Life cycle assessment of videoconferencing with call management servers relying on virtualization

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***Abstract*—Recently, data centres have been called out for their particularly high energy consumption, which already accounts for 1.5% of the total global electricity consumption and is among the world's fastest growing energy consumptions. To reduce the data centres' environmental impacts, technologies such as free cooling and sustainable power sources are used. Another newly developed strategy to improve the energy efficiency of data centres is virtualization, which makes it possible to install several operating systems, known as virtual machines (VMs), so that several tasks and users can share a single server. To evaluate the environmental advantages and burdens of this strategy, assessments tools are required. Several studies have already quantified the energetic and environmental benefits of virtualization but often only considered the use phase and CO_2 improvement. This study uses life cycle assessment (LCA) to evaluate the environmental impacts of Internet use in videoconferencing (VC). Preliminary results show the advantages of virtualization in the manufacturing, use and end-of-life phases. Indeed, when virtualization is implemented, one server can be allocated to several tasks. Therefore, the environmental burden of use and manufacturing will be allocated to the various tasks, decreasing the impact of each one.**

***Index Terms*— Life cycle assessment – Data centre – Virtualization – Videoconferencing**

I. Introduction

A. Context

Our society is increasingly concerned with environmental issues and especially climate change. In the last decades, electricity consumption has become a major challenge, since electricity production represents one-third of worldwide greenhouse gas emissions [1].

Though it is very young as compared to the transport and residential sectors, the information and communication technology (ICT) sector already consumed 8% of the global electricity production in 2008, which was responsible for over 2% of the world's total GHG emissions [2]. ICTs chiefly include computers, telephones, televisions, printers, communications equipment and data centres.

Data centres (DCs) operate like extensive computers and are mainly used for high performance calculation, fast calculation and data storage. DCs house numerous servers, and their consumption may be several kilowatts (kW) to hundreds of megawatts (MW). Their consumption represents 2% of the total electricity consumption of the US and 1.5% worldwide: one-fifth of the total consumption for the ICT sector [3]. But data centre size is not the only problem. Indeed, the data centres' energy consumption increases very rapidly. In 2000, DCs consumed 70.8 billion kWh worldwide, and this number rose to 152.5 billion kWh in 2005—a spike of 115% in a five-year period [3]. Between 2005 and 2010, this increase was lower: only 56% (from 152.5 billion kWh to 237.5) due to the economic crisis and the greater efficiency achieved by the corporations that own the major infrastructures [3].

B. Data centres and virtualization

DCs are sized to meet peak demand. However, only 10 to 50% of their full capacity is used most of the time [4]. This over-sizing would not be a problem if the energy consumption were proportional to the workload. But when 10 to 50% of the capacity is used, 55 to 75% of the maximum energy is needed. DC efficiency therefore often ranges between 0.2 and 0.65, where the efficiency is the ratio between workload and energy use [4]. But there are several options to alleviate the problem. Many papers describe techniques to develop equipment to meet demand, such as dynamic voltage scaling for CPUs [5], dynamic rotation per-minute for hard drives [6] and link state adaptation for networks [7]. This paper explores the virtualization technology, which makes it possible to install several operating systems known as virtual machines (VMs) on a single server. The VMs allow different tasks and users to share a single server [8] and support consolidation, a management strategy that relies on virtualization to concentrate the workload on a small number of servers and switch off the servers that are not required [9].

Cloud computing is a model used to decentralize computational resources through virtualization [10]. Indeed, virtualization can be implemented to provide access to different server pools in one or more DCs. This capacity enables users to access applications, programs, content, infrastructure for high performance calculations, storage and other functions requiring significant computational infrastructure through a real-time communications network.

C. Aim of the study

All of the technologies used to improve DC efficiency must be evaluated in order to quantify the environmental gains. The aim of this project is to quantify the environmental benefits of virtualization used by cloud computing when compared to a standard ICT solution. To reach this objective, a life cycle assessment was carried out to evaluate the environmental burden that is avoided. Life cycle assessment (LCA) is a methodology that quantifies the potential environmental impacts of the entire life cycle of a product or service. This method is particularly suited for environmental comparison since the consideration of the whole life cycle avoids displacement of impacts from one phase to another. But in return LCA needs large amount of data which are very difficult to obtain in such young and competitive sector as ICT. To solve this problem, screening-LCA studies as the one presented in this paper are done where approximated data are used to draw a preliminary picture of the environmental impacts of a product or service [11].

II. Materials and Methods

A. Methods

1) Life-cycle assessment [12]

A life cycle involves four phases: extraction of raw materials, components production, use and end-of-life (EoL). The first phase is the acquisition of the raw materials required to manufacture the product. The second involves all manufacturing, assembly and packaging processes. The third phase is use by consumers, which may require electricity, maintenance, washing, etc. The end-of-life phase includes the landfilling, incineration, recycling or reuse of the product. A fifth phase could be added between each one to account for the transportation required to move the product through the market.

The principles and framework of LCA are described in the ISO 14040 (2006) and 14044 standards, which set out a four-step-analysis: definition of LCA goals and scope, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and life cycle interpretation.

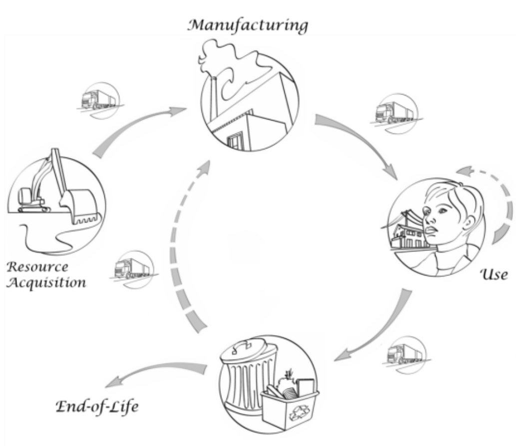

Fig. 1. Life-cycle phases (www.ciraig.org © 2008, reproduced with permission of the CIRAIG)

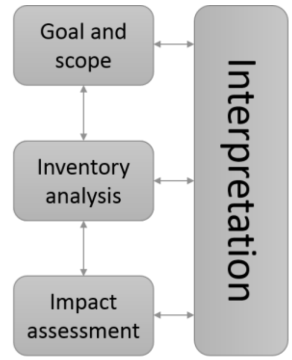

Fig. 2. LCA steps

Definition of the goals and scope: The analyst must define the studied product, system, boundaries, product function, functional unit quantifying the function (which makes it possible to compare two products with same function), system modeling hypothesis and study limitations. This step ensures that the study answers the initial questions and meets the ISO requirements.

Life cycle inventory analysis: The materials extracted from or emitted to the environment by every process in each phase of the life cycle are listed in the inventory. The different flows are sized to meet the amounts required by the functional unit. The result is a list of thousands of substances. The size of this list prevents direct interpretation of environmental impacts.

Life cycle impact assessment: The potential environmental impacts are estimated based on the LCI results. Emissions are linked to impacts with characterization factors, which are determined with environmental models based on cause-effect chains. For example, emissions of tropospheric ozone are linked to human health consequences such as respiratory effects. The LCIA makes it possible to aggregate thousands of substances from the LCI for a small number of environmental impacts. Two levels of aggregation can be used: midpoint aggregation stops early in the cause-effect chain and involves a few dozen impact categories, and endpoint aggregation stops later in the cause-effect chain and involves three to four impact categories.

Finally, in the interpretation step, the results are interpreted based on the hypothesis, boundaries and limitations of the study. As shown in Figure 2, LCA is iterative. Indeed, the interpretation step determines whether the goals of the study are reached or additional work is required. For example, if the life cycle phases with the highest impact contributions use coarse or proxy data, the research may have to be extended in order to obtain more precise data. A new LCI and LCIA will then follow.

2) Cloud computing and virtualization: A challenge for LCA

An LCA of cloud computing is very complicated due to its characteristics, especially when virtualization and the Internet are involved:

- As previously mentioned, virtualization makes a single server available to several users or tasks, making it difficult to determine which proportions of the equipment and energy are consumed by each user/task.
- Most of the corporations that own data centres do not publish information on the equipment they use, making the LCI process more complex. Proxy data are therefore often used, resulting in an uncertain impact assessment.
- The production, manufacturing and end-of-life stages of the life cycles of ICT equipment mainly occur in countries such as China, India, Thailand and Africa. Manufacturing data for China and India are difficult to obtain due to confidentiality issues and the existence of a vast informal ICT waste processing sector makes ICT EoL data very uncertain [13].
- When information is transferred from DCs to users, intermediate equipment is required (e.g. switches, routers and communication lines). It is very difficult or even impossible to know the exact amount and type of equipment used during transfer. Indeed these two parameters depend on user localization [14]. Therefore, calculating the exact number of kWh needed to transfer one GB from one place to another is very complicated. Experts have tried to determine this amount of energy but their estimates ranged from 3.56 kWh/GB for old lines to 0.0056 kWh/GB for the most recent technology [15].

3) Data collection and impact assessment methods

Data collection is key in life cycle analysis because the results may be highly dependent on the accuracy of the information. Two types of data are used in this study: proxy and real measurements.

Proxy data from the ecoinvent 2.2 life cycle database with certain modifications to reflect the grid mix used in the processes was used in this study [16]. Ecoinvent is a database that contains a large amount of LCI data on processes, materials and services in numerous sectors. The database is highly regarded by LCA experts and is incorporated into the SimaPro software, which is used for impact calculation.

The second type of data is mainly composed of electricity measurements of server consumption during videoconferences. This direct measurement of the consumption makes it possible to accurately compare the uses phases of the different scenarios.

The environmental impacts are calculated with the impacts assessment method IMPACT2002+. Four impact categories

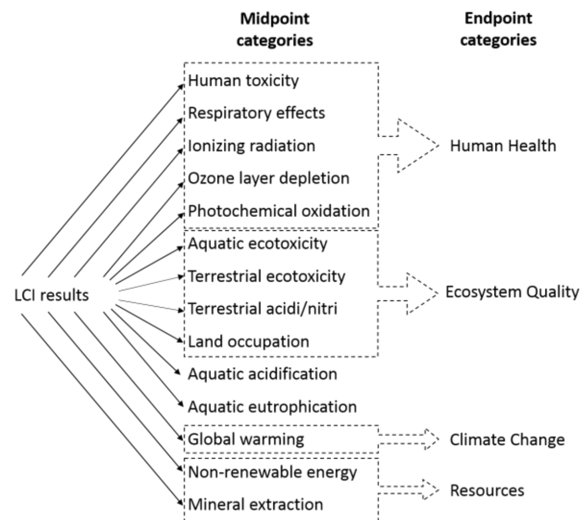

Fig. 3. Impact categories for IMPACT2002+

were used in this study: human health (HH) expressed in DALY (disability-adjusted life years), ecosystem quality (EQ) expressed in percentage of potentially disappeared fraction (the percentage of extinct species in a specific area for a specific time in unit PDF*m²*year), resource scarcity (R) expressed in surplus of energy required to extract new raw materials (MJ) and climate change (CC) expressed in kg of CO_2 equivalent. The different midpoint and damage categories are presented in Figure 3.

B. Systems description and inventory analysis

This section describes all the hypotheses and data used to realize this LCA. One blade servers (BS) is used to obtain data required for life-cycle assessment. This server is composed of 51 blades, on which the IP multimedia system (IMS) managing the video-conferences is installed. The IMS works in three steps: first the users ask a connection request to the IMS, secondly the IMS connects the users together and finally the video-conference takes place. The description is divided in three parts: an explanation of the scenarios compared in this paper, a description of the manufacturing and end-of-life phases and a picture of the use phase.

1) Scenarios

In this study three scenarios of a video-conference system are evaluated. In each scenario, two millions users located in Ontario use every day a video-conference service run with the IMS software. It is assumed all users do not use the videoconferencing service at the same time but according to the daily distribution shown in Fig. 4. This distribution assumes a peak utilization of the video-conference service at 5 pm. Finally, the server running IMS is installed on the blade servers.

The first scenario considers IMS is installed directly on the blade (scenario 1).

The second scenario considers the creation of a VM on the blade on which the IMS is installed (scenario 2).

The third scenario considers the use of two servers with VMs installed on each one and IMS software installed on each

VM (scenario 3). This scenario has been designed for the case in which the videoconference service must never be interrupted. Therefore, in this scenario, two blade servers are located in two different places. Indeed in the case where one blade would stop working the second blade could be ready to fulfill the task.

The LCA functional unit to compare the three scenarios is: “manage a video-conference service for two billion customers over one year, five times a day”.

2) Manufacturing and end-of-life

a) Blade server

For this study, proxy data from ecoinvent 2.2 were used. The different processes used to model one blade servers and their end-of-life are presented in Table 3. One blade servers is composed of 51 blades and network access devices that has been approximated to 57 desktop computers, 1.5 network access devices and 18 routers. EoL of network access device, routers and blades has been approximated to desktop computer dismantling. Network access device is considered equivalent to 7.5 kg of desktop computer dismantling, the routers to 90 kg and the blades to 285 kg. This gives a blade servers weight close to 382.5 kg. In this study, when 1 kg of electronic waste is processed, three-fifths are manually dismantled in China and two-fifths is mechanically dismantled in the US.

TABLE I. ECOINVENT PROCESSES

Product modeled		Ecoinvent process use	
Number of item	item	Number of item	Item (ecoinvent)
1	BS	57	Desktop computer, without screen, at plant/GLO U
		1.5	Network access devices, internet, at user/CH/I U
		18	Router, IP network, at server/CH/I U
382.5 (kg)	EoL of BS	229.5 (kg)	Dismantling, desktop computer, manually, at plant/CH U
		153 (kg)	Dismantling, desktop computer, mechanically, at plant/GLO

Only a small part of blade servers is needed to handle the calls. To attribute this small portion of manufacturing and EoL impacts to videoconferencing, three allocation factors are used. One for blades, the second for network equipment and the last for dismantling. In this paper a distinction is made between the cores assigned to videoconferencing and the cores used for videoconferencing. In the first case the cores not used directly by videoconferencing but not available to any other tasks are accounted (scenario 1). In the second one only cores used for videoconferencing are considered.

To calculate the first allocation factor, the average number of cores assigned to videoconferencing was divided by the average number of cores used in the blade. In scenario 1 (without virtualization), the two figures are equal since the blade handles only the calls. In scenario 2 (with virtualization and 1 blade), the average number of cores assigned to videoconferencing is 1.75. An average load ratio of 70% of the blade is considered in this paper, meaning that 8.4 cores are used at all times (for videoconferencing but also for other tasks). The allocation factor is then equal to 21% (1.75/8.4), which means that one fifth of a blade is needed to handle the VC. In scenario 3 (with virtualization and 2 blades) two blade servers are used and the average number of cores assigned to videoconferencing in each blade is 1.29. Which means an allocation factor equals to 15.4% (1.29/8.4) for two blades or an allocation factor equals to 30.8% for one blade (since the impacts of two blades are equal to two times the impacts of one blade the allocation factor just needs to be multiplied by two). The allocation factors presented here are calculated for the use of one blade. To obtain the allocation factor for the blade servers, the previous result must be divided by 51 since there are 51 blades in one blade servers. This gives three allocation factors equal to 1.96%, 0.41% and 0.60%.

The allocation factors used for network access devices and routers are calculated based on the number of cores used for videoconferencing. In scenario 2 and 3 (virtualization on 1 and 2 blade servers) this factor is equal to the factor for the blades since the number of cores assigned to videoconferencing and used for it are equal. But it is not the case for scenario 1. In the latter one the average number of cores used for videoconferencing is 1.63. Which gives an allocation factor equals to 0.38%.

The allocation factors used for end-of-life are calculated similarly to previous ones. Therefore the dismantling of blade use the blades allocation factor and dismantling of network access device and router use the allocation factors previously calculated for these devices. It is possible to calculate a total allocation factor for EoL by summing the allocation factors weighted by device weight. The allocation factors for manufacturing and EoL are presented in the Table II.

TABLE II. ALLOCATION FACTORS

Item	Ecoinvent process use	Allocation factors		
		S 1	S 2	S 3
BS	Desktop computer, without screen, at plant/GLO U	1.96%	0.41%	0.60%
Network equipment	Network access devices, internet, at user/CH/I U	0.38%		
	Router, IP network, at server/CH/I U			
EoL	Dismantling, desktop computer, manually, at plant/CH U	1.56%		
	Dismantling, desktop computer, mechanically, at plant/GLO			

b) Laptops

It is assumed that download and upload speed for videoconferencing is equal to 500 kbps, which correspond to the bandwidth requirement for high quality video call in Skype [17]. A second assumption is that 20 MB are exchanged during one call. Therefore the call duration can be calculated and is equal to 5min20s. With the use time of the laptop it is possible to calculate the allocation factor for this one. A laptop with a life time of 4 years, 8 hours per day, 5 days per week and 50 weeks per year is considered. This results in an allocation factor of 0,000011 for each user so an allocation factor of 0.000022 for each call (since two users are considered per call). The impacts due to laptop are calculated using the process "Laptop computer, at plant/GLO" from ecoinvent 2.2 and the allocation factor calculated previously. The process from ecoinvent contains the LCI of the entire life-cycle of a laptop. The impacts due to manufacturing, production and EoL phases are named the embodied impacts.

3) Use

Use phase impacts are related to electricity consumption by blade servers, network and laptops.

a) Blade servers use

In scenario 1 and 2, the video-conference service does not require more than one blade. In Scenario 3 two blade are used. The power consumption of one blade can be modeled with equation 1 [18]:

$$P = P_0 + m \times Load_{CPU} \qquad (1)$$

Where P is the blade power consumption in Watts, m is a constant equal to 1.8, P_0 is the base consumption of one blade and equal to 60 W (energy required to keep the server active) and $Load_{CPU}$ is the blade processor load.

The load of the processor, $Load_{CPU}$, is obtained from measurements made with and without the virtual machines while IMS is running and processing call requests. When the IMS application is directly running on a blade then 405 000 calls/hour causes a 93% load of one core (the average load of the processor is obtained by dividing the measured load by 12). When the IMS application runs on a virtual machine installed on a blade then 360 000 calls/hour cause a 97% load of 1 core.

The number of calls/hour is computed with the daily load distribution and the numbers of users and call/users/day. Then, assuming the load of a processor core is a linear function of the calls processed per hour, the power consumption per hour of a blade can be computed using the daily load distribution (Figure 4), the number of users and the number of calls per user per day.

In Scenario 2 and 3 (virtualization on 1 and 2 blade servers) since the processor is used for several tasks the base consumption of one blade is only partially attributed to videoconferencing. The allocation factors are calculated similarly to previous ones. So the number of cores used for videoconferencing is divided by the total number of cores used in the blade. The equation (1) can be transformed to give directly the power for videoconferencing (P_{VC}).

$$Scenario\ 1: P_{VC} = P_0 + m \times Load_{CPU} \qquad (1)$$

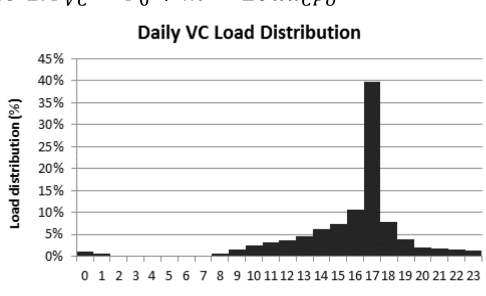

Fig. 4. Daily video-conferencing load distribution

$$Scenario\ 2: P_{VC} = \frac{nb_{vc}}{T} \times P_0 + m \times Load_{CPU-VC} \qquad (2)$$

$$Scenario\ 3: P_{VC} = 2 \times \left(\frac{nb_{vc}}{T} \times P_0 + m \times Load_{CPU-VC}\right) \quad (3)$$

Where nb_{vc} is the cores number used for videoconferencing, T is the total cores number used in the blade and $Load_{CPU-VC}$ is the load processor used for videoconferencing. It should be noted that $Load_{CPU-VC}$ is not equal to $\frac{nb_{vc}}{T}$. In the first expression, partial cores are considered. In the second one nb_{vc} need to be integer and T take into account the average load ratio. For example if 14% of one core is used for videoconferencing, $Load_{CPU-VC}$is equal to 1.17% (0.14/12) and $\frac{nb_{vc}}{T}$ is equal to 11.9 % (1/8.4).

Another comment is that $Load_{CPU-VC}$ in scenario 3 is two times smaller than $Load_{CPU-VC}$ in scenario 2 since the load is shared between two blades.

b) Network: data transfer

It is assumed that the amount of data transmitted per user during each video-conference is 20 MB. Additionally, a data packet of 10 kB is sent by the user at the beginning of each video-conference to connect on IMS. For all data transmissions, the result from Coroama et al. [19] has been used, which gives a consumption of 0.1993 kWh/GB.

For the first and the last equipment, the process "Network access devices, internet, at user" from the data base ecoinvent 2.2 has been considered with the allocation factor from the same data base. This process takes into account the whole life cycle of the router, except the use phase already considered previously [16].

c) Laptops

The power required by the laptop during videoconferencing is evaluated to 30W which give an energy consumption of 0.00267 kWh per call (since the call duration is 5min 20s) [16]. Electricity impacts are described in the next section.

d) Electricity

Since the power consumption of the blade server changes at each hour it is required to model electricity generation on an hourly basis. Power generated by each power plant in Ontario has been computed from [20] over year 2012 for each hour. Then each technology has been modeled according to ecoinvent life cycle inventory database:

TABLE III. ENERGY SOURCES

Energy source	Ecoinvent process
Biomass	Electricity, at cogen 6400kWth, wood, allocation exergy/CH U
Coal	Electricity, hard coal, at power plant/NPCC U
Hydro	Electricity, hydropower, at reservoir power plant, non alpine regions/RER U
Natural gas	Electricity, natural gas, at power plant/NPCC U
Nuclear	Electricity, nuclear, at power plant boiling water reactor/US U
Oil	Electricity, oil, at power plant/UCTE U
Wind	Electricity, at wind power plant 800kW/RER U

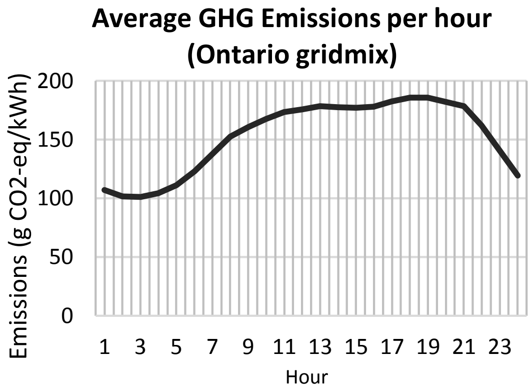

Fig. 5. GHG emission of Ontario grid mix

Since the behavior of the users do not change over seasons an average of the Ontario hourly power mix has been computed for year 2012. It is then possible to calculate the environmental impact with the following equation.

$$IMPACT = \sum_{i=1}^{number\ of\ technologies} IMPACT_i \times ratio_i$$

IMPACT represents the environmental impact considered (climate changes, human health, etc.) per kWh for the grid mix, $IMPACT_i$ is the environmental impact considered per kWh for technology i and $ratio_i$ is the proportion of technology i in the grid mix.

The hourly GHG emissions of the Ontario grid mix are presented in Figure 5.

III. Result

The present results originate from a screening LCA based on many assumptions and approximated data with a high uncertainty as discussed in section IV. The results are presented in two parts: the first describes the total impacts of videoconferencing and the second concentrates on impacts linked to blade servers.

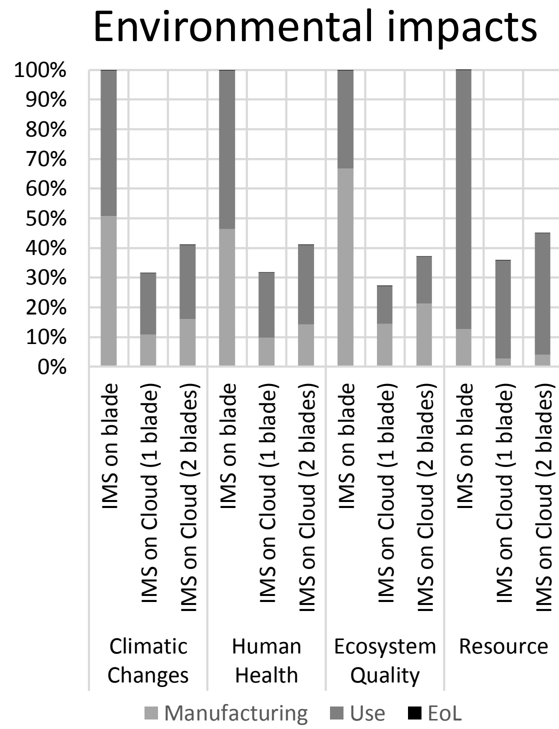

Fig. 6. Environmental impacts for server

A. Videoconferencing Impacts

The results for videoconferencing are presented in Table IV. Data transmission, laptop embodied impacts and laptop use do not depend on the scenario.

The results presented in Table IV indicate that most of impacts are due to laptop embodied impacts, followed by laptop use, then data transmission and finally blade servers Impacts. These results suggest a very small participation of blade servers' impacts.

B. Blade servers impacts

The environmental impacts of the servers are presented in Figure 6 for the three scenarios: IMS on blade, IMS on Cloud (1 blade) and IMS on Cloud (2 blades). Three phases are

TABLE IV. ECOINVENT PROCESSES

Impact	Scenario	BS			Data transmission		Laptop	
		Factory	Use	EoL	Internet	Router	Embodied Impacts	Electricity
Climatic Changes (kgCO2eq)	1	1,06E+02	1,03E+02	5,05E-01	2,61E+06	4,41E+05	1,98E+07	3,49E+06
	2	2,28E+01	4,34E+01	1,32E-01				
	3	3,36E+01	5,23E+01	1,95E-01				
Human Health (DALY)	1	1,32E-04	1,52E-04	6,24E-07	3,75E+00	4,81E-01	1,60E+01	5,02E+00
	2	2,75E-05	6,29E-05	1,64E-07				
	3	4,06E-05	7,62E-05	2,42E-07				
Ecosystem Quality (PDF*m²*year)	1	3,40E+01	1,69E+01	7,18E-02	3,80E+05	2,38E+04	7,07E+06	5,08E+05
	2	7,32E+00	6,52E+00	1,88E-02				
	3	1,08E+01	8,04E+00	2,78E-02				
Resource (MJ)	1	1,02E+03	7,05E+03	1,17E+00	1,54E+08	7,05E+06	2,26E+08	1,06E+08
	2	2,18E+02	2,67E+03	3,08E-01				
	3	3,22E+02	3,31E+03	4,54E-01				

presented: the production phase including raw materials acquisition and manufacturing, the use phase and EoL. The comparisons between the first and second scenarios highlights the benefits of virtualization used by cloud computing, with a 68% decrease for the climatic change and similar result for the other environmental impacts.

Figure 6 clearly shows that the scenario IMS on blade is the worst option since it has the highest impacts for each category. IMS on Cloud with 1 blade is the best scenario for each category, mainly due to the allocation that attributes all the embodied impacts and energy consumption to videoconferencing in the first scenario and shares the impacts between different tasks in the second and third scenarios.

But despite this unsurprising result, the analysis shows the significance of the embodied impacts when servers are used. Indeed for climate change and human health, the production phase represents almost 40% of the impact and is responsible for over 60% of the ecosystem quality impacts.

IV. Discussion

The impacts assessment for videoconferencing is affected by an important lack of data resulting in approximation and high uncertainty. The laptop manufacturing and use and data transmission are the biggest contributor but rely on the most approximated data.

Indeed laptop data originate from ecoinvent but a very high number of laptop models exist, from the small laptop highly energy-efficient weighting less than 1 kg to the very powerful model consuming an important power and weighting some time more than 4 kg. This variance makes the results for the laptop highly specific to the situation. Previous papers already mention the difficulty to obtain such data, due to the diversity of computers, the fast evolution of this sector and the indisposition of companies to give their data about production phase [21].

The data transmission are the third most important contributor making the hypothesis on the amount of data required for videoconferencing and the energy required per transmitted GB very important. In this study, both were roughly approximated with literature data and expert judgment. In addition, the bandwidth requirements came from Skype standard. But different software and video-quality exist using specific compression method, for example google hangouts indicates a bandwidth requirements of 1000 kbps, which would increase data transmission impact by a factor of two [22].

These approximations make the absolute value of the result very uncertain. For a clear conclusion, more information on laptop model and data transmission is required. However, there are preliminary conclusions based on these uncertain results. First, the different hot spots of a video conference can be identified as the laptop embodied impacts, followed by the laptop use then the data transmission. Secondly, a future data research could focus on impacts differences between laptop models to allow sensitivity analysis on this parameter and on data migration from one laptop to another. Thirdly, future studies to improve VC efficiency could explore data compression and transmission equipment. Finally, results suggest that blade servers' impacts are negligible compared to other contributor. This conclusion could be expected, indeed video-conferencing does not require high calculation from the server but generate an important traffic of data which leads to this result. But even if the gains are small, for larger scale where application addresses to more customers, the emissions avoided would not be insignificant.

Previous papers [14, 23, 24] already attempted to quantify environmental impacts of videoconferencing but with the aim of comparing it to real meeting, with only carbon and energy impacts and often considering a much more complex videoconferencing system. Borggren et al. [14] evaluated different types of videoconferencing equipment and confronted them to meeting in person. Their results indicated lower impacts, in most of the cases, when videoconferencing is used instead of transport. They also indicated the contribution to the total impact of the different equipment used in videoconferencing and similar conclusions were obtain with the highest contribution being the embodied impacts followed by internet connection and finally the electricity used. Similarly, Ong et al. [24] studied the environmental gains obtained by replacing transport by videoconferencing. They also evaluated different types of transport (train, plan and car) and videoconferencing (high quality communication equipment or just laptop). Their results indicated a factor of fifty between the carbon impacts of videoconferencing involving high quality equipment (plasma screen, HD cameras…) and videoconferencing with only a laptop. This result shows, as partially mention previously, how the impacts can change with the system considered.

Another area, already explored in other papers [23,25], which could be integrated in future research about this subject is the rebound effect. Indeed videoconferencing is often presented as "the solution" to reduce transport impacts with teleworking and video-conference instead of real meeting. But two rebound effects result from these solutions. First the time saved by avoiding transport could be used for other activities, which could be more harmful to the environment [25]. Secondly the usability and simplicity of videoconferencing could increase the number of meetings which would partially decreases the environmental gain [23].

Blade servers can be used for other applications requiring less data transmission and more server calculations, methodologies such as LCA could then be used to evaluate the impact of these application and the efficiency of the strategies that are implemented on blade servers.

The blade servers' results are impacted by the same lack of data as the videoconferencing results except for the use phase where real consumption measurements have been done. These results bring two conclusions. First, virtualization can curb an important part of the server impacts. Secondly, the manufacturing impacts cannot be ignored when efficiency strategies are evaluate for ICT. Indeed even if some papers consider the manufacturing in their study [26] most of them study only the energy consumption of it. Even so, two comments must be made on the origin of the data and the allocation model.

The first observation on data origin is very important since, as previously mentioned, the quality of the results reflect the quality of the data. In this paper, the manufacturing and EoL data are from a database with only very rough approximations of the processes, making the results very uncertain and highlighting the importance for future data research into ICT manufacturing and EoL and, more specifically, servers.

The allocation model is also questionable because the results are very sensitive to the choice of method. In this study, several hypotheses could influence the model:

- The average load ratio of 70%, which enhances the benefits of virtualization. With a lower load ratio, the virtualization benefits would decrease, and, in the extreme case in which servers are only used for videoconferencing, there would be no advantages to virtualization since the allocation factor would be 1 in both cases but more energy would be required in scenarios 2 and 3 to create the VM. But with our hypothesis an average load of 21% and 9% would respectively be needed to rise the impacts of scenario 3 and 2 above the impacts of scenario 1. Such low load are very unlikely which decrease the impact on the result of this hypothesis.
- In all scenarios we assumed the load of a processor core is a linear function of the calls processed per hour. This assumption could, however, be incorrect. Therefore additional measurements would be required to test this assumption.

Despite these questionable hypotheses and data, the model makes it possible to roughly evaluate the environmental advantages of virtualization used by cloud computing and shows where additional data are required. Another advantage of virtualisation is highlighted by the hourly GHG emissions of Ontario grid mix, presented in Figure 5. Indeed this one indicates that GHG emissions can go from 101 gCO2-eq/kWh to 187 gCO2/kWh. Therefore if several data centres are used in different provinces or countries it could be possible to use migration to shift the workload to the data centre with the lowest emission factor. This strategy justify the use of hourly grid mix and could decrease the emission due to blade servers' consumption. The virtualization on two blades seems less beneficial than virtualization on one, but improving the stability increase the quality of service which is a very important criteria for some customers.

V. CONCLUSION

Life cycle assessment (LCA) is a methodology to quantify the potential environmental impacts of the entire life cycle of a product or service. It is already in use in many sectors (e.g. automotive, pulp and paper, energy, etc.), but LCA studies in the ICT field are few in number.

This study aims to assess the impacts of videoconferencing. Due to a lack of data, the results are very rough. Still, four preliminary conclusions emerge. First, virtualization can be used to decrease the data centres' environmental impacts. Second, ICT data research must be carried out in order to conduct more accurate studies. Third, it seems justified to consider the embodied impacts in the environmental impacts of ICT, and, fourth, the results suggest that laptop manufacturing constitutes a hot spot of videoconferencing and could be the focus of future research in the ICT field.

Despite the uncertain results obtained here, the LCA method may constitute a reliable ICT evaluation tool if more data were available. Indeed, LCA avoids displacing the impacts that are often neglected when ICT efficiency studies are carried out. Future ICT LCAs should be encouraged in order to develop a much-needed sectorial database.

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