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A data-driven modular approach to the digitalization of maintenance services: the case study of a Carbon Footprint calculator for Ricoh Europe

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Abstract

Original Equipment Manufacturers (OEMs) have an increasing need for the digitalization of their maintenance services, but they are also exposed to a growing pressure on decreasing their environmental performances. In this contribution we present the case of the development of a data-driven modular Carbon Footprint calculator for maintenance services, which involved multiple functions within the office printing business line of Ricoh Europe. A modular approach was followed, which included 5 steps: i) identification of both remote and on-site maintenance services; ii) definition of exemplary customer scenarios; iii) quantification of the greenhouse gases emission factors, iv) identification of key assumptions, v) creation of the maintenance service Carbon Footprint calculator. In total, more than 30 scenarios were developed in relation to the two categories "consumables management" and "fault and incidents management". These scenarios could be compared by the developed tool, leading to a decrease of the potential environmental impacts on climate change ranging from 47% to 85% for the "Consumables Management" category and up to 97% for the "Fault and Incident Management" category, respectively. The digitalization of maintenance services proved to lead to a reduction of potential impacts on climate change and is therefore recommended as a business practice in the sector.

Keywords: office printing; manteinance; climate change; Life Cycle Assessment

Nomenclature

AI	Artificial Intelligence
CF	Carbon Footprint
FSE	Field Service Engineer
GHG	Greenhouse gas
ICT	Information and Communication Technologies
IoT	Internet of Things
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
ML	Machine Learning
OEM	Original Equipment Manufacturers

1. Introduction

The digital transition has a central role in the policies of the European Commission, which is engaged in the promotion of a new generation of technologies that are expected to empower people, businesses, and administrations [1]. Furthermore, the World Economic Forum proposed an Action plan for the digital transition which includes among other recommendations supporting the development of emerging technologies for the digital and sustainable transitions, also called twin transition [2]. The latter represents a very hot topic in the scientific literature, as shown by the review performed by Ferdaus et al.

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[3], which points out the huge importance of digital technologies for the achievement of net-zero strategies. For instance, robotics, Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT) can be extremely beneficial to address the complexity of smart energy systems [3]. Similarly, the challenges and opportunities of the twin transition within the agri-food sector have been investigated [4]. On the other hand, over the undoubted benefits of digital transition in terms of environmental sustainability, the environmental impacts of digital technologies shall not be underestimated [5]. The Life Cycle Assessment (LCA) methodology has been often used to quantify the relevant contribution of Information and Communication Technologies (ICT) in terms of greenhouse gas (GHG) emissions [6,7].

In this context, Original Equipment Manufacturers (OEMs) have an increasing need for the digitalization of their maintenance services, including both preventive maintenances, i.e. the replacement of individual components, and regular servicing to extend product lifespan, and they are also exposed to a growing pressure on improving their environmental performance. According to the considerations presented above, digitalization can potentially mitigate the environmental impact of OEMs, but the actual environmental convenience of the novel ICT solutions should not be given for granted and the benefits of applying LCA for such a purpose are manifold. With reference to the printing sector, Saidani et al. [8] show that LCA can be coupled to ML to improve the eco-design of printing machines: ML algorithms can collect online positive and negative feedback from the customers, and LCA can be used to elaborate these comments to reduce the environmental footprint of manufacturing a printing machine from design. Gard et al. [9] used LCA to compare digital and printing: the authors demonstrate that storing documents in digital format is a winning solution due to the electricity demanded during the printers' use phase. Differently, Kouloumpis et al. [10] oriented the discussion on the end-of-life stage showing that the LCA results of repairing used printers are very similar to the impact of purchasing a new device. To the best of our knowledge there are no studies in literature that focus on printing machines' maintenance services, especially focusing on how digital technologies can support the twin transition in the printing sector.

In this contribution we present the case of the development of a data-driven modular Carbon Footprint (CF) calculator for maintenance services, co-designed with Ricoh Europe, which involved multiple functions within the office printing business line of the company. The CF calculator is a general-purpose calculator for any type of service activity irrespective of whether it is proactive, preventative or emergency, as the model builds out on specific unitary tasks that are part of any service process and not specific to Ricoh. Here we consider Ricoh as a case study, with focus on decarbonization of maintenance services using digital technologies. So the case study is just an example of how the process components and their CF can be combined to fit into a specific service process, but are completely general purpose.

1.1. Ricoh Europe decarbonization strategy

Ricoh Europe has implemented a comprehensive decarbonization strategy as part of its broader sustainability initiatives. The company's approach to sustainability is encapsulated in its "Three Ps Balance" strategy, focusing on Prosperity (economic), People (society), and Planet (environment) [11]. This strategy aims to balance economic growth with environmental stewardship and social responsibility. Ricoh has set science-based targets to reduce its GHG emissions in alignment with the goals of the Paris Agreement. This includes both short- and medium-term milestones for 2030 and 2040, setting increasing levels of GHG emissions reduction, and a long-term goal of achieving net-zero emissions by 2050 [12]. The GHG emissions considered by Ricoh include both direct and indirect contributions. Moreover, Ricoh also has an energy transition plan that is expected to push the renewable energy usage rate first to 50% (in 2030) and then to 100% (in 2040) [12]. Grounding on these high-level targets, Ricoh reviews its action plan every three years to define effective measures aimed at the environmental impact mitigation of the company [12].

Among its initiatives, Ricoh decided to create some environmental impact assessment tools that may support the decision-making and orient the strategies of the company management in a twin transition perspective, i.e.including both the ecological and digital transition. In particular, the CF calculator presented here aims to evaluate whether, and to what extent, providing remote assistance to customers allows to mitigate the carbon footprint of Ricoh services compared to onsite resolution.

2. Materials and methods

The CF calculator developed grounds on a recognized methodology, namely LCA, standardized by ISO 14040 [13] and ISO 14044 [14], which has been applied to a single case study that regards the sector of maintenance services guaranteed by Ricoh to its customers in case of technical issues with their products.

A modular approach was followed, which included 5 steps: i) identification of both remote and on-site maintenance services; ii) definition of exemplary customer scenarios; iii) quantification of the GHG emission factors, iv) identification of key assumptions, v) creation of the CF calculator. This approach has been applied to two different application areas or types of issues, namely "Consumables Management" and the "Fault and Incident Management". The "Consumables Management" area refers to the situations that require ordering and replacing some components; an exhausted toner is selected as a reference component to be replaced in this case study. On the other hand, the "Fault and Incident Management" area is related to the resolution of problems encountered by customers with the usage of a printer. In both cases, the potential benefits of process automation and remote resolution technologies are investigated in terms of GHG emissions mitigation. The 5 steps approach applied in both application areas is represented in Figure 1.

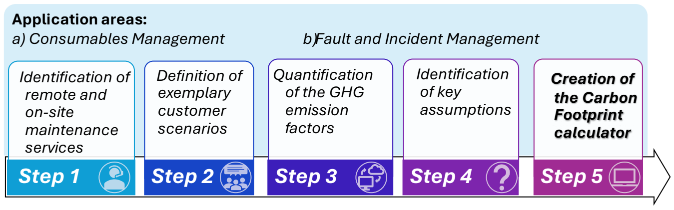

Fig. 1. Sketch of the 5 steps modular approach adopted for the development of the Carbon Footprint calculator.

2.1. Identification of remote and on-site maintenance services

Step 1 of the methodology consists in identifying what are the maintenance services that are provided by Ricoh to its customers. One option regards the possibility that the customer solves the incident independently, which is considered a burden-free option. Otherwise, the customer has to create a ticket to request support and several options are available:

- Automatic ticket creation through the on-line "@Remote" application, which is equivalent to an IoT enabled platform;
- Ticket creation by customers on Ricoh's "eService" digital online platform, which is equivalent to a self-service customer portal;
- Ticket creation by customers via phone call.

In case of "Consumables management" issues, the ticket shall be validated to verify the need to order a new toner. First, an automatic validation is attempted: in case automatic validation is passed, a new toner is automatically shipped to the customer. If the automatic validation fails, the request is subject to manual validation from the helpdesk which can accept the shipment of a new toner or decline the request. The functional unit here is the "management of 1 order".

When the ticket refers to a "Fault and Incident Management" issue, the customer has different solutions to communicate with Ricoh. The automated options (that do not imply manual operations from the helpdesk agents) are a chat and a phone call with an AI agent, which may decide to escalate the call to a physical agent of the helpdesk if necessary. As an alternative, customers can contact the helpdesk via email or phone. In the easiest cases, the virtual assistant or the helpdesk can solve the problem. Otherwise, the helpdesk involves the support of a Field Service Engineer (FSE): first remote resolution is attempted, and onsite visits are chosen only when necessary. Furthermore, in order to prevent future issues, both the Ricoh helpdesk and FSEs can order parts in advance allowing the customer to solve the issue independently in the future. Moreover, in the CF calculation it is considered that Ricoh employees are allowed to work from home for part of their working time. Therefore, the environmental impact of commuting shall be considered only in case employees work from office. For the "fault and incident management" the functional unit is the "resolution of 1 problem".

2.2. Definition of exemplary customer scenarios

Depending on the specific issue encountered by the customer, several maintenance service scenarios are evaluated, therefore the system boundaries considered by the calculator depend on the specific case study identified. For example, after a ticket is created with one of the options described in the previous section, the path that brings from the ticket creation to the problem resolution depends on the complexity of the issues. A simple problem could be solved by the helpdesk after a short phone call or a few emails. Differently, the helpdesk may fail to solve complex issues and forward the request to a FSE. The FSE may solve the problem remotely or with an onsite visit. In other words, it could be necessary to create scenarios including multiple combinations of maintenance operations. Figure 2 represents with a flowchart the logic followed by Ricoh in proposing maintenance service solution packages.

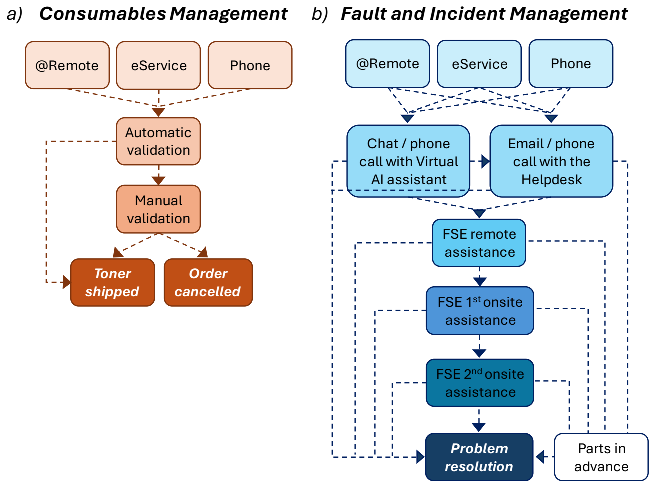

Fig. 2. Flowchart of the maintenance services operations to solve issues related to a) "Consumables Management" and b) "Fault and Incident Management" application areas.

As highlighted in Figure 2, covering all possible combinations of maintenance service operations (represented as dotted lines in the scheme) implies the design of a remarkable number of scenarios requiring different types of data, especially for the "Fault and Incident Management" area. The experience gathered by Ricoh was important to rationalize the options and propose the most realistic exemplary customer scenarios, giving high priority to remote and automated maintenance operations. More specifically, 9 scenarios are created for the "Consumables Management" area and 31 scenarios for the "Fault and Incident Management".

2.3. Quantification of the greenhouse gases emission factors

The CF calculator aims to assess the GHG emissions of each scenario proposed by Ricoh grounding on LCA as reference methodology [13,14]. For this purpose, we used SimaPro 9.6 [15] as LCA software and Ecoinvent 3.9.1 [16] in its cut off version as a data source to calculate the GHG emissions factors of maintenance service operations. The Climate Change indicator of the Environmental Footprint 3.1 life cycle impact assessment (LCIA) method [17] has been selected, which is based on the IPCC2021 methodology. The GHG emission factors are expressed as grams of equivalent carbon dioxide [g CO2 eq]. Ecoinvent 3.9.1 datasets have been used to model the emission factors of different transport ways and internet usage. Land transports have been modeled to consider people's travels (i.e. FSE travels and Ricoh employees commuting) and consumables' shipments. Data gathered from scientific literature instead have been used to model the emissions associated with AI queries [18,19] and with phone and email communications [20]. A summary of the emissions factors is available in Table 1. The emission factors of several transport ways (e.g. car, electric car, electric scooter) have been combined to assess the emissions associated with commuting: based on an internal survey conducted by Ricoh, quantitative data about commuting and the remote working time have been collected.

Table 1. Greenhouse gas (GHG) emission factors of Information and Communication Technologies (ICT) technologies, people, and freight transports.

Impact source	Value	Unit	Source
Internet usage	0.159	g CO2 eq/min	market for internet access, work, 0.2 Mbit/s {GLO} [16]
Phone call	0.100	g CO2 eq/min	[20]
Queries to an AI agent	0.600	g CO2 eq/query	[18,19]
Email (without attachment)	4.000	g CO2 eq/email	[20]
Car	357.44	g CO2 eq/person/km	market for transport, passenger car {RER} [16]
Electric car	359.62	g CO2 eq/person/km	transport, passenger car, electric {GLO} [16]
Electric scooter	230.81	g CO2 eq/person/km	transport, passenger, electric scooter {GLO} [16]
Motor scooter	53.70	g CO2 eq/person/km	market for transport, passenger, motor scooter {GLO} [16]
Bus	133.49	g CO2 eq/person/km	market for transport, regular bus {GLO}[16]
Bicycle	118.67	g CO2 eq/person/km	market for transport, passenger, bicycle {GLO}[16]
Walking	11.79	g CO2 eq/person/km	-
Lorry	0.149	g CO2 eq/kg/km	market for transport, freight, lorry, unspecified {RER} [16]

2.4. Identification of key assumptions

Several assumptions are necessary to convert the emission factors summarized in Table 1 into the overall GHG emissions associated with the maintenance service operations listed in Figure 2. For instance, the emissions of ticket creation with @remote and eService have been associated with internet usage. Therefore, since the corresponding emissions are referred to 1 minute of internet usage (i.e. the functional unit), the time needed to open a ticket has to be assumed and multiplied by the corresponding emission factor. Similar considerations apply for all operations in the two application areas, e.g. the duration of the phone calls during a ticket creation or a problem resolution, and the number of queries forwarded to AI while automatically validating a ticket or chatting with a virtual agent. A list of all the key assumptions is available in Table 2.

Table 2. List of the key assumptions in the “Consumables Management” and the “Fault and Incident Management” areas.

Assistance Operation	Impact source	Variables	Function	RICOH manual intervention
@remote	Internet	Ticket creation time	Ticket creation	No
eService	Internet + commuting	Time to create a ticket	Ticket creation	Yes
Phone	Phone call + commuting	Time to create a ticket	Ticket creation	Yes
Automatic validation	Queries to an AI agent	Number of queries	Ticket validation	No
Manual validation	Internet + commuting	Time for manual validation	Ticket validation	Yes
Toner shipped	Lorry	Distance, Mass of a toner	Resolution	No
Order cancelled	Internet + commuting	Time for order cancellation	Resolution	Yes
Chat/phone call with AI assistant	Queries to an AI agent + Phone call	Number of queries, Phone call duration	Assistance	No
Email/phone call with the Helpdesk	Phone call + Email + commuting	Phone call duration, Number of emails	Assistance	Yes
FSE remote assistance	Phone call	Phone call duration	Assistance	Yes
FSE onsite assistance	Car	Distance	Assistance	Yes
Order parts in advance	Lorry + Internet + emails + commuting Avoided the impact of previous operations	Distance, Mass of a toner, Time to order the parts, number of emails	Assistance	Yes

2.5. Creation of the Carbon Footprint calculator

The CF calculator is a tool that can be used by Ricoh managers to evaluate what scenarios are the most impacting in terms of GHG emissions depending on the request of the customer. Also, it allows to identify which maintenance operations are the most impacting, which is fundamental to support prioritization of decisions in terms of achieving the GHG reduction targets of the company, based on actual primary data. Therefore, the CF calculator is designed to be flexible enough to allow the users to play with the variables of the model and check how the results change accordingly. For instance, depending on the problem that must be solved, the duration of the phone calls or the number of emails exchanged between the customer and the maintenance service may be variable, as well as the distance that shall be covered by the FSE to reach a customer in an onsite visit. Table 2 collects the variables of the model for each operation service. As a demonstration, the next section will show the results that can be obtained by the calculator using some typical values for the variables in Table 2 that are not shown in this paper for confidentiality reasons.

3. Results and discussion

This section presents a demonstration of the results that can be assessed by the CF calculator; proposed scenarios are labeled with letters: Scenarios A-I for Consumables Management and J-AN for Fault and Incident Management.

3.1. Consumable Management

Figure 3 represents an exemplification of the GHG emissions that can be associated with the Consumable Management area. Due to confidentiality, these values are expressed in relative terms as the focus is to identify the gap between the different scenarios.

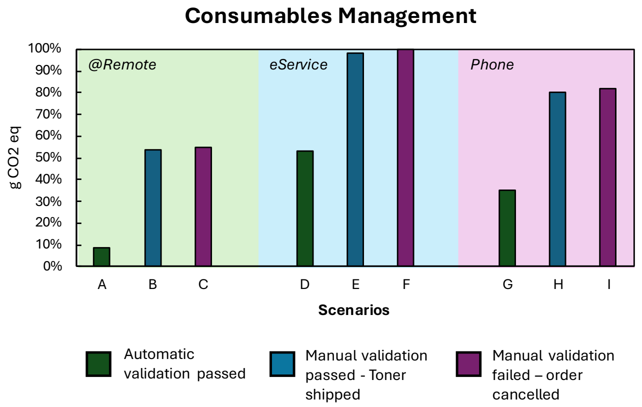

Fig. 3. Exemplification of the results obtained by the Carbon Footprint calculator for the Consumables Management scenarios.

The histograms represented in Figure 3 underline that among the ticket creation solutions, @Remote allows to cut the GHG emissions compared to other options. One reason is that @Remote (Scenarios A, B, and C) is less time-consuming than the other solutions and it does not imply any manual intervention. Indeed, when tickets are created via non automated procedures such as eService (Scenarios D, E, F) or Phone (Scenarios D, E, F), the GHG emissions associated with commuting are also accounted for, and they represent a major source of emissions compared to the ticket creation itself. Interestingly, in this case study, the creation of a ticket via phone results to be less impactful than the eService because a 1-minute phone call implies less emissions than 1 minute of internet usage (Table 1). Another observation from Figure 3 is that when manual validation is involved (Scenarios B, C, E, F, H, I) the GHG emissions remarkably increase compared to automated validation processes (Scenarios A, D, G). Specifically, the reduction in GHG emissions achieved through automatic validation ranges from 47% to 85%, depending on the ticket creation mode. Not surprisingly, the manual validation is more time-consuming. Furthermore, when manual validation fails some additional emissions occur due to order cancellation operations, that are online.

3.2. Fault and Incident Management

Concerning the Fault and Incident Management area, several scenarios are compared as illustrated in Figure 4. Although the large number of scenarios under consideration, Figure 4 highlights that three clusters can be identified; these clusters depend on the number of onsite visits of the FSE.

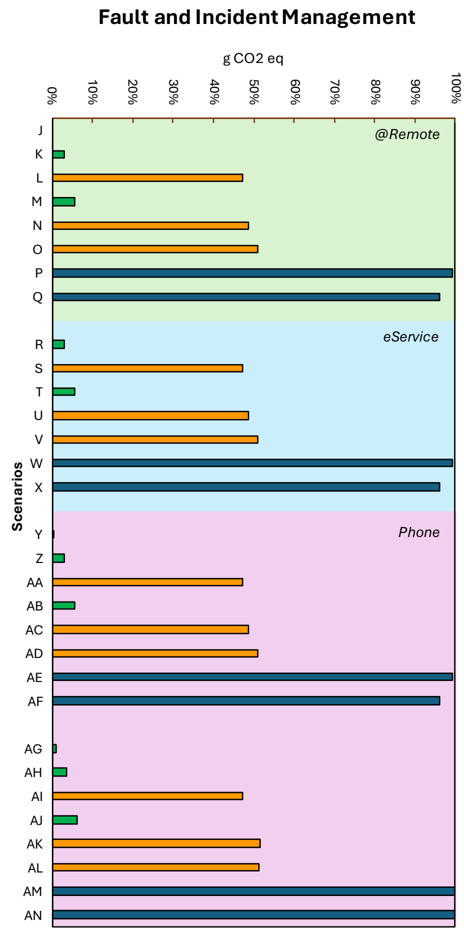

Fig. 4. Exemplification of the results obtained by the Carbon Footprint calculator for the Fault and Incident Management scenarios

In case the FSE visits the customer twice (columns in red), the GHG emissions turn out to be the highest. Differently, in those scenarios where only one onsite visit is necessary (in orange), we observe a reduction on average of 50% of the GHG impact. The third cluster gathers the scenarios that do not imply any onsite visit, and all issues are resolved fully remotely (in green). Under these conditions, the impacts of the maintenance service are negligible, showing percentage reductions of up to 97% compared to other scenarios, as highlighted by the histograms in Figure 4. Therefore, the number of onsite visits represents by far the most influencing factor in the Fault and Incident Management application area. When onsite visits are present, the way tickets are created (with @Remote, eService, Phone) and the way faults are resolved remotely (AI, phone calls, emails) has a lower relevance. Moreover, from Figure 3 and Figure 4, it is possible to observe that the resolution of faults and incidents, even when managed remotely, is more impactful than Consumable Management issues. The latter implies the acquisition and validation of a request for component replacement, while the former can determine some complex interactions between the maintenance service and the customer. Also, the environmental benefits of ordering parts in advance turn out to be quite limited.

5. Conclusions

Here we presented the development of a CF calculator that aims to evaluate the GHG emissions associated with Ricoh maintenance services management. The development of the calculator has been performed in collaboration with Ricoh who supported the project with extensive data and information. Two application areas were identified: i) Consumable Management, and ii) Fault and Incident Management. LCA was used as a reference methodology for the development of the tool that follows a 5 steps approach. The CF calculator models several maintenance service scenarios to calculate their life cycle GHG emissions; scenarios are created grounding on the combination of different assistance operations. The model has been designed to be flexible as the user can play with the variables to assess the variations of the results. These variables are related to the duration of phone calls and the internet usage time, as well as the number of emails or queries exchanged between the customer and a virtual or physical assistant. The results show that the automation and the remote resolution of issues are key strategies to mitigate the GHG emissions associated with assistance services. In particular, preventing travel from home to office is important to reduce the emissions in Consumables Management areas, and avoiding onsite visits is strategic for the Fault and Incident management area. These results are reinforcing the need for dematerialization of services, which has been observed in other fields, and is consistent with Ricoh's decarbonization strategy which is oriented to enforce process automation and remote working. Since the digitalization of maintenance services has proven to lead to a reduction of potential impacts on climate change, it is therefore recommended as a business practice in the printing sector.

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