Erasmus+

GIVE

Taking into account the effects of digital education on the environment in the EU

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

Green IT for VET Providers

MY TRAINING BOX
hubblo
UNIVERSIDADE LUSÓFONA
EVTA European Vocational Training Association

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Taking into account the environmental effects of digital education in the EU

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01. Introduction

Every step we take has a footprint

Nowadays, every file has a digital version of its analogue version, and this conversion is called digitisation. All individuals, organisations and sectors have adopted this method and migrate the necessary information to digital environments. VET providers are also one of the beneficiaries of this technology. However, every opportunity comes with an impact, every step we take has a footprint, and in the digital world that translates into environmental impact.

Green IT for VET

Distance learning is regularly cited as an opportunity to reduce the environmental impacts of education by reducing the need for travel to and from the learning location and by reducing education facilities. According to SMARTer 2030 (n.d.), location-independent training could allow a saving of 5 billion liters of fuel from traveling and more than 90 millions tons of papers. However, these figures are very controversial, both in the scope of the study and in the methodologies adopted (Roussilhe, 2021). Indeed, significant limitations have been identified in these studies (Longaretti et al., 2021; Rasoldier et al., 2022), such as the extrapolation of non-representative statistical data or the use of overly optimistic assumptions.

The VET sector's priority was to digitize learning materials to enhance digital learning, but now this sector needs to consider the environmental impact caused by this technology, which has accelerated since the COVID-19 crisis. Therefore, VET providers need to make strategic and organisational changes to implement a sustainable digital training process and develop digital training content.

Green IT for VET (GIVE) providers is an Erasmus+ project for a total duration of 24 months. This project is implemented by four different partners from three European countries: France, Portugal and Belgium.

01. Introduction
Partners of the project

GIVE

aims to reduce the environmental impact of digital learning, promote green digital skills for VET providers and contribute to innovation in VET. To achieve its goal, the project developed a clear first methodology for VET providers on the environmental impact of digital learning.

My Training Box is a French digital training solutions provider. Their range of solutions includes Learning Management Systems, digital training content (video, podcast, text, assessments), and consulting. One of their digital products is My Green Training Box, the first free access digital training streaming platform on sustainable development which focuses on several areas such as Agriculture, Ecological construction and more. The other French partner is Hubblo, a company specialised in the environmental impact assessment of digital services and systems. Hubblo develops and relies on open methods, data and open-source tools. COFAC is a non-profit cooperative, responsible for the management of Lusófona University in Portugal. The university offers a large number of vocational and continuous training courses according to the life-long learning development paradigm. EVTA (European Vocational Training Association), from Belgium, is the result of the cooperation between VET providers from different EU countries in the framework of the Euroqualification project. It became an important stakeholder in the field of human capital development, participating in various cooperation and harmonisation tables, providing support to its member organisations and ensuring that their needs and expectations are met. It focuses on the development of VET within the framework outlined by Europe 2020.

GIVE aims to reduce the environmental impact of digital learning, promote green digital skills for VET providers and contribute to innovation in VET. To achieve its goal, the project developed a clear first methodology for VET providers on the environmental impact of digital learning. In order to do so, the first step was to conduct the first-ever research on the practices of VET sector professionals related to digital learning development and implementation on environmental impact. Subsequently, this white paper has been produced to enhance the green skills of VET providers based on the results of the study. It is about Green IT for the VET sector and how to create digital training considering its environmental impact.

Furthermore, a training course will be created to develop green skills in the players of the VET sector. Through this whitepaper and the training course, we aim to raise awareness of the VET sector and support teachers and trainers to gain green skills. The training course can be accessed free of charge by anyone through the platform My Green Training Box[1].

[1] www.mygreentrainingbox.com

02. Motivations

2.1 The impacts of ICT

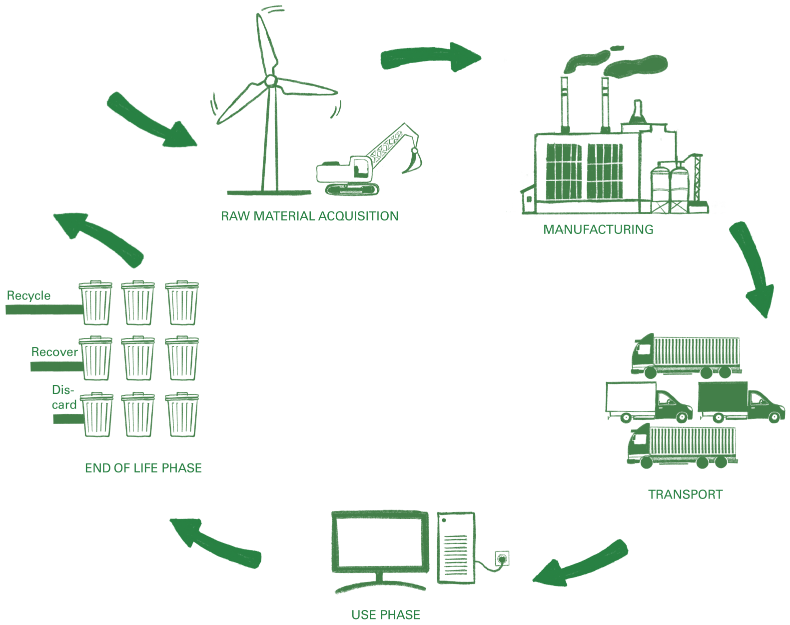


Figure 1. Life Cycle Diagram

Direct Impacts

Despite its apparent immateriality, Information and Communication Technologies (ICT) have major environmental impacts which cannot be neglected. Indeed, digital services rely on physical assets, which are responsible for environmental damage. In a European study published in 2021 for the European Parliamentary group of the Greens/EFA, it was evaluated that ICT represents 4.2% of European GHG emissions. The usage[2] of ICT represented 9.3% of European electricity consumption. More problematically, these impacts are growing rapidly and could reach 6 to 8% of global greenhouse gas emissions in 2025.

The environmental impacts of ICT occur at all steps of the lifecycle of IT equipment and infrastructure. Those steps are usually described as follows: raw material acquisition, which corresponds to the impacts related to the extraction and production of raw materials, manufacturing phase, which corresponds to the impacts of producing the final product from raw materials, transport, which corresponds to the transport of the final product to its place of usage, use phase, which corresponds to the impacts induced by the usage of the products - in the context of ICT, the impacts related to usage are mostly induced by the consumption of electricity - and finally, the end-of-life phase which corresponds to the impacts associated to waste treatment - whether recycled, recovered or discarded. In Europe, 53% of the green gas emissions of end-user devices occur outside the use phase. Thus, it is mandatory to take into account all those lifecycle steps to fully account for the impacts of a digital product or service.

[2] Use phase of the equipments and infrastructure on European soil.

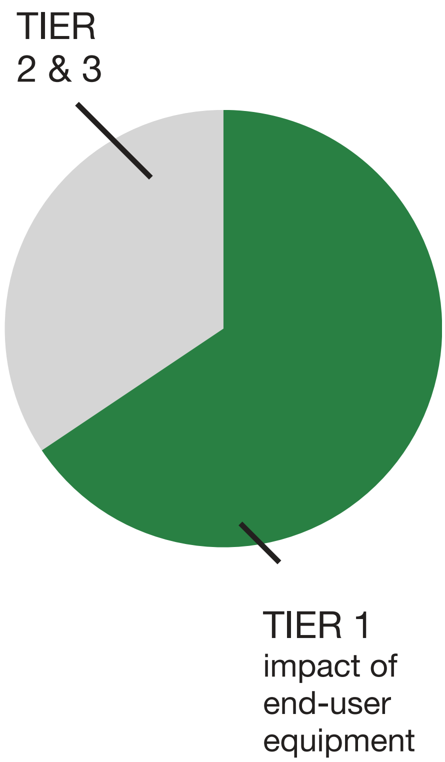
The impacts of ICT
2.1.1 Direct impacts

65,6%

of the green gas emissions of ICT in Europe are attributed to end-user equipment.

The environmental impacts of ICT occur throughout its value chain. One of the most significant elements affecting the value chain is the impact of end-user equipment. In Europe, end-user equipment are responsible for 65,6% of the green gas emission of ICT. But other items of the value chain should also be considered, such as the impact related to network infrastructure (TIER 2), and finally the data centre (TIER 3), which are both responsible for the other 34,4% of the green gas emission of ICT in Europe. Note that these figures only take into account the infrastructures that are present in Europe. ICT is a globalised value chain, and many services used in Europe are hosted outside of it. Therefore, the impacts related to TIER 3 are likely to be underestimated.

Finally, the environmental impacts of ICT are not limited to green gas emissions. Indeed, ICT is a major consumer of non-renewable fossil and mineral resources. The manufacturing phase of IT equipment involves many types of minerals, and these materials are in competition with other sectors such as renewable energies. It is essential to consider these impacts to understand all the environmental effects induced by digital technologies. This study will focus on the emissions of greenhouse gases to account for global warming, due to a lack of public environmental data for our perimeter. **However, readers should keep in mind that digital learning will cause further environmental damage, and solutions to reduce them should be implemented without omitting these other impacts.**



The impacts of ICT
2.1.2 Enablement effects

ICT is often presented as a way to reduce the environmental impacts of other sectors. These types of effects have been defined by different names such as enablement effect, abatement effect, positive impacts or scope4.

We can define two main mechanisms through which ICT can reduce the environmental impacts of other activities: **the optimization effect,** which corresponds to the reduction of the impact of a reference process by the integration of IT components and **the substitution effect,** which corresponds to the digitization of a polluting process.

Measuring those effects are out of the scope of this study because the methodologies to take them into account are still very immature. Still, we have decided to identify the potential environmental benefit of digital learning and discuss them in the qualitative part of our study.

Substitution example

A smart meter can substitute manual energy readings, reducing the need for a car to move an agent.

Optimization example

A GPS allows for optimizing the time and distance of a trip, inducing a possible reduction of the fuel consumption associated with this trip.

The impacts of ICT
2.1.3 Indirect effects

Finally, indirect effects of ICT are socio-economic phenomena occurring as a consequence of the deployment and usage of digital products or services. The associated impacts can be supported by the product or service itself or by external systems as a consequence of the deployment or the usage of the service.

Central in the literature on this topic, the "**direct rebound effect**" corresponds to an increase in the consumption of a technology due to improved efficiency (cost, impacts, complexity, resources...). The direct rebound effect reduces the abatement effect of a technology by offsetting it with an increase in its use. The ability of ICTs to accelerate the transformation of production and consumption patterns is responsible for several rebound effects described in the literature (Bieser & al. 2018; Gossart, 2015). In addition, **indirect rebound** corresponds to the overconsumption of another product or service due to a reduction of a constraint (price, time, complexity, ...) on the studied service achieved through IT components.

Other indirect effects have been described in the literature, such as the economy-wide rebound or the systemic transformation (Horner & al., 2016).

Direct rebound example

The facilitation of travel enabled by GPS could lead to an absolute increase in travels.

Indirect rebound example

The savings allowed by the optimization of the heating consumption through connected thermostats can be used to buy more impactful products or services.

The impacts of ICT
2.1.3 Indirect effects

Digitalisation seems to induce many indirect effects (Börjesson & al., 2014) (Horner & al., 2016) (Hilty & al., 2015). It is currently unclear how to identify these effects and assess their magnitude, whether on a global or service-specific scale. Yet, their environmental impacts may be more significant than their direct impacts (Hilty, 2018). Global impact analyses never take them into account; few narrower analyses include them. There is no consensus on the methodologies to be used to identify, assess and contain the indirect effects of digitalisation. Such uncertainties make any conclusion on the benefits of digitalisation very limited (Santarius & al., 2020).

We propose to use the classification given by Horner & al. (2016) detailed in Table 1. We add the stacking effect induced by partial substitution of a reference process - a part of the digitized product or service is stacked on the existing one without substituting it, resulting in an absolute increase of impacts. Measuring the impacts induced by such effects is out of the scope of the study. Firstly, because the existing studies addressing the topic are very preliminary, and secondly because we would need to analyze external systems affected by those effects, which involves a more global study.

Still, identifying the indirect effects of digitalisation is a preliminary step for future assessments. Besides, it brings a wider view of the impacts induced by digital learning and will help us establish recommendations to flatten the impacts induced by those effects, even if they cannot be measured.

Determining the net impact of a solution is therefore very complicate. Still, to give a wide view on the outcomes of digital learning in Europe we have chosen to present both directs, enablement and indirect impacts. Direct impacts will be assessed for greenhouse gas emissions. Enablement and indirect effects will be discussed in the qualitative part of our work.

Table 1. The classification given by Horner & al. (2016)

Effect	Source
Efficiency/Optimization	Horner & al. (2016)
Substitution	Horner & al. (2016)
Stacking effect	-
Direct rebound	Horner & al. (2016)
Indirect rebound	Horner & al. (2016)
Economy-wide rebound (Structural change)	Horner & al. (2016)
Systemic Transformation	Horner & al. (2016)

02. Motivations
2.2 Digital Learning

What is digital learning ?

In the frame of the GIVE project, we defined digital learning as all teaching and learning activities that require digital technologies. Those activities can be synchronous or asynchronous and remotely or face-to-face.

All learning and teaching process are including digital assets:

- Self-learning on a Learning Management System (LMS)
- Video conferencing online training courses
- Blended learning
- Face-to face courses using laptop computer or interactive white board …/…

For the vocational education and training (VET) sector, digital technology is undoubtedly a vector of progress. Lifelong learning makes sense thanks to access to online content through MOOCs, distance learning platforms, online conferences, and replays of numerous webinars.

Video conferencing and distance learning tools have helped to limit mass school drop-out during the recent health crisis. Virtual reality allows the learning of very precise technical gestures through repetition in a secure environment. Artificial intelligence allows training courses to be individualised and adapted to the learner. Digital technology is also useful for the ecological transition, thanks, for example, to applications designed to optimise energy consumption. But digital technology has also an impact, and its environmental footprint is growing every year.

We can imagine that digital learning is less impactful than face-to-face training, because there is no more transport - unless the learner must travel to take the digital training course - no more paper - unless the learner prints out the course materials - and no more training rooms to heat in winter or ventilate in summer - unless each participant heats or ventilates his own home.

Due to the wide range of circumstances, the line is thin and digital learning must be considered in the broadest sense.

02. Motivations
2.3 Responsible Digital Learning

Sustainable digital learning is part of a broader approach that includes the pillars of sustainable development and notions of CSR to propose digital technology that has less impact on the planet, but that is also more accessible to all, and that offers value. These are the pillars:

The accessibility of our digital content

Digital accessibility is a fundamental notion highlighted by the Web Content Accessibility Guidelines (WCAG). Do we make our digital learning content and courses perceivable, adaptable, distinguishable, operable, navigable, understandable, compatible for all users?

The environmental impact of our digital content

Developing digital content and learning practices less impacting for the planet that takes into consideration best digital sustainable practices to implement sustainable digital learning.

The life cycle of our digital content

Determining the Life Cycle of a digital training course is useful to understand and manage the digital learning courses form its creation to its end of life.

Finally, the objective is still to create pedagogical value through our digital training content and to allow learners to improve their knowledge and skills. Generations of learners and methods have changed, and we must adapt. We are not going to go backwards on digital and we are not going to "recreate" the school of the last century. But let’s think about simpler digital content, without implementing massive impacting digital productions, and by placing our knowledge and our pedagogy at their very heart.

02. Motivations
2.4 Existing studies

Several studies have discussed the environmental impacts of education, especially in higher education (HE). In a systematic literature review, Valls-Val & Bovea (2021) reported an impact per HE student between 0.06 to 10.94 tCO2 eq. When taken into account by publications, student commute is one of the most important sources of carbon emissions, the first or the second source of impact on average (Valls-Val & Bovea, 2021) (Filimonau & al, 2020). In Deutschland, Marieke & al. (2018) showed that 40 to 90% of the impacts of HE institutions could be allocated to students' commute. In a qualitative analysis, they later showed the importance of focusing on student motivation for choosing their mean of transportation as a first step for the reduction of the impacts of higher education. (Marieke & al. (2020)

Interestingly, few studies related to HE have considered electronic equipment in their environmental analysis. Auger & al. (2021) have developed a configurable tool to model the carbon emissions induced by one HE student during a year. They attempt to take into account digital activities, considering only the direct carbon impacts of end-user equipment. On the other hand, several studies have specifically considered the environmental impacts of digital learning platforms.

Considering the impacts of education, other studies have focused on the opportunity given by digital learning to reduce its impacts. Digital learning is often called online learning or distance learning. Those formulations can have different meanings depending on the author. Different definitions have been given to categorise those different types of learning processes. For some, digital learning is defined by the distance between the participants, while for others it's the proportion of content delivered online which characterises digital learning. Allen & al (2003), for instance, have defined three types of online learning depending on the proportion of content delivered online (Table 2). Digital learning could also be defined by the usage of digital services or equipment in the context of learning. If defined as such, we could argue that the prevalence of digital services and equipment in the educational environment of developed countries makes the vast majority of the educational process, in some way, already digitalised.

02. Motivations
2.4 Existing studies

Table 2. Definition of online learning depending on the proportion of online content Allen & al. 2003

Proportion of content delivered online	Type of course	Typical Description
1 to 29%	Web facilitated	Course which uses web-based technology to facilitate what is essentially a face-to-face course. Might use Blackboard or WebCT to post the syllabus and assignments, for example.
30 to 79%	Blended/Hybrid	Course that is a blend of the online and face-to-face course. Substantial proportion of the content is delivered online, typically uses online discussions, typically has some face-to-face meetings
80+%	Online	A course where the vast bulk of the content is delivered online. Typically, has no face-to-face meetings.

The potential reduction permitted by digital learning relies on its capacity to substitute participants commuting or optimize the energy consumption related to education facilities. Several publications have discussed the net impacts of digital learning. While some have reported only the avoided emissions, others have taken into account the new direct impacts induced by it. In a comparative study between a regular period and a lockdown period in a UK university, Filimonau & al (2020) have reported a reduction of impacts lower than anticipated due to a fixed amount of resources needed to keep the university running (IT room, general services, etc) and new emissions induced by student and staff housing (heating, digital devices, …). Besides, it is important to note that the substitution of traditional learning with digital learning has been shown incomplete (Filimonau & al, 2020) (Marieke & al., 2020). Coroama & al. (2020) have highlighted the importance of accounting for partial substitution when conducting a net analysis.

From the literature reviewed, although some studies have mentioned the importance of taking into account the indirect impacts of digital learning (Caird & al., 2015), no study has integrated them. However, some studies have addressed the indirect impacts related to a similar process: home office or teleworking (ADEME, 2020).

Finally, the potential environmental gain resulting from digital learning should be balanced by its social implications. In order to account for these social implications, Marieke & al. (2018) have aggregated the pros and cons related to its deployment according to practitioners.

03. Qualitative Methodology

In the following section, we present the methodology that has been conducted during the qualitative part of our work.

The main objectives of our qualitative study are (1) to identify heterogeneous usage behaviours in Europe regarding digital learning in order to include them in our survey and in our configurable impact model, and (2) to identify modifications in consumption or production patterns (i.e. indirect effects) induced by digital learning.

Since we conduct exploratory research, we do not want to presuppose too much of a definition for digital learning services. However, we still need some elements to launch the study. For instance, we need to identify which stakeholders should be invited into the discussions.

3.1 Defining the scope of the study

3.1.1 Life phases

Even if the study is driven by a qualitative analysis of the usage, it doesn’t mean that we only study the "use" phase of the system. Studies have highlighted the importance of the impacts of the other use phases (manufacture, end of life, transport). It is critical to look at every step of the life cycle of the service under research to avoid pollution transfers[3] from one phase to another.

3.1.2 Stakeholders identification

We don’t want to excessively presume on the scope of the process under study, since it is an outcome of the qualitative analysis. However, to discuss the usage of the service understudy, we need to identify the stakeholders involved in the process. We directed a primary interview with university teachers, university learners, and platform providers involved in GIVE project. We identified some links between them in order to drive our questions (Figure 2).

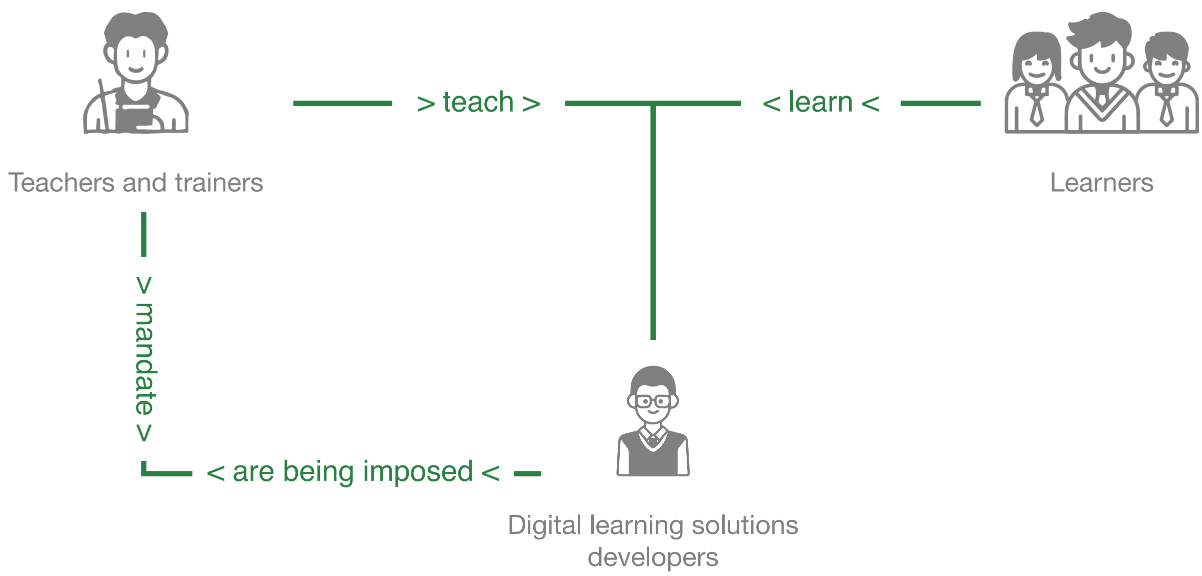


Figure 2. Identification of stakeholders and their relationships in the context of digital learning

[3] The transfer of pollution corresponds to a transfer of impact from one environmental criteria to another environmental impact criteria.

03. Qualitative Methodology
3.2 Focus groups

We have decided to conduct focus groups as our qualitative methodology. This was motivated by the capacity of these types of groups to produce data from participant interaction. In a moderated group discussion, participants will have to position their practices and experiences in consideration of the other participants' responses. Moreover, the collaborative nature of the focus group makes it possible to react and add information that participants wouldn't have considered mentioning in a questionnaire or a one-to-one interview. Finally, focus groups are cost-effective since they make it possible to collect data on several participants at the same time (Kontio & al., 2008).

While focus groups can be used to obtain data regarding attitudes, feelings, beliefs, experiences, reactions, ideas, understanding, and perceptions, (Prudence Plummer-D'Amato, 2017) (Gibbs, 1997) we mainly want to focus on participants' digital learning experiences. Kontio & al (2008) have shown that focus groups were well suited to gather data related to experiences in the context of software engineering. We show in Table 3 how those questions are related to our objectives.

Focus groups have been widely used in exploratory phases of studies as a way to bring new hypotheses on a specific topic or to drive a secondary study (Anita Gibbs, 1997)(Kontio & al, 2008). Since focus groups are conducted on a very little sample of a population, the outcomes of the qualitative part of our work won't be extrapolated to the overall population under study, but will be used to provide a framework for building our survey, creating a model and bringing hypotheses regarding the indirect effects of digital learning.

Table 3. Relation between the issue addressed by focus group according to Kontio & al. (2008) and our objectives

Issues addressed by focus group according to Kontio & al., (2008)	Objectives of our study
"Recognizing past experience that can be studied in more detail by other methods"	Highlighting past experience of digital learning in order to feed a quantitative study
"Initial evaluation of potential solutions, based on practitioner or user feedback"	Identifying the acceptability of good practices given by the participants
"Collecting "lessons learned" recommendations"	Highlighting the potential evolution in habit induced by digital learning
"Identifying potential root causes of phenomena"	Identifying the usage behaviors and social dynamics supporting the evaluated impacts

Focus groups
3.2.1 Designing focus groups

Table 4. Focus group list

COUNTRY	INSTITUTION	PARTICIPANT TYPE	ANIMATOR
France	*Professional*	*Platform provider*	*Hubblo & MGTB*[4]
France	*Professional*	*Trainers*	*Hubblo & MGTB*
France	*Universities*	*Learners*	*Hubblo & MGTB*
Portugal	*Universidade Lusófona*	*Trainers*	*Universidade Lusófona*
Portugal[5]	*Universidade Lusófona*	*Learners*	*Universidade Lusófona*
Belgium	*Professional*	*Trainers*	*EVTA*

We have decided to organise 6 focus groups. Our focus groups have been designed to be conducted with 3 to 6 participants. The participants weren't paid for their participation. We segmented our focus groups regarding the role of the participant in the process of digital learning:

- Learner/Student
- Trainer/Teacher
- Platform and content provider

To cover a variety of backgrounds, we organised the focus groups in three different European countries, in professional and academic contexts, each covering a different field of study. Partners from the GIVE project each animated one to three focus groups.

Since the focus group is a way to highlight the widest typology of usage, we decided to have a wide type of socio-economic profiles and experiences. We didn't look for representativeness, since we are looking for a wide variety of experiences and practices, but we have looked for heterogeneity. For learners, we selected participants from different fields of study, for content and platform creators we have selected people developing different digital content on different supports, for trainers we have selected both participants from different fields using different digital learning supports. We have assumed that digital learning had become mainstream in Europe since COVID-19 lockdown. We tried to select both experts that had experience before COVID-19 and participants recently involved in such processes in order to highlight the specificity of digital learning as a constraint.

We didn't organise over-recruiting since we have had some issues finding enough participants for each focus group. One of the focus groups was transformed into an interview due to the lack of participants.

A questionnaire has been sent to gather data on each of the participants in order to avoid a live collection of data which would have wasted discussion time.

[4] My Green Training Box

[5] This focus group was transformed into an interview due to a lack of participants

Focus groups

3.2.2 Conducting the focus group sessions

2-hour format - 4 main topics

We have chosen a 2-hour format due to the participant's limited availability. We have identified 4 main topics of discussion.

- Teaching methods
- Evolution of practices
- Tools: Technologies and equipment
- Perception: advantages and drawbacks

12 questions to address

We have listed 12 questions to address. We weren't able to ask all the questions, but we mainly focused on addressing the 4 topics in each of the focus groups in order to gather data on the same topics across the focus group. We introduced the goals and rules to the participants as followed:

1. *Presentation of the context of study*
2. *Presentation of moderators and the participants*
3. *Ask participants to fill in the online questionnaire if they haven't*
4. *Thanking participants for their presence*
5. *Inform that the results of the session are strictly confidential and that no identification of individual responses will be done. The outcomes of the session will be strictly used to gather insights into the scope of the current project*
6. *Ask for honest answers, and recall that there are no right or wrong questions*
7. *Estimated time: 120 min.*
8. *Request that there are no parallel or private conversations and that the group discussion is done in a civilised and orderly fashion.*

We mentioned to the participants when they were a change in the topic. We presented the topics in the following order:

1. *Teaching methods*
2. *Evolution of practices*
3. *Tools: Technology and equipment*
4. *Perception: advantages and drawbacks*

Focus groups

3.2.2 Conducting the focus group sessions

We have chosen a classic round table where the participants were allowed to react to any participant's statements. The speaking order was randomly set and changed between two questions. We tried to distribute speaking time equally between participants.

The moderator took some notes in order to help the animation. All the sessions have been recorded, and the sessions conducted in French and English had their audios transcribed. We first generated a transcript from a speech to text API, then we manually went through each of the transcripts once to improve their quality.

We tried to paraphrase the participants' experiences and perceptions between each topic to validate our understanding of their statements.

We concluded the focus groups with the following questions:
Would you like to add something that has not been covered and that you consider relevant?
Do you have some suggestions or ideas regarding how to identify resources used in the scope of digital learning?

We finally thanked the participants and told them we would provide feedback on the ongoing research.

Focus groups

3.2.3 Data analysis

A labelling work has been conducted from the video recording, notes, and transcriptions. The purpose of this step was to extract usage behaviours and indirect impacts from participants' experiences. Since this step was exploratory, it has been conducted in an iterative manner in collaboration with the GIVE project's partners.

We used "Taguette"[6], an open-source application that helps to manipulate qualitative data from text documents. We first created the labels given in Table 5 and used the tool to tag the text accordingly. The definitions of each tag were created iteratively, depending on what was identified in the text.

Citations are provided in the results section when necessary. The companies, places, and individuals' names are anonymised. Spurious words are removed. In addition to the focus group outcomes, we used references from the literature to confront our findings with other studies when it was necessary.

Table 5. Label's description

Label name	Description
Software resource	Item related to software used in a digital learning process
Hardware resource	Item related to digital devices used in a digital learning process
Specific usage behaviors	An interesting behavior, which differs from what has been observed in the literature or in other focus groups
Indirect effects	An statement that describes a potential indirect effect induced by digital learning
Causes	A statement that describes a cause for a behavior
Covid-19	Items specific to COVID-19 period (lock-down, curfew, limitation of mobility,...)
Good practice	Practices define as a good environmental practices by users

[6] https://www.taguette.org/

04.Survey

A survey was developed to achieve two distinct goals: providing much needed data to the development of the impact assessment module and to provide insights that can be used for future research and practical application. In this regard, some of these insights should inform on important stakeholders and decision-makers on the best strategies to be implemented in future policies to ensure that sustainability becomes a cornerstone of educational policies.

This survey was conducted between September and December of 2022. The sampling procedure can be established as a convenience sample with a snowball approach, since every participating organisation was responsible to reach out to their own contacts, and the fact that each contact was also asked to reach out to their partners and act as a dissemination agent. Snowball sampling is a commonly used non-probabilistic sampling strategy in studies that are conducted online, such as this one, and that are focused on technology focused outcomes, allowing not only an extended geographical reach, but also a broader and more comprehensive approach to data collection. Concerning sample size calculations, no formal sample size procedure was defined, as both the endpoints (outcomes) and the nature of the present study are mostly exploratory. However, the consortium set out to collect a minimum sample of 300 stakeholders in the education/training context. These included not only students and learners, but also teachers, trainers, and educational training materials creators. Also, given the extent to which it was possible to take advantage of previous partners and ongoing collaborations, the sample also included those -although in a more limited proportion- that are responsible for managing and decision-making in educational and training institutions.

To implement a sound data collection strategy, each partner had a specific target: 100 participants to be collected by My Training Box, the same amount to be collected_by Universidade Lusófona (COFAC), and the same for the international sample. Overall, the objectives of the data collection were achieved and surpassed, with the final analysis sample comprising 372 participants spawning across most European countries. This provides a sound depiction of the European landscape, although no formal sample size calculations were performed. For this reason, no inferential analysis was performed and therefore, generalisations on the results of the survey should be conducted with care.

Survey

4.1 Survey and Questions

372

participants completed the survey. The majority of the sample was composed of female respondents, in which 19-24 years old, 45-54 years old and 35-44 years old were the most represented age cohorts (see table 6).

The survey was developed by a team of experts from the participating institutions. Firstly, variables concerning the characterisation of the sample were identified. Secondly, three scenarios were developed following the conclusions of the exploratory methodology used in the Focus Group. And lastly, a set of questions for the characterisation of each scenario were identified, trying, as much as possible, to create a coherent structure that would be common to all.

Therefore, in the implementation of the survey, the following four sections were used:

1. Characterisation of the sample – Gender, country, age, role in the educational context, and digital equipment used in their daily activities;
2. Scenario 1 – 1 hour of videoconference course (Synchronous learning online) – videoconference tools used, traveling, distance, mode of transportation, and reason to travel, digital devices purchased;
3. Scenario 2 – 1 hour of self-learning course (Asynchronous learning online) – digital devices used during the course, the time needed to develop materials for a 1-hour course, digital materials used, communication tools used, traveling, distance, mode of transportation, and reason to travel, digital devices purchased;
4. Scenario 3 – 1 hour of face-to-face learning (Synchronous learning in the classroom) – digital equipment used, digital contents used, the printing of materials, traveling, distance, mode of transportation, and reason to travel, digital devices purchased.

Most of the variables collected in the present survey concerning the characterisation of the practices in each of the scenarios were used for the development of impact assessment and are therefore explained in section 5 of the present white paper.

Survey

4.2 Respondents' Characterisation and Scenario Results

The survey was completed by 372 participants. The majority of the sample was composed of female respondents (n = 211, 56.7%), in which 19-24 years old (n = 94, 25.3%), 45-54 years old (n = 89, 23.9%) and 35-44 years old (n = 74, 19.9%) were the most represented age cohorts (see table 6).

Table 7. shows the role of respondents in their organisation. About one third of the sample are teachers or trainers, with learners representing the largest group among the study participants (n = 132, 35.5%).

Regarding the question "Do you usually bring your own digital devices or do you use the school, university or company's devices?", 47% (n = 175) of the sample bring their own digital device to work, while just over half of the sample use the organisation's digital device (n = 95, 25.5%) or both (n = 96, 25.8%).

Table 7. Which title best represents your current position in your organisation?

	n	%
Teacher	52	14,0
Trainer	71	19,1
Learner	132	35,5
Digital learning managers and designers	53	14,2
Other	58	15,6
Total	366	98,4
Missing	6	1,6
Total	372	100,0

Table 6. What is your age?

	n	%
Under 18 years old	3	0,8
19-24 years old	94	25,3
25-34 years old	61	16,4
35-44 years old	74	19,9
45-54 years old	89	23,9
55-64 years old	39	10,5
65 years and older	6	1,6
Total	366	98,4
Missing values	6	1,6
Total	372	100,0

Survey
4.2 Respondents' Characterisation and Scenario Results

The study also assessed the use of digital equipment by the respondents in their daily activities (see Table 8). The digital equipment less used is the interactive whiteboard (n = 285, 81.7%), followed by the Tablet (n = 252, 72.2%) and the desktop (n = 227, 65%). Conversely, the laptop (n = 12, 3.4%) and the smartphone (n = 54, 15.5%) are the equipment with a lower proportion of non-usage.

Concerning the Scenario results, synchronous online learning (n = 263, n = 70.7%) is the most common scenario, followed by synchronous learning in the classroom (n = 253, 68%) and asynchronous online learning (n = 189, 50.8%).

Table 8. Which equipment don't you use in your daily working activities?

	n	%
Smartphone	54	15,5 %
Laptop	12	3,4 %
Desktop	227	65,0 %
Tablet	252	72,2 %
Interactive whiteboard	285	81,7 %
Beamer (Video Projector)	194	55,6 %
Second-screen	164	47,0 %
Microphone	183	52,4 %
Headset	71	20,3 %
Total	1442	413,2 %

Concerning the synchronous learning scenario, Table 9 shows the distribution of usage of each of the videoconference tools. In line with the practices following the pandemic, Zoom is still the most used videoconference tool (85.8%), followed by Google Meet (36.7%) and WebEx (8.4%). Concerning digital practices in this scenario, most of the users keep their cameras on (74.9%), screen share (83.7%), and use instant communication (87.5%) and collaborative (60.1%) tools. Only 20.5% print their digital materials. Lastly, only 23.2% of the respondents had to purchase a new device to attend the synchronous learning activity.

Table 9. Which videoconference tools you use?

	n	%
Zoom	194	85,8 %
Google Meet	83	36,7 %
Teams	1	0,4 %
WebEX	19	8,4 %
Other	36	15,9 %
Total	333	147,3 %

For the Asynchronous Online Learning scenario, Table 10 shows the distribution on the usage of digital solutions. Text (89.4%), Quiz (89.4%) and Videos (84.6%) are the most commonly used.

Table 10. Digital contents and practices in the asynchronous online learning scenario

	n	%
Video	159	84,6 %
Text	168	89,4 %
Quiz	168	89,4 %
Audio	107	56,9 %
Other	38	20,2 %
Streaming	137	72,9 %
Downloading	150	79,8 %
Printing	46	24,5 %
Total	973	517,6 %

Concerning communication tools used in the asynchronous online learning scenario (see Table 11), email (92.6%), messaging systems (95.8%), and Forum (92.6%) are the preferred options. Only 13.2% of the participants indicated that they had to purchase new digital equipment in order to attend this learning scenario.

Table 11. Communication tools used in the asynchronous online learning scenario

	n	%
Forum	175	92,6 %
Email	183	96,8 %
Letter box (delivered where the coursework)	158	83,6 %
Messaging system (chat, chat bot, etc.)	181	95,8 %
Total	697	368,8 %

For the third scenario, the classroom synchronous learning, two specific variables should be considered. Firstly, we must consider the type of digital content used in one hour of this learning scenario. Table 12 shows the most frequently used contents. Slide presentations (94.8%) are used by almost all the participants in the scenario, followed by PDF contents (58.2%). In this scenario, 38.3% of the participants print their learning materials, but only 11.5% needed to purchase new digital equipment to participate in the scenario.

Table 12. Type of digital content used in one hour of this learning scenario

	n	%
Slides Presentation	236	94,8 %
Video	59	23,7 %
PDF	145	58,2 %
Other	32	12,9 %
Total	472	189,6 %

For all the scenarios, one variable should be noted. Concerning the use of equipment, Table 13 shows the proportion of not usage of each piece of equipment per scenario. As expected, the laptop is the one with the lower proportion of non-usage across all the scenarios, while the interactive whiteboard is the one with the highest proportion of non-usage regardless of the scenario observed.

Table 13. Which equipment don't you use for your 1-hour learning activity?

	Synchronous Learning		Asynchronous Online Learning		Classroom Learning	
	n	%	n	%	n	%
Smartphone	140	54,1 %	116	62,4 %	122	48,6 %
Laptop	14	5,4 %	10	5,4 %	13	5,2 %
Desktop	201	77,6 %	148	79,6 %	200	79,7 %
Tablet	218	84,2 %	160	86,0 %	216	86,1 %
Interactive Whiteboard	233	90,0 %	181	97,3 %	219	87,3 %
Beamer (Video Projector)	234	90,3 %	177	95,2 %	156	62,2 %
Second-screen	133	51,4 %	95	51,1 %	171	68,1 %
Microphone	167	64,5 %	110	59,1 %	214	85,3 %
Headset	117	45,2 %	70	37,6 %	191	76,1 %
Total	1457	562,5 %	1067	573,7 %	1502	598,4 %

4.3 Final remarks

As previously discussed, the objectives of the survey were two-fold. Some of the variables that are not discussed in this current section were used to inform the model to be discussed in the next section of this white paper. Again, although the sample is interesting in size, given the absence of formal sample size calculation, the non-probabilistic sampling strategy, and the exploratory nature of the present study, inferences should not be performed. It also applies for the comparison between scenarios. Instead, the current results are a stepping stone for future research that can build on this first exploratory approach to sustainable digital practices.

05. Impact assessment methodology

Different scenarios and usage behaviours

One of the main outcomes given by the qualitative study is the different scenarios and usage behaviours. We created a model to match our qualitative findings as precisely as we could. This model was later applied to Europe from our survey result and for several use cases. We propose to detail here the impact assessment methodology that was applied to build the model.

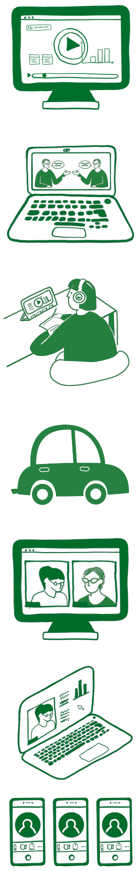
We have chosen to use only publicly available data. This choice is motivated by multiple reasons:

- The intention to make this study as reproducible as possible.
- The study focuses majorly on the mechanisms causing the impacts rather than the impacts themselves.
- For financial limitation
- For time limitation

Because of that choice and because multi-criterion data on digital components are difficult to obtain, only global warming potential (measured in carbon equivalent) will be assessed. We are aware that environmental impact assessment should be as multi-criteria as possible to avoid pollution transfers and to make the public more aware of the diversity of impacts caused by human activities. We hope that future publicly available research focusing on multi-criteria analysis of digital components will emerge.

Furthermore, we have chosen a bottom-up approach, which requires the identification of the resources needed in the fulfilment of a digital learning process and aggregates each of their environmental impacts on all their life cycle (manufacture, transport, usage, end of life). We have tried to match as much as possible geographical and temporal representativeness. Our geographical perimeter is the European Union, and the year of reference is 2020. If several data are available, the one with the largest impact is used as a conservative strategy.

We highlighted five main physical resources involved (see section 6.1): *Tier 1* which refers to the end-user devices, *Tier 2* which refers to the network between the end user and the data center, *Tier 3* which corresponds to the data center's hosting services, the transport of persons and finally the domestic energy consumption.



5.1 Tier 1

5.1.1 Manufacture, transport, and end of life

Bordage & al. have conducted a study for the GREENS/EFA European Parliament group on the impacts of ICT usage in Europe (The Greens EFA, 2021). We used data from this study, which provides average impact factors for digital equipment with a European perimeter. Impacts for Tier 1 were reported per type of device. We extracted the carbon emissions for manufacture, transport, and end of life (sometimes referred as embodied emissions) and reported them in Table 6. We only focused on the devices that were identified during our qualitative study: laptops, tablets, smartphones, desktops, and second monitors. We have excluded video projectors and peripherals.

To allocate these impacts on a specific digital learning process, we decided to use an allocation based on use time. We have chosen to rely on the usage duration (i.e. the total duration when the device is used during its lifecycle) instead of the time of possession (i.e. the total duration of possession). This approach lets us allocate the totality of the embodied emissions of the device to the services it fulfils, whereas an allocation based on the time of possession would not allocate the off and idle time to any service.

Table 14. Embedded emissions of identified devices (The Greens EFA, 2021)

	Laptops	Tablets	Smartphones	Desktops	Second monitors
Climate change (kg CO2 eq.)	1,88E+02	1,00E+02	8,42E+01	2,80E+02	6,90E+01

5.1 Tier 1

5.1.1 Manufacture, transport, and end of life

We evaluate the usage duration of the product on the average usage per day to the average lifespan of each device (*eq 1*).

(eq1) life_usage
= use_time_per_day * lifespan * 365

The total impact of embodied emissions can then be allocated based on the amount of time the equipment is used during the training session (*eq 2*). Our usage hypotheses are reported in Table 15.

(eq2) impact_d_on_p
= (embodied_impact / life_usage) * process_usage_duration

Table 15. Usage hypotheses for embodied emission of end-user devices

Devices		Frequency of usage per day use_time_per_day (hour)	Average lifespan lifespan (year)	Average use time in the life cycle life_usage (hours)
	Laptops	3,56	4	5197,6
	Tablets	3 (hypotheses)	3	3285
	Smartphones	2,41	2,5	2199
	Desktops	3,54	5,5	7107
	Second monitors	3,8	6	8322

By default, we used data provided in the report ICT Impact study for the lifespan (VHK and Viegand Maagøe, 2020) and data from the Global Webindex Device Report (2020) for the usage frequency.

5.1 Tier 1

5.1.2 Usage impact

In the case of digital devices, the usage impacts consist exclusively of the impacts induced by direct (on the electrical network) or indirect (on batteries) electrical consumption. Thus, usage impacts can be defined as the product of duration, power consumption, and electrical impact factor (*eq3*). The duration is given as an input of the model, depending on the average duration of the device in the context of the process (1 hour by default).

(eq3) usage_impact
= duration * power_consumption * electrical_impact_factor

The power consumption for the identified devices was extracted from the ICT Impact study sponsored by the European Commission (VHK and Viegand Maagøe, 2020). We have chosen to use the value for 2020 to match our year of reference. The values were given in kWh per year. We used the average use time per day to get the average electrical consumption per hour (*eq 4*).

(eq4) hourly electrical consumption
= yearly electrical consumption / (average use time per day * 365)

On the one hand, we allocate the idle consumption to the average usage consumption. On the other hand, we don't account for the variation of the electrical consumption, which depends on the workload of the device. All the figures are reported in Table A1. We used the electrical impact factors from Scarlat & al. (2022) based on the electrical mix of European countries in 2019 aggregated by Eurostat (2020). We used the impact factor of the electricity consumed at low voltage, which includes the online loss and the exchange of electricity between countries. We reported an impact factor for each country and a European average, see Table A2. The country of usage is a parameter of the model which will adapt the electrical impact factor in the usage equations.

5.2 Tier 2

Different approaches have been conducted to model the impacts of the internet network. It includes modelling, physical measures, or the usage of secondary data (Aslan & al., 2017). When allocating the impacts to a specific data transfer over the network, several strategies have been proposed.

The per GB approach is the most commonly used. It consists in evaluating the global impacts of a network on a specific perimeter and dividing it by the quantity of data being transferred through it. Several studies have given an electric factor accounting for the use phase in kWh/Go (Coroama & Hilty, 2014) (Malmodin & Lunden, 2016) (The Shift Project, 2019).

As we want to account for all the phases of the life cycle of our service, we cannot use these allocation factors. Other studies have given an allocation factor in kgCO2eq. Go on all the life cycles of the network function (The Greens EFA, 2021) (ARCEP & ADEME, 2022). The main limitation of the *per GB approach* is that it differs from the physical phenomenon behind the transfer of data. Indeed, Malmodin & al. (2020) have shown that the impacts caused by data transferring aren't proportional to the volume of data transferred, but rather a function of the installed capacity.

Another approach could be to allocate the impacts based on the number of lines involved in the process. The impact of a line on a particular process can then be allocated over the time the process uses the line (*eq 5*).

(eq5) impact_line_on_process
= (yearly_impact_line / year_usage_hour) *
process_usage_duration

Other approaches exist to allocate the impact marginally, with a fixed impact allocation per line and a variable impact allocation based on data volume. The power model proposed by Malmodin & al. (2020) follows this principle. Even if this approach is promising, we lack data to characterise the consumption profile of network equipment, its manufacture, and end-of-life impacts.

Instead, we have chosen to implement in the model both a *per GB* and a *per line* approach and adapt the approach depending on the context. In order to follow a conservative strategy, a low-volume process should have an impact allocated *per line*, whereas a high-volume process should be allocated on a *per GB* basis. *Per GB* and Per line allocation factors have been extracted from the study for the GREENS/EFA European Parliament group, both for mobile and fixed lines (The Greens EFA, 2021). They have been reported in Table 9.

The impacts relative to usage, manufacture, transport, and end of life are given in an aggregated manner which makes it impossible to report them separately. We can set as a hypothesis that European data transfer transits through Europe, thus it is acceptable to use this data where usage impact has been measured based on the European electrical emission factor.

Table 16. Network emission factor

Type of allocation	Mobile network - Impact factor (kgCo2eq.)	Fix network - Impact factor (kgCo2eq.)
Per line	9,85	81,2
Per Go	0,096	0,0307

5.3 Tier 3

The services used in the context of digital learning are mostly hosted as SaaS applications either on private or public cloud. Few studies exist on how to allocate the impacts of cloud platforms to specific service usage. Moreover, data relative to cloud providers are very scarce and may differ importantly from one provider to another.

To account for tier 3, we used secondary sources of data that used a top-down approach to allocate the impact of common service to a functional unit. They measured the overall impact of their data center (DC), allocated them to the different services based on physical resource usage *(eq 6)*, and finally divided the impact by the number of functional units being processed *(eq 7)*.

For each type of services, we extracted the electrical consumption and manufacture impact separately in order to configure the usage impact based on the datacenter location (which depends on the electrical emission factor of the datacenter location). The detailed equations can be found in the model.

This approach is very limited since it uses the outcomes of only one or two studies. More studies reporting emissions factors for TIER 3 would be needed to build empirical impact factors.

We used the electrical impact factors from Scarlat & al. (2022) reported in Table A2 for European data centers. For other countries, we used the electrical impact factors from *Ember Climate's data explorer*[7], which reports electrical impact factors for most countries in the world.

(eq 6) Impact_service_n = total_impact_DC * service_allocation_factor

(eq 7) Impact_function_unit_service_n = Impact_service_n / nb_functional_unit

Table 17. Electrical consumption and manufacture impact factors for tier 3 services

Service	Functional unit	Electrical consumption (kWh)	Manufacture impact (KgCO2eq.)	Source	Note
Streaming	h	0,00226	0,00002	(Umweltbundesamt, 2021)	
Videoconference	h/participant	0,00413	0,00034	(Umweltbundesamt, 2021)	
Data storage	Go/year	0,009	0,198	(Umweltbundesamt, 2021) & (Charret & al., 2020)	Averaged on 7 datacenters from both study

[7] https://ember-climate.org/data/data-explorer/

5.4 Transport

In some cases, detailed in the result section, digital learning requires the use of transportation. For this type of transport, we have chosen to only account for the impacts of individual cars. Even if we highlighted other means of transport (mostly low-carbon transport means), such as electrical mobility, bike, public transport, we have not included their impacts. This has been motivated by several reasons:

- The lack of generic data on the impacts of low-carbon transport
- The lack of specific data for Europe
- Our wish to promote low-carbon transport

We used the average CO_2 emissions per km from new passenger cars published by EEA and accessible through Eurostat (Eurostat 2022). The data gives an average of emissions per km by new passenger cars in a given year for a given country.

We modelled the impacts of transport for a given emission factor. The factor depends on the selected country. It can either be averaged on the available years, or a specific year can be selected. The impact is later measured by multiplying the emission factor by a given distance *(eq 8)*. To take into account carpooling, we implemented in the model an occupancy rate *(eq 9).*

(eq 8) tranport_impact = impact_fator(location) * distance

(eq 9) tranport_impact = (impact_fator(location) * distance) / occupancy_rate

5.5 Domestic energy consumption

The energy consumed in the participants' homes induces greenhouse gas emissions. Distance learning increases the amount of time participants spend in their homes. This increase leads to an overconsumption of energy.

We have retrieved the overconsumption in each European country based on Roder model (2014). The model was initially developed for the overconsumption of household energy in the context of teleworking in Germany. We adapted the model with specific data from Eurostat for each European country for 2020. This method model the consumption per person per household per hour from a fixed part, which corresponds to the consumption that occurs with or without the presence of the inhabitant and a variable part, which corresponds to a consumption with the presence of the inhabitant. The variable part is fixed at 30% of the fixed consumption. We attribute the impact of the overconsumption (variable part) as a function of the duration of the learning process considered. It should be noted that this approach is extremely simplistic.

We propose to compare these data with the figures of the IEA on the European perimeter in 2020, which proposes an over-consumption induced by teleworking for a household composed of only one member.

5.5 Domestic energy consumption

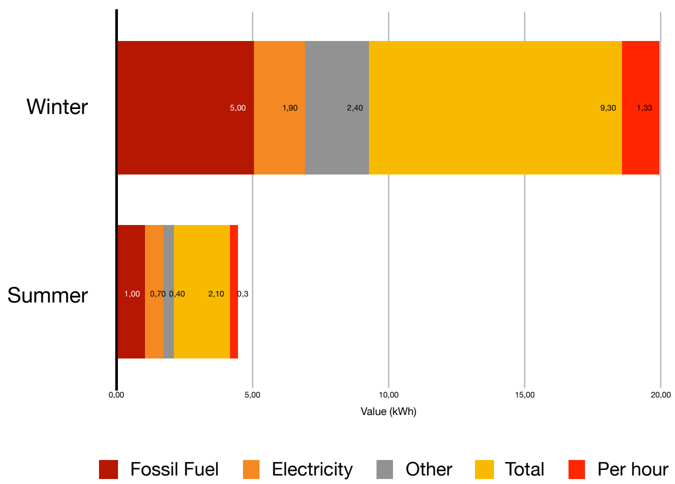
We adapted the figures of IEA for a 7-hour working day. It gives an average overconsumption of 0,3 in summer, which corresponds to 67% less than what we get with the Roder's model and 1,33 in winter, which corresponds to 48% more than what we get with the Roder's model. The average value over a year is 0.8 kWh at the European level, which corresponds to the same order of magnitude as the Roder model on the European perimeter (0,9 kWh).

To account for the uncertainty of the model and the lack of detailed data sources to compare it with, we decided to provide a range of +/- 50% to account for the energy related to domestic energy consumption. The values for each European country are available see Table A3.

It should be noted that this approach is very limited, as it does not take into account several factors:

- The composition of the households. A household with teenagers, for example, is more likely to use distance learning and has specific energetic characteristics.
- The primary data used had already incorporated variable consumption induced by distance learning (in 2020 households were already involved in distance learning). There is therefore a risk of double counting.

Table 18. Average change in energy demand from one day of home working for a single household - (IEA, 2020)



- The cross effects induced by households with several members following distance learning or teleworking.
- The specific consumption during the hours of digital learning (probably no energy related to the kitchen or the shower room, use of a computer, …)

To account for the green gas emissions of domestic energy consumption, we provide an impact factor for each country per kWh. We use the share of energy by source consumed by households for residential purposes, provided by Eurostat[8], in combination with the impact of each energy source taken from ADEME "Base carbone".

The impact factors are specific to the European perimeter when available, and on the French perimeter if not. We use the impact factor from Table A2 for the impact of electricity. Since several impact factors are available and subject to debate among practitioners, we propose a maximum and a minimum value for each country in order to propose a range of values. All the values used are reported in tables; Table A4, Table A5 and Table A6.

[8] https://ec.europa.eu/eurostat/databrowser/bookmark/6b7f39aa-308d-4c4f-be02-3f09a83f0dd1?lang=en

06. Creating the scenario
6.1 Functional units

Environmental impact analyses of process are reported on a functional unit. It corresponds to the reference unit provided by the system. The choice of functional units is critical since it may change the results of the study (Matheys et al., 2007). It must correspond to the function provided by the system rather than the physical principle that allows the system to function. It is therefore relevant to characterise the functional unit from the users' perspectives.

During our focus group, most participants delimited their digital courses by time duration. Thus, we have chosen to use an hour of digital learning as our functional unit.

"When you have to facilitate 4 hours."
"You had to do a 7-hour training day."

Some professional trainers characterised a course in terms of a teaching unit. It could be, for instance, ECTS credits (European Credit Transfer and Accumulation System) in the academic context. Although this functional unit corresponds more precisely to the nature of the function studied, we have decided not to select this option. The main reason is the difficulty of qualifying a homogeneous teaching unit applicable to heterogeneous contexts (synchronous or asynchronous, professional or academic, in autonomy or within an institution, etc).

Since digital learning sessions are followed by a heterogeneous number of participants – from a few people in synchronous professional training to several thousand in some asynchronous training – we have decided to report the impacts per participant. The functional unit chosen is, therefore:

One hour of digital learning session for one participant

6.2 List of involved resources

6.2.1 Service involved

We tried to identify the resources that were involved in the context of a digital learning class. We used the results from the focus group to characterise the resources. We have tried to make this list as exhaustive as possible.

We have chosen to group the different services mentioned by the participants regarding their usage during a digital learning session.

Table 19. Digital services identified during the qualitative study

Name	Description	Example given during the focus groups
Videoconference tool	Tools for synchronous oral and/or visual communication of learners with trainers	Teams, Zoom, Jitsi, Google Meet, Webex, Skype
Synchronous collaboration	Tools for synchronous collaboration of learners with trainers or among themselves	Klaxoon, BCast, Mural, Metro-retro, Jamboard, Socrative, Mentimeter, Kahout!, Wooclap nextcloud, Doodle
Content creation	Tools allowing the creation of training content in various formats (text, interactive content, video, slides)	PowerPoint, Adobe Captivate, Adobe creative suite, Audacity
Communication channel	Tools allowing asynchronous communication between learners and trainers or between learners themselves	Email, SMS, Slack, chat
Storage cloud	Tools for storing training content or work related to a learning process by learners and trainers	Dropbox, Google Drive, OneDrive, Moodle, Nextcloud, LectureCast
LMS	Tools allowing the storage of training content or work related to a learning process	Moodle, My Green Training Box
Evaluation tools	Tools for synchronous or asynchronous evaluation of learners	Google Form, specific evaluation tools from universities

6.2 List of involved resources

6.2.1 Service involved

Participants who have attended their first digital learning sessions during the Covid crisis tend to have listed fewer tools than people who were used to this type of classes before the crisis. The invariants for synchronous sessions were *communication channels* and *videoconference*. Most participants mentioned that their organisation had a Learning Management System (LMS) which was underused or not used at all.

Some trainers who participated in our focus group mentioned that the choice to use one type of tool over another was up to them and depended on their pedagogical strategy and class format. However, the choice of a specific tool depends on external constraints. In some cases, the institution in which the trainer delivers his classes will impose a service provider. This is mainly the case for *video conferencing tools*. This type of constraint clashes with the participants' desire to use more accessible or virtuous tools.

“they impose tools on me [at] universities”

"We are often stuck by the fact that only Teams can be used. [...] we had other options that were more virtuous, open source for instance, but that wasn’t allowed in companies."

Other constraints related to the accessibility of the software were mentioned. Indeed, the training of people who have difficulties with digital tools influences the choice of tools used.

"it's only Zoom because it is accessible to them."

6.2 List of involved resources

6.2.2 End-user equipment involved

Whereas resources associated with TIER 2 and TIER 3 have been identified through digital services, TIER 1 is characterised by the hardware equipment directly used by the participants. Based on their responses, mostly from the topic "Tools: Technologies and equipment", we identified 7 end-user types of equipment involved in a digital learning session. They are reported in Table 20.

The equipment involved in digital learning can have different origins. It can be fully owned by the participant, who can use it partially or totally for digital learning. It can be shared by people from the same household, or it can be borrowed from the institution.

Table 20. Digital equipment identified during the qualitative study

Name	Example given during the focus groups
Desktop	Mac mini
Webcam	Improved working comfort by investing in a webcam
Headset	Improved working comfort by investing in a headset
Laptop	PC, Macbook
Second screen	Improved working comfort by installing a second screen
Smartphone	Follow-up of a course during a mobility
Specific high-tech equipment	Virtual reality headset for training in public speaking

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One of the participants in the learner focus group mentioned the use of a smartphone when following a class outside his workspace.

"[I use] my phone sometimes when I move around"

The use of smartphones in online courses is known to the producers of digital learning platforms, who can implement compatible tools. The use of the smartphone is presented by one of the participants in the focus group of platform producers as an existing but not recommended behaviour.

"You can be trained with your iPhone, even if it is not recommended."

Finally, we have found that high-tech equipment could be used in the context of digital learning. The example of virtual reality was mentioned and discussed during one of the focus groups, in which several participants were producing virtual reality content.

"When you want to train with virtual reality, you'll need a PC with a virtual reality helmet"

6.2 List of involved resources

6.2.3 Other resources involved

In addition to the above resources, we identified other non-digital resources involved in the process of digital learning. We decided to include them when their associated impacts could be directly attributed to the digital process, i.e. their usage in the context of a digital learning process involves an extra environmental cost. They are reported in Table 21.

Different from what can be expected, transportation was still necessary for several learners and trainers. Indeed, while most of the participants follow digital sessions from their homes, others still need to move in order to follow a session. Different reasons have been mentioned:

- Lack of network connection
- Lack of digital devices
- Digital illiteracy
- Environment not suitable for learning/teaching
- The design of some of the courses, such as hybrid classes
- New mobilities (see part 6.4.6)

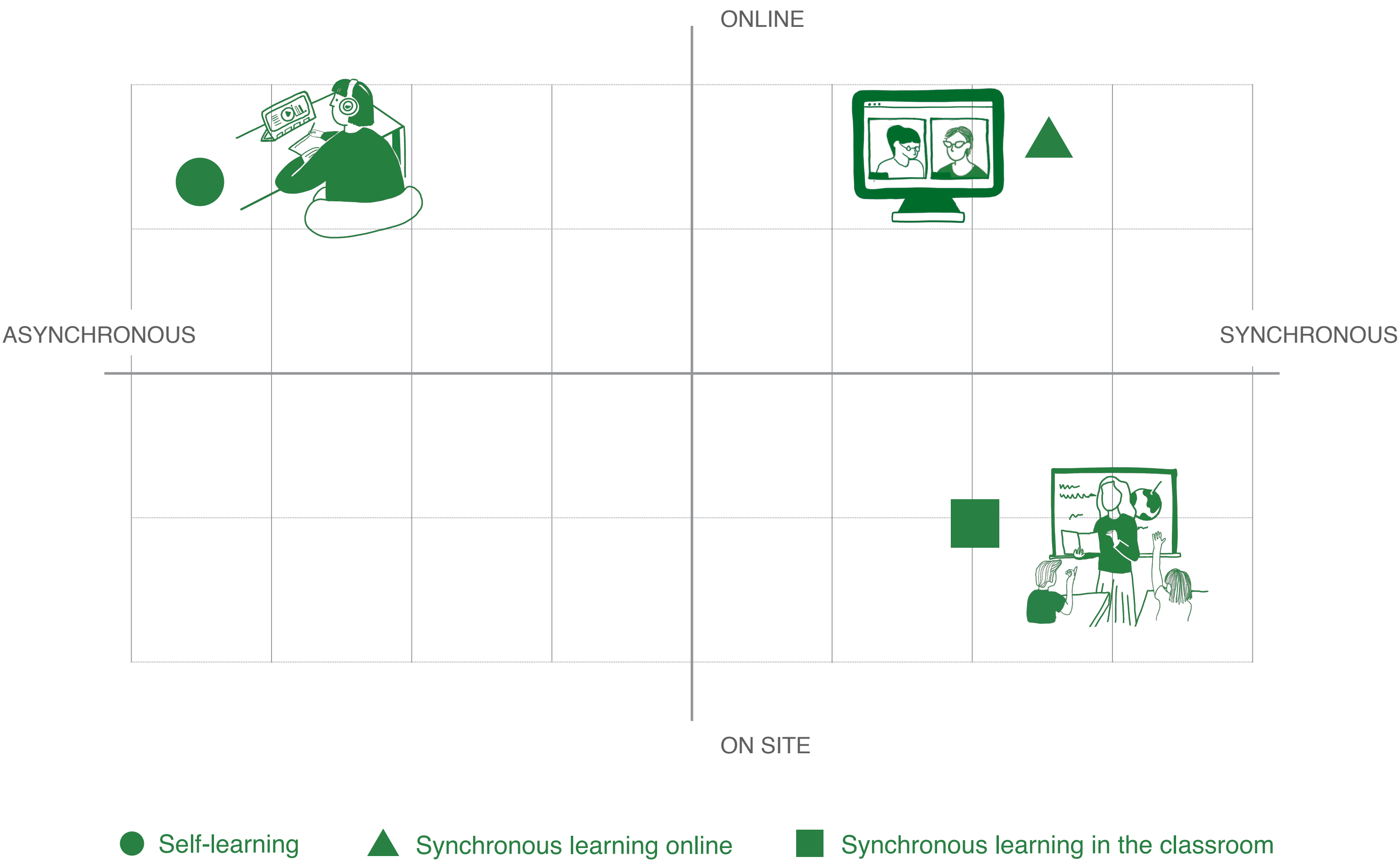
“the biggest obstacle today for the massification of users is not hardware equipment, but rather the connection’s quality”

“they didn't have 3 computers at home, and not even 3 rooms to be able to have speakers in parallel"

As mentioned in section 5 overconsumption of domestic energy induced by digital learning must also be taken into account. No participants in the focus group have mentioned it. However, we have still decided to include it, as this resource has been mentioned in the literature (Caird & al., 2015; Filimonau & al, 2020).

Table 21. Other resources identified during the qualitative study

Name	Description	Example given during the focus groups
Transportation	Remaining travel required to follow digital courses	Travel to a coworking space
Domestic energy consumption	Overconsumption of domestic energy during digital classes	-



6.3 Digital learning stories

Different learning processes could be qualified as digital learning. This was seen during the focus groups as participants had different definitions and often needed some clarifications.

"Can we talk about both e-learning and distance learning? Are we talking about both? As well as what [company] does, for example, with training that is accessible in e-learning and what I did for [company] last week remotely?"

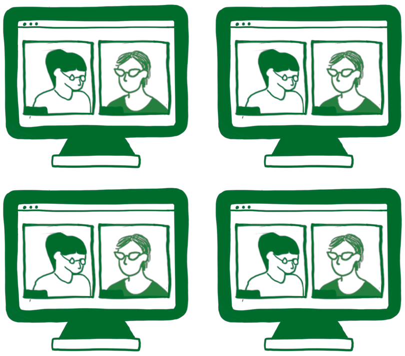
We were able to identify 3 digital learning stories during the focus group. The clustering was motivated by the similarities in the ICT usage, the synchronicity or non-synchronicity, and the relative location of each of the participants. The chosen clustering is represented in *figure 6.* For each scenario, specific usage behaviours that could have an impact on the overall process were reported in order to be implemented in the model. Our scenarios partially cover the existing categories given by Allen & al. (2003) reported in Table 2.

Furthermore, we identified two main types of stakeholders across the focus groups. A first group that we call the *beginners,* who had little or no experience in digital learning before the COVID-19 crisis, and the *experts* who were already used to this type of process, which was their main activity.

For each scenario, we gave a description, including all digital and non-digital resources involved. We also describe what we call extreme cases, which refer to variations from the initial scenario that has been identified during the focus group. The model must allow the modelling of all these different scenarios as well as the identified specific behaviours. Each element is supported by quotes from the focus groups.

6.3 Digital learning stories

6.3.1 Synchronous learning online



Typical scenario

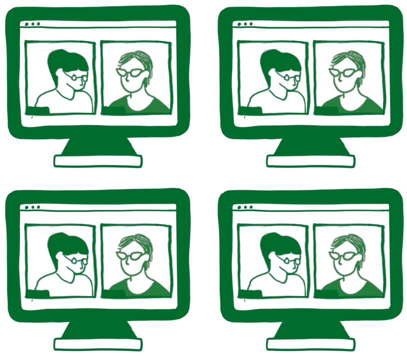
A teacher creates content, on a presentation tool, or modifies an already created content. The content can be composed of text, images, and videos. Content, planning, communication canal, and cloud storage, often are organised by the institutions in a Moodle-like platform. The teacher sets up his class on the institution's platform. The learners connect to the platform to access the planning and the resources. A class composed of many learners and one teacher connect themselves to a videoconference tool with their end devices at the time of the course. The teacher usually shares his camera, and few learners turn on their cameras. The teacher uses multiple pedagogical mediums. He can share a presentation, and make the learners participate through synchronous collaboration tools.

A part of the class can be dedicated to autonomous learning. The teacher sends instructions via a communication channel (instructions typically are hosted on cloud storage). The learners work asynchronously on their work and send it back through a communication channel for asynchronous or synchronous correction. Progress reports can be done one-to-one with teachers and learners.

After the class, teachers and learners keep in contact and share documents (homework, questions, etc) through their Moodle-like platform or their communication channel.

6.3 Digital learning stories

6.3.1 Synchronous learning online



The vast majority of *beginners* mentioned synchronous learning through videoconference tools as the main process that could be qualified as digital learning. Those types of courses are very close to the classical on-site courses. The oral and visual exchanges were replaced by a videoconference tool. One expert presented this type of course in a satirical way as: ***"zoom with a PowerPoint"***

It was sometimes the only process mentioned by *beginners* when referring to digital learning. Most of them encountered this type of process during the different lockdowns or during strikes for one French participant. It was found that *experts* were critical of this type of learning process which, according to them, did not take sufficient advantage of the digital assets. ***"basically we transformed a PowerPoint support, we put it in a zoom, we say that we do distance learning and virtual classes but, very often, we are very far from it"***

The *experts* presented this type of course in a more complex way. They segmented those courses into synchronous and asynchronous sessions. According to one stakeholder, digitalisation of the class makes it easier for the teacher to personalise learner's support during the asynchronous part of the class. ***"at distance, we will be on a more individualised follow-up."*** Whether for *experts* or *beginners*, this type, of course, allows participants to retrieve the mechanisms of a face-to-face classroom through the digital tool. We can cite the collaboration with post-its, facilitated by digital tools. ***"It allowed me to rediscover the functioning of post-it notes [...] the digital post-its are more advanced than the regular one. To have the same functionalities as the regular ones, we had to prepare for a long time"***

The main devices used to follow video conferences were laptops and desktops. Some participants use multiple devices in order to maximise their comfort during a session. We can mention the second screen but also phones which can serve as a second screen for chatting or to search resources.

Finally, in the university context, the sessions are sometimes not mandatory. The fact of moving the session online has been, for some, a way to increase their attendance (due to easier access to the classes) while for others it was an incentive to reduce their attendance. For one student, the recording of the sessions could be another incentive to reduce student attendance.

"I had large face-to-face lectures. Some of them were recorded so that we could re-listen to them afterward at home or if we didn't want to come"

This type of digital course could be in some cases totally asynchronous when the records were the only way to access the course. We don't refer to this type of class as *face-to-platform* since such courses have no intention of being scalable.

"My professor was filming himself and putting the videos on [platform]"

6.3 Digital learning stories

6.3.2 Self learning

Typical scenario

An institution either develops, buys, or rents a moodle-like platform to host learning content. A content creator creates a course, the course is formatted in accordance with the moodle-like platform. Different content formats might be implemented : text, video, audio, interactive pages, auto-evaluations, etc. The institution can develop specific contents or host external contents on their platform.

A course is followed autonomously by 0 to n learners, discontinuously. The course can stay hosted for an undefined period of time. Some sessions can be organised during specific periods.

This type of scenario was mostly encountered in a professional context or by *experts* in the academic context. The main reason for using this format was the need or the will to scale the learning process.

"as we're on a big organisation, it seemed the only possible solution"

Some participants follow asynchronous learning autonomously on digital platforms that are not managed by their institution. This was even more notable for university student learners. The typology and format of contents hosted on this platform are heterogeneous. It goes from text to video, audio, interactive or virtual reality content.

"format, such as videos, podcasts, self-assessment, etc."
"we have a platform of virtual reality contents"

Those platforms are mostly used autonomously and asynchronously by learners. However, they might be used totally or partially in the context of face-to-face training. This behaviour is important to note since it induces commuting.

"It's a tool that can be used asynchronously, but it can also be used synchronously and it is used in universities, training organisations, companies, etc. It can even be used in the classroom."

6.3 Digital learning stories

6.3.3 Digitised face-to-Face

Typical scenario *A digital content is created by the trainer with one-to-many synchronous collaboration tools or an autonomous learning tool. On the day of the class, trainers and learners travel to the class location with several means of transport. Trainers and learners often travel for various classes.*

The trainer animates the class alternatively with direct oral communication and through the digital tool on his device. Learners also have devices, either their own end devices or specific devices related to the digital content format (provided by the institution).

From participant testimonies, the materials used during on-site classes are heterogeneous. While some use notebooks, others use laptops to take notes. However, all learners who participated in our focus group needed digital devices before the class time for registering for class and managing their schedule, and after the class for asynchronous discussions with the trainers or the other learners. From the participant's answers, we can assume that all university and professional face-to-face classes need digital devices and infrastructures at some point.

"In the classroom, we do everything on our computers. I mean, I don't see anyone who have only a pen and a paper."

It should be noted that the participants are not representative and that it is possible that this statement is not totally true, especially for the more practical topic.

The pedagogical content can be printed, projected, or sent through communication channels. The pedagogical material is typically shared in one or two formats. In some cases, digital contents are the central pedagogical material. One participant, for instance, creates virtual reality content and animates professional face-to-face classes. Those classes require VR headsets lent by the institution. Another participant created digital content for second-grade classes (on-site).

"So we're more about equipping teachers, educators, people who are going to intervene with young people in the classroom."

6.3 Digital learning stories

6.3.4 Hybrid

Typical scenario *A class is organised by a trainer in different modules. While some modules are organised face-to-face, others are on distance synchronous or asynchronous (autonomous learning).*

Several participants mentioned a hybrid scenario composed of several modules, each corresponding to a scenario presented above. Due to the heterogeneity of the cases identified, we have chosen not to include it in our survey and impact assessment.

This type of scenario is a mix of the above scenarios. According to several participants, this scenario happens when an institution begins to mature with digital learning. We noticed that *expert* profiles were more likely to mention hybrid scenarios. In some cases, hybrid refers to a mix of synchronous and asynchronous learning - via videos or MOOCs for instance. The term adaptive learning or mixed approach was given by some experts. In that case, the use of digital tools is a way to individualise training courses.

"it can be 1/3 in zoom and 2/3 in videos recordings of previous years"

"What we call it adaptive learning, which means that we do both synchronous and asynchronous learning, but we are mainly focused on the learner, which means that we individualise the training courses."

The term *blended learning* was also given by some experts. In that case, hybrid refers to a portion of the course being online and a portion being face-to-face. **"I also do blended learning, with a bit of everything, [...] self-training parts, synchronous parts, web conferences. And then there was one day of face-to-face training."**

While for *beginners* the hybrid model was a way to have access to their course in an easier manner by varying the means of access, for *experts*, this model is rather a way to personalise the training for each learner. In that case, digital tools are a way to individualise learners' support, especially in the case of classes with a large number of participants. **beginner:** *"it's not bad to have the choice between on site and on distance"* **expert:** "We do a blended approach. [...] with digital, it's easy to manage a class of 30 students and differentiate the pedagogy between each individual."

This type of teaching organisation seems to persist beyond the COVID period. Indeed, some participants reported a willingness of their institutions to establish minimum rates for distance education. ***"In traditional higher education there have been real upheavals and that, in my opinion, is really perennial. I see in the various school that directors want to make minimum 30% of distance learning."*** Some institutions are equipped or are in the process of equipping themselves with recording tools to make all courses available online, thus facilitating the implementation of a hybrid organisation. On the one hand, the recordings can allow for a hybrid mode where some of the participants follow online and others in the classroom, on the other hand, they can be reused in the context of asynchronous modules for subsequent years, for example. ***"it's hybrid, recorded with a camera during the course, but also face-to-face course"***

This approach is preferred by most *beginners* for comfort and convenience, and also by most *experts* because of the pedagogical individualisation it allows. In addition, as Marieke Versteijlen & al. (2021) suggest that this type of class could be the best trade-off between carbon reduction and quality education.

"it is good to have a mix"

07. Results : Impacts assessments of several scenarios

For each scenario identified in section 6 we have applied our model to both an average European use case and another hypothetical use case of interest. The average European use cases are modeled with average European impact factors and survey variables.

Our objective in this section is to show through different examples the order of magnitude of the environmental impact of digital learning in Europe. **Note that the different scenarios were not designed to be compared and, as such, should not be**. The goal of this section is not to determine the best digital learning scenario, but rather to understand what sizes the impacts of each scenario.

As defined in the methodology section, the impacts related to TIER 3 are difficult to estimate in the context of our study. Thus, the impacts related to TIER 3 are probably underestimated.

Tier 1 *refers to the end-user devices*

Tier 2 *refers to the network between the end user and the data center*

Tier 3 *corresponds to the data center's hosting services.*

7.1 Synchronous digital learning

7.1.1 Average European Scenario (AES)

We use average values for the European use case taken from our survey. We use average European impact factors. The impact related to networking is evaluated with the "per line" method. All the values used are reported in Table A7. With the average values taken from the survey result, the footprint of a 1-hour session is valued between 8,79E+00 kgCO2eq. and 1,92E+01 kgCO2eq. (1,31E+01 kgCO2eq. in average), Table A8.

The footprint of a 1-hour session per person is estimated between 4,07E-01 kgCO2eq. and 8,91E-01 kgCO2eq. (6,06E-01 kgCO2eq. in average). The equivalence[9] for the average value can be seen in Figure 3.

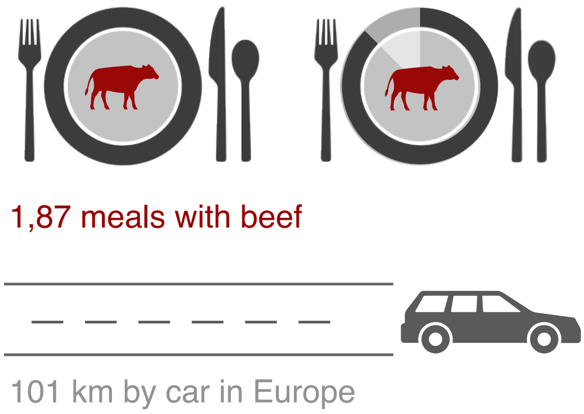


Figure 3. The equivalence for the average value of a 1-hour session per session – AES

The main source of impact comes from the over-consumption of energy in the accommodation of distance learning participants, which represents between 27.9% and 67% of the average impact of a session. This is due to the high proportion of students attending classes in their accommodation (94.3%).

The second most important share is related to the participants' transport. Indeed, our survey showed that even in the case of synchronous distance learning, a proportion of participants had to travel (5.7%). This share, although small, has a significant impact on the session (between 16% and 35%). According to our model and in the average travel conditions (40 km) the impact induced by the commute of one participant is more important than the one linked to the overconsumption of energy in the accommodation of one participant.

If we look at the impacts related to digital resources, terminals are the main source of impacts. This is mainly due to the large number of terminals involved, and in particular the use of several terminals per participant (2,3). **It can be noted that the impacts linked to the manufacturing, transport and end-of-life phases represent more than half of the impacts.** This can be explained by the quantity of terminals used whose embedded impacts are significant.

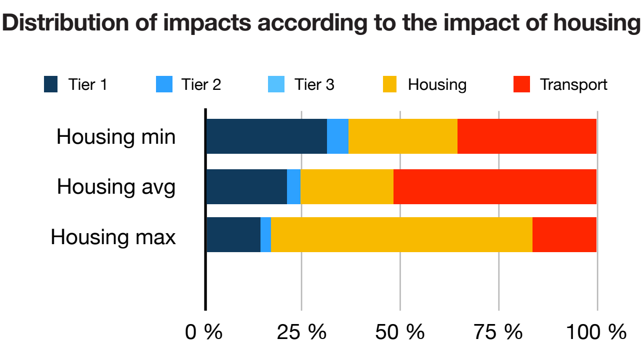


Figure 4. Distribution of impacts according to the impact of housing – AES – Synchronous DL

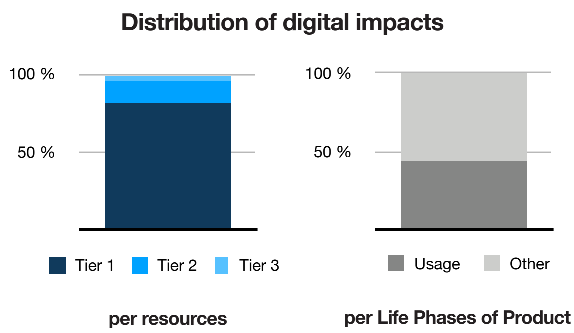


Figure 5. Digital impact distribution per resources and per life phases of a product – AES – Synchronous DL

[9] The selected equivalents are taken from https://impactco2.fr/. ImpactCO2 is an ADEME project which is part of Datagir.

7.1 Synchronous digital learning

7.1.2 Online university lecture in Portugal (Use Case 1)

Let's now apply the model to a specific use case: **a videoconferencing lecture course with 59 students and 1 professor in a Portuguese university.**

We choose a minimalist case where each student uses only one piece of equipment. The types of equipment used are equally divided between laptops, smartphones and fixed computers. 1 GB of online storage is used for this specific class and stored for a year (the duration of an academic year). Both storage and videoconference service are hosted in a cloud environment in the US. We suppose that all students follow the class in their homes and thus avoid the use of transport but increase the energy consumption related to their house. All other variables are set with default values. All the impacts factors are specific to the Portuguese energy mix. All the values used are reported in Table A9.

In this scenario, the impact of 1-hour session is valued between 7,52E+00 kgCO2eq. and 2,80E+01 kgCO2eq. (1,54E+01 kgCO2eq. in average), Table A10.

The impact of a 1-hour session per person is estimated between 1,25E-01 kgCO2eq. and 4,66E-01 kgCO2eq. (2,57E-01 kgCO2eq. in average).

Considering that this course is delivered in 2-hour sessions during the 36 academic weeks, we estimate the impacts of the course to be between 5,42E+02 kgCO2eq. and 2,01E+03 kgCO2eq. (1,11E+03 kgCO2eq. in average). The equivalence for the average values can be seen in Figure 6.

The main source of impact comes from the energy used by the participants during the session. It is estimated that it represents between 55% and 90% of the impacts attributable to this session.

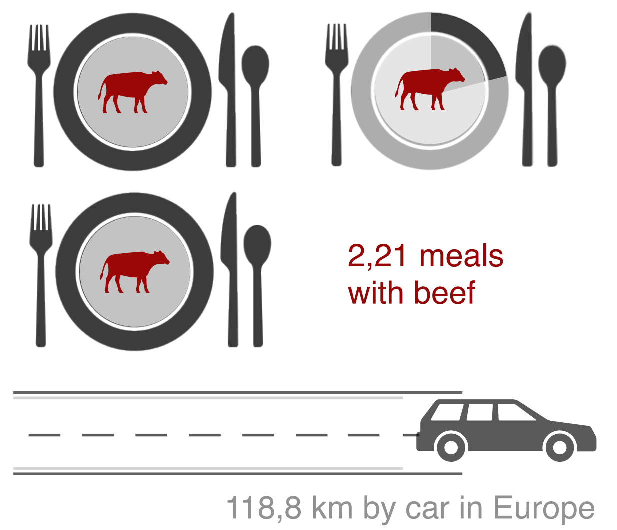


Figure 6. The equivalence for the average value of a 1-hour session per session (59 students and 1 professor)

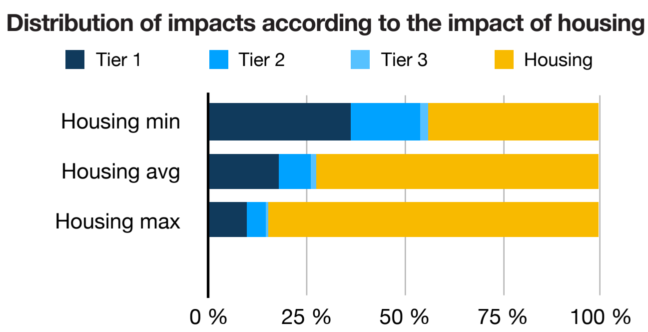


Figure 7. Distribution of impacts according to the impact of housing – Use Case 1

7.1 Synchronous digital learning

7.1.2 Online university lecture in Portugal (Use Case 1)

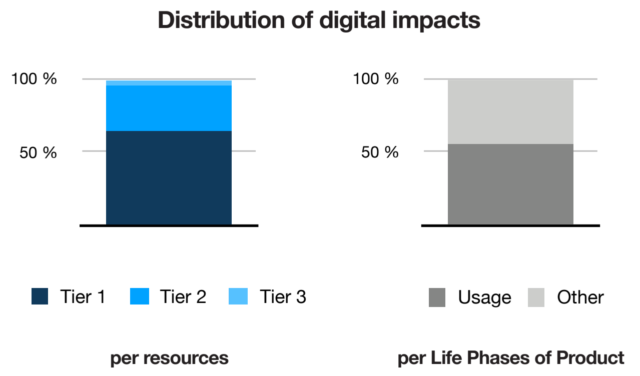


Figure 8. Digital impact distribution per resources and per life phases of a product – Use Case 1

If we look at the impacts related to digital resources, terminals are the main source of impacts. This is mainly due to their large number (60). It can be noted that the impacts linked to the manufacturing, transport and end-of-life phases represent half of the impacts, the other half being carried by the use phase. This can be explained by the quantity of terminals used of which embedded impacts are significant.

The use phase is not negligible, as the carbon intensity of the Portuguese energy mix is rather high (in comparison to the European average). **It should be noted that terminals on battery (laptop, smartphone) have a proportionally lower impact on usage than terminals on mains (desktop, screen) because their electricity consumption is optimised to maximise the duration of use per charge, Figure 10.**

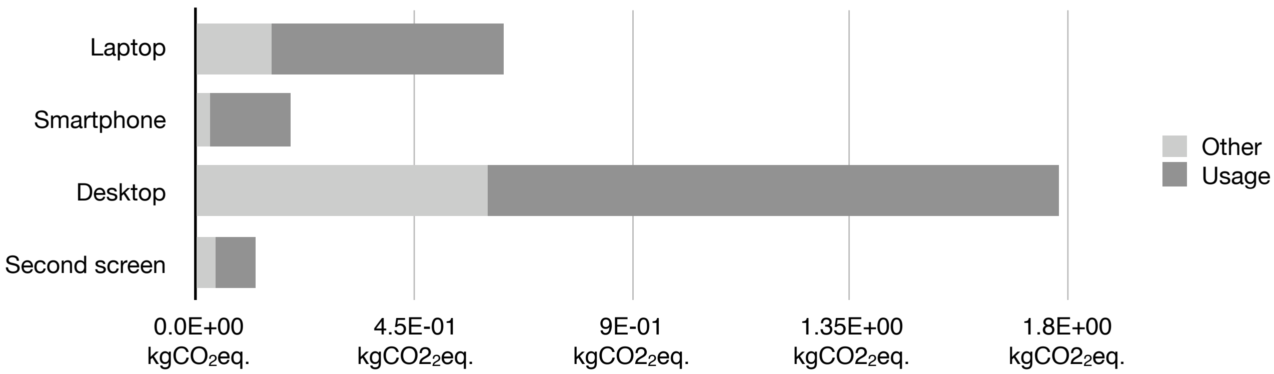


Figure 9. Impact of the use of digital resources per device

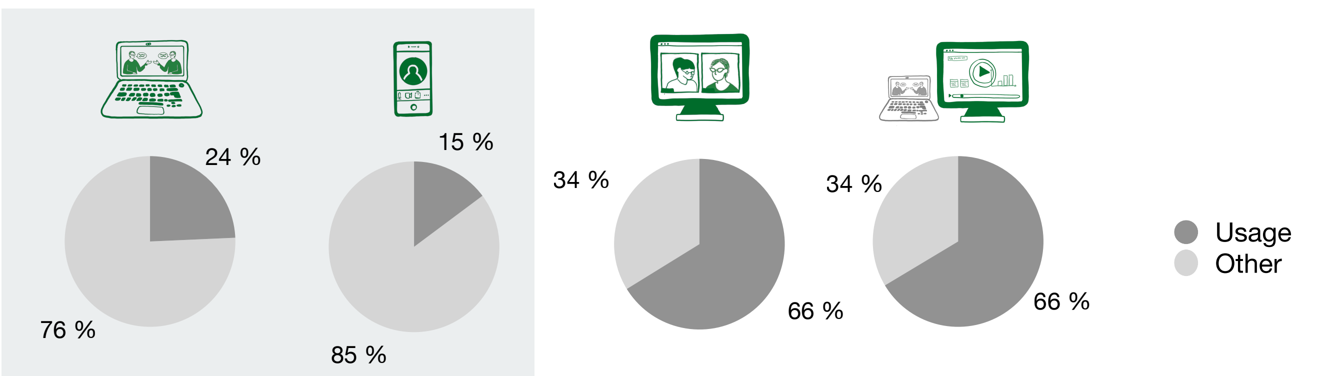


Figure 10. The percentage of the impact of the use in the lifecycle of the device

7.2 Asynchronous digital learning*

7.2.1 Average European Scenario (AES)

We use average values for the European use case taken from our survey. We use average European impacts factors. The impact related to networking is evaluated with the "per line" method. For Tier 3, we only take into account the impacts related to video content delivery (via streaming). All the values used are reported in Table A11.

With the average values taken from the survey result, the footprint of 1-hour session for 1 learner is valued between 3,59E-01 $kgCO_2eq$. and 8,44E-01 $kgCO_2eq$. (with an average value of 5,58E-01 $kgCO_2eq$.), Table A12. The equivalence for the average value can be seen in Figure 11.

Impacts related to transport and domestic energy represent the major part of the impact of such session (between 70% and 85%). Although only 2% of the participants uses their car, transport represents one of the major footprint of a session (between 22 and 45%).

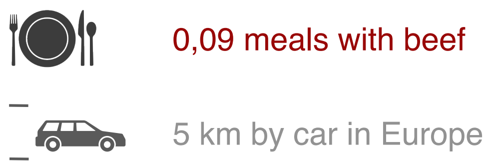


Figure 11. The equivalence for the average value of a 1-hour session per session per participant – AES

If we look at the impacts related to digital resources, terminals are the main source of impacts. This is mainly due to the large number of terminals involved, and in particular the use of several terminals per participant (2,2). It can be noted that the impacts linked to the manufacturing, transport and end-of-life phases represent more than half of the impacts. This can be explained by the quantity of terminals used of which embedded impacts are significant. Still, the impact related to the use phase is not negligible due to the carbon intensity of the European electrical mix (0,334 $kgCo_2eq$./kWh).

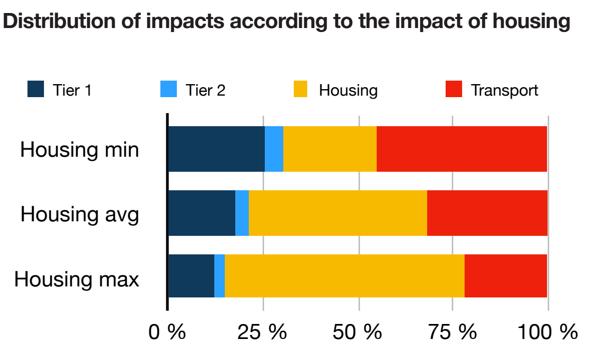


Figure 12. Distribution of impacts according to the impact of housing – AES – Asynchronous DL

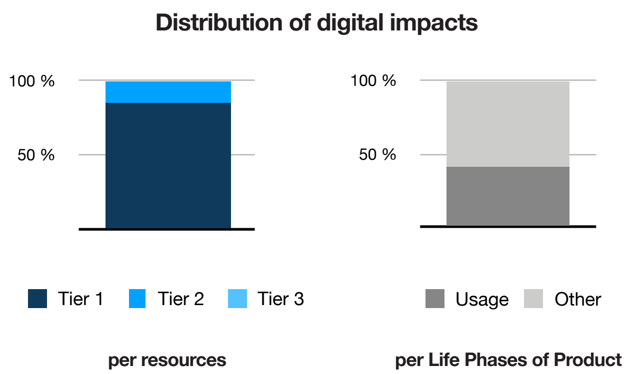


Figure 13. Digital impact distribution per resources and per life phases of a product – AES – Asynchronous DL

*We don't take into account the impacts related to the development of the platform or the content.

7.2 Asynchronous digital learning

7.2.2 Moodle based learning platform for the Belgium market (Use Case 2)

Let's now apply the model to a specific use case: **a Moodle based platform used in the Belgium market. We evaluate the impacts of 1 session of one hour for 300 learners. The session is based on video content (streaming). The platform is hosted in Belgium.**

Half of the learners follow the session at their place since they own a laptop, the other half need to commute to their institution where they have a desktop. Half of them commute by car, with an average distance of 25 km (round trip). All other variables are set with default values. All the impacts factors are specific to the Belgium energy mix. All the values used are reported in Table A13.

In this scenario, the impact of 1-hour session is valued between 3,16E+02 kgCO2eq. and 3,97E+02 kgCO2eq. (3,53E+02 kgCO2eq. in average), Table A14. The impact of a 1-hour session per person is estimated between 1,05E+00 kgCO2eq. and 1,32E+00 kgCO2eq. (1,18E+00 kgCO2eq. in average). The equivalence for the average values of per session can be seen in Figure 15.

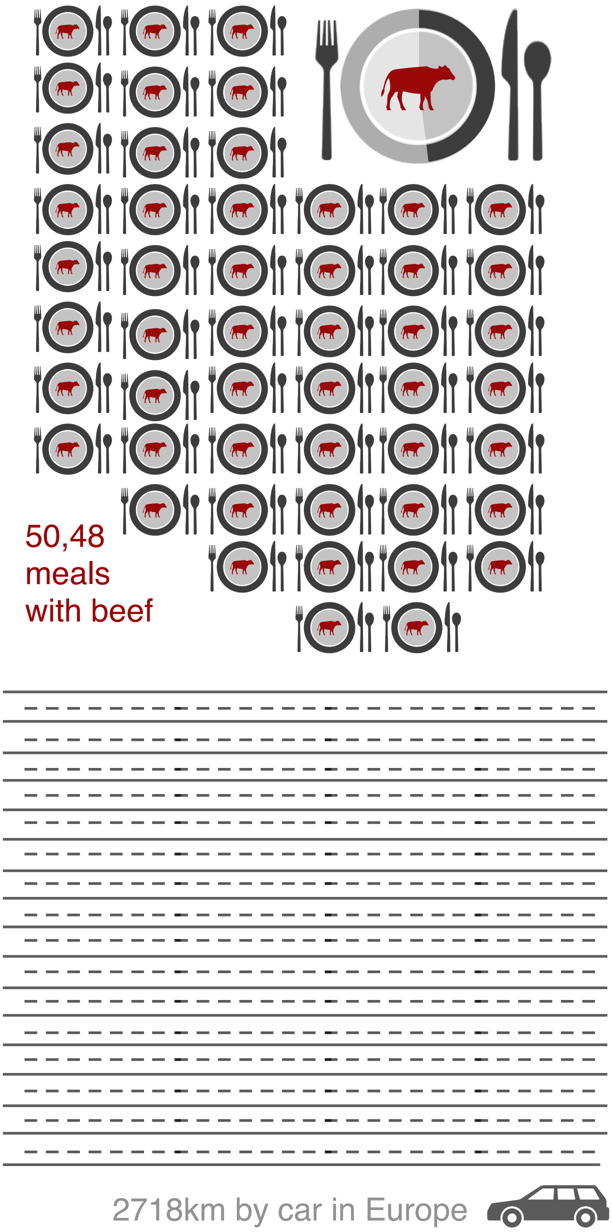


Figure 14. Equivalence of the impact of a 1-hour session in Belgium in terms of a meal with beef and kms by car in Europe

7.2 Asynchronous digital learning

7.2.2 Moodle based learning platform for the Belgium market (Use Case 2)

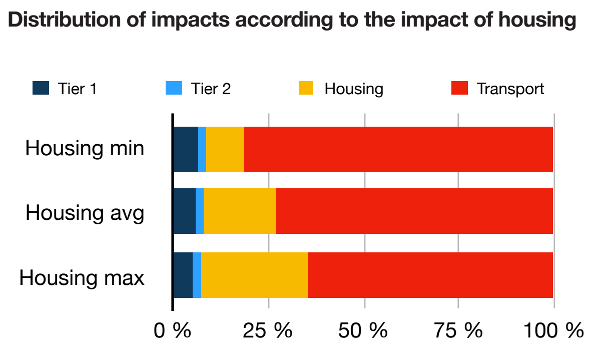


Figure 15. Distribution of impacts according to the impact of housing – Use Case 2

Impacts related to transport and domestic energy of participants represent the major part of the impacts of such session (between 85% and 91%). Although only a quarter of the participants use their car, transport represents the major footprint of a session (between 65% and 81%).

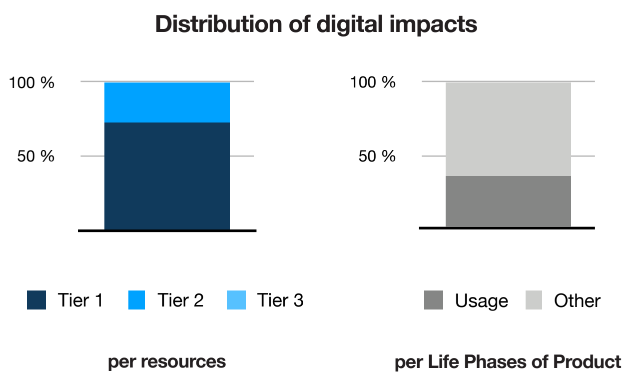


Figure 16. Digital impact distribution per resources and per life phases of a product – Use Case 2

Here again, the impact linked to digital resources is borne mainly by the user terminals (70%). This is followed by the impact of network usage (27%). The use of streaming leads to a significant consumption of data, which explains the important share of the network in this scenario. It should be noted that the impacts linked to TIER 3 (data centres) are probably underestimated.

7.3 Digitalised face-to-face

7.3.1 Average European Scenario (AES)

We use average values for the European use case taken from our survey, as well as average European impacts factors. The impacts related to the use of data centres (TIER 3) and the network (TIER 2) are excluded from this scenario due to the difficulty of determining the digital resources used in a classroom setting. A more specific study should be carried out to determine the digital practices within the European face-to-face classes. All the values used are reported in Table A15.

With the average values taken from the survey result, the footprint of 1-hour session is valued at 9,33E+01 kgCO2eq. in average, Table A16.

The footprint of a 1-hour session per person is estimated between 3,49E+00 kgCO2eq. in average. The equivalence for the average value for per session is in Figure 18.

The main source of impact (96.5%) is linked to the transport of participants by car (only the impacts linked to the transport of people by car are considered).

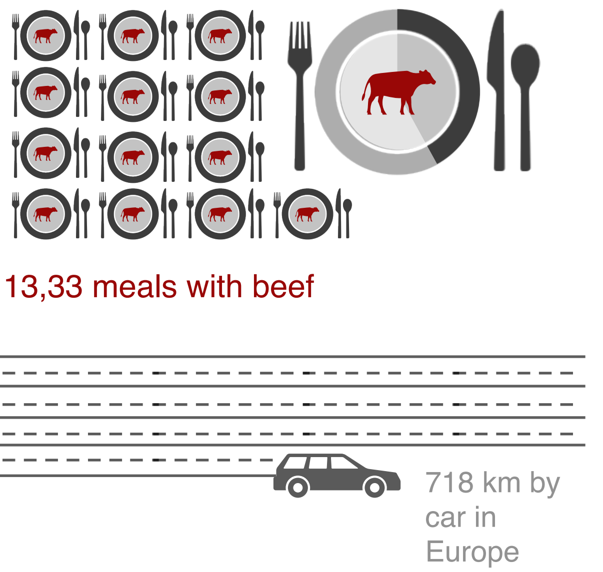


Figure 17. Equivalence of the footprint of a 1-hour session in terms of km driven in Europe by car and a meal with beef – AES – Digitalised face-to-face

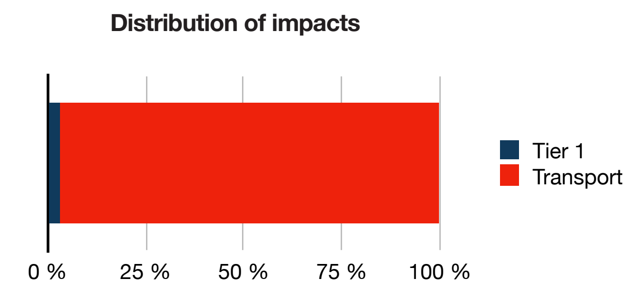


Figure 18. Distribution of impacts – AES

7.3 Digitalised face-to-face

7.3.2 Professional face-to-face French class (Use Case 3)

Let's now apply the model to a specific use case: **a professional face-to-face on-site class, where 9 learners and one trainer attend the session.**

In this scenario, the training institution provides a tablet for each learner and trainer. The tablets have a high renewal rate (1.5 years versus 3 years on average in Europe) and are only used for training purposes. We assume that all digital contents are available locally. Thus, no impacts related to network or cloud services are considered.

All learners have to commute to the teaching site. Half of them commute by car, with an average distance of 20 km. All other variables are set with default values. All the impacts factors are specific to the French energy mix. All the values used are reported in Table A17.

In this scenario, the impact of 1-hour session is valued at 1,51E+01 kgCO2eq, see Table A18. The impact of a 1-hour session per person is estimated at 1,51 kgCO2eq. Considering that this course is delivered during a day (7-hour sessions) during 4 days, we estimate the impacts of the course to be 1,05E+02 kgCO2eq. The equivalence[10] of per session can be seen in Figure 20.

In such a scenario, the transportation of participants is responsible for most of the impacts (90%). Only user terminals are considered in this approach. They represent 10% of this session.

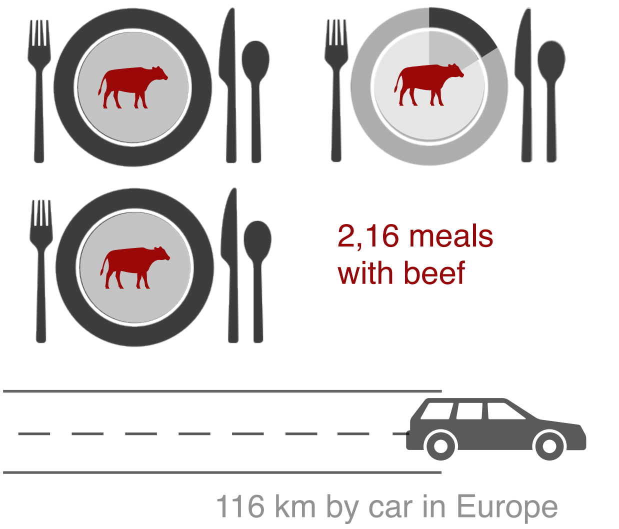


Figure 19. Equivalence of the footprint of a 1-hour session in terms of km driven in Europe by car and a meal with beef – Use Case 3

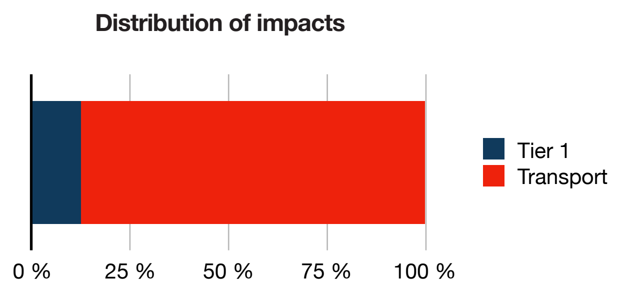


Figure 20. Distribution of impacts – Use Case 3

[10] The selected equivalents are taken from https://impactco2.fr/. ImpactCO2 is an ADEME project which is part of Datagir.

7.3 Digitalised face-to-face

7.3.2 Professional face-to-face French class (Use Case 3)

Almost all the impacts of user terminals are caused by the manufacturing, transport and end-of-life phases. This is due to several reasons:

- The French energy mix considered has a low carbon intensity (0.098 kgCo2eq./kWh, which is 3.5 times less than the average European mix). Emissions related to electricity consumption (use phase) are therefore low.
- The renewal rate of the tablets used in this scenario is very high (every 1.5 years), so the embedded emissions represent an important part associated to a session.
- In this scenario, the tablets are under-used (1 hour per day), so the embedded emissions represent an important part associated with a session.

This institution could modify its tablet purchase and use policies to reduce its impact. For example, let's imagine that the lifespan of its tablets (S1) increases to 5 years and that it decides to share them among several classes in a day, leading to a use of its tablets of 4 hours per day. The embedded emissions remain the most important part, partly because of the low carbon intensity of the French electrical mix, but the absolute impact associated to tablets is reduced by a factor of 13.

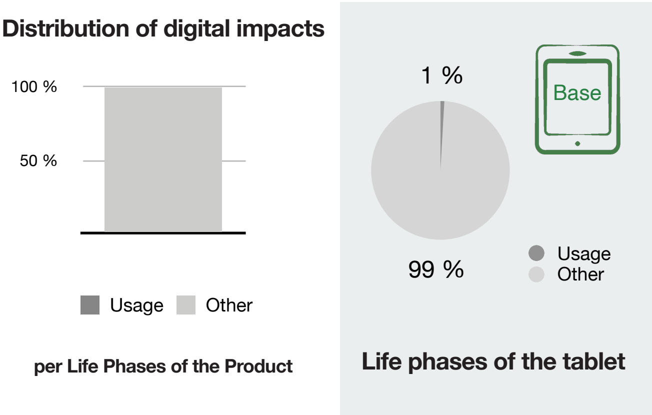


Figure 21. Digital impact distribution per life phases of the product (Ex. Tablets) – Use Case 2

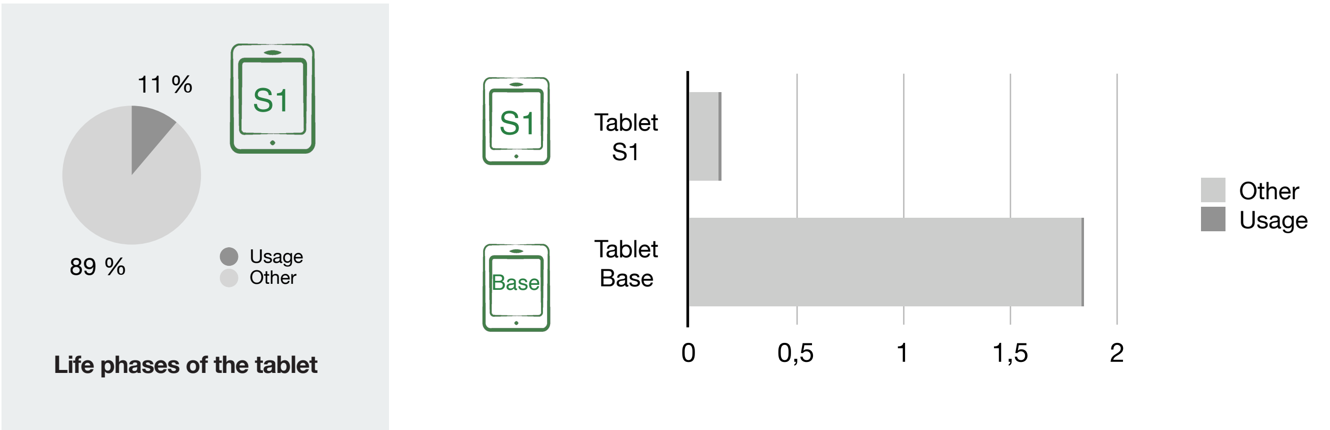


Figure 22. Repartition of digital impact distribution per life phases of the product with comparison of the impacts of a table in between two scenarios

7.4 First conclusions

The main conclusions that can be drawn from these different evaluations are:

- Impacts related to non-IT resources (transport and domestic energy consumption) are more important than those related to IT resources.
- There is a trade-off between the avoided impacts of transportation and the overconsumption of domestic energy. The substitution of commutes will result in overconsumption in learners' and trainers' domestic energy consumption, while the commute to their institutions would reduce the impacts related to domestic energy consumption.
- A participant who has to travel to attend a course has a greater transport-related footprint than the domestic energy consumption-related impacts of a participant who does not travel - under the travel conditions considered.
- The over-consumption of domestic energy depends on the country, but remains important for any country.
- The impact related to digital resources remains a minority in all scenarios and does not seem to be affected by taking the course face-to-face or remotely.
- Most of the time, the impact related to IT resources are mostly carried by the embodied impacts.
- TIER 1 is the most impacting TIER in all scenarios.
- The lifespan of the equipment is one of the most important variable in the impact of a digital learning session. The longer the equipment lasts, the lower the impact of the session.

08. Results : Indirect effects

The previous section has given some orders of magnitude to understand the so-called direct impacts induced by a digital course. However, this section provides a partial view of the impacts of distance education. Indeed, the introduction of digital processes in the education context have led to socio-economic changes in the production and consumption of both learning and other services that may lead to new environmental impacts. We propose to detail and characterise the indirect impacts identified during the focus groups. When relevant, we propose to match the effects identified to one or several of the indirect effect types defined in Table 1.

8.1 Commuting reduction

As mentioned in section 2, digital learning is presented in the literature as a way to reduce the impacts of education, in great part through the reduction of learners' and trainers' commutes. This reduction seemed obvious to all participants. We also highlighted the reduction in long-distance travel in the case of learners or trainers living abroad. It is not yet possible to know if this effect will last in time or will remain limited to the Covid-19 pandemic.

"I didn't go anywhere, not even to London for a year, even though I was supposed to. I live in [city] and as a result, I didn't go to London for more than a year"

"There are some teachers who have refused to travel and who remain in their home country."

This can be qualified as a *substitution effect,* since digital learning has the ability to substitute on-site learning, reducing the impacts related to learners' and trainers' commute.

Beyond simply reducing trips, some studies have pointed out that an overall reduction in trips can reduce the effects of congestion during peak hours (ADEME, 2020):

- Making public transport more attractive
- Reducing travel time and pollution

However, this positive effect should be counterbalanced by the rebound effects induced by the increased attractiveness of less congested transport networks. Indeed, it has been shown that a reduction in transport network congestion can lead to a re-increase in their use (Hymel et al., 2010).

8.2 Reduce the energy consumption of educational buildings

A second positive effect associated with the digital learning process is the reduction of the energy consumption in educational buildings.

In the short term, the implementation of digital learning could reduce the energy consumption of buildings through a substitution effect. Although the reduction of energy consumption seems to be directly related to the number of classes delivered in a building, this effect seems to be more complex to evaluate. Indeed, some scientific publications which have studied the effects of university energy consumption reduction during COVID have shown that the reduction was only marginal (Filimonau & al, 2020). This could be explained by the need to maintain a level of energy consumption for administrative functions and a lack of energy management within educational buildings.

Even so, some universities are relying on this substitution effect to reduce their energy costs. This is the case of the University of Strasbourg, which decided to close its facilities for 2 weeks in a context of energy crisis[11].

In the long term, the generalisation of distance learning could lead to the abandonment and metallisation of certain educational buildings. However, it is not yet possible to assess the credibility of such a scenario. Furthermore, it is also not possible to evaluate the net effects of such a dynamic. Indeed, it could reduce building-related impacts but could increase the remaining travel times, increasing the impacts of employee and learner transportation.

8.3 New daily short-distance travel

As seen above, digital learning has the capacity to reduce pollution induced by commuting. In spite of this reduction, we have identified the occurrence of new short-distance trips made possible by the reduction of constraints following the introduction of digital training processes.

Some participants mentioned an increase in free time due to the elimination of the commute to their place of instruction. In some cases, this free time was used for other activities involving transportation.

"Going to parks or things like that. In coffee shops a lot, too, which was not possible before."

For some learners, their residence does not allow them to take online courses in good conditions. We can talk about accessibility issues. Several reasons were cited. The lack of a sufficient internet connection or the lack of computers. One participant mentioned that the equipment shared by a household is sometimes not sufficient to meet all digital needs. The work environment was also cited as a reason, as some learners do not benefit from a sufficiently quiet situation. Also, the difficulty with ICT of some learners leads to a need for support in order to use computers. Such support is often done face-to-face. Finally, the desire to reconnect with peers was also a given reason.

[11] https://www.francetvinfo.fr/economie/energie/crise-de-l-energie-la-fermeture-prolongee-a-l-universite-de-strasbourg-est-validee_5465512.html

“There are children or families who do not have internet so it is impossible to do digital training”

“I had 2/3 trainees who had to move elsewhere to follow a training course because they lived in white zones”

“one of the first obstacles [...] is indeed this lack of knowledge of the digital world.”

“to go back and forth at [person]’s and [person]’s or at [person]’s to study with peers"

Third places have been developed in some territories to help increase accessibility (places different from workplaces or home). Those places can provide internet connection, digital devices, support, etc.

“If they have a bad connection, or they don't have an efficient computer to follow the training, they have the possibility to go to third places which are distributed on the whole territory of [Region], it means that they have the possibility to go on a third place close to their place of residence to have the adequate equipment to effectively follow the training”

“Today, we are actually talking with some communities that want to set up third places that would be places where you could take your training.”

If such places are a promising approach to let the population access digital training, it reduces the benefit of travel reduction. This drawback was mentioned by one participant, who weighed it against the social benefit.

"20 years ago, I was convinced that distance learning was better because there was no need to travel. [...] today, in fact, the question is to ask ourselves that in certain cases, [...] it's better that there be a place where users will have access to equipment where they can train, access education, even if there will be travel [...], but it will create a social value”

This can be qualified as a *direct rebound,* since the reduction of the time constraint allowed by digital learning could paradoxically lead to new consumption of short distance transport, creating new environmental impacts.

8.4 New long-distance travel

In addition to the possible new short-distance travel, we have also highlighted new long-distance travel induced by digital learning. Those types of travel might have important impacts since they are less likely to be done with low-carbon transportation modes.

Some participants mentioned the possibility of taking their courses from a second home, which implies transportation to it. Similarly, some participants mentioned the organisation of trips to another region or country during class periods.

“I even allowed myself to go on vacation, for example, to [region] to visit [person] something I wouldn't have allowed myself to do before [...] So it's true that it allows me to take more time off and to be less at home. [...] I took the time to move around because I needed to have an environment that was other than my room and my kitchen. I was working”

“long term travel, we'll say. Not vacations, but to study outside my home, and my place of residence, but no daily travel, you know, long-term travel rather than daily travel”

This can be qualified as a *direct rebound,* since the reduction of the time and attendance constraints allowed by digital learning could lead to new consumption of long and medium distance transport, creating new environmental impacts.

8.5 Education effect

The role of education for the alignment of our society within the planetary boundaries is regularly cited as a way to reduce the impacts of all sectors of activity.

We could mention the education of citizens on global environmental issues. It is also the case in the context of professional training, beginning with good environmental practices up to the support to the transformation of practices (agriculture, industrial...).

Finally, the role of education is also crucial to support the socio-economic transformations induced by the policies of ecological transition (change of professional horizons, elimination of certain industries, increase of human needs in others...).

The education effect is not specific to digital learning. However, digital learning offers new training channels which might help its generalisation.

8.6 Content obesity

We found that digital learning had participated in the overall increase in the production and provision of learning content. The redundancy of content was one given reason. Since each institution could have its own platform, content could be hosted in multiple locations.

"In fact, the same content will be used X times everywhere"

The business model of training content is another given reason. Indeed, generalist platforms in competition with each other must offer content covering the broadest possible disciplinary fields, leading to redundancy.

"When you are a consumer, you want to look at something on mathematics and you have 46 platforms that propose it, because these are markets and everyone is trying to earn a living on them"

Content obesity is the consequence of under-mutualisation of contents and platforms, leading to redundancy.

"There is not this aspect of mutualisation."

This must be put in perspective with the opportunity to offer more personalised training content, allowing wider access to training for the population.

"[it] broadened the scope of our clients, reaching people who didn't necessarily have an idea of distance learning, so it's quite positive, to have changed habits"

This phenomenon can be qualified as *a direct rebound,* since the introduction of digital learning has increased the overall production of learning contents. The production and maintenance of new digital content lead to new environmental impacts related to development and hosting.

8.7 Increased consumption of training content

Most of the learners who participated in our focus group reported an increase in the number of online courses followed. The number of courses delivered by their institution were stable, but participants reported an increase in the courses followed autonomously, independently of their institution. The familiarisation with digital learning, the diversity of the content provided online and the possibility to follow learning content at low or no cost outside the context of an institution were the main causes given during the focus groups.

> ***“I think there has been a lot more video content in the last five years, it is pretty much democratised."***
>
> ***“There is a multiplication of usage, a diversification of usage, and a multiplication of digital channels to reach learners in different ways. It is a trend that is taking hold”***

This phenomenon can be qualified as *a direct rebound,* since the introduction of digital learning has increased the overall production and consumption of learning content. While some digital courses have substituted on-site courses, others should be attributed to new consumption. Thus, we could also argue that digital learning has led to a *stacking effect* of training content. The absolute increase in digital content consumption might lead to new environmental impacts.

8.8 Dusty content shelve

A great deal of learning content is replicated into enterprise Moodle-like platforms in order to be integrated into the internal training plan. **We have noticed that learning content often stays on the institution's platform, even if they are outdated or not being followed. Those resources will induce resource consumption such as storage.** Registering content in a platform and hosting it induces environmental impacts, for little or no need. To describe this problem, the image of content resting on a shelf was given.

"it ends up on the shelves because it doesn't meet an identified need"

"we could talk about the contents on the shelf."

Thus, we refer to these phenomena as the dusty content *shelf effect*, which is mainly caused by the economic model of learning content purchase. Since most of the economic investment has already been made upon purchase, contents are kept on the platforms, sometimes with no monitoring or decommissioning process.

"Well, they have content that they paid for and that has never been used"

The fact that their contents could remain on a shelf without being used was a real problem raised by the experts during the focus groups.

"it is a fear, [...] that we put in place solutions that work in a punctual way"

The qualification of the need is therefore of great importance. One expert told us some of the important questions he asked during an interview with a potential client to reduce this effect.

"you need a platform, why in fact? What are you going to put on that platform, and who is going to build the content that is going to be on this platform ?"

This effect increases teaching-related impacts without providing additional value.

8.9 Software obesity

Today, digital learning relies on multiple types of software programs (see section 6.1.1). From stakeholders' feelings, the number of available tools used in digital learning has risen recently. On the one hand, this is viewed as a good opportunity to improve the quality of the courses.

"There are more resources and more tools that can allow a lot more exchange and interactivity."

"20 years ago [...] we had nothing, there were no tools, [...] today it's true there are so many things that are being developed"

"There are a plethora of tools, for example, whiteboards, of post IT tools and so on."

On the other hand, pieces of software can be used in an uncoordinated way. **One participant even used the term *software obesity*. For instance, people in the same institutions often use different tools to achieve the same purpose, which can lead to software inconsistency.**

" which is a bit of, I think, an obesity of the, of the software, of the solutions"

"They all have a little bit of the same functionality,"

"What would be great is to have a tool like zoom, which integrates interactive solutions"

The cost reduction of the platform is one reason mentioned for the multiplicity of softwares used. A good deal of SaaS software can be partially used for free, thus it reduces the selection constraints, as the use of software in a course is not subject to validation by the institution. This phenomenon can be qualified as a *direct rebound,* since a reduction in the price and selection constraints have led to an increase in the overall consumption of digital learning software.

"we realise today that there are plenty of free solutions"

Another reason given by the experts was the attachment of the institutions to the tools rather than to the teaching methods.

"There is a fixation on tools. How many times have we met companies, schools, and training organisations; They call you to increase their competence in distance learning, or they want to develop distance learning internally. And the first thing they talk to you about, they were talking to you at the time, but still, it's the platform. You come to an appointment, I need a platform and here it is, I need a platform but great but how does it go before the platform? "

"It's true that there is a fixation on tools."

8.9 Software obesity

Some participants have highlighted the lack of integration of software to the existing devices or to the training process. For instance, little training on digital learning software is given to trainers.

"In fact, I had a lot of tools in my cupboards, but nobody knows how to use them."

"They have cabinets full of tools and solutions that are developed by R&D innovation services in Paris [...], it is never integrated in the devices."

"It has never changed, so we have a multitude of digital tools that are not used because they have not been designed for the users, that is to say that a teacher is imposed a tool."

All of these effects can lead to an under usage of software since the needs they are supposed to fulfill are not well-defined. Under usage could qualify either the use of software in a few classes or the partial use of the functionalities offered by the software. A participant explains this effect by a lack of functional exploration by the trainers.

"They never go to the end of the tools. [...] There's no functional exploration."

This phenomenon can be qualified as a *direct rebound,* since the introduction of digital learning has increased the overall production of learning software. The production and maintenance of new software can lead to new environmental impacts related to their development or their usage.

8.10 Familiarisation with online consumption

The evolution of habits brought by digital learning has had consequences on the consumption of other digital content by the participants. **In general, university students have reported a great increase in their digital consumption.** It is difficult to say whether the cause was the lockdown or the introduction of digital learning.

One of the elements mentioned was the multiplication of social events such as family reunions, association meetings, or public events. A part of this increase can be attributed to the partial (hybrid) or total substitution of on-site events. However, according to the participants, another part of the increase is due to the introduction of new events. Some participants directly attributed the creation of those new events to their familiarization with videoconference tools in the context of online learning.

"It can be a reflex to use video conferencing even for things that are not necessarily work or study related. Especially with family or friends that we didn't do before."

“But it's true that even in associations’ meetings, we do much more videoconference than before”

In the professional context, this increase has also been highlighted, but it was mostly attributed to the familiarization of distance tools in the context of teleworking.

We could argue that digital learning has participated in the *systemic transformation* and increase of online consumption, resulting in a possible increase in the associated impacts.

8.11 New equipment effect

Digital learning process implies a need for a digital workplace for learners and trainers. When this material is not available to learners or trainers, it can imply the consumption of new materials.

Different from what we expected, digital learning wasn’t an important reason given for the purchase of computing devices (laptop, smartphone, desktop), because all participants already owned at least one of them.

University students reported that laptops were already mandatory to follow their on-site courses. In some cases, the universities could rent or loan the equipment. In the professional context, a great part of the participants used their professional equipment.
However, most participants reported the investments in other non-mandatory hardware equipment to improve their comfort during online classes: headset, ergonomic office chair, second screen, Bluetooth mouse, etc.

“I invested in Bluetooth headsets and maybe it was a little bit related to online courses”

“So the only thing I had to do was buy a camera to have a micro camera on the Mac Mini”

“It is interesting to have a double screen for both trainers and the learners”

“It was just a bonus, I'm doing fine with or without my headphones”

The purchase of those equipments can be allocated mainly to the process of digital learning, since they were mainly purchased for following digital learning sessions. However, participants used them for other processes after having invested in them.

It was mentioned that the increasing demand for computing power by softwares used in education could lead to an early renewal of devices. For instance, one participant had some overheating issues when doing videoconferences.

"It causes overheating. I'm forced to turn off the video in general [...] otherwise the Mac Book Air would have heat up significantly, and that is not at all pleasant in terms of sound "

While individual had few modifications in their consumption of digital devices, it is different for institutions. Indeed, it was reported that some institutions had had to make important investments to support the digitalisation of their classes.

“There has been an emergence, a growing demand, even exponential, on the needs of digitalisation. Also, the local authorities who realised that in terms of infrastructure, it was not ready either in terms of servers, of flow, of connectivity, [...] ...”

The participation of digital learning process or software in the purchase and early renewal of digital devices leads to new impacts caused by the manufacture, transport, and end of life of new equipment.

8.12 “Dusty equipment” effect

In the professional context, employees use their professional devices. Most of them are given by their organisation for the fulfilment of daily task. Their usage in the context of digital learning is secondary. When specific high-tech devices (like VR headset) are needed for the class, the equipment is automatically lent to the participants either by the institution or by the training organisation. In the academic context, devices can be lent to a specific student on social or medical criteria or automatically distributed to all class. This has been observed in schools. While participants value these initiatives in many cases, it has been shown that equipment are often underused. Several reasons have been mentioned.

8.12 “Dusty equipment” effect

When all learners are provided with equipment, device duplication can occur, since some learners might already own one.

"Our customers are already equipped, we try to adapt, we don't make them buy things to buy things that. I hate all that, I've seen in my life too many shelves of tablets that have never been used"

Sometimes, the equipment provided is not integrated into the pedagogical strategies of the institution. Thus, the provided devices won’t be used by the teaching staff during their classes. This can be caused by inconsistent choice with the required usage or a lack of training of learners and trainers.

“We have cabinets full of tablets because a few years ago we, we tried to deal with it, we realised that it was that it was another business. Besides customers were not happy because we were providing them with an Android tablet. They all wanted an iPad."

“I see that, in general, they are over equipped”

“So teachers end up with tablets with an LMS on them that they are not trained for”

In the academic context, the equipment distribution model can be questioned. According to the stakeholders, politics have focused on device distribution rather than on the support of practice evolutions (content creation, training of learners and trainers, etc). Several reasons have been mentioned, such as a buzzword effect (see section 8.13) or the greatest ease for politics to unlock investment rather than operating budget.

“Their are large digital plans in education, which often end up investing 80 percent of their budget in hardware”

“In general, communities love tohos make equipment plans. Firstly, it can be photographed. Secondly, it's a capital budget and not an operating budget, so it is not a problem.”

Moreover, several participants mentioned a significant underutilisation of specific high-tech equipment, in particular virtual reality headsets. This is even more problematic knowing the rapid technological evolution, inducing a regular renewal to benefit from the latest technological advances.

It can be concluded that the divergence between the investments in pedagogical devices and the pedagogical strategy can lead to an underutilisation of the equipment.

The distribution and regular renewal of this equipment has significant environmental impacts relatively to the limited value it brings to the education process.

8.13 Buzzword effect

Whether in the academic or professional context, we identified during the focus group a tendency of the institution to invest in high-tech equipment and software in order to mark the modernity of the institution independently of its pedagogical strategy. One participant qualified this effect of *fashion effect* and used the term *buzzwords*.

"I think that there are fashion effects on buzzwords"

The term *wow effect* has also been used to characterise such an effect.

"the problem is that we are always on the Waouh effect. Well, I speak especially about virtual reality. I, will invest on virtual reality, so that i can make marketing on the subject. On the other hand, there is no question about the pedagogy, once again, about the effects of the training"

The technologies regularly cited are AI, virtual reality and more recently the metaverse.

"right now we find the meta-verse in the call for projects"

Such an effect can be seen in the public and private funding directed towards projects using high-tech products and services. For some participants, although these technologies can be useful, their omnipresence in the calls for projects is not valuable. They regret the fact that the people financing those projects aren't well aware of their usage in the context of digital learning.

"I'll take the AI that today is necessary for all the funding. They are very useful on some types of learning [...], there is a real added value and sometimes not"

"I've been seeing it for 10 years, there are regularly must-haves in any answer, and that doesn't necessarily correspond to a use that is at the top of the necessity."

"if you don't write in it, that there's AI, [...] you're going to look like an idiot to them, in fact, it's not innovative, [...] we have to tell them things that they don't understand, and as they don't understand, they say "damn, it's super innovative, it's great, we're going to finance it"

Again, the discrepancy between the funding of pedagogical tools and the pedagogical strategy leads to investments in technologies that will be underused.

"there's a divorce between bosses, who are more interested in the marketing part of the story, and the educators"

"When we talk about education and training, it is good to start from the approaches and users and the pedagogical ambition and then the technology, which should be at the service of the pedagogy and not the opposite."

This effect stimulates the high-tech market and investments by presenting new applications in the context of digital education. Thus, it could participate in an *economy-wide rebound* in the high-tech sector. This must be closely observed given the significant impacts associated with this sector.

9. Effects Synthesis

We synthesise in Table 22 all the environmental effects related to digital learning documented in this study. For each effect, we qualify its class (direct impact, enabling effect or indirect effect) and its type according to the classification proposed in Table 1.

Table 22. Digital services identified during the qualitative study

Effects	Class of effect	Type of effect (From Table 1)
TIER 1 impacts	Direct impacts	-
TIER 2 impacts	Direct impacts	-
TIER 3 impacts	Direct impacts	-
Transport impacts	Direct impacts	-
Domestic energy consumption impacts	Direct impacts	-
Commuting reduction	Enabling effect	Substitution
Reduction of the energy consumption of educational buildings	Enabling effect	Substitution
Education effect	Enabling effect	-
New daily short-distance travel	Indirect effect	Direct rebound
New long-distance travel	Indirect effect	Direct rebound
Content obesity	Indirect effect	Direct rebound
Increased consumption of training content	Indirect effect	Direct rebound & stacking effect
Dusty content shelves	Indirect effect	-
Software obesity	Indirect effect	Direct rebound
Familiarization with online consumption	Indirect effect	Systemic Transformation
New equipment	Indirect effect	-
Dusty equipment	Indirect effect	-
Buzzword effect	Indirect effect	Economy-wide rebound

10. Recommendations

10.1 General

Analysis of the direct impacts of 1-hour online education showed that the main impacting resources of a digital learning process are, by order of importance:

- Transportation of learners and trainers
- The over-consumption of buildings
- Embedded emissions from user terminals
- Emissions related to the consumption of user terminals
- Embedded and usage emissions related to digital infrastructures (network and data-centres)

Many of the actions needed to reduce these impacts must be undertaken at the level of European public policies. We do not propose here an exhaustive list of these general orientations. Nevertheless, we can mention at the level of public policies: the insulation of buildings, the development of soft mobility, the reduction of high emission mobility, the regulation of new digital infrastructure deployment, the decommissioning of some infrastructures, etc.

Infrastructure optimisation actions must also be implemented by digital infrastructure operators. The rebound effects induced by the optimisation of infrastructures must be carefully considered. It must be kept in mind that these optimisations should reduce the sector's emissions in absolute terms and not in relative terms.

In the next parts of this report, we will focus on recommendations that can be implemented by the actors of the digital learning sector, i.e. educational institutions, platform and content providers, trainers and finally learners.

10. Recommendations

10.2 At institutions level

10.2.1 Equipments

The reduction of the impacts related to equipment is mainly achieved by:

- Avoiding equipment duplication
- Extending their life span to reduce the renewal rate
- Sizing the equipment to the right size, i.e. providing equipment whose configuration is adapted to the usage. If the equipment is undersized, it will need to be replaced early, while if it is oversized, it will have a greater embedded impacts and will consume more electricity than needed.

In the case where the institution offers equipment to users, the following recommendations may apply:

- Study the real needs before investing in equipments to avoid having unused equipment
- Opt for contracts with long guarantees
- Distribute equipment only to users who do not have equivalent equipment to avoid duplication. This implies that institutions should allow the use of personal equipment.
- Share equipment among several classes to reduce the number of equipment purchased by the institution
- Buy used or refurbish equipments
- Set ambitious life span targets, e.g. 3 times the European average life span
- Systematically propose protection for user terminals
- Reallocate equipment according to changing needs. Equipment that is no longer powerful enough for one purpose may remain so for others.

Your institution also bears a responsibility for the equipments owned by learners and trainers. Several recommendations can be applied to reduce these impacts:

- Promote repair and upgrading by offering self-repair workshops or a repair services
- Promote responsible use and purchasing of equipment (long lifespan, right sizing, refurbish, etc)
- Establish a second-hand market within your institution

10.2.2 Content & services

- Avoid duplication of services.
- Ensure that the services used by the institution are compatible with a maximum number of terminals (different generations, different types of terminals) to avoid pushing users to renew their equipment.
- Establish a content management policy to remove content that is no longer relevant (not used, not up to date) and to study the need for new content. Encourage the updating of content rather than the purchase or creation of new content.

10.2.3 Transport and building

- Promote active and low-carbon modes of transportation such as bicycles and public transportation in the city.
- Promote carpooling in low-density areas through the implementation of incentive policies and carpooling platforms between users.
- Reduce emissions from buildings through thermal insulation and energy-saving measures (reduce heating temperatures, reduce the use of air conditioning).
- Make energy use in buildings controllable to avoid using energy in empty classrooms.

10.2.4 Other

Rationalise schedules to avoid hybrid days (one part remote and one part face-to-face) in order to mutualise the impact of transportation on a limited number of days.

10. Recommendations

10.3 At platform and content providers level

- Establish a content management policy to remove content that is no longer relevant (not used, not up to date) and to study the need for new contents. Encourage the updating of content rather than the creation of new content.
- Establish a feature management policy to remove features that are no longer relevant and study if new features address real costumer needs.
- Opt for a service economy based on an offer of service and not of contents, to avoid duplication and underutilisation of content within institutions.
- Eco-design your platform.
- Lighten the content:
    - Reduce content quality (video, images, etc)
    - Reduce the use of video
    - Favour lighter content type (from podcast to video, from file to web content, from ppt to compressed format like PDF)
- Since end-user devices represent an important part of the environmental impact of digital learning, it is essential that program and content developers maximise their compatibility with all types of end-user devices to avoid early renewal.
    - Compatible with the maximum generations
    - Compatible with the maximum type of equipment
    - Compatible with low flow rate
    - Separate evolutionary and corrective updates to let users keep incompatible equipment with the latest versions of your platform while benefiting from security correctives.

10.4 Trainers

- Study the needs for digital equipment in your class.
- Study the services and content offered by your institution to avoid duplication.
- Ensure the compatibility of the services and content used on all the terminals used by the students to avoid pushing your learners to buy new equipment.
- Participate in discussions relative to the purchase of equipment, services and content to ensure that they meet your needs.

10.5 Learners

- Expand the lifespan of your equipment.
- Use low carbon transport, mainly public transport or bicycle.

Conclusion

Digitisation has been integrated in the majority of educational contexts in Europe, whether on synchronous or asynchronous, face-to-face or distance learning. Despite the beneficial societal effects on access to education, digitisation also has environmental consequences that need to be considered by the educational sector.

To propose an initial view of these impacts, we chose to model the carbon footprint of three typical scenarios of digital education in Europe. Focus groups were conducted in three European countries to define these scenarios and to identify the indirect environmental effects of digital learning.

The results provided by the model reveal that the main impact come from the over-consumption of energy in the participants' homes and the residual transport of learners. The impacts caused by digital resources (terminals, networks, and datacenter) come in second position. In all scenarios, user terminals represent the most significant impact of digital resources because of the number of devices involved in the learning process (at least one per person). Generally, the embedded impacts (extraction, manufacturing and end-of-life of digital equipment) represent the major part of the impacts of digital resources before the impacts related to the use phase. This distribution (between usage and embedded impacts) depends on the country where the process takes place, the energy mix of the countries being more or less carbon intensive.

We also proposed a classification of the indirect effects induce by digital learning. We can mention the enablement effects, in particular the reduction of the participant commute, the reduction of the energy consumption of the educational facilities and the education effects. Furthermore, we have also highlighted some rebound effects such as new short and long distance trips as well as software and hardware obesity effects, notably due to the lack of purchase and decommissioning strategies of institutions. Finally, we can also mention the buzzword effects that pull the sector towards new high-tech solutions, which might lead to import impacts in the future.

These results suggest that digital education cannot be seen as the only solution to reduce the environmental impacts of education. The transition toward a more sustainable education relies mostly on our capacity to achieve our global sustainable objectives such as the decarbonisation of transport and electricity mix as well as the insulation of buildings. Institutions and individuals can act marginally by adopting sustainable practices such as extending the lifespan of their equipment. Ultimately, digital resources appear as an additional educational possibility that must be part of a global pedagogical strategy which considers the balance between educational benefits and environmental risks.

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Appendix

Table A1. Usage characteristics for end-user devices

Device	Yearly electrical consumption (kWh/year)	Average use time per year (hour/year)	Average power consumption (Wh)
Laptops	30,96	1299	24
Tablets	18,6	1095	17
Smartphones	3,9	880	4,4
Desktops	104,39	1292	81
Second monitors	70	1387	50
Desktops + monitor	-	-	81+50=131

Table A2. European impact factor from low-voltage electricity consumed (Scarlat & al. 2022)

Country	Code	Impact factor (kgCo2eq./kWh)
Europe	EEE	0,334
Austria	AUT	0,264
Belgium	BEL	0,23
Bulgaria	BGR	0,544
Croatia	HRV	0,372
Cyprus	CYP	0,791
Denmark	DNK	0,158
Estonia	EST	0,472
Finland	FIN	0,141
France	FRA	0,098
Germany	DEU	0,422
Greece	GRC	0,78
Hungary	HUN	0,338
Iceland	ISL	0,026
Ireland	IRL	0,384
Italy	ITA	0,356
Latvia	LVA	0,325
Lithuania	LTU	0,321
Luxembourg	LUX	0,338
Malta	MLT	0,463
Netherlands	NLD	0,45
Poland	POL	0,805
Portugal	PRT	0,324
Romania	ROU	0,464
Slovakia	SVK	0,346
Slovenia	SVN	0,307
Spain	ESP	0,279
Sweden	SWE	0,04

Table A3. Roder (2014) model applied to European countries

Country	Variable consumption per 1h adapted from Roder (2014)	50 %	**-50 %**
European Union - 27 countries	0,90	1,36	0,45
Belgium	1,17	1,76	0,59
Bulgaria	0,57	0,86	0,29
Czechia	1,09	1,64	0,55
Denmark	1,38	2,08	0,69
Germany	1,19	1,79	0,60
Estonia	1,17	1,76	0,59
Ireland	1,05	1,58	0,53
Greece	0,59	0,89	0,30
Spain	0,51	0,76	0,25
France	0,97	1,45	0,48
Croatia	0,96	1,44	0,48
Italy	0,85	1,28	0,43
Cyprus	0,70	1,05	0,35
Latvia	0,94	1,40	0,47
Lithuania	0,81	1,21	0,40
Luxembourg	1,43	2,15	0,72
Hungary	0,83	1,24	0,41
Malta	0,37	0,55	0,18
Netherlands	0,93	1,40	0,47
Austria	1,27	1,91	0,64
Poland	0,75	1,13	0,38
Portugal	0,49	0,74	0,25
Romania	0,68	1,02	0,34
Slovenia	0,08	0,12	0,04
Slovakia	0,77	1,16	0,39
Finland	1,61	2,41	0,80
Sweden	1,08	1,62	0,54

Table A4. Carbon intensity of each energy source used in the building sector in Europe

SIEC (Labels)	Min (kgCO2eq./kWh PCI)	Source	Max (kgCO2eq./kWh PCI)	Source	Comment
Solid fossil fuels peat peat products oil shale and oil sands	0,374	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,421	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Average of Charbon à coke, Charbon à vapeur, Charbon sous-bitumineux, Houille arrondis au 10eme
Natural gas	0,239	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,244	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Eur. Gaz naturel
Liquefied natural gas	0,238	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,238	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Gaz naturel liquéfié (GNL)
Oil and petroleum products	0,329	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,329	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Fioul domestique (FOD)
Liquefied petroleum gases	0,27	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,27	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Propane / Butane
Other kerosene	0,312	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,312	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Kérosène (jet A ou A1)
Gas oil and diesel oil	0,329	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	0,329	https://bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?solides3.htm	Fioul domestique (FOD)
Renewables and biofuels	0,0302	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/37	0,816	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/37	Biodiesel - changement d'affectation des sols scénario maximum
Solar thermal	0	Hypothesis	0,045	IPCC	
Ambient heat (heat pumps)	Elec factor/1	Multiple specialised sources	Elec factor/6	Multiple specialised sources	Efficiency of 3 kwh PCI per kwh of electricity
Primary solid biofuels	0,0109	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/36	0,0174	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/36	Déchets bois - """Adjuvantés"" (Broyat criblé sans Sortie du Statut Déchet classés non dangereux)" - Max value
Biogases	0,014	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/462	0,142	https://bilans-ges.ademe.fr/fr/basecarbone/donnees-consulter/liste-element/categorie/462	Biopropane - à base d'huile de colza 0.142 kgCO2e/kWh PCI
Electricity	Elec factor	See table 10	Elec factor	See table 10	
Heat	0,004	https://bilans-ges.ademe.fr/fr/accueil/documentation-gene/index/page/Reseau_de_chaleur	0,455	https://bilans-ges.ademe.fr/fr/accueil/documentation-gene/index/page/Reseau_de_chaleur	

Table A5. Proportion of final energy consumption in households in 2020 per European country - from [NRG_D_HHQ__custom_4463338]

SIEC (Labels)	Solid fossil fuels peat peat products oil shale and oil sands	Natural gas	Liquefied natural gas	Oil and petroleum products	Liquefied petroleum gases	Other kerosene	Gas oil and diesel oil	Renewables and biofuels	Solar thermal	Ambient heat (heat pumps)	Primary solid biofuels	Biogases	Electricity	Heat
1-Europe	2,88 %	32,02 %	0,00 %	12,53 %	0,00 %	0,49 %	9,65 %	19,17 %	0,86 %	2,48 %	16,08 %	0,13 %	25,08 %	8,33 %
Belgium	0,41 %	38,63 %	0,00 %	32,32 %	0,00 %	0,35 %	29,61 %	8,28 %	0,32 %	1,32 %	6,39 %	0,00 %	20,18 %	0,18 %
Bulgaria	4,17 %	4,03 %	0,00 %	0,89 %	0,00 %	0,00 %	0,05 %	36,07 %	0,48 %	0,00 %	35,59 %	0,00 %	40,99 %	13,85 %
Czech Republic	9,99 %	25,65 %	0,00 %	0,66 %	0,00 %	0,00 %	0,00 %	31,23 %	0,20 %	2,58 %	28,45 %	0,00 %	18,98 %	13,49 %
Denmark	0,00 %	13,69 %	0,00 %	4,05 %	0,00 %	0,02 %	3,24 %	23,90 %	0,29 %	5,26 %	18,36 %	0,00 %	21,77 %	36,58 %
Germany	0,55 %	37,52 %	0,00 %	22,45 %	0,00 %	0,01 %	20,76 %	14,03 %	1,24 %	2,17 %	9,86 %	0,51 %	18,85 %	6,62 %
Estonia	0,11 %	5,96 %	0,00 %	0,73 %	0,00 %	0,00 %	0,20 %	41,81 %	0,00 %	0,00 %	41,81 %	0,00 %	18,21 %	33,17 %
Ireland	11,56 %	18,83 %	0,00 %	42,98 %	0,00 %	31,44 %	8,86 %	2,58 %	0,45 %	1,31 %	0,83 %	0,00 %	24,04 %	0,00 %
Greece	0,07 %	10,36 %	0,00 %	29,55 %	0,00 %	0,06 %	28,15 %	23,53 %	6,58 %	1,96 %	14,04 %	0,00 %	35,25 %	1,23 %
Spain	0,32 %	24,08 %	0,00 %	17,13 %	0,00 %	0,00 %	11,17 %	15,84 %	1,85 %	1,24 %	12,68 %	0,00 %	42,62 %	0,00 %
France	0,05 %	27,78 %	0,00 %	11,13 %	0,00 %	0,41 %	8,77 %	21,97 %	0,46 %	6,09 %	15,42 %	0,00 %	35,87 %	3,20 %
Croatia	0,08 %	21,34 %	0,00 %	4,57 %	0,00 %	0,00 %	2,61 %	46,03 %	0,50 %	0,64 %	44,58 %	0,00 %	22,96 %	5,01 %
Italy	0,00 %	51,97 %	0,00 %	6,10 %	0,00 %	0,01 %	2,51 %	20,52 %	0,59 %	0,31 %	19,43 %	0,00 %	18,57 %	2,84 %
Cyprus	0,00 %	0,00 %	0,00 %	30,20 %	0,00 %	3,67 %	16,81 %	27,22 %	17,24 %	3,80 %	4,22 %	0,00 %	42,58 %	0,00 %
Latvia	0,12 %	9,85 %	0,00 %	4,69 %	0,00 %	0,00 %	2,92 %	40,61 %	0,00 %	0,00 %	40,60 %	0,00 %	13,54 %	31,19 %
Lithuania	2,43 %	12,16 %	0,00 %	3,81 %	0,00 %	0,00 %	1,54 %	34,03 %	0,00 %	1,94 %	32,10 %	0,00 %	18,25 %	29,31 %
Luxembourg	0,05 %	52,10 %	0,00 %	27,35 %	0,00 %	0,11 %	27,15 %	4,20 %	0,52 %	0,47 %	3,21 %	0,00 %	16,30 %	0,00 %
Hungary	1,20 %	64,36 %	0,00 %	1,69 %	0,00 %	0,00 %	0,00 %	0,58 %	0,31 %	0,22 %	26,92 %	0,00 %	22,18 %	10,00 %
Malta	0,00 %	0,00 %	0,00 %	14,67 %	0,00 %	0,00 %	0,15 %	13,33 %	4,88 %	7,12 %	1,34 %	0,00 %	72,00 %	0,00 %
Netherlands	0,00 %	67,90 %	0,00 %	0,39 %	0,00 %	0,06 %	0,08 %	5,95 %	0,24 %	1,56 %	4,08 %	0,00 %	22,76 %	3,00 %
Austria	0,30 %	21,26 %	0,00 %	14,04 %	0,00 %	0,00 %	13,61 %	29,53 %	1,68 %	2,58 %	25,09 %	0,00 %	23,12 %	11,75 %
Poland	28,40 %	18,81 %	0,00 %	3,35 %	0,00 %	0,00 %	0,37 %	15,60 %	0,41 %	1,62 %	13,58 %	0,00 %	14,05 %	19,79 %
Portugal	0,00 %	9,74 %	0,00 %	14,92 %	0,00 %	0,00 %	1,76 %	36,33 %	2,01 %	8,47 %	25,41 %	0,00 %	38,98 %	0,03 %
Romania	0,56 %	34,03 %	0,00 %	3,53 %	0,00 %	0,00 %	0,00 %	38,31 %	0,00 %	0,00 %	38,31 %	0,00 %	14,66 %	8,91 %
Slovenia	0,00 %	9,84 %	0,00 %	12,38 %	0,00 %	0,00 %	9,95 %	41,64 %	0,96 %	4,41 %	36,27 %	0,00 %	29,14 %	6,99 %
Slovakia	1,96 %	41,66 %	0,00 %	0,24 %	0,00 %	0,00 %	0,00 %	22,81 %	0,26 %	1,35 %	21,17 %	0,00 %	18,40 %	14,92 %
Finland	0,07 %	0,45 %	0,00 %	5,18 %	0,00 %	0,00 %	4,17 %	30,87 %	0,05 %	9,44 %	21,38 %	0,00 %	35,83 %	27,60 %
Sweden	0,00 %	0,26 %	0,00 %	3,07 %	0,00 %	0,00 %	1,47 %	12,35 %	0,14 %	0,00 %	11,96 %	0,25 %	50,88 %	33,43 %

Table A6. Carbon intensity of final energy consumption in households in 2020 (kgCO2eq./kWh)

Country	MEAN (kgCO2eq./kWh)	MIN (kgCO2eq./kWh)	MAX (kgCO2eq./kWh)
1-Europe	0,37	0,27	0,47
Belgium	0,38	0,35	0,42
Bulgaria	0,44	0,27	0,62
Czech Republic	0,35	0,19	0,51
Denmark	0,28	0,10	0,46
Germany	0,40	0,32	0,47
Estonia	0,36	0,12	0,60
Ireland	0,47	0,45	0,48
Greece	0,61	0,50	0,71
Spain	0,34	0,28	0,41
France	0,28	0,18	0,37
Croatia	0,37	0,18	0,57
Italy	0,32	0,23	0,41
Cyprus	0,64	0,52	0,76
Latvia	0,34	0,11	0,57
Lithuania	0,33	0,13	0,54
Luxembourg	0,38	0,36	0,40
Hungary	0,27	0,24	0,30
Malta	0,46	0,39	0,53
Netherlands	0,30	0,27	0,34
Austria	0,36	0,22	0,51
Poland	0,40	0,29	0,52
Portugal	0,38	0,22	0,53
Romania	0,35	0,18	0,52
Slovenia	0,39	0,21	0,58
Slovakia	0,31	0,18	0,44
Finland	0,29	0,10	0,48
Sweden	0,17	0,04	0,29

Table A7. Values for synchronous digital learning for the average European scenario

Name	Value	Source
General		
Participants	21.6 (average)	Survey - 263 valid participants
Duration	1 hour	Functional unit
TIER 1		
Location	Europe	European scenario
Smartphone / Units	10,1	Survey - 123 (46,8%)
Smartphone / Usetime per process	3,63 hours	Survey
Smartphone / Usetime per day	2,41 hours	Global Webindex Device Report (2020)
Smartphone / lifespan	2,5 years	VHK and Viegand Maagøe, (2020)
Smartphone / Average power	4,43 W	Table 9 from VHK and Viegand Maagøe (2020)
Laptop / Units	20,5	Survey - 249 (94,7%)
Laptop / Usetime per process	4,58 hours	Survey
Laptop / Usetime per day	3,56 hours	Global Webindex Device Report (2020)
Laptop / lifespan	4 years	VHK and Viegand Maagøe, (2020)
Laptop / Average power	23,83 W	Table 9 from VHK and Viegand Maagøe (2020)
Desktop / Units	5	Survey - 62 (23,6%)
Desktop / Usetime per process	4,96 hours	Survey
Desktop / Usetime per day	3,54 hours	Global Webindex Device Report (2020)
Desktop / lifespan	5,5 years	VHK and Viegand Maagøe, (2020)
Desktop / Average power	80,79 W	Table 9 from VHK and Viegand Maagøe (2020)
Second screen / Units	10,7	Survey - 130 (49,4%)
Second screen / Usetime per process	4,37 hours	Survey
Second screen / Usetime per day	3,8 hours	Global Webindex Device Report (2020)
Second screen / lifespan	6 years	VHK and Viegand Maagøe, (2020)
Second screen / Average power	50,47 W	Table 9 from VHK and Viegand Maagøe (2020)
Tablet / Units	3,7	Survey - 45 (17,1%)
Tablet / Usetime per process	2,89 hours	Survey
Tablet / Usetime per day	2 hours	hypothesis
Tablet / lifespan	3 years	VHK and Viegand Maagøe, (2020)
Tablet / Average power	16,99 W	Table 9 from VHK and Viegand Maagøe (2020)

TIER 2		
Network proxy	per line	
Connection time per process	1 hour	
Internet usage per day per person	3,3 hours	Global Webindex Device Report (2020)
Number of internet user per line	2,3	Average household size in Europe (27) from Eurostat (2020)
Mobile network	30 %	Hypothesis
Fix network	70 %	Hypothesis
TIER 3		
Location	Europe	
Videoconference / Hours	1 hour	By definition of the scenario
Videoconference / NbParticipants	21.6	Survey
Transport		
Location	Europe	
Method	Average	
Cars / Units	0,6	Survey - 5.7% need to travel, out of this, 47% use the personal car
Average distance (km)	40 km	Survey
Domestic energy consumption (Housing)		
Location	Europe	
Number of remote participants	20,37	Survey - 94,3% are not traveling

Table A8. Distribution per source for synchronous digital learning for the average European scenario

Tier 1	2,74E+00 kgCO2eq.
Tier 2	4,66E-01 kgCO2eq.
Tier 3	1,61E-02 kgCO2eq.
Transport	3,11E+00 kgCO2eq.
Housing	6,75E+00 kgCO2eq.
Housing (min)	2,45E+00 kgCO2eq.
Housing (max)	1,29E+01 kgCO2eq.

Table A9. Values for the online university lecture in Portugal scenario

Name	Value	Source
General		
Participants	60	60 participants
Duration	1 hour	Functional unit

TIER 1		
Location	Portugal	European scenario
Smartphone / Units	20	Use case
Smartphone / Usetime per process	1	Use case
Smartphone / Usetime per day	2,41 hours	Use case
Smartphone / lifespan	2,5 years	VHK and Viegand Maagøe, (2020)
Smartphone / Average power	4,43 W	Table 9 from VHK and Viegand Maagøe (2020)
Laptop / Units	20	Use case
Laptop / Usetime per process	1	Use case
Laptop / Usetime per day	3,56 hours	Global Webindex Device Report (2020)
Laptop / lifespan	4 years	VHK and Viegand Maagøe, (2020)
Laptop / Average power	23,83 W	Table 9 from VHK and Viegand Maagøe (2020)
Desktop / Units	20	Use case
Desktop / Usetime per process	1	Use case
Desktop / Usetime per day	3,54 hours	Global Webindex Device Report (2020)
Desktop / lifespan	5,5 years	VHK and Viegand Maagøe, (2020)
Desktop / Average power	80,79 W	Table 9 from VHK and Viegand Maagøe (2020)
TIER 2		
Connection time per process	1 hour	
Internet usage per day per person	3,3 hours	Global Webindex Device Report (2020)
Number of internet user per line	2,3	Average household size in Europe (27) from Eurostat (2020)
Mobile network	30 %	Hypothesis
Fix network	70 %	Hypothesis
TIER 3		
Location	US	
Storage / GB/year	1 GB/year	Use case
Videoconference / Hours	1 hour	Use case
Videoconference / NbParticipants	60	60 participants
Domestic energy consumption		
Location	Portugal	Hypothesis
Number of remote participants	60	60 participants

Table A10. Distribution per source for use case 1

Tier 1	2,73E+00 kgCO2eq.
Tier 2	1,30E+00 kgCO2eq.
Tier 3	1,95E-01 kgCO2eq.
Transport	0,00E+00 kgCO2eq.
Housing	1,12E+01 kgCO2eq.
Housing (min)	3,30E+00 kgCO2eq.
Housing (max)	2,38E+01 kgCO2eq.

Table A11. Values for asynchronous digital learning for the average European scenario

Name	Value	Source
General		
Duration	1 hour	Functional unit
TIER 1		
Location	Europe	European scenario
Smartphone / Units	0,38	Survey - 73 (38%)
Smartphone / Usetime per process	3,86 hours	Survey
Smartphone / Usetime per day	2,41 hours	Global Webindex Device Report (2020)
Smartphone / lifespan	2,5 years	VHK and Viegand Maagøe, (2020)
Smartphone / Average power	4,43 W	Table 9 from VHK and Viegand Maagøe (2020)
Laptop / Units	0,95	Survey - 179 (94.7%)
Laptop / Usetime per process	5,01 hours	Survey
Laptop / Usetime per day	3,56 hours	Global Webindex Device Report (2020)
Laptop / lifespan	4 years	VHK and Viegand Maagøe, (2020)
Laptop / Average power	23,83 W	Table 9 from VHK and Viegand Maagøe (2020)
Desktop / Units	0,22	Survey - 41 (21.7%)
Desktop / Use time per process	5,07 hours	Survey
Desktop / Use time per day	3,54 hours	Global Webindex Device Report (2020)
Desktop / lifespan	5,5 years	VHK and Viegand Maagøe, (2020)
Desktop / Average power	80,79 W	Table 9 from VHK and Viegand Maagøe (2020)

Second screen / Units	0,5	Survey - 94 (49.7%)
Second screen / Usetime per process	5,68 hours	Survey
Second screen / Usetime per day	3,8 hours	Global Webindex Device Report (2020)
Second screen / lifespan	6 years	VHK and Viegand Maagøe, (2020)
Second screen / Average power	50,47 W	Table 9 from VHK and Viegand Maagøe (2020)
Tablet / Units	0,15	Survey - 29 (15,3%)
Tablet / Usetime per process	2,95 hours	Survey
Tablet / Usetime per day	2 hours	hypothesis
Tablet / lifespan	3 years	VHK and Viegand Maagøe, (2020)
Tablet / Average power	16,99 W	Table 9 from VHK and Viegand Maagøe (2020)
TIER 2		
Network proxy	per line	
Connection time per process	1 hour	
Internet usage per day per person	3,3 hours	Global Webindex Device Report (2020)
Number of internet user per line	2,3	Average household size in Europe (27) from Eurostat (2020)
Mobile network	30 %	Hypothesis
Fix network	70 %	Hypothesis
TIER 3		
Location	Europe	
Streaming / NbParticipants	0.427	Survey - 42,7% have video content
Streaming / Hours	1	
Transport		
Location	Europe	
Method	Average	
Cars / Units	0,02	Survey - 5,3% need to travel, out of this, 30% use the personal car
Average distance (km)	81.2 km	Survey
Domestic energy consumption		
Location	Europe	
Number of remote participants	0,947	Survey - 94,7% are not traveling

Table A12. Distribution per source for asynchronous digital learning for the average European scenario

Tier 1	1,18E-01 kgCO2eq.
Tier 2	2,16E-02 kgCO2eq.
Tier 3	1,05E-04 kgCO2eq.
Transport	2,11E-01 kgCO2eq.
Housing	3,14E-01 kgCO2eq.
Housing (min)	1,14E-01 kgCO2eq.
Housing (max)	5,99E-01 kgCO2eq.

Table A13. Values for Moodle based learning platform for the Belgium market

Name	Value	Source
General		
Participants	300	300 participants
Duration	1 hour	Functional unit
TIER 1		
Location	Belgium	European scenario
Laptop / Units	150	Use case
Laptop / Use time per process	1	Use case
Laptop / Use time per day	3,56 hours	Global Webindex Device Report (2020)
Laptop / lifespan	4 years	VHK and Viegand Maagøe, (2020)
Laptop / Average power	23,83 W	Table 9 from VHK and Viegand Maagøe (2020)
Desktop / Units	150	Hypothesis
Desktop / Usetime per process	1	Hypothesis
Desktop / Usetime per day	3,54 hours	Global Webindex Device Report (2020)
Desktop / lifespan	5,5 years	VHK and Viegand Maagøe, (2020)
Desktop / Average power	80,79 W	Table 9 from VHK and Viegand Maagøe (2020)
TIER 2		
Data exchanged (GB)	150 GB	0,5 GB per person (Hypothesis)
Mobile network	30 %	Use case
Fix network	70 %	Use case
TIER 3		
Location	Belgium	Use case
Streaming / NbParticipants	300	Use case
Streaming / Hours	1	Use case

Transport		
Location	Belgium	Use case
Method	Average	
Cars / Units	75	Use case
Average distance (km)	25	Use case
Domestic energy consumption		
Location	Belgium	Use case
Number of remote participants	150	Use case

Table A14. Distribution per source for use case 2

Tier 1	2,01E+01 kgCO2eq.
Tier 2	7,54E+00 kgCO2eq.
Tier 3	1,63E-01 kgCO2eq.
Transport	2,58E+02 kgCO2eq.
Housing	6,76E+01 kgCO2eq.
Housing (min)	3,07E+01 kgCO2eq.
Housing (max)	1,11E+02 kgCO2eq.

Table A15. Values for face to face learning for the average European scenario

Name	Value	Source
General		
Participants	26.7 (average)	253 participants
Duration	1 hour	Functional unit
TIER 1		
Location	Europe	European scenario
Smartphone / Units	13,8	Survey - 131 (51,8%)
Smartphone / Usetime per process	3.51 hours	Survey
Smartphone / Usetime per day	2,41 hours	Global Webindex Device Report (2020)
Smartphone / lifespan	2,5 years	VHK and Viegand Maagøe, (2020)
Smartphone / Average power	4,43 W	Table 9 from VHK and Viegand Maagøe (2020)
Laptop / Units	25,3	Survey - 240 (94,9%)
Laptop / Usetime per process	4.56 hours	Survey
Laptop / Usetime per day	3,56 hours	Global Webindex Device Report (2020)
Laptop / lifespan	4 years	VHK and Viegand Maagøe, (2020)
Laptop / Average power	23,83 W	Table 9 from VHK and Viegand Maagøe (2020)
Desktop / Units	5,6	Survey - 53 (21%)
Desktop / Usetime per process	4.12 hours	Survey
Desktop / Usetime per day	3,54 hours	Global Webindex Device Report (2020)
Desktop / lifespan	5,5 years	VHK and Viegand Maagøe, (2020)
Desktop / Average power	80,79 W	Table 9 from VHK and Viegand Maagøe (2020)
Second screen / Units	8,7	Survey - 82 (32,4%)
Second screen / Usetime per process	4.74 hours	Survey
Second screen / Usetime per day	3,8 hours	Global Webindex Device Report (2020)
Second screen / lifespan	6 years	VHK and Viegand Maagøe, (2020)
Second screen / Average power	50,47 W	Table 9 from VHK and Viegand Maagøe (2020)
Tablet / Units	3,9	37 (14,6%)
Tablet / Usetime per process	4.03 hours	Survey
Tablet / Usetime per day	2 hours	hypothesis
Tablet / lifespan	3 years	VHK and Viegand Maagøe, (2020)
Tablet / Average power	16,99 W	Table 9 from VHK and Viegand Maagøe (2020)

Transport		
Location	Europe	
Method	Average	
Cars / Number of passenger	12	Survey - 114 (45%)
Average distance (km)	57,8 km	Survey

Table A16. Distribution per source for face to face learning for the average European scenario

Tier 1	3,30E+00 kgCO2eq.
Transport	9,00E+01 kgCO2eq.

Table A17. Values for professional face-to-face French class

Name	Value	Source
General		
Participants	10	10 participants
Duration	1 hour	Functional unit
TIER 1		
Location	France	Use case
Tablet / Units	10	Use case
Tablet / Use time per process	1	Use case
Tablet / Usetime per day	1 hour	Use case
Tablet / lifespan	1,5 years	Use case
Tablet / Average power	16,99 W	Table 9 from VHK and Viegand Maagøe (2020)
Transport		
Location	France	Use case
Method	Average	
Cars / Units	5	Use case
Cars / Number of passenger	1	Use case
Average distance (km)	20	Use case

Table A18. Distribution per source for use case 3

Tier 1	1,84E+00 kgCO2eq.
Transport	1,33E+01 kgCO2eq.

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