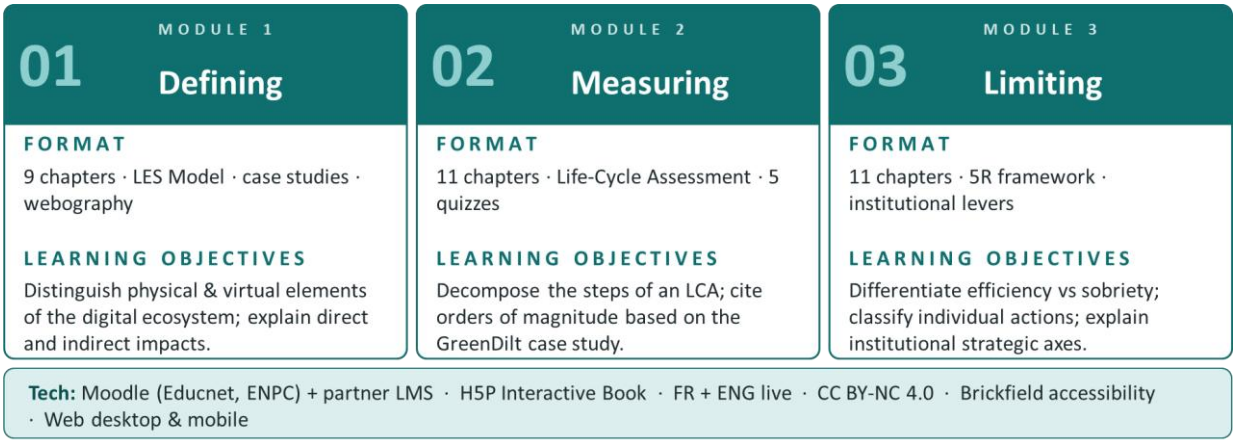


Figure 10: Illustration of the GreenDiLT SPOC freely shared on the Moodle platform.

The modules are available in French and in English, with care taken over accessibility, and can be followed on a computer or a phone. Screenshots of two videos are given in **Figure 11** to give an idea of the content proposed in this SPOC.

After the first sessions, 152 people had signed up (88 in French, 64 in English) and worked through the three modules in 330 attempts. The feedback gathered at the end was warm: an average score of 3.65 out of 4, close to 91% satisfaction. Learners felt the content matched its stated goals very well (at least 3.86 out of 4), and pointed to the quiz questions as the part that still needs work (3.0 to 3.3 out of 4), which we are now revising. As often happens with open courses that no one is obliged to finish in order, few learners went through every module, but registrations should keep rising now that the resources remain freely available on the partners' platforms.

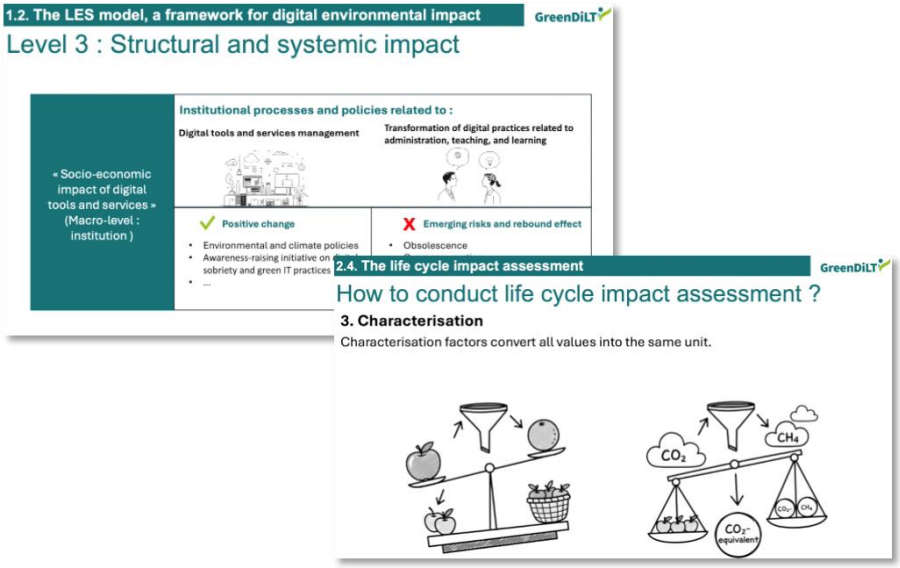


Figure 11: Screenshots of two videos from the GreenDiLT online modules.

5.2. GreenDiLT Academy: the board game

The second way of training is meant to be lived together, in the same room: GreenDiLT Academy, a board game for six to eight players split into two teams. Each player joins a fictional academy and tries, alongside the others, to deal with the environmental impacts of digital technology in their institution. The game has two aims — to open people's eyes to responsible digital issues, and to push them to spot and adopt concrete actions they could carry back to their own workplace. The material can be downloaded and printed for free under the Creative Commons CC BY-NC-ND 4.0 license.

Each team follows two opposite tracks as illustrated in **Figure 12**: one for Sustainability (a green pawn) and one for Impact (an orange pawn), a layout that makes the central idea tangible — every digital choice feeds one or the other. A turn has three moments. First the team draws a Problem card and moves its Impact pawn forward, then picks up a handful of collective action cards. Next, each player plays an individual action card to advance the green pawn and answers a quiz question to earn resource tokens. Finally, the team spends those tokens to put its collective actions into play, moving the green pawn further along. Landing on a star square draws an Event card — a challenge, a bonus or a penalty — and when the game ends, the team whose green pawn has travelled furthest wins.

GreenDiLT Co-funded by the European Union

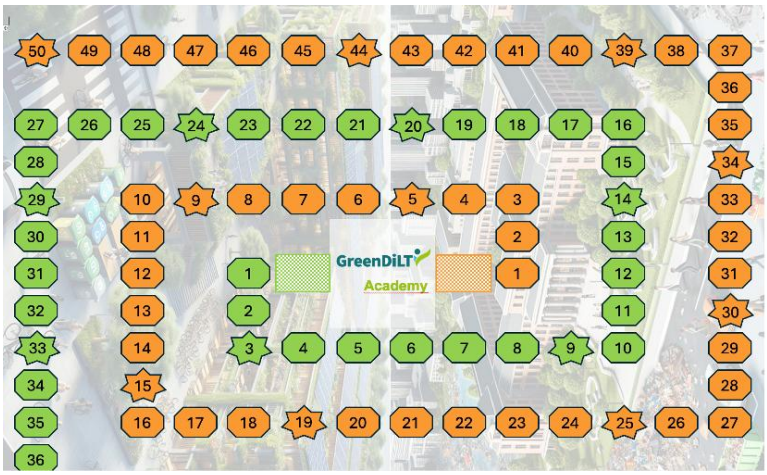


Figure 12: The GreenDiLT Academy board game.

The cards cover ten everyday problems of digital technology in education, from planned obsolescence and electronic waste to overconsumption, received ideas, power-hungry infrastructure, the energy used by devices and by online services, our dependence on screens, courses designed without thought for their footprint, and questionable digital practices. Each one can be tackled at two levels at once: collective actions that belong to the institution — extending the life of equipment, donating or pooling devices, recycling, adding environmental clauses to purchases, choosing energy-saving equipment or renewable power — and individual actions within everyone's reach — looking after your devices, switching them off, cutting down on emails and screens, printing responsibly, favouring low-tech activities or using open-source software. Examples of cards are shown in **Figure 13**. Behind the cards lie the same notions taught online — the 5R, sobriety rather than mere efficiency, and the distinction between direct and indirect impacts — but here they are met through play. At the end, a table linking each problem to the actions that solve it best turns the game into a structured moment of discussion.

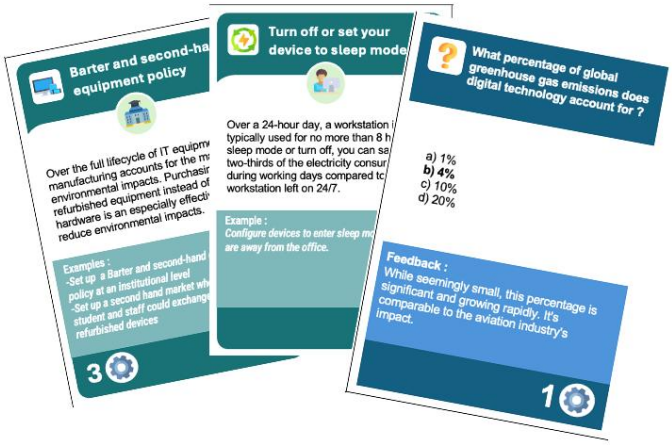


Figure 13: Action and quiz cards of GreenDiLT Academy.

The game was not designed in one go: it went through three versions shaped by the players themselves. The first, in early 2025, set out the cards and the basic rules and was tried in French; the second, in June 2025, tidied up the rules and rebalanced the scoring and was played in English; the third, in November 2025, came with rewritten cards, a redesigned board, an event system and challenges between teams.

GreenDiLT Co-funded by the European Union

Over seven sessions, 89 people played. The reception was excellent — between 93% and 100% rated it good or very good, and remarkably steadily from one version to the next. More importantly, players felt they had learned something: on average they placed themselves 1.7 points higher on a ten-point scale after playing (from 5.7 to 7.2 in March, 6.3 to 8.1 in the English session, and 6.1 to 7.8 in November). Versions in other languages are now being prepared so that the game can travel beyond the project.

5.3. Key concepts for grasping environmental impacts

Both training modalities rest on a small set of concepts chosen to give stakeholders a reading of the environmental impacts of digital technology that stays simple to grasp yet complete enough to act on. Rather than overwhelming learners with technical detail, the course and the game introduce four complementary keys: a model to locate impacts, a method to measure them, and two principles to reduce them.

5.3.1. The LES model

The first key is the LES model (Levels of Environmental Sustainability), which sorts the impacts of digital technology into three levels as illustrated in **Figure 14**:

- The first level gathers the direct impacts, those of the natural resources, energy and materials needed to manufacture, power and dispose of equipment;
- The second level covers the indirect effects that flow from the way users behave — the time spent online, the volume of data exchanged, the rate at which devices are renewed;
- The third level concerns the systemic effects driven by institutional policies, from purchasing rules to infrastructure choices.

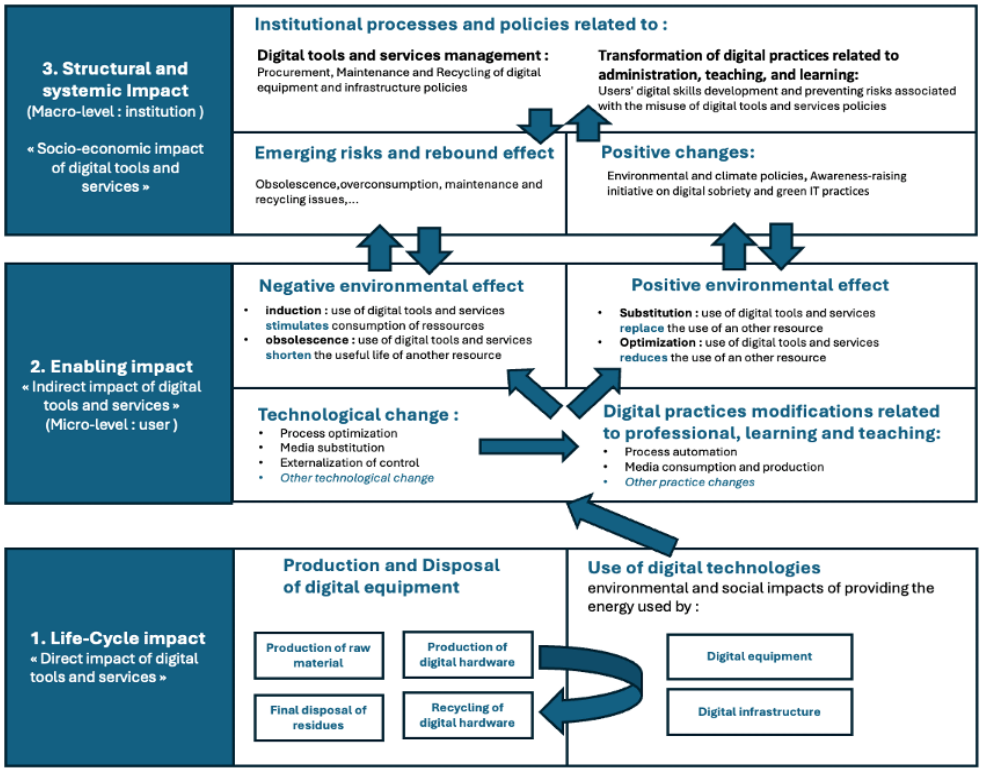


Figure 14: The LES model (adapted from Hilty and Aebischer, 2015).

GreenDiLT Co-funded by the European Union

Placing a given practice on this ladder helps each person see where their own room for manoeuvre lies, and reminds everyone that the most visible gestures are not always the most important.

5.3.2. The LCA methodology

The second key is life cycle assessment (LCA), presented in a deliberately simplified form through the GreenDiLT study carried out at Politecnico di Milano. Learners follow its logic, step by step: a clear question, a functional unit that makes scenarios comparable — here, one student attending ten hours of lectures and fifteen hours of independent study — a perimeter of what is counted and what is left out, and finally the comparison of results. The Politecnico figures give the method flesh: moving from a fully face-to-face model to a fully online one cuts greenhouse-gas emissions by roughly 65%, mostly because commuting all but disappears, while part of the burden shifts towards home energy use and digital infrastructure. The aim is less to memorise numbers than to understand that an honest comparison depends entirely on what is being measured and on the boundaries one chooses to draw.

5.3.3. Digital sobriety and digital efficiency

The last two keys are principles for acting. Digital sobriety asks the prior question — do we really need this use, this device, this resource? — and is placed ahead of digital efficiency, which seeks to do the same thing with less. The two are complementary, but sobriety comes first because efficiency gains are easily cancelled out by rebound effects. These principles are then made operational through the 5R — refuse, reduce, reuse, repair and recycle — a simple ladder that ranks actions from the most effective, refusing or reducing a use, down to recycling, which only deals with what could not be avoided. Together, the LES model, a simplified LCA, sobriety and the 5R give stakeholders a shared and accessible language to discuss a subject that is too often felt to be abstract and technical.

5.4. Key insight of the training

Two main insights emerge from the two modalities once they are taken together. The first is that the issue of environmental impact of digital technology is not a simple topic. The direct impact lies at different levels: the manufacturing of equipment, its daily use, and the networks and data centers behind online services. They do not all behave in the same way: reducing one can quietly increases another, as when replacing travel with online teaching shifts emissions from transport towards home energy and digital infrastructure. Highlighting this reality prevents learners against false good ideas and against the belief that a single ’green’ solution exists, by revealing hidden aspects and rebound effects that remains most of the time hidden.

The second insight is to stay practical. Teachers face a real contradiction: their institution pushes them to digitalise their courses for innovation, openness and accessibility, and at the same time asks them to cut their environmental footprint. The two goals often pull in opposite directions. The training names this tension instead of hiding it, so that a digital tool is chosen for what it really brings, not by habit. It also makes clear that the environmental side is rarely the only thing that matters: it has to be thought about together with how people learn and how the institution works, or it simply won’t stick. In the end, sustainability is never only about the environment — it also has to fit teaching quality, social value and accessibility, which is why no single way of teaching is best in every case.

Finally, both the course and the game insist that individual and collective actions only bear fruit when they are coordinated. Everyday gestures — switching off a device, keeping it longer, limiting unnecessary uses — matter, but they soon reach their limit without the structural decisions that frame them: how an institution buys, maintains and disposes of its equipment, how it designs its

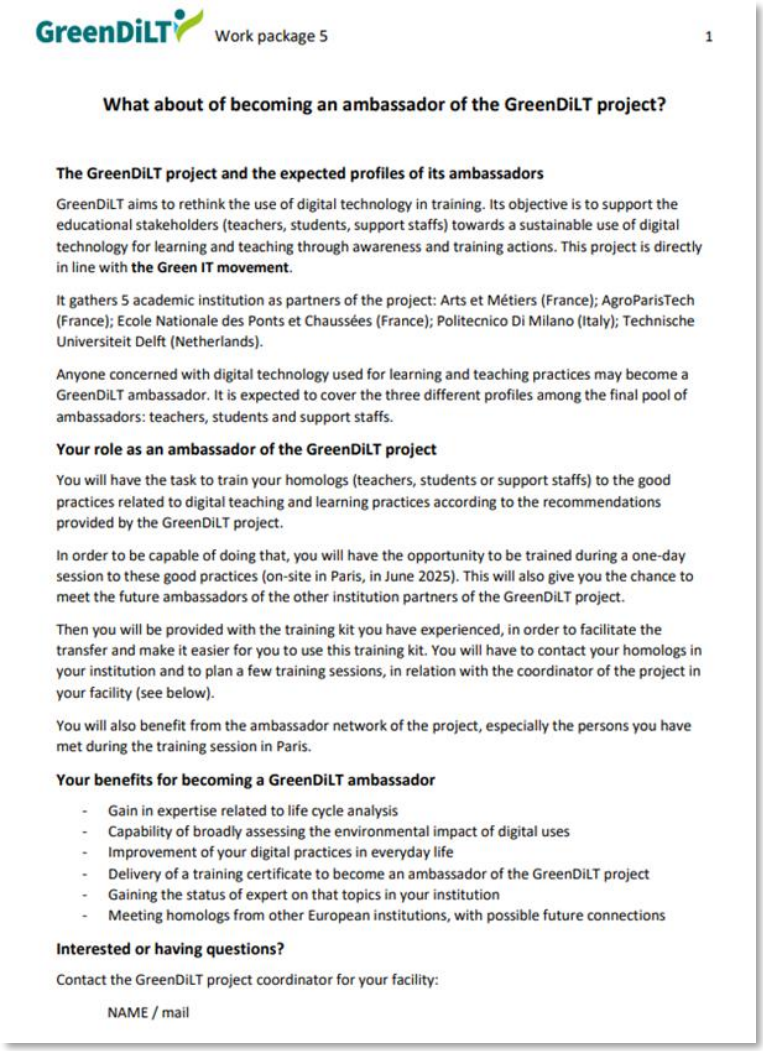
infrastructure, and the responsible-digital policy it sets for its whole community. Conversely, institutional rules take hold only if staff and students understand and share them. It is this dialogue between personal habits and collective choices, rather than either one on its own, that GreenDiLT places at the heart of a credible path towards more sustainable digital practices.

5.5. Ambassador network

To promote the dissemination of the GreenDiLT training resources as well as good digital practices within our institutions (and possibly at a broader scale), we created a network of ambassadors covering the three targeted profiles (students, teachers, and support staff).

5.5.1. Recruitment of the ambassadors

Before recruiting, the roles of the GreenDiLT ambassadors were detailed in a one-page sheet as illustrated in **Figure 15**. This sheet was available in French as well as in English, with the contact person specified for each target institution within the consortium.



GreenDiLT Work package 5 1

What about of becoming an ambassador of the GreenDiLT project?

The GreenDiLT project and the expected profiles of its ambassadors

GreenDiLT aims to rethink the use of digital technology in training. Its objective is to support the educational stakeholders (teachers, students, support staffs) towards a sustainable use of digital technology for learning and teaching through awareness and training actions. This project is directly in line with **the Green IT movement**.

It gathers 5 academic institution as partners of the project: Arts et Métiers (France); AgroParisTech (France); Ecole Nationale des Ponts et Chaussées (France); Politecnico Di Milano (Italy); Technische Universiteit Delft (Netherlands).

Anyone concerned with digital technology used for learning and teaching practices may become a GreenDiLT ambassador. It is expected to cover the three different profiles among the final pool of ambassadors: teachers, students and support staffs.

Your role as an ambassador of the GreenDiLT project

You will have the task to train your homologs (teachers, students or support staffs) to the good practices related to digital teaching and learning practices according to the recommendations provided by the GreenDiLT project.

In order to be capable of doing that, you will have the opportunity to be trained during a one-day session to these good practices (on-site in Paris, in June 2025). This will also give you the chance to meet the future ambassadors of the other institution partners of the GreenDiLT project.

Then you will be provided with the training kit you have experienced, in order to facilitate the transfer and make it easier for you to use this training kit. You will have to contact your homologs in your institution and to plan a few training sessions, in relation with the coordinator of the project in your facility (see below).

You will also benefit from the ambassador network of the project, especially the persons you have met during the training session in Paris.

Your benefits for becoming a GreenDiLT ambassador

- Gain in expertise related to life cycle analysis
- Capability of broadly assessing the environmental impact of digital uses
- Improvement of your digital practices in everyday life
- Delivery of a training certificate to become an ambassador of the GreenDiLT project
- Gaining the status of expert on that topics in your institution
- Meeting homologs from other European institutions, with possible future connections

Interested or having questions?

Contact the GreenDiLT project coordinator for your facility:

NAME / mail

Figure 15: Detailed sheet (English version) designed for the recruitment of GreenDiLT ambassadors.

The main role of these ambassadors was to share best digital practices with their peers. To do so, they had to participate to ambassador training sessions organized in face-to-face during the project, with dedicated training related to key-concepts as well as to get familiar with the training resources created. So, benefits of becoming such an ambassador were also pointed out in the sheet (especially gaining in expertise related to LCA or meeting homologs from European institutions), in order to encourage colleagues and students to be volunteer.

Recruitment was performed by contacting targeted persons by email or in face-to-face, with possible recall required in case of no answer.

5.5.2. Training the ambassadors

We organized two transnational ambassadors training session. The first one was delivered at Arts et Métiers (Paris, France) in June 2025, gathering in total 16 participants from four partners of the consortium. A lecture was delivered to provide them with key knowledge related to assessing environmental impacts with the LCA methodology. Then group activities were organized to favor ambassadors' discussions across profiles and institutions. This training day was a success, with a majority of ambassadors claiming for another training day session until the end of the project.

Thus, another session was organized in May 2026 at POLIMI (Milano, Italy) during half a day. Ambassadors had the opportunity to test our training resources, and to think about local action plans in order to train their peers and disseminated best digital practices.

Finally, we were able to build a network of near 30 ambassadors among the consortium partners. Each ambassador was awarded a digital open badge (see **Figure 16**) in recognition of his/her expertise and commitment in the project.



Figure 16: The digital open badge delivered to each of our 28 ambassadors.

6. Conclusions

Digital teaching and learning practices are common in higher education, with GAI gaining in popularity. Using an online survey, we were in capacity of drawing an inventory of most common practices among teachers, students and support staff within GreenDiLT consortium institutions. Data collected clearly showed a lack of knowledge of our communities regarding collective and individual actions to take in order to reduce digitalization environmental impacts. In addition, staff as well as students were in demand of being trained to methodologies capable of addressing the environmental impacts of digital practices as well as to good practices.

LCA methodology proved to be efficient in assessing environmental impacts. Assumptions were made relative to the functional unit as well as the teaching and learning scenarios, but these were considered realistic knowing the local practices and institutional contexts within the GreenDiLT consortium. Similar results were obtained among partners, with discrepancies observed that were due to different

local contexts. Practical recommendations could be proposed, giving ideas for future actions to limit environmental impact of digital practices.

Attractive training resources were created, that may be reused free of charge due to sharing under a creative common license. They offer online self-training with short modules that will be proposed to all stakeholders in higher education. Also, the GreenDiLT Academy board game provides the opportunity to create group dynamics and reflection on this issue of greening digital practices.

Creating an ambassador network was found efficient to disseminate good digital practices and to facilitate the use of our training resources. This was integrated with local green initiatives, especially to initiate or reenforce a green digital movement locally within the consortium institutions.

References

Filho W.L., Salvia A.L., Beynaghi A., Fritzen B., Ulisses A., Avila L.V., Shulla K., Vasconcelos C.R.P., Moggi S., Mifsud M., Anholon R., Rampasso I.S., Kozlova V., Iliško D., Skouloudis A. & Nikolaou I. (2024) Digital transformation and sustainable development in higher education in a post-pandemic world, *International Journal of Sustainable Development & World Ecology*, 31(1), 108–123. http://dx.doi.org/10.1080/13504509.2023.2237933

GIVE (2023) Taking into account the effects of digital education on the environment in the EU. The GIVE white book.

Giusti G., Farrapo Junior A. C., Sigahi T. F. A. C., Saltorato P., Vieira J. G. V., & Silva D. A. L. (2023). A multicriteria approach for consumption footprint in higher education institutions before and during the COVID-19 pandemic. *International Journal of Life Cycle Assessment*, 28(12), 1735–1755. https://doi.org/10.1007/s11367-023-02225-2

Hilty L.M. & Aebischer B. (2015) ICT Innovations for Sustainability. *Advances in Intelligent Systems and Computing* (AISC), volume 310.

Lopes Silva D. A., Giusti G., Rampasso I. S., Junior A. C. F., Marins M. A. S., & Anholon R. (2021). The environmental impacts of face-to-face and remote university classes during the COVID-19 pandemic. *Sustainable Produdction and Consumption*, 27, 1975–1988. https://doi.org/10.1016/j.spc.2021.05.002

Moro C., Mills K.A., Phelps C. & Birt, J. (2023) The Triple-S framework: ensuring scalable, sustainable, and serviceable practices in educational technology. *International Journal of Educational Technology in Higher Education,* 20:7. https://doi.org/10.1186/s41239-022-00378-y

Pinzone, M., Sarti, F. & Amodeo, E. (2026) What is the environmental impact of digitally enhanced education? Findings from a life cycle assessment of educational scenarios at an Italian university. *International Journal of Life Cycle Assessment*, 31, 112. https://doi.org/10.1007/s11367-026-02656-7

Ricardo-Barreto C., Jabba Molinares D., Llinás H, Peña Santodomingo J., Astorga Acevedo C., Acevedo Rodríguez P., Baloco Navarro C., & Villarreal Villa S. (2020) Trends in using ICT resources by professors in HEIs (Higher Education Institutions). *Journal of Information Technology Education: Research,* 19, 395-425. https://doi.org/10.28945/4601

Riffiod N., Montfort A. (2026) GreenDilt LCA report, Ecole des Ponts (ENPC), project 2026 (confidential)

Sarti F. (2025). Evaluating the Environmental Impact of Digitally-Enhanced Education: A Comparative Life Cycle Assessment of Educational Scenarios in an Italian University. Master's Thesis, Politecnico di Milano. Available at: POLITesi Repository

Appendices

Appendix 1 – GreenDiLT consortium communications page 32

Appendix 2– Details of LCA methodology for assessment pages 33-38

GreenDiLT Co-funded by the European Union

Appendix 1 – GreenDiLT consortium communications

G. Buisson, S. Mraihi, N. Lepannetier, V. Camel, E. Amodeo, M. Pinzone (2025) Former à un usage responsable du numérique dans les espaces d'enseignement et d'apprentissage grâce aux ressources GreenDiLT. *Game session organized at the LearningLab Network 2025 workshop*, Caen, France.

S. Mraihi, V. Camel, N. Lepannetier, G. Buisson, L. Montaigne, E. Amodeo, M. Pinzone, R. Tamboer, N. Kapelan (2026) GreenDilT : une initiative pour analyser l'impact environnemental des pratiques numériques en formation à l'échelle de cinq établissements européens. *Oral communication presented at the AUPTIC Education 2026 congress*, Lausanne, Switzerland. https://drive.google.com/file/d/1HKFm1hNJonwMJuAa34we_5J-R-06VpNc/view

G. Buisson, S. Mraihi, N. Lepannetier, V. Camel, E. Amodeo, M. Pinzone (2026) Former les écosystèmes pédagogiques à la sobriété numérique dans l'enseignement supérieur : analyse du besoin et proposition de contenus de formation dans le cadre du projet GreenDiLT. *Oral communication presented at the AUPTIC Education 2026 congress*, Lausanne, Switzerland. https://drive.google.com/file/d/16fwCWRGTfveHAP7uD9PSBGecx1bQcWwj/view

M. Pinzone, F. Sarti, E. Amodeo (2026) What is the environmental impact of digitally enhanced education? Findings from a life cycle assessment of educational scenarios at an Italian university. The *International Journal of Life Cycle Assessment*, 31:112. https://doi.org/10.1007/s11367-026-02656-7

M. Pinzone, E. Amodeo (2026) Assessing the carbon footprint of academic digital practices: a life cycle-based calculator for higher education stakeholders. *Poster presented at the 2nd Global Cleaner Production Conference (GCPC)*, Melia Sitges, Spain.

E. Amodeo, M. Pinzone (2026) Comparative life cycle assessment of educational scenarios in higher education: a French university case study with considerations on artificial intelligence. *Poster presented at the 2nd Global Cleaner Production Conference (GCPC)*, Melia Sitges, Spain.

Appendix 2– Details of LCA methodology for assessment

Life Cycle Assessment (LCA) is a comprehensive tool used to evaluate the environmental aspects of a product, service, or system throughout its entire life cycle. It encompasses all stages from raw material extraction, production, usage, and disposal, providing a complete view of the environmental impact. LCA is especially useful for comparing different systems or processes, including teaching modalities, as it allows for the identification of the key environmental burdens associated with each phase of a product's or system's life.

According to the ILCD Handbook (International Reference Life Cycle Data System), a widely recognized guide on LCA standards, four critical phases involved in an LCA study are defined:

1. **Goal and scope definition:** This initial phase sets the context for the LCA study. It defines the purpose of the assessment, the system boundaries, and the functional unit. The functional unit is a quantitative description of the function provided by the system under study and is critical for ensuring comparability. For example, in a teaching context, the functional unit could be defined as "the delivery of one hour of instruction to a student." The system boundaries determine which processes are included in the analysis (e.g., energy used for classroom heating and electricity consumption for servers during online lectures).
2. **Life cycle inventory (LCI)**: The LCI phase involves collecting data on all the inputs (e.g., raw materials, energy) and outputs (e.g., emissions, waste) associated with the system. This phase requires extensive data collection across all life cycle stages and can be resource-intensive.
3. **Life cycle impact assessment (LCIA):** In the LCIA phase, the data gathered in the inventory is translated into environmental impacts. This involves categorizing emissions and resource uses into impact categories such as climate change, human toxicity, and resource depletion, or CO_2 emissions in relation to the impact assessment method selected.
4. **Interpretation**: This final phase is about interpreting the results of the LCA model by identifying the key drivers of environmental impact, and making recommendations for reducing these impacts. This phase also involves assessing the limitations and uncertainties in the data.

The **Figure A2.1** proposes a visual framework of LCA methodology.

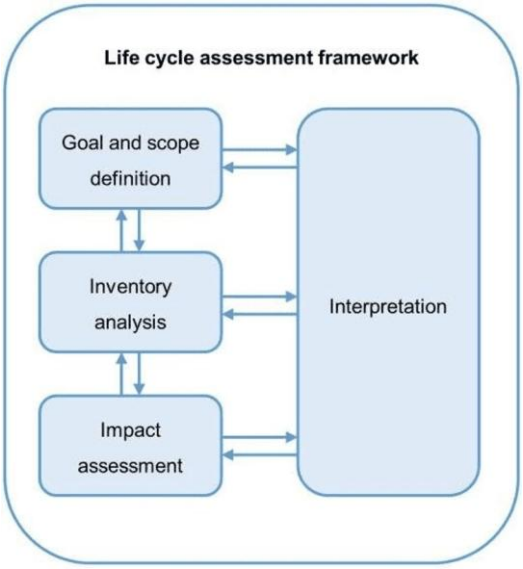


Figure A2.1: Phases of LCA study, source: ISO 14040:2006

GreenDiLT Co-funded by the European Union

LCA is particularly well-suited for the objectives of the impact assessment of educational scenarios as it provides a structured and scientifically recognized method for comparing the environmental impacts of the teaching modalities to be examined. The nature of LCA framework allows for a full assessment of all factors contributing to environmental impact, from energy usage in online learning to transportation emissions in face-to-face teaching, thus applying this framework will enable quantifying and comparing emissions associated with different educational scenarios.

Goal and scope

The LCA was conducted to evaluate the environmental impacts associated with different higher education delivery models, including face-to-face, hybrid, and fully online learning. While climate change (Global Warming Potential, GWP) represents the primary impact category, additional environmental indicators were also assessed through the Life Cycle Impact Assessment (LCIA).

The study follows an attributional LCA approach in accordance with the International Reference Life Cycle Data System (ILCD, 2010) guidelines. The objective is to identify the main environmental hotspots associated with each educational model and provide evidence-based recommendations to support more sustainable educational practices.

The functional unit was defined as 25 learning hours per student, corresponding approximately to 1 European Credit Transfer and Accumulation System (ECTS) credit in several European higher education systems (European Commission: Directorate-General for Education Sport and Culture, 2015). The functional unit includes:

- 10 hours of classroom instruction;
- 15 hours of independent study;
- the share of lecturer activities required for course preparation (30 hours), examination preparation and grading (10 hours);
- administrative support activities (6 hours).

Teaching and administrative workloads were estimated through surveys involving lecturers and support staff and allocated assuming an average class size of 130 students, representative of standard courses at Politecnico di Milano.

The system boundaries follow a cradle-to-gate approach, including the use phase but excluding end-of-life processes due to limited data availability. The assessment focuses exclusively on activities directly related to teaching and learning. Peripheral activities such as food consumption, library use, and cafeteria services were intentionally excluded to isolate the environmental impacts generated by educational delivery. This differs from broader educational LCAs such as Silva et al. (2021) and Giusti et al. (2023), which include additional campus activities.

Life Cycle Inventory

Educational scenarios

The Life Cycle Inventory (LCI) considered a range of educational delivery configurations representative of current higher education practices (Allen and Seaman, 2003). The analysis focused exclusively on lecture-based teaching activities, excluding laboratory and project-based courses due to their institution-specific infrastructure requirements.

GreenDiLT Co-funded by the European Union

Seven scenarios were modelled:

- Face-to-face: conventional classroom teaching with all participants on campus.
- Hybrid with live streaming and recordings: 75% of students attend in person, while 25% participate remotely through live streaming or recorded lectures.
- Hybrid with live streaming: remote participation exclusively via synchronous streaming.
- Hybrid with recordings: remote participation exclusively through asynchronous recorded lectures.
- Blended learning: approximately half of the educational activities are delivered online through recorded content and half in person.
- Fully online – synchronous: all teaching is delivered through live streaming platforms.
- Fully online – asynchronous: all learning materials are accessed through recorded lectures (e.g., MOOCs).

Across all scenarios, learning outcomes, educational content, and instructional hours were assumed to be equivalent, ensuring functional comparability. For scenarios including recorded lectures, recordings were assumed to be available to all students during independent study, resulting in full utilization of the recorded material.

Inventory data

Foreground data describing the educational systems were collected directly from Politecnico di Milano, primarily within the Department of Management, Economics and Industrial Engineering. Primary data included energy consumption, ICT equipment, commuting patterns, streaming activities, and institutional operational data.

Background processes—including electricity generation, fuel production, ICT manufacturing, network infrastructure, educational materials, and server production—were modelled using the *Ecoinvent 3.10* database whenever available. Where database information was unavailable, secondary data from the scientific literature were adopted.

Building construction impacts for university and residential infrastructures were excluded because their contribution to the functional unit was considered negligible.

The inventory includes:

- household and university energy consumption for lighting, heating and cooling (ISTAT, 2021; Politecnico di Milano, 2023);
- ICT devices, networking equipment and Learning Management Systems (Malmodin et al., 2014; Hischier et al., 2014; Tabata and Wang, 2021; Ahmadi Achachlouei et al., 2015);
- educational materials (Arushanyan et al., 2013; Ahmadi Achachlouei et al., 2015);
- commuting data for students, faculty and staff (Politecnico di Milano Home–Work/University Mobility Survey, 2021);
- streaming and recording data based on institutional CISCO data;
- generative Artificial Intelligence energy consumption (Argerich and Patiño-Martínez, 2024).

Background inventory data were primarily sourced from **Ecoinvent 3.10**, complemented by literature sources including Cheung et al. (2018), Dell (2019), as well as Argerich and Patiño-Martínez (2024).

GreenDiLT Co-funded by the European Union

Allocation Procedures

All inventory data were normalised to the functional unit using activity-based allocation procedures.

- Household energy consumption for heating, cooling and lighting was converted from annual consumption to hourly values and allocated to the portion of the dwelling used for educational activities. University energy consumption was allocated according to classroom and office occupancy using institutional energy data.
- ICT electricity consumption was calculated using literature values combined with survey data describing device ownership and usage patterns. Transportation impacts were estimated from commuting distances and modal shares, assuming one round trip every eight hours of educational activity.
- Manufacturing impacts of ICT equipment, projectors and networking infrastructure were amortised over their expected operational lifetimes according to actual usage hours. Server production impacts were allocated according to the storage capacity occupied by educational content.

Additional modelling assumptions included:

- an average class size of 130 students;
- exclusion of microphones, headphones and router manufacturing due to negligible contribution;
- uniform allocation of student device use across lectures and independent study;
- modelling of printed educational materials through reading-rate assumptions;
- representation of public transportation using rail transport datasets;
- assessment of server and projector manufacturing only for Global Warming Potential where inventory data were available.

Life Cycle Impact Assessment

The collected data were modelled with SimaPro, a software specifically designed for LCA studies, and suitable for this research due to its comprehensive features and extensive database integration, namely Ecoinvent. SimaPro provides a platform for analyzing life cycle inventory (LCI) data and supports various impact assessment methods for translating inventory data into quantifiable environmental impacts such as CO_2 emissions.

SimaPro is well-suited for meeting the specific objectives of this research, which include:

- Quantitatively assessing the environmental impact of different teaching modalities: SimaPro's extensive databases and impact assessment methods allow for accurate emissions and resource use calculation for each modality;
- Identifying key factors influencing environmental impact: SimaPro's settings in relation to results display enable the identification of the processes that contribute most to each teaching model's environmental footprint, whether it be energy use in online learning or commuting in in-person teaching.

The impact was calculated using the Intergovernmental Panel on Climate Change (IPCC) method, a method for calculating greenhouse gas emissions and their potential impact on global warming. The IPCC method focuses specifically on climate change impacts, providing characterisation factors for greenhouse gases over different time horizons, typically 20, 100 and 500 years. This method converts the emissions of various greenhouse gases into a common unit of carbon dioxide equivalents (CO_2 eq), based on their global warming potential (GWP). Specifically, the 100-year time horizon was used.

For enlarging the impact analysis it could be suggested to integrate the results using the ReCiPe 2016 Midpoint (H) v1.07 methodology (Huijbregts et al., 2017). The midpoint approach was selected to provide a robust and harmonised assessment of environmental impacts across the analysed scenarios. Climate change was evaluated using the GWP indicator, expressed as kg CO_2-equivalent, following the characterization methodology described by Joos et al. (2013) and the IPCC (2014).

The results were subsequently compared across educational scenarios to identify the principal environmental hotspots associated with different teaching delivery models and to support evidence-based recommendations for reducing their environmental footprint.

References

Ahmadi Achachlouei, M., Moberg, Å., & Hochschorner, E. (2015) Life Cycle Assessment of a Magazine, Part I: Tablet Edition in Emerging and Mature States. Journal of Industrial Ecology, 19(4), 575–589. https://doi.org/10.1111/jiec.12227

Allen, I. E., & Seaman. J. (2003) Seizing the Opportunity: The Quality and Extent of Online Education in the United States, 2002 and 2003. Wellesley, MA: Sloan Consortium.

Argerich MF, Patiño-Martínez M. (2024) Measuring and Improving the Energy Efficiency of Large Language Models Inference. IEEE Access. 12:80194–80207. https://doi.org/10.1109/ACCESS.2024.3409745

Arushanyan, Y., Ekener-Petersen, E., & Finnveden, G. (2013) Lessons learned - Review of LCAs for ICT products and services. In Computers in Industry (Vol. 65, Issue 2, pp. 211–234). https://doi.org/10.1016/j.compind.2013.10.003

Cheung CW, Berger M, Finkbeiner M. (2018) Comparative life cycle assessment of re-use and replacement for video projectors. Int J Life Cycle Assess. 23(1):82–94. doi:10.1007/s11367-017-1301-3. https://doi.org/10.1007/s11367-017-1301-3.

Dell. 2019. Life Cycle Assessment of Dell PowerEdge R740. https://corporate.delltechnologies.com/content/dam/digitalassets/active/en/unauth/data-sheets/products/servers/lca_poweredge_r740.pdf.

European Commission: Directorate-General for Education Sport and Culture Y.(2015) ECTS users' guide 2015. Publications Office of the European Union.

Giusti, G., Farrapo Junior, A. C., Sigahi, T. F. A. C., Saltorato, P., Vieira, J. G. V., & Silva, D. A. L. (2023) A multicriteria approach for consumption footprint in higher education institutions before and during the COVID-19 pandemic. International Journal of Life Cycle Assessment, 28(12), 1735–1755. https://doi.org/10.1007/s11367-023-02225-2

Hischier, R., Coroama, V. C., Schien, D., & Achachlouei, M. A. (2014) Grey energy and environmental impacts of ICT hardware. Advances in Intelligent Systems and Computing, 310, 171–189. https://doi.org/10.1007/978-3-319-09228-7_10

Huijbregts MAJ, Steinmann ZJN, Elshout PMF, Stam G, Verones F, Vieira M, Zijp M, Hollander A, van Zelm R. (2017) ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int J Life Cycle Assess.* 22(2):138–147. https://doi.org/10.1007/s11367-016-1246-y.

ILCD Handbook: Specific guide for Life Cycle Inventory (LCI) data sets. (n.d.). https://doi.org/10.2788/39726

ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN. (n.d.). In-Person vs Online Learning Statistics. (2024). https://upskillwise.com/in-person-vs-online-learning-statistics/

International Reference Life Cycle Data System (ILCD) handbook : framework and requirements for life cycle impact assessment models and indicators. (2010). Publications Office.

International reference life cycle data system (ILCD) handbook general guide for life cycle assessment: provisions and action steps. (2011). Publications Office.

ISTAT (2021) Consumi energetici delle famiglie. https://www.istat.it/it/archivio/272110

Malmodin, J., Lundén, D., Moberg, Å., Andersson, G., & Nilsson, M. (2014) Life Cycle Assessment of ICT: Carbon Footprint and Operational Electricity Use from the Operator, National, and Subscriber Perspective in Sweden Malmodin et al. LCA of ICT Networks from the Operator, National, and Subscriber Perspective. Journal of Industrial Ecology, 18(6), 829–845. https://doi.org/10.1111/jiec.12145

Silva, D. A. L., Giusti, G., Rampasso, I. S., Junior, A. C. F., Marins, M. A. S., & Anholon, R. (2021) The environmental impacts of face-to-face and remote university classes during the COVID-19 pandemic. Sustainable Production and Consumption, 27, 1975–1988. https://doi.org/10.1016/j.spc.2021.05.002

Politecnico di Milano. (2021) Home-work / university com-mute plan. https://www.polimi.it/il-politecnico/chi-siamo/documenti-strategici/piano-spostamenti-casa-lavoro-universita

Politecnico di Milano. (2023) Energy Report. https://www.commissionenergia.polimi.it/bea-bilancio-energetico-di-ateneo/

Tabata, T., & Wang, T. Y. (2021) Life cycle assessment of CO_2 emissions of online music and videos streaming in Japan. *Applied Sciences* (Switzerland), 11(9). https://doi.org/10.3390/app11093992

GreenDiLT Co-funded by the European Union

Erasmus+

GreenDiLT



Co-funded by the European union

CC BY NC ND

July 2026