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Exploring the Environmental Impact of Telemedicine: A Life Cycle Assessment

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Abstract. Background: Telemedicine has emerged as a potential solution to mitigate the significant greenhouse gas emissions of the healthcare sector. A comprehensive evaluation is required to quantify the environmental benefits of its implementation. Objectives: The study aims to compare the environmental sustainability of in-person and virtual examinations for heart failure patients. Methods: A standard life cycle assessment has been applied to quantify the equivalent CO_2 of direct and indirect activities required to release a medical examination (virtual or physical) for a patient in an Italian hospital. Inputs of the analysis include electronic devices of hospital and patients, energy consumption, wastes, internet usage and patient travel. Depending on the type of visit (virtual or physical), inputs have been processed differently, considering actual consumption and utilization. Results: Televisit reduces emissions from 9.77 $kgCO_2e$ to 0.41 $kgCO_2e$. Transport and internet data use are key inputs for in-person (i.e., 98%) and telemedicine visits (i.e., 72%), respectively. Discussion: Given the frequent car travels, telemedicine emerges as a tool to improve environmental benefits and reduce time for patients and caregivers.

Keywords. telemedicine, life cycle, carbon footprint, environmental impact, sustainable development

1. Introduction

The increasing negative impacts of climate change on human health requires more efforts to mitigate emissions and alleviate the overall environmental burden [1]. The healthcare sector, while crucial for addressing patient needs. It participates significantly to environmental impact, becoming one of the largest contributions to greenhouse gas (GHG) emissions [2]. Chronic patients care is responsible of a significant amount of healthcare carbon footprint, due to the release of long-term assistance, repetitive follow-up examination and monitoring devices [3]. Specifically, cardiovascular and heart failure (HF) chronic diseases affect millions of people worldwide [4], representing a significant aspect of this burden.

Several research studies have highlighted telemedicine as a potentially effective solution to mitigate the environmental impact of healthcare, aiming to balance emissions without compromising the quality of care [5][6]. Telemedicine techniques have found extensive application in chronic patients' management, allowing also the reduction of the travel to hospitals. Following the increase adoption of these promising technologies,

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it is crucial to quantify overall environmental impacts generated by their use. Hence, standardized, and quantitative methods should be developed and applied to evaluate impacts across the life cycle [7]. Several studies have investigated travel reductions, focusing on its associated aspects [8] (e.g., distance avoided, transportation mode, time, and cost savings, ...). However, these analyses are often confined to direct environmental impacts of telemedicine processes. Recently, a few articles have applied life cycle assessment (LCA) to analyze environmental sustainability of remote care. LCA has been developed in the industrial field for the evaluation of all life cycle phases of product and processes. It includes materials extraction, production of disposable and reusable equipment, transportation, utilization of products and materials, energy consumption, and disposal [9]. Previous evaluations have considered only activities performed during the time of a televisit [10]. A comprehensive analysis should include also indirect activities, required to perform the medical examination.

Hence, the present study aims to conduct a comprehensive LCA of virtual and in-person visits, encompassing the entire phases of the care process. The methodology is applied to a real case, involving chronic patients from the HF clinic of an Italian hospital. This care provider has begun trials of televist to manage the critical phase of the Covid-19. Remote and face-to-face processes are compared basing on GHGs emissions, for quantifying the environmental sustainability of remote care.

2. Methods

A standard life cycle assessment has been applied to evaluate the sustainability of a care process for chronic HF patients, comparing traditional in-person follow-up examinations to virtual examinations. Steps have been derived from ISO 14040/14044 (ISO (International Organization for Standardization), 2006a/2006b)) [11][12]. The approach has been applied to evaluate follow-ups appointments, that do not require the employment of additional specific medical devices.

2.1. Goal and scope definition

The analysis aims to quantify the amount of equivalent CO_2 (CO_2e) associated to the activities required to deliver virtual and in-person follow-up examination. The functional unit has been defined as a complete process to perform a medical examination (virtual or physical) for a single HF patient. As both care processes serve the same function (i.e., refer patient's clinical conditions), a comparative analysis between the two modalities can be conducted. Information has been acquired during previous research [13] and include both the activities carried out during the medical examination and the ones required to engage patients and assess the quality of service. Figure 1 shows inputs included in system boundaries and their contribution for the phases of the care process. The impact of devices, wastes and transportation and Italian electricity mix came from primary data. Secondary data have been used to get energy consumption [14] and network data usage. For the latter, a minimum network bandwidth for various operations has been approximated, considering a data rate of 0.015 kWh/GB. Each visit lasted an average of 15 minutes. For patients connected via televisit, only laptop use has been included. Conversely, for patients attending in-person visits, an average round trip travel of 30 km has been considered. Given the mountainous region and the limited public transportation service, only travel by private car has been calculated. For these types of visits, protective personal equipment has not been used. Heating and lighting in rooms have omitted in the analysis, as they have been deemed non-discriminatory factors.

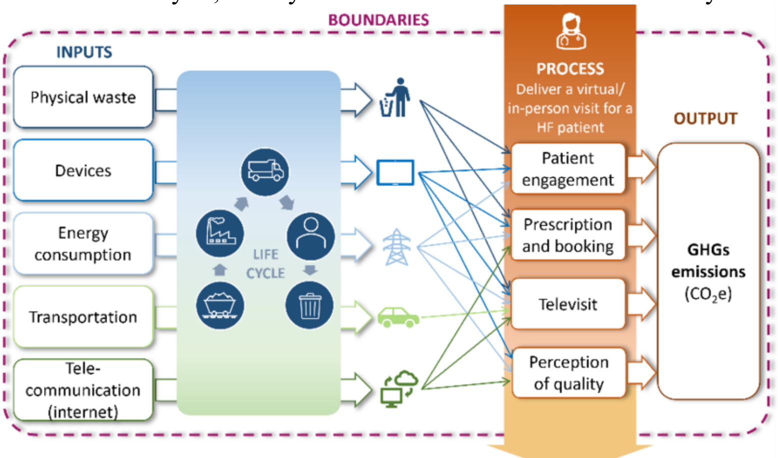

Figure 1. System boundaries and inputs flows for calculating GHGs outputs.

2.2. Life cycle inventory

Inventory has been defined acquiring real data, thanks to the collaboration between the hospital and the university. When information was not available, secondary data has been extrapolated from scientific literature [14]. Inventory has been imported in FootprintCalc [15], a free footprint calculator, used to evaluate the environmental impact during the function life cycle. EcoInvent V3.8 database [16] has been used for transportation assessment. In addition, impacts of internet network usage has been manually included.

2.3. Calculation of emissions

The amount of CO_2e has been computing for the functional unit by summing the impacts of inputs included in Table 1. The same inputs, necessary to release the patient medical examination, have been considered in both cases, to carry out the comparison. Depending on the mode of service release (in-person or virtual), the inputs have been processed differently, considering actual consumption and utilization.

The calculation of device usage has been performed using the following formula:

$$\frac{CF \times time\ of\ use}{life\ span} \tag{1}$$

In formula (1), CF identifies the kilograms of CO_2e of the entire life cycle, calculated by means of the FootprintCalc database [15]. The amount of paper sheets and hand sanitizer used have been extrapolated from the process. The energy consumption of devices has been determined based on the Italian electricity mix. Using emission factor electricity, kilograms of CO2e per kWh were derived. Transportation emissions have been calculated considering an average Euro 5 car in EcoInvent V3.8 [16]. Finally, network data usage has been quantified as defined by Sillcox et al. [9], summing internet usage and server utilization, according to the following formulas:

$$Interet\ usage = E \times I \times D \times t \times \frac{3600}{800} \quad (2)$$

$$Server\ usage = E \times W \times t \quad (3)$$

In formula (2) and (3), E represents the amount of GHGs per kWh (0.31 $kgCO_2e/kWh$), calculated using the Italian electricity mix. I is the energy density of the internet (0.015 kWh/GB), D is the internet data transfer rate (Mbps), and W is the wattage of the server (0.6 kWh/server [9]).

Table 1. Life cycle inventory related to the defined functional unit (F.u.).

Inputs		**F.u. (Televisit process)**	**F.u. (In-person process)**
Devices	1 desktop (hospital)	42 min	20 min
	1 laptop (patient)	27 min	5 min
	1 webcam/microphone/ sound system	15 min	0 min
	2 local network area	69 min	25 min
	2 telephones	0 min	16 min
Physical wastes	Paper sheets, FSC 80 gr/m2	0.75 m2	0.88 m2
	Hand sanitizer (benzyl alcohol)	0 kg	0.003 kg
Transportation	Car travel	0 km	30km
Energy consumption	Desktop	0.105 kWh	0.05
	Laptop	0.018 kWh	0.003 kWh
	LAN	0.023 kWh	0.008 kWh
	Webcam	0.0024 kWh	0 kWh
	Sound system	0.001 kWh	0 kWh
	Microphone	0.0006 kWh	0 kWh
	Telephone	0 kWh	0.0011 kWh
	Printing process	0.75 m^2	0.88 m^2
Network data usage	Webpage/applications	35 min (5.5 Mbps)	17 min (5.5 Mbps)
	Upload/download	430 KB	90 KB
	Email/fax sending	4 units	2 units
	Videocall (2 participants)	15 min (13.6 Mbps)	0 min

3. Results

The quantity of CO_2e generated during the telemedicine process has been resulted significantly lower compared to that produced in a traditional in-person visit scenario, decreasing from 9.77 $kgCO_2e$ to only 0.41 $kgCO_2e$ (Figure 2a).

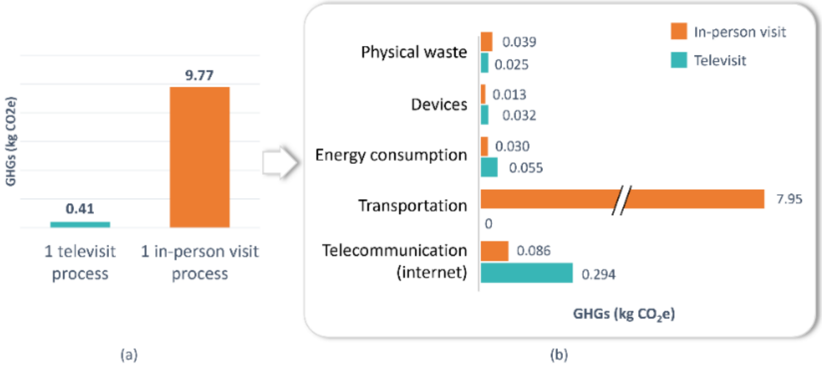

Figure 2. Total GHGs emissions related to the life cycle of a process to deliver in-person and virtual visit.

The primary sources of GHGs emissions of televisit process (Figure 2b) have been identified in the use of internet data (i.e., 72%) and the consumed energy (i.e., 14%). Minor contributions have involved the use of paper materials (i.e., 6%) and the life cycle of the devices (i.e., 8%). During the in-person visit process, emissions have been mainly associated with travel of patients to the hospital (i.e., 98%). A modest contribution came from the use of internet data (i.e., 1%), paper waste and hand sanitizing gel (i.e., 0.4%), and the energy consumption due to device usage (i.e., 0.4%). The impact of the life cycle of the devices can be considered negligible, given the short duration of their use.

4. Discussion

Comparing a single visit for HF patients, telemedicine results in a drastic reduction of over 95% in CO_2e emissions compared to traditional in-person appointments. The findings highlight a significant environmental benefit resulting from the reduction of car travels. In the literature, few studies have adopted an LCA approach, allowing for a standardized and comprehensive assessment. Among these, transportation has emerged as the most critical aspect [17][7]. In the considered province of Bergamo, patient transportation emerges as a critical issue. The hospital's location outside the city extends public travel times, often necessitating the change of different public transportations. For this reason, patients often choose to use private cars, increasing related emissions. A deeper evaluation, including hybrid/electric vehicles, could offer more insights. Despite the analyzed limited distance, telemedicine shows benefits not only in terms of environmental sustainability but also in saving time for both patients and caregivers. Indeed, considering the traffic conditions in the area, Google Maps estimates approximately 50 minutes by car to cover that distance. Additionally, patients must spend time for searching parking and arriving ahead of the appointment. Thus, the adoption of telemedicine can also be seen as an improvement in social impact. Reached benefits could be especially relevant for patients with chronic conditions, requiring long-term assistance and periodic follow-up analyses.

Despite often being overlooked, telecommunication internet usage emerged as the most impactful component within the telemedicine process (i.e., 72%), due to both televisit delivery and management activities. GHGs missions of internet usage almost doubled from in-person (i.e., 0.098 kgCO_2e) to virtual examination (i.e., 0.295 kgCO_2e). While the impact generated by internet use is considerably lower than that emitted by patient transportation, an efficient management of digital activities can further contribute to emissions reduction. In real practices, the elimination of valueless information can minimize environmental costs. Conversely, the transitioning to energy-efficient devices presents a promising prospect for significantly enhancing overall impact [18]. However, despite the reachable benefits, it is essential to define the appropriateness of televisit, which lacks the specific instrumentation available in a hospital setting [19].

In conclusion, given the considerable adoption of televisit and remote care activities, the ability to objectively quantify impacts becomes fundamental to move beyond theoretical discussions and provide actionable insights. In contrast with the most employed approaches, this research considers all stages of inputs life cycle, from material extraction to waste management. Furthermore, a novel perspective has been defined by analyzing both direct and supporting activities, required for the visit execution. Sensitivity and data quality analyses will be investigated at later and more articulated stage, overcoming the limitations of the present study. Future work will extend the evaluation to other environmental indicators and incorporate the social aspect, as essential issued to move towards a sustainable development framework.

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