Applications and Challenges of Life Cycle Assessment in the Context of a Green Sustainable Telco Cloud

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Abstract. An LCA was conducted on a novel Telco-grade cloud technology. Server cloudification has been found to significantly reduce the environmental life cycle impacts as compared to a non-cloud situation. Improving service quality is possible without drastically increasing the life cycle impacts as compared to the non-cloud situation. In this LCA, a novel methodology was used to model electricity flows during ICT use to better reflect the temporal variation in electricity generation by utilities and electricity consumption by ICT. Nevertheless, numerous methodological challenges remain unresolved and more research is required to improve the LCA methodological framework for ICT.

Keywords: Information and communication technologies · ICT · Cloud computing · Life cycle assessment · LCA

1 Introduction: ICT and the Environment

Information and communication technologies (ICT) are pervasive in our society and are often perceived as contributing to our increased overall efficiency in terms of time, money and energy [1–3]. So far, most of the attention has been focused on ICT electricity consumption during use [4–7]. While it is estimated that the global electricity consumption by ICT is constantly rising [4, 8–10], ICT use is expected to slow the increase in future energy demands and thus moderate the emission of greenhouse gases (GHGs) [11, 12]. Nevertheless, electricity consumption by ICT during the use phase is not the only issue. Indeed, the ICT life cycle involves raw materials extraction, manufacturing, handling and shipping of ICT equipment and end-of-life electronic waste management. Moreover, the environmental impacts are not limited to GHG emissions. While climate change is an important issue, resource depletion, ecosystem quality, biodiversity and human health should not be disregarded when evaluating the environmental impacts of ICT. All of these indicators may be taken into account using life cycle assessment methodology (LCA) [13]. Some LCA studies on ICT have revealed that ICT manufacturing generates more impacts than ICT use [14, 15] —or at

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least represents a significant part of the life cycle impacts [16, 17]. LCA is also used to compare ICT systems and conventional options that provide the same function [18–21]. In these comparisons, reductions in GHG emissions and energy consumption may be achieved with ICT in certain contexts, depending on sensitive parameters including the number of ICT devices considered, the frequency of ICT use, transport distances and the energy mix. However, ICT may cause more metal depletion than conventional technologies [14], thus confirming that the life cycle approach constitutes a relevant method to evaluate ICT. Still, few LCAs have been conducted in the ICT sector and there are many methodological challenges [22], including electricity flow modeling. The issue is addressed in this paper by applying a recent methodological development in LCA to evaluate a new Telco-grade cloud technology.

2 Method

2.1 Life Cycle Assessment

The LCA method has been harmonized in the ISO 14040-44:2006 standard series. It consists in four steps: (1) the goal and scope to define key LCA parameters (e.g. system boundaries, functional unit.); (2) the inventory, which aims to establish the list of all substances extracted and emitted from and to the environment; (3) the environmental impact assessment based on the inventory results and according to several environmental indicators and (4) the interpretation of the LCA results (e.g. contribution and sensitivity analysis, uncertainty assessment and management).

2.2 The Green Sustainable Telco Cloud

The Green Sustainable Telco Cloud (GSTC) is a project led by Professor Mohamed Cheriet at École de technologie supérieure (Université du Québec, Canada) and supported by Ericsson, the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Prompt Consortium (www.promptinc.org) through the Equation Initiative (www.equationict.com), in collaboration with the University of Toronto and Polytechnique Montréal (Université de Montréal). As part of this project, an innovative Telco-grade cloud technology was developed to minimize cloud computing impacts on the environment (see www.synchromedia.ca/node/870 for more information). The principle of the GSTC is to move software applications to the cloud instead of using them directly on the servers: virtual machines are installed on the servers and software applications are then run by the virtual machines.

2.3 Scenarios

In this paper, the deployment of the GSTC is investigated at the Canadian scale. It is supposed that the GSTC technology is installed in three data centres located in the Canadian provinces of Alberta, Ontario and Québec. These regions were chosen for their differences in electricity generation. The energy mix in Alberta is mainly fossil fuel (coal and natural gas) while Ontario is more balanced (nuclear power, fossil fuel (natural gas) and renewable energy (hydropower)) and Québec uses mainly renewable energy (hydropower). Indeed, it is relevant to present the new LCA developments in electricity flow modeling in the context of different mixes. Moreover, the three provincial ICT sectors contribute the most to the gross domestic product of the national ICT sector [23].

In this scenario, the GSTC hosts an instant messaging service (IMS) with three million users. It is assumed that there are one million users in each region and that every user uses the service ten times a day. It is also assumed that the global use of the service during the day is in line with web browsing activity statistics [24], yielding time-dependent service usage during the day (Fig. 1). For the purpose of the calculations, the scenario is modeled for 2011, 2012 and 2013.

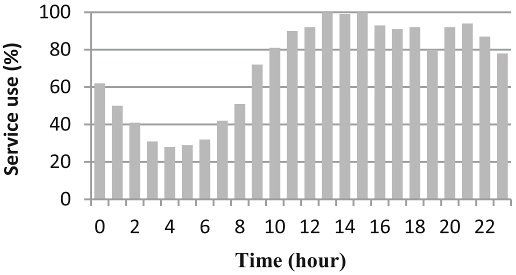

Fig. 1. Service use by time of day

Two types of GSTC configurations are evaluated. In the first case, the GSTC is installed on a single server in each region (scenario 1). In the second case, the GSTC is installed on two servers in each region with the server load equally dispatched between them (scenario 2). The purpose of scenarios 1 and 2 is to evaluate the environmental impacts to enhance the quality of the GSTC service. Finally, a third case is considered: a server running IMS without GSTC technology (reference scenario). This third case is used to assess the benefits and downsides of the GSTC technology as compared to a more conventional technology. In all cases, the servers are Ericsson blade systems (EBS).

2.4 LCA of GSTC

Goal and scope

The purpose of this LCA is to compare different server configurations used to provide an ICT service. Therefore, similar parts of the different life cycles can be excluded from the study. Concretely, this LCA focuses on the servers since the user data transmission and end-user devices are the same in the three scenarios. Data transmission by server synchronization in scenario 2 is included in the system. The functional unit in this LCA is *to provide an IMS service to three million users (locations and user behaviours defined in the scenarios) from 2011 to 2013*. Unlike standard LCAs, the data used to model electricity flows are regionalized and temporally disaggregated to better reflect the reality of electricity generation. Indeed, electricity modeling has been reported as very sensitive in terms of ICT LCA results [15, 25, 26].

Inventory

Manufacturing, handling and shipping. The ecoinvent database [27] is used to model the manufacturing of ICT equipment. Table 1 presents the ecoinvent processes used to model the EBS. For confidentiality reasons, the data used to model the manufacturing phase are not provided. The ecoinvent processes corresponding to the global, China and the rest of world region (GLO, CN and RoW in Table 1 in the Appendix[1]) were selected to prevent the implicit assumption made by ecoinvent that ICT equipment is specifically manufactured in Europe. However, it would be better to use processes corresponding to the Asian region, where the electronic components are expected to be manufactured. In the model, after manufacturing, the electronic components are packaged in corrugated board boxes and transported from Asia to Sweden. Then, the EBS are assembled and shipped to Canada.

Use. The electricity consumption by the servers is computed from an empirical equation (Eq. 1) obtained from energy measurements made on the server while running IMS with different numbers of users and with or without the GSTC [28].

$$P_{server} = P_0 + m \times \%\ CPU. \tag{1}$$

- Where P_{server} is the power demand of the server (W)
- P_0 the power demand of the server (W) when no CPU is used
- m is an empirical constant (W)
- $\%CPU$ is the load of the CPU that depends on the number of users requesting an IMS connection (Rh) and the server capacity to process requests (C_X or C_{GSTC}, see Eq. 3). A load greater than 100 % means more than one CPU is used.

  Rh is obtained from Eq. 2:

$$R_h = \frac{N \times D \times L_h}{\sum_{h=1}^{24} L_h}. \tag{2}$$

- Where N is the number of user per server (N = 1,000,000 users)
- D is the number of connection per day per user (D = 10 connections)
- L_h is the service load (%) at hour h (L_h is presented on Fig. 1)
- C_X and C_{GSTC} are empirical constants (%) related to the CPU load and measured while submitting different numbers of requests for IMS connections to the server with GSTC installed (C_{GSTC}) and without (C_X). Then $\%CPU$ can be calculated from Eq. 3:

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[1] https://dl.dropboxusercontent.com/u/92014052/appendix.pdf.

$$\%\ CPU = R_h \times C_i. \tag{3}$$

Where C_i is C_{GSTC} (scenarios 1 and 2) or C_X (reference scenario).

Finally, Eq. 4 represents the server power demand ($P_{server}(h)$) at hour h:

$$P_{server}(h) = P_0 + m \times \frac{N \times D \times L_h}{\sum_{h=1}^{24} L_h} \times C_i \tag{4}$$

The method developed by Maurice et al. [29] is used to model electricity generation. Historical data are collected from AESO [30] and IESO [31] to model hourly electricity generation in Alberta and Ontario for 2011, 2012 and 2013. Since public historical data on electricity generation in Québec are aggregated at the month level [32], the model developed by Maurice [33] was used to extrapolate hourly electricity generation in Québec. Then, the hourly energy mixes computed using ecoinvent (version 3) processes (see Table 2 in the Appendix) are used to model the impacts of electricity consumption by the server (as presented hereafter, an allocation factor is applied on the term P0).

In scenario 2, the two servers are synchronized. Based on expert assessment, it is estimated that 1 % of the 2 GB server database of IMS users is updated every day. Assuming the synchronization is made every ten minutes, 0.83 MB must be transmitted every hour between the two servers. Then, the value of 2.7 × 10-5 kWh/Gb [34] was used to compute the electricity consumed by data transmission for synchronization.

End of life. As for the manufacturing phase, the modeling of the end of life of the ICT equipment is carried out with ecoinvent. Global region processes were chosen. While the electronic waste is considered to be managed in North America and emerging countries, the global modeling in ecoinvent does not make it possible to assume that the processes occur exclusively in Europe. Moberg et al., who considered Sweden and China for the end of life of mobile phones [15], used a similar approach. The end of life modeling consists in ICT equipment dismantling and recycling (the mass of recycled materials was computed with a model developed by Hischier [35]). Then, an environmental credit (computed in ecoinvent) is given to the recycled materials assuming an equivalent amount of primary production of these materials is avoided. The service life of an EBS is supposed to be five years (based on expert assessment).

Allocation. Different services share some of the ICT equipment considered in the studied systems. Therefore, allocation factors are computed to attribute the environmental impacts of the equipment to each service based on the approach proposed by Vandromme et al. [36].

Server use: The server has several CPU that may be used independently when the GSTC technology is installed on the server. Thus, the base-load electricity consumption (P0) must be allocated between the different services provided by the server. The allocation assumes an average CPU load of 70 % for CPU not used by IMS. Thus, the allocation factor for P0 is provided by Eq. 5:

$$f(h) = \frac{Number\ of\ CPU\ used\ for\ IMS\ at\ hour\ h}{70\%\ \times Number\ of\ CPU\ on\ a\ server} \tag{5}$$

In the reference scenario, the server is entirely dedicated to IMS and P0 is not allocated between different services.

Server manufacturing and end of life: An EBS hosts several servers but only one is used to provide IMS in every scenario. In scenarios 1 and 2 (GSTC installed), the allocation is based on the average number of CPU used by IMS during the entire use phase (Eq. 6). In the reference scenario, the allocation is based on the total number of CPU in a server since they are all dedicated to IMS (Eq. 7). In both cases, it is assumed that the remaining CPU of the EBS have an average CPU load of 70 %.

$$f_{GSTC} = \frac{Average\ number\ of\ CPU\ used\ for\ IMS}{70\%\ \times Number\ of\ CPU\ of\ the\ EBS} \tag{6}$$

$$f_X = \frac{Number\ of\ CPU\ on\ a\ server}{70\%\ \times Number\ of\ CPU\ of\ the\ EBS} \tag{7}$$

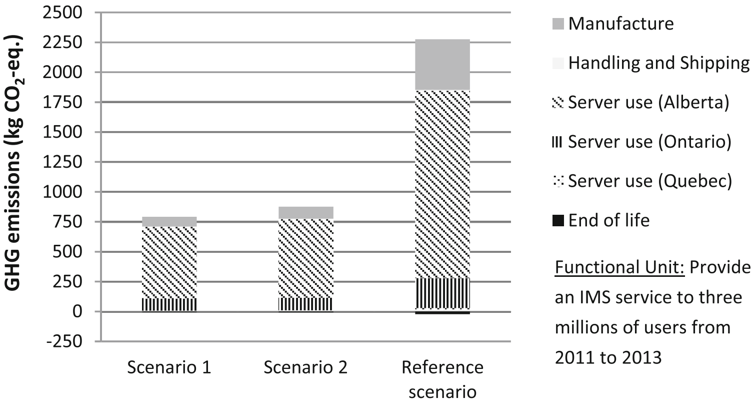
Impact assessment method

Impacts were computed using the Simapro (version 8) LCA software [37] and several impact assessment methods in order to include all the environmental indicators recommended by the European Telecommunications Standards Institute [38] and the International Telecommunication Union [39] for ICT studies. The environmental indicators and the corresponding impact assessment methods are listed in Table 3 in the Appendix.

3 Results

Figure 2 presents the GHG life cycle emissions of each scenario. It appears that the GSTC technology leads to a significant reduction in emissions as compared to the reference scenario. This observation is also made for all the other environmental indicators (not shown in Fig. 2). The explanation is that cloud computing (scenarios 1 and 2) makes it possible to use servers for more tasks than in the non-computing situation (reference scenario). Therefore, impacts related to the manufacturing and use of the servers are shared between more services, making the life cycle impacts of IMS lower in the cloud computing situation than in the non-cloud computing situation. It is also observed that, in the cases of Ontario and Alberta, the use phase contributes the most to the server life cycle impacts. In the case of Québec, ICT equipment manufacturing is the main contributor to the servers' life cycle impacts. This result is due to the difference in energy mixes: electricity generation in Ontario (balanced mix) and Alberta (fossil mix) are far more polluting than in Québec (hydro mix) for most environmental indicators. Handling, shipping and end of life contribute minimally to the life cycle impacts in all scenarios for most of the environmental indicators. As expected, the manufacturing phase has significant impacts on the natural resources indicators (mineral resources extraction, land use and water use). The environmental benefits of precious metal recycling appear negligible as compared to the other life cycle impacts of the servers. This may be explained by the weaknesses of the mineral resource indicator in LCA (see Discussion section).

Figure 2 also shows that adding a second server (scenario 2) to improve the quality of service does not significantly impact the life cycle GHG emissions. Indeed, emissions increase by less than 10 % when a second server is added. This result is also observed for other environmental indicators with a similar increase in impacts. These findings are in line with previous GSTC technology assessments in other contexts [29, 33, 36, 40–43].



Functional Unit: Provide an IMS service to three millions of users from 2011 to 2013

Fig. 2. Comparison of GHG life cycle emissions

4 Discussion

Conducting an LCA on ICT presents many challenges at each methodological step [22, 26]. In terms of the goal and scope, the system borders may be difficult to establish since ICT may provide several different functions. ISO standards recommend avoiding multi-functional process impact allocation by system expansion. In the case of ICT, all of these functions must therefore be included within the system borders. In this study, impact allocation was chosen instead of system expansion because it would have considerably complicated the LCA if the hundreds (if not thousands) of services that may be provided by an EBS were included in the scope of the study. A system expansion would have been better in theory but, from a practical perspective, it may be suitable to do an allocation based on the capacity of the EBS to provide simultaneous services (i.e. an allocation based on the number of CPU used by IMS). The definition of the functional unit may also create an issue in LCA because the impacts attributed to a function provided by an ICT are often strongly related to ICT user behaviours [26], meaning that user behaviours should be included in the functional unit to prevent comparison of LCAs of a same function with different user behaviours. Still, the geographic context and the year of study should also be considered when comparing ICT LCAs.

The life cycle inventory of ICT is problematic due to the lack of accurate data to represent the technologies. Indeed, confidentiality reasons usually prevent LCA practitioners from obtaining specific data from ICT manufacturers. Moreover, even when data is released, the significant number of components made by different electronic manufacturers in a single ICT device makes the ICT data collection for LCA complex. For this reason, few ICT LCAs use manufacturer data and there are very few ICT data in LCA databases [44]. In this study, we used ecoinvent data, which are assumed to be of good quality. However, they are not expected to exactly describe the EBS. Indeed, rapid technological innovation in the ICT sector makes the inventory data obsolete within a couple of years [26, 45]. Also, the manufacturing of ICT equipment involves high purity materials that are known to have major environmental impacts that may not be systematically captured in LCA due to a lack of data [46]. Thus, in this study, the environmental impacts related to the manufacturing phase should be considered very uncertain. Similar conclusions were drawn by Hischier et al. [14] and Moberg et al. [15] when they compared LCAs based on manufacturer data versus ecoinvent data. However, data quality is often an issue in ICT LCA studies [45, 47–49]. Nevertheless, future works will include manufacturing phase modeling based on more specific data to model the EBS and ecoinvent will be used for the rest of the inventory. Malmodin et al. [50] recommend such data combinations. Another problem in ICT LCA is electricity generation modeling [15, 25, 26]. On one hand, ICT electricity consumption may vary in time while, on the other hand, electricity modeling in LCA is usually based on annual average electricity generation data. Therefore, the impacts computed in LCA are more or less uncertain depending on the standard deviation of electricity generation toward the average generation. To overcome this problem, it is proposed to use temporally disaggregated data for retrospective LCA [29]. When ICT are used in a smart context to minimize emissions in real-time, the real-time electric grid is usually considered. However, since the smart management of ICT causes changes in local power demand, the marginal sources of electricity affected by these changes should also be considered. A predictive method based on historical electricity generation data was developed for this purpose and is recommended for the real-time optimization of ICT [42].

As previously mentioned, user behaviours are often reported to be very sensitive in ICT LCA. While it is easy to create a scenario that represents a user behaviour, it is more difficult to make it fit with actual user behaviours. For this reason, ICT LCAs should be seen more as *what if* scenarios rather than *reality* scenarios. The problem of modeling user behaviours may especially occur when a large-scale ICT deployment is evaluated. Indeed, in this situation, all user behaviours should be reflected in the study (assuming the scale is extensive enough to involve all users). Otherwise, the study may diverge from the real potential environmental impacts. One aspect of user behaviours that is known to be problematic in modeling is the rebound effect of ICT use [51–53]. In this study, the user behaviours were characterized only by web browsing activity statistics. The IMS use that would replace other equivalent functions was not evaluated. Since this substitution may be expected to be the same in all scenarios, its omission should not affect the results of the comparison. However, it could be argued that the improved quality of service in scenario 2 would make IMS more competitive with other equivalent services. In that case, the substituted services should be included in the scope of the study. Furthermore, assuming IMS is increasingly used, it would be relevant to evaluate whether IMS is used as an extra service or as a substitute for another service (e.g. cellular telephone conversation or face-to-face meeting). Introducing psychological parameters characterizing the users could improve the accuracy of user behaviour modeling in ICT LCAs. The modeling of the end of life of ICT is challenging in LCA. First, the real outcome for ICT equipment is unclear. The rate of recycling and the mode of recycling (manual or mechanical) are poorly documented. This is partially due to the shipping of electronic waste to emerging countries, where the recycling of valuable products is usually carried out by informal organizations that do not report their activities. Moreover, it is not clear how the environmental credits attributed to recycling should be computed and shared between those providing the materials for recycling and those using recycled materials to manufacture the product [54, 55]. Also, the natural resource depletion indicators are not mature enough to properly represent the impacts of resource depletion [56]. Current methods underestimate the real impact on these indicators. Resolving these two methodological challenges in LCA could possibly increase the positive contribution of electronic waste recycling in ICT studies.

5 Conclusion

LCA constitutes an efficient framework to evaluate the environmental impacts of products and services and was used to study the environmental performance of a new Telco-grade cloud technology. The results clearly demonstrate that server virtualization enhances energy efficiency and multitasking, leading to less significant environmental life cycle impacts as compared to non-virtualized servers. However, conducting LCAs on ICT is challenging due their specificities. The definition of the studied ICT system, the allocation of the impacts of multifunctional equipment, the lack of inventory data and ICT user behaviour modeling remain important issues in ICT LCA. Nevertheless, an increasing number of LCAs are addressing ICT and methodological issues are progressively pinpointed and resolved. In this paper, a new method to model electricity flows during the ICT use phase makes it possible to account for both the geographic and the temporal contexts of ICT electricity consumption.

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