



Environmental and social impacts of a televisit process: Combined qualitative and life cycle assessment

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ABSTRACT

The healthcare sector is a significant contributor to global greenhouse gas emissions, largely due to resource-intensive care processes. Telemedicine represents an innovative solution for managing chronic patients, with the potential to reduce environmental impacts and improve healthcare accessibility. However, current literature lacks a standardized approach to comprehensively assess the environmental and social effects of such practices. The study aims to overcome current limitations evaluating the environmental and social impacts of televisits as an alternative to traditional in-person follow-up visits for chronic heart failure (HF) patients in a large Italian hospital. The Life Cycle Assessment (LCA) steps ensure an objective and standardized environmental evaluation. Data on social and human-related aspects for preliminary mapping of social impacts has been acquired by means structured interviews. Environmental LCA using the ReCiPe 2016 method quantifies the environmental impacts of one in-person or remote visit process for a one patient, including direct and indirect emissions from transportation, energy use, paper materials and telecommunications. Internal hospital stakeholders were involved in defining aspects of interest for initial mapping of social impacts. Results demonstrate that televisits significantly reduce environmental impacts, particularly in relation to patient transportation. On the social side, stakeholders reported benefits in terms of patient's experience, care continuity, and improvement of clinical workflows. The study emphasizes the necessity of establishing continuous impact monitoring systems to ensure long-term sustainability and efficiency. By demonstrating the environmental benefits and social acceptability of televisits, this research contributes to the development of evidence-based strategies that can enhance both patient care and sustainability in the healthcare sector.

1. Introduction

The healthcare sector is responsible for a significant environmental impact, contributing to greenhouse gas (GHG) emissions, waste generation, and pollution. According to the 2022 Lancet Countdown report, healthcare related emissions have increased to 2.7 Gt CO₂ equivalent (CO₂e), accounted for 5.2 % of global emissions (Sijm-Eeken et al., 2023). The GHG Protocol declares that the main sources of environmental impacts can be related to direct emissions owned or controlled by healthcare providers (i.e., on-site energy use, heating, anesthetic gases, and transport) or indirect emissions from the energy used by health systems and from the supply chain (Greenhouse Gas Protocol, 2025). Hospitals have been identified as one of the most energy-intensive and wasteful facilities. Specifically, hospitals are consistently 2–3 times more energy-intensive than other commercial and industrial buildings due to their continuous operation, stringent heating,

ventilation, and air conditioning (HVAC) requirements [<https://doi.org/10.3390/en12193775>]. The estimation of impacts accounts for 36 % of all healthcare-related GHG emissions in the USA and 44 % in Australia (Or and Seppänen, 2024). The contribution includes for example diagnosis and treatment, medical equipment, food services, transportation, construction and maintenance of the buildings (Or and Seppänen, 2024).

Given the growing environmental impacts associated with the healthcare sector, there is a critical need for robust methodologies to objectively quantify these effects. Accurate and reproducible approaches are essential to measure emissions, resource consumption, and waste generation in healthcare settings. Such methodologies should be comprehensive, allowing for consistent monitoring and comparison across different institutions and regions. This urgent need is also highlighted by the 2030 Agenda, which establishes a deep connection between healthcare and environmental sustainability, acknowledging that

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human health is intrinsically linked to the health of the planet (Transforming Our World, 2025). This interconnection is supported by the Sustainable Development Goals (SDGs), as defined in Goal 3 (i.e., human health and well-being) and Goals 6, 13, 14, and 15, focused respectively on clean water and sanitation, climate action, life below water, and life on land. Furthermore, environmental effects are drivers of environmental changes and climate impacts, which, in turn, affect human health and well-being, leading to broader social consequences (Rocha et al., 2022; Rocque et al., 2021). As a result, the healthcare sector, whose primary objective is to safeguard human health, must consider both the environmental and social impacts of its activities. In line with the goals of the 2030 Agenda, integrating social impact assessment into sustainability evaluations plays a key role in achieving comprehensive and effective analysis. Therefore, a systematic approach that considers both environmental and social dimensions is crucial to effectively pursue these objectives and promote sustainable development (Padilla-Rivera et al., 2020).

The effort in the management of chronic conditions has become increasingly significant in recent years (Ferrara et al., 2022). The growing incidence of the population affected by chronic diseases is responsible for continuous care demands from healthcare facilities. Chronic patients often require long-term assistance, leading to frequent medical examinations, increased workload, and significant patient mobility to care centers. The high use of resources required to manage chronic patients is responsible for a high number of emissions (Richie, 2021). Therefore, chronic care can exert additional pressures on both the healthcare system and the environment. For this reason, evaluation of the impacts generated is crucial to be able to discuss and improve chronic patient management pathways.

While the healthcare sector presents distinct challenges, such as the management of hospital waste, there are several strategies that can be implemented to address its substantial environmental impact. The literature identifies key opportunities that are currently being explored, including the enhancement of energy efficiency through the construction of new, more sustainable facilities and the increased adoption of renewable energy sources. Additionally, improving waste management practices, particularly through the recycling of non-hazardous waste, represents a critical approach to mitigating the sector's ecological footprint. (Rasheed et al., 2021; Rabin et al., 2024). Among these alternatives, telemedicine has emerged as a possibility to mitigate the carbon footprint of the healthcare sector while ensuring care continuity (Rodler et al., 2023). Specifically, telemedicine includes all medical and health care activities that enable the provision and support of care at a distance through information and communication technologies (ICT) (Telemedicine: A Guide to Assessing Telecommunications in Health Care, 2025; Tozour et al., 2021). Telemedicine includes a broader range of activities (Haleem et al., 2021); televisits emerged in the literature as the most widely adopted (Kruse and Heinemann, 2022). Indeed, the delivery of remote follow-ups improved the accessibility to outpatient services by reducing the frequent travel and shortening long waiting lists, particularly for patients requiring routine and quick check-ups (Anawade et al., 2024).

Currently, telemedicine is widely employed for the management of chronic patients, involving a close monitoring and a fast communication among healthcare providers and patients (Ma et al., 2022; Williams and Shang, 2024; Savoldelli et al., 2024a; Sten-Gahmberg et al., 2024). In literature, telemedicine has demonstrated several benefits. As presented in the systematic review by Nguyen et al. (Nguyen et al., 2021), televisits show comparable outcomes to in-person visits in terms of clinical results, healthcare quality, access, utilization, and costs. Additionally, remote care can reduce environmental impacts by minimizing travel, lowering energy consumption in healthcare facilities, and decreasing waste generation associated with in-person visits (Rabin et al., 2024). Given the diffusion and resource consumption related to telemedicine activities, it becomes increasingly crucial the implementation of methodologies for evaluating the impacts generated. For this reason, the

present study aims to integrate the measurement of care activities' ecological effects to reduce the environmental impacts, while analyzing the quality and effectiveness of patient treatment.

2. Scientific background

Given the urgent need for action in limiting the environmental impacts of the health sector, several studies in literature have investigated the effects related to the adoption of telemedicine in care pathways.

The authors have previously reviewed the literature, analyzing 91 articles from a pool of 477 and focusing primarily on the environmental, social, and economic impacts of telemedicine, with emphasis on how these impacts are assessed (Savoldelli et al., 2024b). While studies agree on the environmental benefits, the quantification of these impacts varies considerably due to different methodologies and healthcare delivery models used. The social impacts assessed predominantly include patient experience and time saved in traveling. However, there's a noted lack of comprehensive consideration for other stakeholders, such as caregivers. Economic assessments largely focused on travel cost savings and productivity losses related to in-person consultations. Despite numerous studies, literature lacks a standardized methodology for a comprehensive sustainability assessment. Most evaluations are fragmented and often concentrate on transport-related factors, leaving out broader life-cycle considerations and stakeholder involvement.

Other recent studies have broadened their analyses, in order to include additional aspects, such as energy consumption and the use of digital devices (Morcillo Serra et al., 2022; Cockrell et al., 2022; García-Berná et al., 2021). The most followed approach aims to quantify environmental impacts by converting resource consumption into CO₂e, using dedicated databases and formulas. Despite the growing interest, fragmented evaluations still indicate a lack of standardization and reproducibility in the telemedicine context.

The application of a standard methodologies, such as the life cycle assessment (LCA) allows for objective and comparable results by applying a standardized set of indicators (Roesch et al., 2020). While LCA is increasingly employed in healthcare, particularly for analyzing and comparing clinical tools and devices (Drew et al., 2022; Savoldelli et al., 2023), its application in telemedicine is still in its early stages. Keller R.L. et al. (Keller et al., 2021) have applied LCA to determine which area of a hospital contribute most to the environmental impact. In other cases, as in the research of Hernández-de-Anda M. T. et al. (Hernández-de-Anda et al., 2023), this standard methodology has been applied to estimate the impacts of specific care processes or hospital clinics. Studies of Sillcox et al. (Sillcox et al., 2023) and Thiel C. L. et al. (Thiel et al., 2023) have performed the analysis of televisits in one or more clinics. In these cases, the input included refers to the activities performed during the visit. Other indirect activities such as patients' data input, appointments scheduling, payment services are missing. However, all these direct and indirect activities are part of the process followed to release the medical examination to the patient. Therefore, a comprehensive impacts analysis should consider a broader process.

To improve efficacy, especially in the health sector, environmental assessment must be complemented with an analysis of social impacts. LCA traditionally investigates the environmental impacts like carbon emissions, energy use, resource depletion, water use, and toxicity (Ciacci and Passarini, 2020). While LCA allows for a deep and objective quantification of environmental impacts, it overlooks the other sustainability pillars. This can lead to an incomplete understanding of the overall sustainability of a product or process (Dong et al., 2018). Despite the social impacts are crucial for the healthcare sector, they are generally not addressed by traditional LCA. Therefore, to get a full picture of sustainability, LCA needs to be combined with other assessments, such as Social Life Cycle Assessment (S-LCA) for social impacts.

Telemedicine could improve access to care, enhance patients' management and increase cost-effectiveness (Priescu and Oncioiu, 2022). However, the current literature offers a fragmented and limited

assessment of the social implications of telemedicine on other stakeholders (Savoldelli et al., 2024b). For this reason, in order to provide a better interpretation of the results and to understand the actual benefits generated by the introduction of telemedicine activities, environmental LCA analysis should be complemented with a social assessment.

According to defined context, the research aims to perform a complete evaluation of follow-up examinations, investigating the environmental categories by applying a LCA evaluation. Specifically, the study quantifies the environmental effects related to televisit and in-person visits for chronic heart failure (HF) patients. The analysis includes all activities of the process required to release the medical examination in a large Italian hospital. Therefore, a preliminary qualitative social analysis is performed.

In the following section, the article introduces the main phase of the methodology followed to combine social and LCA analysis. Application to a case study is presented. Environmental and social results are shown and discussed. Finally, conclusions are drawn.

3. Methodology

3.1. Combined social and life cycle assessment

The methodology has been subdivided in two steps, as shown in Fig. 1. The first part of the methodology follows the steps of the life cycle assessment (LCA), in line with the ISO14040-14044 (International Organization for Standardization, 2006a/2006b) guidelines (ISO (International Organization for Standardization), 2006a; ISO (International Organization for Standardization), 2006b): i) goal and scope definition, ii) life cycle inventory, iii) life cycle impact assessment, iv) results interpretation. In this first analysis, characterization factors at midpoints

and endpoints are used to estimate the environmental indicators. As second step, LCA has been integrated with a first qualitative analysis of social implications of telemedicine. A series of interviews have been prepared and submitted to each stakeholder involved in the televisit process. The approach aims to go beyond the patient-centered perspective, which is the most commonly analyzed in literature, by providing a broader and more systemic view of the social impacts of telemedicine. Therefore, environmental assessment is preliminary integrated with a social perspective to provide a more comprehensive evaluation of the overall impact of the process under study. (See Fig. 2.) (See Table 1.)

The methodology has been applied to the Italian hospital the ASST Bergamo Est, which has been actively involved in telemedicine trials since before the COVID-19 pandemic. Specifically, an analysis of the process of in-person visits and televisits at the HF clinic has been conducted.

3.2. Follow-up examination for HF patients

Heart failure (HF) is a condition that develops when the heart is unable to pump enough blood to meet the body's needs (Castiglione et al., 2022). Due to its high global prevalence, HF is a growing contributor to reduced quality of life for patients and increasing hospitalization and care costs (Lee et al., 2023). Despite significant advances in HF treatment in recent years, thanks to the introduction of new drugs and devices, mortality remains a critical issue (Spitaleri et al., 2021; McDonagh et al., 2021). Since early detectable physiological measurement changes may occur before the onset of symptoms, timely detection of an impending crisis is crucial to prevent hospitalizations and premature deaths.

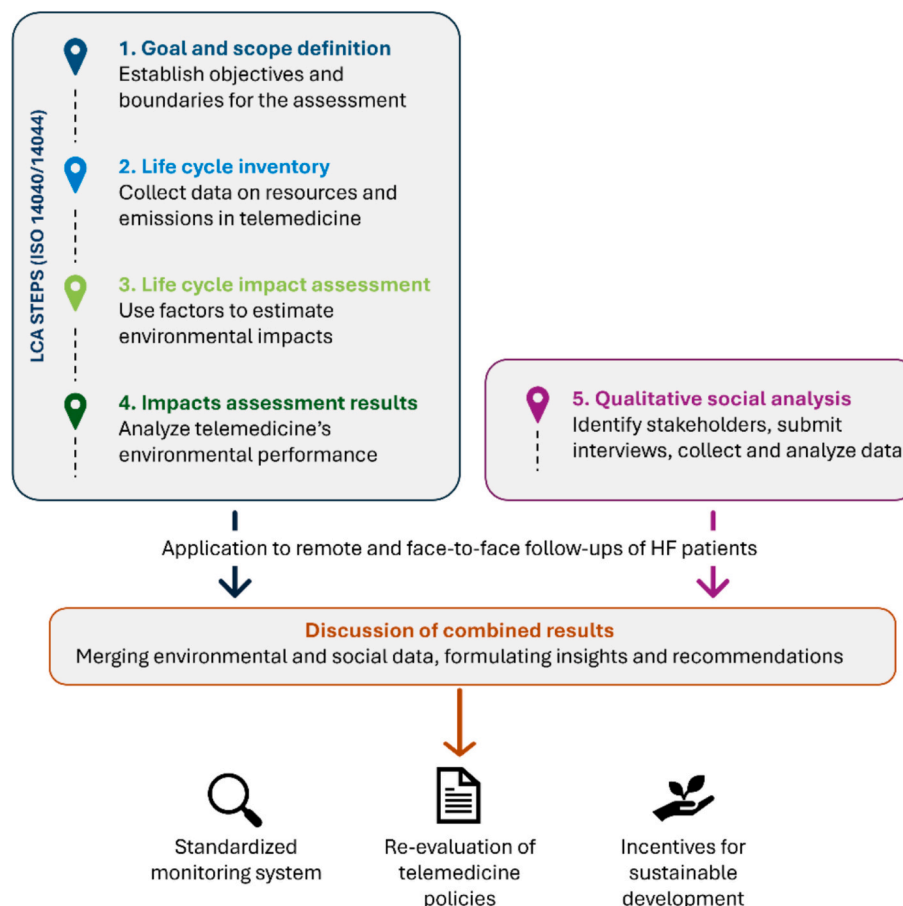


Fig. 1. Main steps of the proposed methodology to evaluate environmental and social impacts of telemedicine follow-ups.

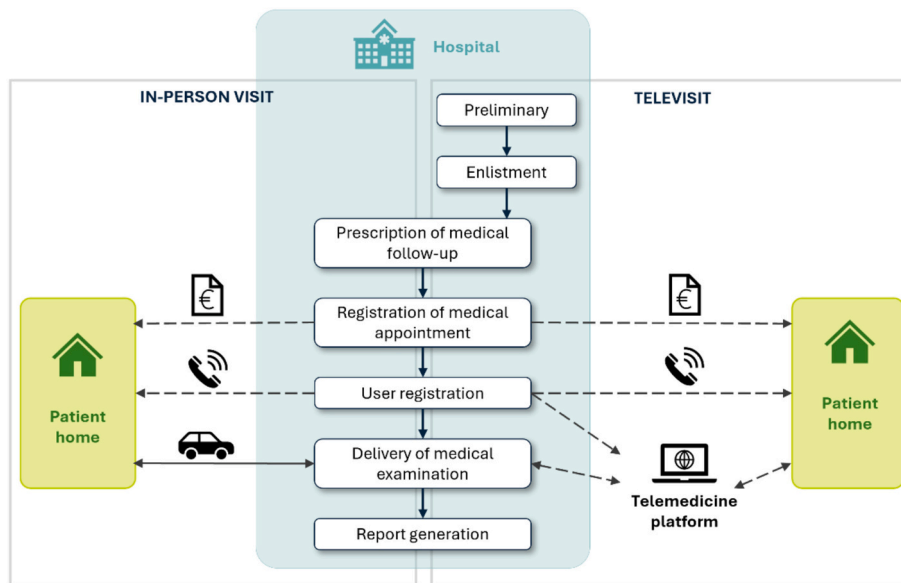


Fig. 2. Outline of visit and televisit process for HF patients.

Table 1
Comparative life cycle inventory of telemedicine vs in-person follow-up examinations for HF patients.

Input	Quantity		Unit
	Televisit	In-person visit	
Office paper, 80 g/m2	6,00E-02	2,00E-02	kg
Toner laser printer	2,40E-04	8,00E-05	kg
Electricity to print	1,20E-02	5,81E-03	kWh
Electricity router standby mode	1,16E-02	5,98E-03	kWh
Use of desktop (electricity and materials)	1,01E+00	8,93E-01	hr
Use of laptop (electricity and materials)	2,00E-01	0	hr
Internet access (electricity and materials)	8,59E-01	7,76E-01	hr
Internet access – videoconference (electricity and materials)	2,34E-01	0	hr
Electricity for document upload/download	2,21E-04	9,45E-05	kWh
Electricity phone call	4,00E-04	4,00E-04	kWh
Car transport	0	30	km

Medical follow-ups are essential for chronic HF patients, who can remain in a stable phase for extended periods, ranging from a few months to several years (Savoldelli et al., 2024a). During the stability period, patients undergo therapy, have periodic blood tests, and consult with nurses and physicians regarding their health status. In follow-up activities, the patient or caregiver can interact directly with the specialist. These interactions are particularly useful for adjusting medication dosages or developing new treatment plans. Additionally, doctors can review blood test results and discuss any changes in health indicators. A lack of continuous and effective monitoring can lead to a deterioration in the patient’s condition, resulting in an increased risk of acute events and hospitalization (Sapna et al., 2023). In this context, the use of technology and the integration of telemedicine activities have proven effective in better managing complex patients, allowing for tracking disease progression and enhancing patient engagement.

The HF clinic considered in this study is a secondary care facility; patients are initially referred to other clinics or by their primary care physicians. After the initial in-person visit to assess their clinical condition, patients are taken under the clinic’s care, which will monitor them on a cyclical basis going forward. As chronic patients requiring repeated visits, those included in the study have direct access to appointments, facilitated by a referral issued during the previous visit, and do not need to contact their primary care physician to schedule follow-

up appointments.

During follow-ups communication between patients and clinicians occurs synchronously, through verbal exchanges and document sharing. The patient is not physically examined by the doctor, and no specific medical equipment is used. Therefore, since the follow-up does not require physical contact between the doctor and the patient, the process can be carried out through both traditional in-person visits and televisits.

Excluding the first assessment visit, that requires additional specific tests and evaluations, the process for both in-person and remote visits for HF patients involves seven distinct phases (Fig. 1):

- Preliminary phase: following a doctor’s request, meetings with telemedicine staff are conducted to define activities and train medical personnel. Concurrently, a request is made to open the televisit schedule. This phase is present only for the televisit process.
- Patient enlistment: after an in-person visit, the doctor suggests remote follow-up appointments. If the patient agrees, they must sign a consent and privacy form. Also in this case, the enlistment is present only in the televisit process.
- Prescription of medical appointment: the specialist prescribes the examination (physical or virtual) using an application, generating a prescription which is either printed or emailed to the administrative staff.
- Registration of medical appointment: this involves scheduling the appointment. For non-exempt patients, a payment bill is generated at the time of scheduling of the examination.
- User registration: if eligible, the patient is registered on the telemedicine platform, and the televisit is scheduled. Otherwise, traditional in-person examinations are scheduled on the agenda. Patients are then contacted by phone and updated about the appointment.
- Delivery of medical appointment: the examination is performed. In the case of televisit, the doctor and patient connect via video call, and relevant medical documents are attached to the platform.
- Report generation: after the visit or the televisit, the cardiologist writes the report in the application, uploads it as an attachment on the platform, and it is automatically integrated into the regional health system.

4. Case study

4.1. Goal and scope definition

Because of the ecological burden of the management of HF disease, the primary objective of the analysis is to quantify the environmental effects generated by a complete follow-up process for an HF patient. According to what is presented in the previous section (Fig. 1), the main function of the considered process is the exchange of medical information between the patient and cardiologist. The procedure also includes activities to support the medical examination, offering a more realistic evaluation of the patient's journey in receiving the service. Since direct contact between the participants of the visit is not mandatory to fulfill this function, a comparative analysis can be conducted. The functional unit is defined as the set of activities performed by hospital staff and the patient to complete one visit (either physical or remote) for a HF patient in the province of Bergamo, located in the north of Italy.

Fig. 3 depicts the input flows considered and the boundaries of the system under analysis. Starting from data of a previous research (Savoldelli et al., 2024c), this study focuses on a cradle-to-use analysis, ending at the usage phase. The production of ICT equipment, such as computers and tablets, has been included despite their environmental impact being very low compared to other impacts. The study has considered the network infrastructure and data centers, focusing on the energy consumption and environmental impact of servers, routers, and internet network. The utilization phase has included the energy consumption of devices used by patients, physicians, and servers, as well as the duration of video consultations and data transfer processes, which influence overall energy demand. The study also accounts for the impacts of avoided car trips for medical consultations. On the other hand, end-of-life phase and disposal of electronic equipment have been excluded, such as WEEE management, recycling, and disposal, as well as the environmental impact of constructing medical facilities.

For each phase of the visit and televisit protocol, the input flow necessary to fulfill the system's function has been identified. Emission sources have been investigated, considering direct and indirect activities of the process. Emissions of the equipment needed to provide paper materials have included raw materials, production, and transportation.

Disposal has not been considered, assuming that all paper is collected and recycled, as performed in other similar studies (Kwon et al., 2024). The analysis considered the electricity purchased and consumed for the electronic devices' activity. Additionally, emissions related to the production and distribution of electronic devices have been also included. Similarly, for telecommunication services, the analysis involves indirect emissions linked to the electricity consumed by hospital systems (such as servers, routers, and communication devices) as well as emissions associated with the production and maintenance of the infrastructures. Notably, the end-of-life phase of electronic devices, such as computers and printers, has been neglected, due to their limited use during the functional unit of the study compared to their average lifespan as reported by manufacturers (Arushanyan et al., 2014). Finally, patient transportation via private car to reach the hospital has been included in the analysis, as it represents indirect emissions closely tied to the system's functionality.

Meetings with the telemedicine team of the hospital have been crucial for the data collection process. Specifically, the telemedicine team is a multidisciplinary group composed of doctors, healthcare workers, administrative staff, and an engineer who manages the technical aspects. When data could not be directly extracted from the documentation of the follow-up process, average values have been utilized and compared with those available in the literature. All decisions have been made by discussing with the hospital staff, who are knowledgeable and directly involved in the relevant issues.

4.2. Life cycle inventory analysis

For each sub-function of the process, the flows required to fulfill the specified function have been analyzed. To conduct comparative analysis, the collected information has been employed for the definition of the inventory, which was divided into two scenarios: the first related to the televisit process and the second to the traditional in-person visit process.

Within the category of printed materials, paper sheets and ink used to print the documents for each activity have been included. The number of A4 paper sheets has been determined by analyzing process data. An average value of 0.02 g of toner per sheet printed with a laser printer was

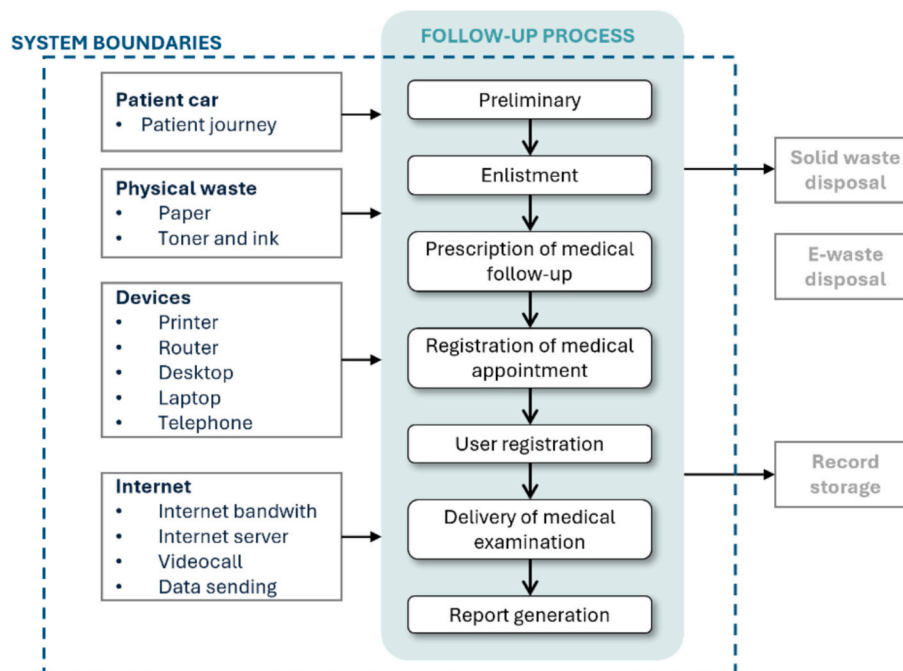


Fig. 3. System boundaries and input flow.

considered, based on a 5 % coverage (ISO/IEC 19752, 2004). Five different types of devices have been included in the inventory: printer, hospital desktop computer, patient laptop, router, and telephone. For the printer, only the energy consumption related to the active printing phase and the “ready to print” mode has been considered. For the desktop computer and laptop, both energy consumption and product materials have been included. For the router, energy consumption in both standby and active phases for internet browsing, including video-conferencing, has been considered, along with the device materials. Average usage times have been calculated by analyzing process data, considering an average televisit duration of 7 min. The materials of the telephone have been neglected, while only energy consumption has been included, using average values from the literature (Savoldelli et al., 2024c). The uploading and downloading documents involves an average file size of 100 KB, and the energy consumption for internet and server use has been calculated as indicated by Savoldelli et al. (Savoldelli et al., 2024c):

$$\left(0.015 \frac{kWh}{GB} \times 0.001 GB\right) + \left(0.3 \frac{kWh}{GB} \times 0.001 GB\right)$$

The sending of an email has been approximated to upload a document. Finally, considering the mountainous geography of the province of Bergamo and the limited availability of public transport in the study area, only the transportation by private car has been taken into account, with an average distance of 30 km for the round trip to the hospital. The vehicle fleet of the province was used (Automobile Club Italia Open Parco Veicoli, 2025) to calculate the percentage of different types of cars in circulation.

For these visits, personal protective equipment (PPE) was not considered. Similarly, heating and lighting of the room were omitted, as they were not considered relevant to the analysis (Thiel et al., 2023).

4.3. Life cycle impact assessment

The life cycle impact assessment has been conducted using Simapro software and the EcoInvent V3.9.3 database. The ReCiPe 2016 Midpoint (H) V1.08 and ReCiPe 2016 Endpoint (H) V1.08 methods (Huijbregts et al., 2017) have been chosen to include inventory data results in a set of standard indicator categories. The ReCiPe 2016 Midpoint (H) method evaluates environmental impacts at an intermediate level, characterizing them into 18 specific categories representing various environmental processes: Global warming (GW), Stratospheric ozone depletion (SOD), Ionizing radiation (IR), Ozone formation Human health (OFHH), Fine particulate matter formation (FPMF), Ozone formation Terrestrial ecosystems (OFTE), Terrestrial acidification (TA), Freshwater eutrophication (FE), Marine eutrophication (ME), Terrestrial ecotoxicity (TEc), Freshwater ecotoxicity (FEc), Marine ecotoxicity (MEc), Human carcinogenic toxicity (HCT), Human non-carcinogenic toxicity (HnCT), Land use (LU), Mineral resource scarcity (MRS), Fossil resource scarcity (FRS), and Water consumption (WC). In contrast, the ReCiPe 2016 Endpoint (H) method evaluates environmental impacts at a more aggregated level, assessing three main categories: Human health, Ecosystems, and Resources. The Hierarchist (H) perspective is the most common and represents the default view, balancing the trade-off between prevention and risk tolerance.

4.4. Impacts assessment results

To compare the environmental burden of remote and in-person follow-up examinations, the midpoint and endpoint categories have been quantified and included in Table 2.

Fig. 4 and Fig. 5 illustrate the total environmental impacts associated with the telemedicine and in-person visit processes, respectively. For the telemedicine process, Fig. 4, the main contributions to the overall impact arise from the transportation phase (which is significantly

Table 2

Comparative environmental impact of televisit vs in-person follow-up visits: results across midpoint and endpoint impact categories.

Midpoint impact categories	Code	Unit	Televisit	In-person visit
Global warming	GW	kg CO ₂ eq	9,82E-02	1,07E+01
Stratospheric ozone depletion	SOD	kg CFC11 eq	6,71E-08	3,48E-06
Ionizing radiation	IR	kBq Co-60 eq	1,50E-02	1,95E-01
Ozone formation, Human health	OFHH	kg NO _x eq	2,98E-04	2,59E-02
Fine particulate matter formation	FPMF	kg PM2.5 eq	1,82E-04	1,04E-02
Ozone formation, Terrestrial ecosystems	OFTE	kg NO _x eq	3,10E-04	2,80E-02
Terrestrial acidification	TA	kg SO ₂ eq	3,67E-04	2,36E-02
Freshwater eutrophication	FE	kg P eq	6,86E-05	1,84E-03
Marine eutrophication	ME	kg N eq	1,15E-05	3,33E-04
Terrestrial ecotoxicity	TEc	kg 1,4-DCB	5,55E-01	5,64E+01
Freshwater ecotoxicity	FEc	kg 1,4-DCB	1,03E-02	8,71E-01
Marine ecotoxicity	Mec	kg 1,4-DCB	1,35E-02	1,12E+00
Human carcinogenic toxicity	HCT	kg 1,4-DCB	6,72E-03	9,23E-01
Human non-carcinogenic toxicity	HnCT	kg 1,4-DCB	1,86E-01	9,59E+00
Land use	LU	m ² a crop eq	7,42E-02	2,87E-01
Mineral resource scarcity	MRS	kg Cu eq	5,86E-04	5,90E-02
Fossil resource scarcity	FRS	kg oil eq	2,84E-02	3,13E+00
Water consumption	WC	m ³	3,27E-03	3,00E-02
Endpoint impact categories				
Human health		DALY	2,76E-07	2,18E-05
Ecosystems		species.yr	1,15E-09	4,41E-08
Resources		USD2013	8,24E-03	1,26E+00

reduced but not entirely eliminated), as well as from the enlistment and preliminary phases.

Fig. 5 presents the environmental impacts associated with the in-person visit process. It is evident that the delivery of the medical appointment accounts for most of the total impact.

As demonstrated by the results in Fig. 6, televisit process reached a lower impact at each midpoint indicator. When comparing individual categories, the most significant differences are in TEc, followed by GW, HnCT, and FRS (amounting to 55.86 kg 1.4-DCB, 10.64 kg CO₂ eq, 9.41 kg 1.4-DCB, and 3.10 kg oil eq, respectively). (See Fig. 7.)

As shown in Fig. 4, the same trend has been obtained considering the endpoints indicators, the damage on human health, the ecosystem and resources. The imbalance between in-person visits and remote visits is evident, with the impact almost zeroing out in the case of televisits.

4.5. Qualitative social analysis

In the present study, the LCA analysis has been combined with a qualitative social analysis based on interviews. A group of stakeholders involved in both televisit and in-person visit processes have been identified. Stakeholders of a care process are individuals, groups, or organizations that are involved in or influence the planning, delivery, and outcomes of care for patients (Petkovic et al., 2023). Specifically,

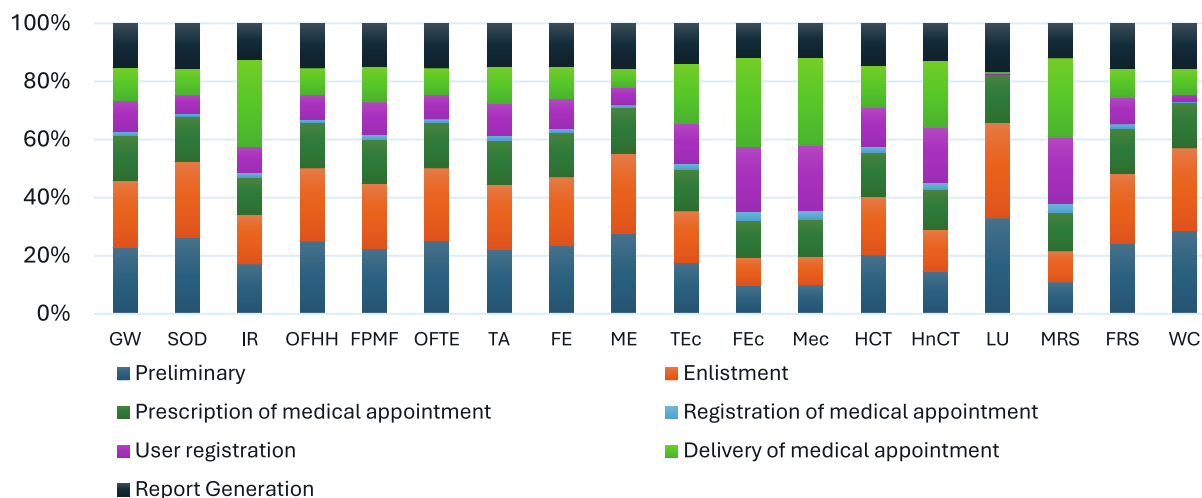


Fig. 4. Midpoint categories results of televisit processes.

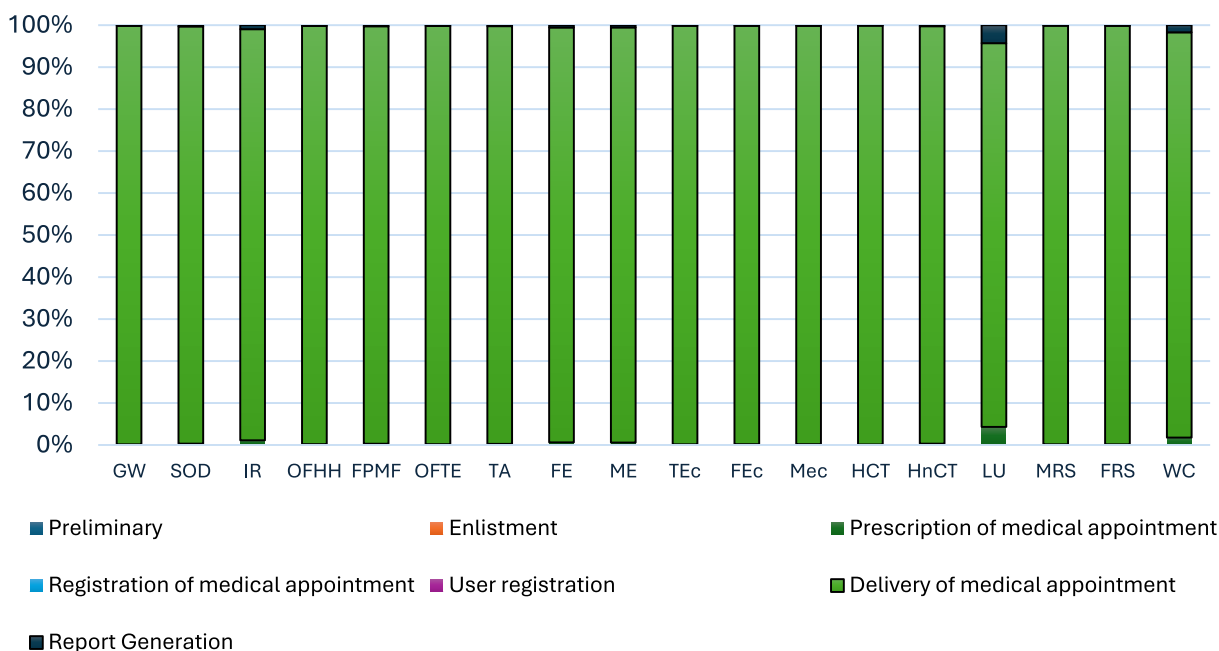


Fig. 5. Midpoint categories results of in-person visits processes.

hospital staff workload is actively engaged in telemedicine processes, in the management and in the delivery of digital activities (Lawrence et al., 2022). While it is well established in the literature that physicians and healthcare professionals play an active role in telemedicine processes, social impact assessments have typically focused on the patient’s perspective. As a result, the viewpoint of healthcare and support staff involved in these processes is often overlooked. Therefore, to address this gap, the study has included stakeholders within the hospital structure to provide a broader and more comprehensive perspective. Specifically, a wide range of hospital stakeholders have been involved, including not only medical and care personnel but also managerial, administrative, and executive staff. This approach ensures a more holistic understanding of the social aspects at play, which is essential for the development of meaningful and comprehensive social impact indicators in future studies. Specifically, the analysis includes 14 stakeholders: the telemedicine team leader, a process management engineer, two administrative staff, the head of healthcare professionals, two nurse managers, an information systems technician, the director, and five

physicians from various operational units.

For each stakeholder, a series of interviews have been prepared, according to his role and main activities. While the core structure of the interviews remained consistent, different versions have been developed based on the specific stakeholder to ensure greater precision and accuracy in the analysis of results. Survey structures have been included in the supplementary material.

The interviews for the staff providing the televisit service focused on exploring their perception of the service and any technological issues or challenges encountered. A specialized interview has been conducted with the socio-health director to better understand the logistical and organizational impact of the service. For administrative staff, questions have been formulated regarding the transition from paper to digital management, covering both in-person and remote visits. Finally, questions for the IT staff have been more oriented towards the management of technology. Table 3 compares the main characteristics of different interviews. The comparison of detailed structure of surveys for medical and non-medical personnel has been included in the supplementary

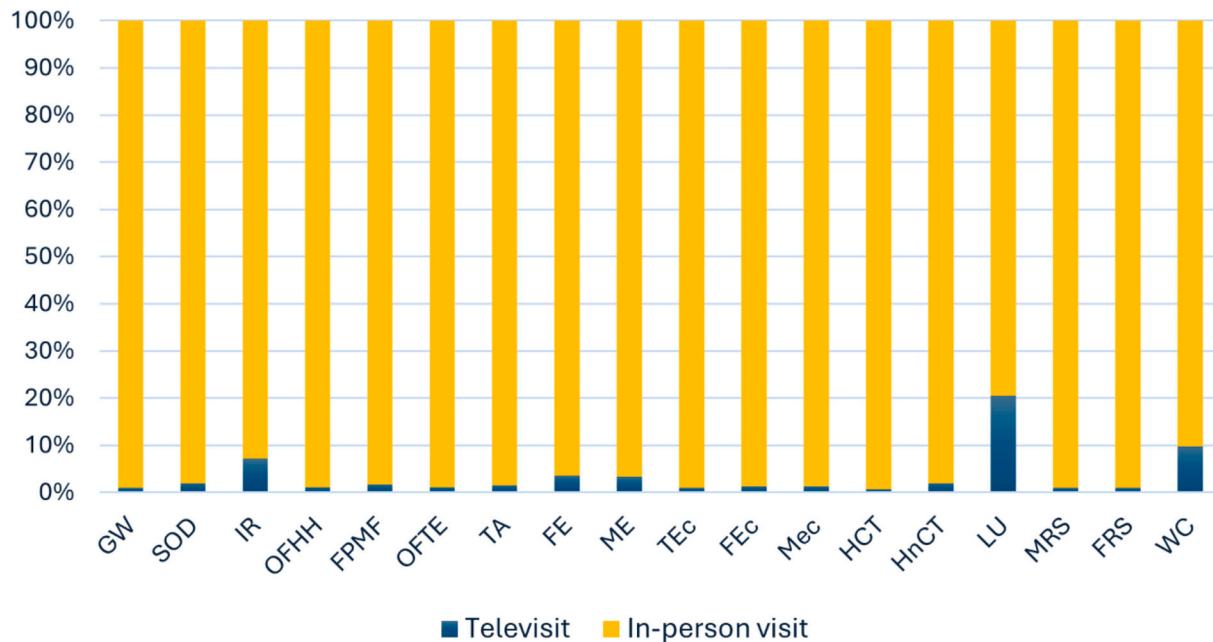


Fig. 6. Comparison midpoint categories results of televisit and in-person visits processes.

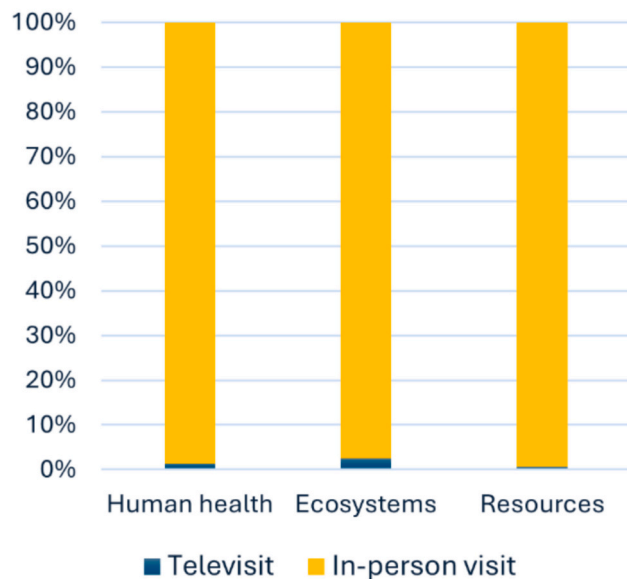


Fig. 7. Endpoint categories results of televisit and in-person visits processes.

material.

Face-to-face interviews have been conducted in situ with a representative member of each stakeholder group. The interviews have been transcribed, and finally their content analyzed.

5. Discussion

In the traditional in-person visit process, transportation has emerged as the predominant impact across all midpoint categories. Travel of patients reached an impact ten times greater than paper use, the second largest impact source. For this reason, results have demonstrated that televisit process is significantly less impactful compared to in-person visit. When excluding patient transportation from the in-person process, the results reverse, showing televisits as more impactful across all

Table 3

Overview of stakeholder interviews employed to map social impacts of telemedicine.

Stakeholder	Main Focus	Distinctive Aspects
Healthcare Providers	Direct experience with televisit, impact on patients and workload.	Detailed analysis of benefits and operational challenges.
Non-Healthcare Staff	Organization, management, and logistical impact.	Examine the service from an organizational perspective.
IT and Technical Support	Technological and cybersecurity aspects of televisit.	Detailed technical assessment.
Healthcare Management Administrative Staff	Strategic and institutional impact. Organizational and bureaucratic impact.	Management and policy-making approach. Process optimization-oriented approach.

midpoint categories (Fig. 8). Therefore, to better compare and discuss the different sources of emissions, a third scenario has been created, which does not consider the patient’s travel from home to the hospital for the visit.

The environmental impact of transportation has emerged also in other articles in literature reviews (Ravindrane and Patel, 2022; Lokmic-Tomkins et al., 2022); studies found an environmental benefit of telemedicine versus face-to-face follow-ups reducing GHG emissions from travel (Morcillo Serra et al., 2022; Cockrell et al., 2022). The study of Thiel C. L. et al. (Thiel et al., 2023) highlights that transportation is the leading contributor to GHG emissions from in-person visits, with a reported increase in emissions when all patient travel is modeled as occurring via passenger car. Specifically, in-person visit emissions increased by 77 % when this assumption was made, illustrating the substantial impact of travel mode on overall emissions.

5.1. Contribution of process activities

Fig. 9 analyzes the contribution of individual activities in the telemedicine and in-person visit processes across the 16 midpoints. As previously defined, when considering the complete traditional in-person visit process, the medical examination phase emerges as the most

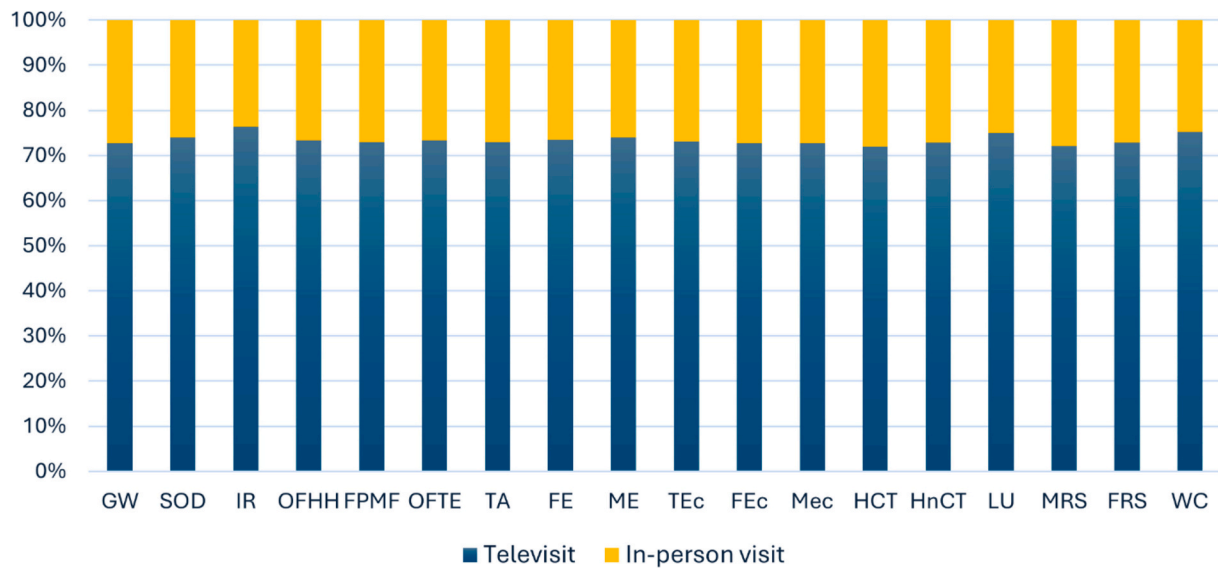


Fig. 8. Detail midpoint categories result of tele-visit and in-person visits processes, avoiding transportation.

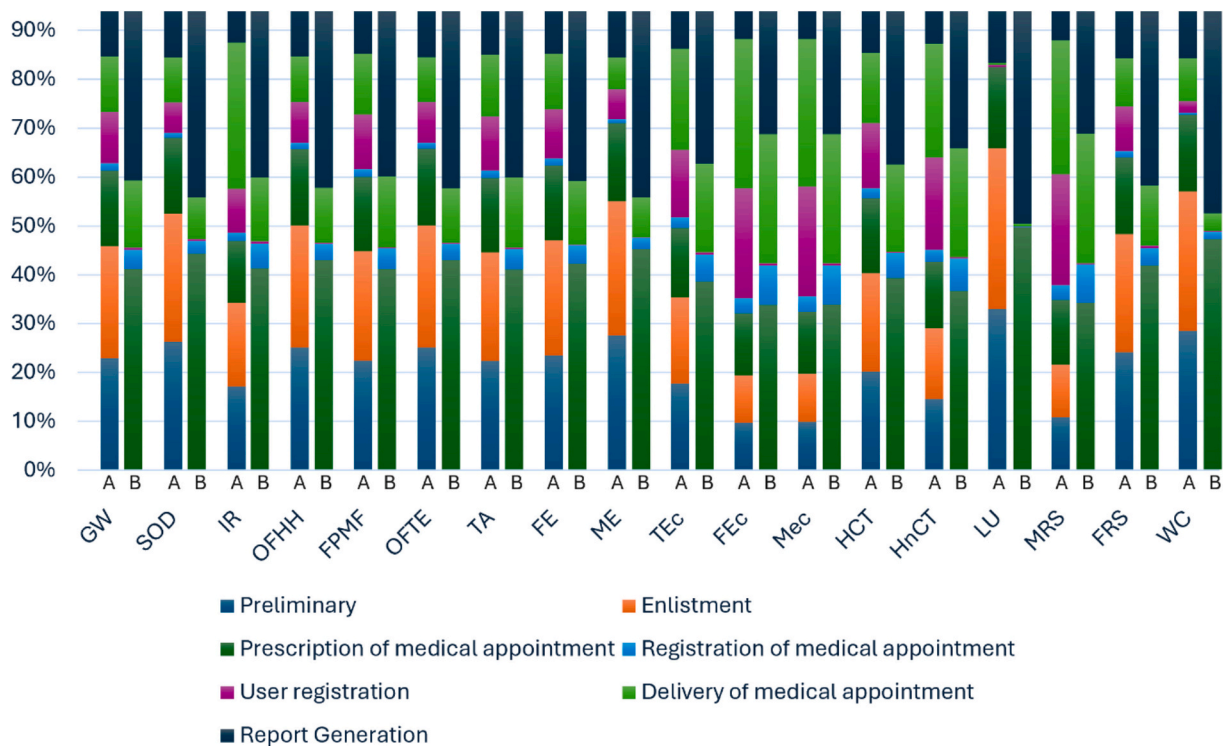


Fig. 9. Midpoint categories result of in-person visits (scenario A) and televisit (scenario B) processes, avoiding transportation.

impactful aspect with a very significant difference. Therefore, the two scenarios were compared while excluding vehicle usage.

In scenario A, which involves in-person visits avoiding transportation, the environmental impact is homogeneously distributed among the different process activities. Although there are no significant differences, the registration of medical appointment is the least impactful phase in all midpoint categories. In contrast, in scenario B which includes telemedicine, report generation and prescription emerge as the most impactful phases compared to the others. The delivery of the medical visit has obtained a middle score, while the remaining activities are associated with lower impacts.

The same trend is also demonstrated by the results for endpoint

indicators, as shown in Fig. 10. The findings are derived from the use of resources at different stages of the process. In particular, the use of paper materials is responsible for most of the impacts for each of the indicators, followed by the use of electronic devices and their energy consumption.

LCA studies consistently demonstrate that telemedicine achieves significant reductions in healthcare-related global warming potential (GWP), primarily through the elimination of travel-related emissions, with GWP savings ranging from 70 to 95 % depending on transport modes, trip distances, and regional contexts. Moreover, results in literature align with emissions driven by digital infrastructure (e.g., data centers, networks) and device energy use result, which are much smaller

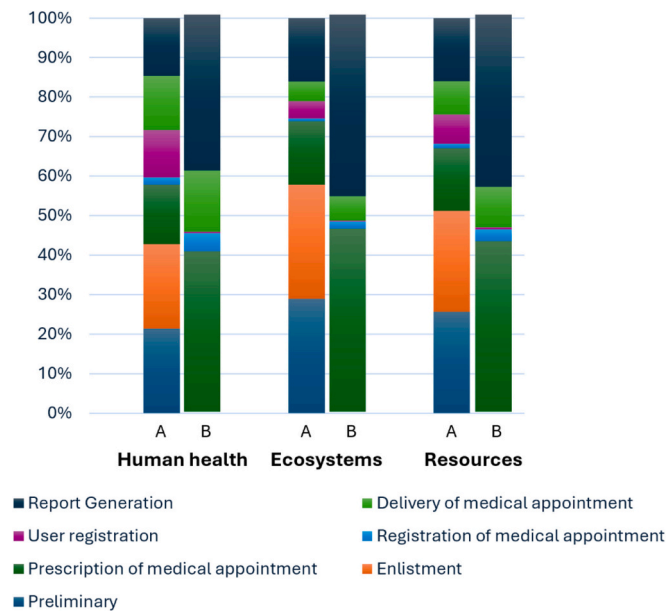


Fig. 10. Endpoint categories result of in-person visits (scenario A) and televisit (scenario B) processes, avoiding transportation.

However, only few papers fully account for life-cycle impacts.

5.2. Global warming evaluation

Among the several LCA environmental impact indicators, discussions of this study focus on global warming, measured through the quantification of CO₂e. Indeed, CO₂e is the most commonly used indicator in hospital and healthcare-related environmental assessments, as it aligns

with current policy frameworks and professional discourse. This indicator provides a standardized metric that facilitates comparisons among different greenhouse gases based on their global warming potential (GWP) (Eurostat Statistic Explained, 2025).

As shown in Fig. 11a, transportation is responsible for the majority of CO₂e emissions during a traditional in-person visit. This value is comparable to findings currently present in the literature (Smith et al., 2023). As highlighted in the article by Savoldelli et al. (Savoldelli et al., 2024c), in the province of Bergamo, where this research is contextualized, travel of patients to the hospital has been identified as a critical factor. The hospital covers a geographically extensive area, from flatlands to mountainous regions, reaching about 50 % of the population in the province of Bergamo (ASST Bergamo Est, 2025). Consequently, one of the challenges the hospital faces is the high volume of travel from mountainous areas and tourist regions near the lakes. Furthermore, the hospital is located outside the city, making it difficult to reach via a single public transport option. As a result, patients often choose to use private vehicles, increasing related emissions.

Despite the analyzed distance being relatively short, telemedicine offers advantages not only in terms of environmental sustainability but also in time savings for both patients and caregivers. Considering traffic conditions in the area, Google Maps estimates approximately 50 min of driving time to cover this distance. Patients must also allocate time to find parking and arrive early for their appointments. The benefits can be particularly significant for patients with chronic conditions who require long-term care and regular follow-up assessments.

Excluding transportation aspects (Fig. 11b), it can be observed that other factors, such as paper materials, IT equipment, internet consumption, and energy, are greater in the telemedicine process compared to the traditional approach. The impact generated using paper materials reached one of the most significant results. Although the telemedicine process aims to digitize operations and reduce paper consumption, the initial phases require the completion of physical documents and files.

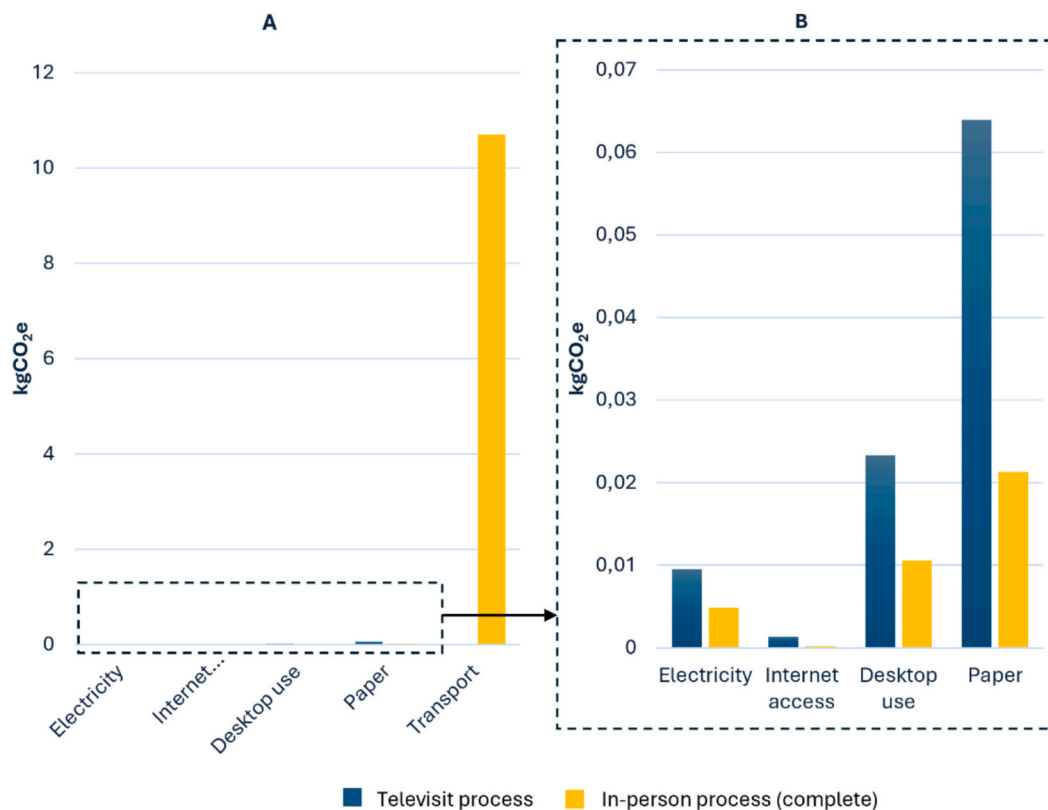


Fig. 11. Global warming emissions sources, considering the complete processes (A) and avoiding transportation (B).

The impact should decrease by changing the functional unit of the study to consider a greater number of telemedicine visits per patient. Indeed, paper materials are primarily utilized during the engagement phase, which does not recur in subsequent telemedicine visits for the same patient.

While the impact responsible for internet use and technology is significantly lower than that produced by patient transportation, efficient management of digital activities can further contribute to reducing emissions. For example, eliminating unnecessary information can lower environmental costs. Conversely, transitioning to low-energy devices can offer the opportunity to significantly improve overall impacts.

5.3. Analysis of social aspects

Despite the reached benefits, the investigation of impacts on stakeholders it is essential to define the appropriateness of the televisit.

The telemedicine team leader expressed a primary interest in expanding the use of televisit throughout the patient care process, aiming to create a broad and functional network of services. The main goal of the process management engineer is complete televisit-related projects within agreed timelines and parameters. The head of healthcare professionals seeks to ensure that the service complies with regional regulations. The two interviewed nurses shared an interest in increasing the team’s project outcomes and telemedicine results. Conversely, the IT technician focused on making televisit sessions technologically effective and efficient, providing support, and anticipating positive changes. The administrative staff are responsible for patient recruitment, phone contact, and scheduling. The socio-health director aims to reach an increasingly larger user base. The physicians involved in the project aim to improve patient follow-up and care pathways, helping patients perceive their care journey as a service that meets their needs, and expanding the service with hybrid teleconsultation projects and other telemedicine services.

The results of 5-point Likert scale questions, which assess the impact of televisits on external factors associated with medical performance, have been summarized in Table 4. The responses have been categorized into three main areas, including patients’ experience, medical aspects and organizational aspects. Within each category, aspects of interest on different social issues have been defined. Each social aspect has received a level of importance from stakeholders, through a 5-point likert scale. The highest interest of stakeholders has been highlighted in reducing patient travel, achieving a maximum score of 5 points. The second position has been reached by the improvement of care continuity, optimization of workload, and reduction of overcrowding, which collect a score of 4.6 points. The collection of clinical data obtained the lower score, despite the positive result of 3.8 out of 5 points.

Table 4
Stakeholder perceptions of televisits on patient experience, medical performance and organizational efficiency based on 5-point Likert scale results.

Category	Social aspect	Likert score	Importance
Patient experience	Travel reduction	5	High
	Quality of patient-clinician contact	4	Medium
	Fast follow-up examinations	4.4	Medium
Medical aspects	Assistance continuity improvement	4.6	Medium-high
	Medical compliance improvement	4.4	Medium
	Clinical data collection	3.8	Medium-low
Organizational aspects	Workload optimization	4.6	Medium-high
	Overcrowded reduction	4.6	Medium-high
	Waiting lists reduction	4	Medium
	Visits overlapping	4	Medium

On the social side, the findings also have shown the interest of stakeholders in transportation; this aspect has reached the highest level of importance. The physical movement of patients results in easily detectable impacts related to time lost during travel, time spent searching for parking and getting to the clinic. Additionally, this often requires the presence of a caregiver, who invests his time to follow the sick person, losing hours of work. However, in addition to these results, the analysis has revealed other social aspects related to the implementation of telemedicine in clinical practice. Stakeholders view telemedicine as an effective solution to optimize waiting lists and reduce workload, enhancing communication between doctor and patient when necessary and avoiding losing time.

The importance of improving continuity of care underscores the need to always evaluate the appropriateness of these activities based on the type of patient and their specific care needs. Despite in a preliminary qualitative form, the social assessment, when correlated with the environmental assessment, allows for more comprehensive evaluations and understanding of the true effects of telemedicine on patients.

5.4. Practical implication and future developments

Telemedicine represents a promising approach to reducing the environmental footprint of healthcare services. The study aligns with key policy frameworks promoting sustainable healthcare, such as the European Green Deal and the United Nations Sustainable Development Goals (SDGs), particularly Goal 3 (Good Health and Well-being) and Goal 13 (Climate Action). The results demonstrate that televisits can significantly lower CO₂e emissions, primarily by reducing patient transportation. This finding reinforces the need to integrate telemedicine into national and regional healthcare strategies to support carbon neutrality objectives. Beyond its immediate environmental benefits, telemedicine can play a strategic role in shaping future technological innovations. Ensuring that telemedicine systems are designed according to sustainability principles allows for the development of adaptable platforms that respond to evolving healthcare needs while minimizing resource consumption and environmental impact. A structured, integrated evaluation framework is essential to ensure that decisions are data-driven, transparent, and replicable, providing a solid foundation for sustainable decision-making in healthcare innovation. This approach helps bridge the gap between high-level sustainability goals and the practical implementation of telemedicine, balancing immediate clinical needs with long-term environmental and social priorities.

To maximize the sustainability benefits of telemedicine, healthcare policies should focus on enhancing digital platforms and tools to optimize energy efficiency and minimize the environmental impact of data transmission. The integration of telemedicine within broader hospital sustainability programs—such as green energy procurement and digital transformation—can further strengthen its impact. Additionally, policy-driven incentives for healthcare providers who adopt telemedicine, similar to carbon offset programs in other industries, could accelerate its widespread adoption.

From a practical perspective, implementing sustainable telemedicine requires not only structured methodologies but also targeted incentives. While the proposed framework provides a solid decision-making foundation, additional support measures are necessary for its effective adoption. In this regard, policies play a crucial role. For example, appointing dedicated telemedicine managers within hospital structures can ensure better coordination of digital healthcare strategies in alignment with sustainability goals. Moreover, continuously updating regulations, particularly reimbursement schemes, and integrating real-world case studies from daily medical practice are essential steps in making telemedicine a viable and long-term solution.

6. Conclusions

The growing global adoption of telemedicine requires the

development of tools that can objectively quantify its impacts, moving beyond theoretical discussions and providing insights for informed and efficient decision making. The present study has introduced an innovative approach that integrates environmental and social assessments, overcoming the limitations of fragmentary analyses found in the existing literature and offering an objective methodology for assessing the sustainability of telemedicine.

The research has investigated the environmental and social impacts of telemedicine in the follow-up examinations of chronic HF patients, by applying a standard life cycle assessment (LCA) to both in-person and remote follow-up processes. The study demonstrates that telemedicine significantly reduce environmental impacts compared to in-person visits, primarily by eliminating patient transportation, which accounted for over 90 % of emissions in traditional healthcare settings. The Life Cycle Assessment (LCA) using the ReCiPe 2016 method revealed that telemedicine reduce CO₂-equivalent emissions from 10.7 kg to 0.098 kg per visit, along with substantial decreases in terrestrial ecotoxicity (from 56.4 kg 1,4-DCB to 0.55 kg 1,4-DCB) and fossil resource depletion (from 3.13 kg oil eq to 0.028 kg oil eq). The analysis has incorporated both direct and indirect emissions, including those from administrative support activities. The shift to digital healthcare introduces new environmental burdens, particularly due to electricity consumption for electronic devices and data transmission, with energy use from IT infrastructure contributing to a moderate increase in digital-related impacts. The results also highlight that initial administrative phases of telemedicine still rely on paper documentation, which, despite being a minor contributor, could be further reduced through complete digitalization. Although data availability has offered only an initial view of the impact of telecommunications and digital health data exchange, this integrated approach has been a key step forward.

Moreover, the present approach has extended the environmental evaluation of telemedicine by incorporating social dimensions, revealing improvements in patient experience and continuity of care. Involving 14 stakeholders, the study has explored social aspects from different novel perspectives. Stakeholders' interviews revealed that telemedicine improve accessibility and continuity of care while optimizing healthcare workflow efficiency. Travel reduction was identified as the most significant benefit, scoring 5 out of 5 on the Likert scale among stakeholders, particularly benefiting chronic patients who require frequent follow-ups. Additionally, telemedicine contributed to a 4.6/5 improvement in workload optimization and overcrowding reduction, enhancing operational efficiency.

This study has some limitations. Firstly, the end-of-life phase of electronic devices and energy consumption for hospital room heating and lighting were not included. These exclusions were based on methodological simplifications aimed at focusing on the most relevant impact sources, particularly patient transportation. Future studies should refine these aspects by incorporating the full life cycle of digital infrastructure and hospital energy use to improve impact estimations.

Moreover, the study's findings are based on a single hospital case study, which can limit their generalizability to other healthcare contexts. While this provided a detailed and context-specific analysis, further research should explore different healthcare settings and geographic locations to validate and expand the applicability of the results. Additionally, some input data relied on expert consultations and literature estimates, introducing a degree of uncertainty. Future efforts should prioritize real-time data collection and broader datasets to enhance result accuracy.

Finally, social assessment was conducted qualitatively through stakeholder interviews, without a formal Social Life Cycle Assessment (S-LCA). This approach was chosen to preliminary capture insights from healthcare professionals and administrators, but it did not quantitatively measure social impacts or include direct patient perspectives. Expanding future research to integrate a structured S-LCA and patient-centered evaluations would provide a more balanced view of telemedicine's broader effects.

In conclusion, this integrated approach provides healthcare providers with a valuable resource for the effective and sustainable implementation of telemedicine solutions while balancing environmental and social benefits. Future research should focus on refining social indicators and exploring economic implications, promoting a more balanced and efficient healthcare system. Future challenges concern the expansion of the current analysis, to define a standardized set of social indicators, and to objectively assign appropriate weights to each of them, in order to provide more accurate and reliable assessments.

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Declaration of generative AI in scientific writing

The authors declare that they have not used AI tools to analyze and draw insights from data as part of the research process

CRediT authorship contribution statement

Anna Savoldelli: Investigation, Methodology, Writing – original draft. **Daniele Landi:** Conceptualization, Methodology, Writing – original draft. **Caterina Rizzi:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.eiar.2025.108030>.

Data availability

No data was used for the research described in the article.

References

- Anawade, P.A., Sharma, D., Gahane, S., 2024. A comprehensive review on exploring the impact of telemedicine on healthcare accessibility. *Cureus*. <https://doi.org/10.7759/cureus.55996>.
- Arushanyan, Y., Ekener-Petersen, E., Finnveden, G., 2014. Lessons learned – review of LCAs for ICT products and services. *Comput. Ind.* 65, 211–234. <https://doi.org/10.1016/j.compind.2013.10.003>.
- ASST Bergamo Est, 2025. <https://www.asst-bergamoest.it/it/azienda/la-struttura-aziendale>.
- Automobile Club Italia Open Parco Veicoli, 2025. <https://opv.aci.it/WEBDMCircolante/>.
- Castiglione, V., Aimo, A., Vergaro, G., et al., 2022. Biomarkers for the diagnosis and management of heart failure. *Heart Fail. Rev.* 27, 625–643. <https://doi.org/10.1007/s10741-021-10105-w>.
- Giacci, L., Passarini, F., 2020. Life cycle assessment (LCA) of environmental and energy systems. *Energies* 13, 5892. <https://doi.org/10.3390/en13225892>.
- Cockrell, H.C., Maine, R.G., Hansen, E.E., et al., 2022. Environmental impact of telehealth use for pediatric surgery. *J. Pediatr. Surg.* 57, 865–869. <https://doi.org/10.1016/j.jpedsurg.2022.06.023>.
- Dong, Y., Miraglia, S., Manzo, S., et al., 2018. Environmental sustainable decision making – the need and obstacles for integration of LCA into decision analysis. *Environ. Sci. Pol.* 87, 33–44. <https://doi.org/10.1016/j.envsci.2018.05.018>.

- Drew, J., Christie, S.D., Rainham, D., Rizan, C., 2022. HealthcareLCA: an open-access living database of health-care environmental impact assessments. *Lancet Planet Heal* 6, e1000–e1012. [https://doi.org/10.1016/S2542-5196\(22\)00257-1](https://doi.org/10.1016/S2542-5196(22)00257-1).
- Eurostat Statistic Explained, 2025. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary%3ACarbon_dioxide_equivalent.
- Ferrara, L., Zazzera, A., Tozzi, V.D., 2022. Managing chronic conditions: lessons learnt from a comparative analysis of seven years' policies for chronic care patients in Italy. *Int. J. Integr. Care* 22. <https://doi.org/10.5334/ijic.5686>.
- García-Berná, J.A., Fernández-Alemán, J.L., Carrillo de Gea, J.M., et al., 2021. Energy efficiency in software: a case study on sustainability in personal health records. *J. Clean. Prod.* 282, 124262. <https://doi.org/10.1016/j.jclepro.2020.124262>.
- Greenhouse Gas Protocol, 2025. <https://ghgprotocol.org/>.
- Haleem, A., Javaid, M., Singh, R.P., Suman, R., 2021. Telemedicine for healthcare: capabilities, features, barriers, and applications. *Sensors Int.* 2, 100117. <https://doi.org/10.1016/j.sintl.2021.100117>.
- Hernández-de-Anda, M.T., Taboada-González, P., Aguilar-Virgen, Q., et al., 2023. Environmental impacts of a Mexican hemodialysis unit through LCA. *J. Clean. Prod.* 384, 135480. <https://doi.org/10.1016/j.jclepro.2022.135480>.
- Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., et al., 2017. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* 22, 138–147. <https://doi.org/10.1007/s11367-016-1246-y>.
- ISO (International Organization for Standardization), 2006a. Environmental Management - Life Cycle Assessment - Principles and Framework (ISO 14040:2006). <https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en> (2006).
- ISO (International Organization for Standardization), 2006b. Environmental Management-Life Cycle Assessment-Requirements and Guidelines (ISO 14044:2006). <https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en> (2006).
- ISO/IEC 19752, 2004. <https://www.iso.org/standard/34911.html>.
- Keller, R.L., Muir, K., Roth, F., et al., 2021. From bandages to buildings: identifying the environmental hotspots of hospitals. *J. Clean. Prod.* 319, 128479. <https://doi.org/10.1016/j.jclepro.2021.128479>.
- Kruse, C., Heinemann, K., 2022. Facilitators and barriers to the adoption of telemedicine during the first year of COVID-19: systematic review. *J. Med. Internet Res.* 24, e31752. <https://doi.org/10.2196/31752>.
- Kwon, C., Essayei, L., Spencer, M., et al., 2024. The environmental impacts of electronic medical records versus paper Records at a Large eye Hospital in India: life cycle assessment study. *J. Med. Internet Res.* 26, e42140. <https://doi.org/10.2196/42140>.
- Lawrence, K., Nov, O., Mann, D., et al., 2022. The impact of telemedicine on physicians' after-hours electronic health record "work outside work" during the COVID-19 pandemic: retrospective cohort study. *JMIR Med. Inform.* 10, e34826. <https://doi.org/10.2196/34826>.
- Lee, K.C.-S., Breznen, B., Ukhova, A., et al., 2023. Virtual healthcare solutions in heart failure: a literature review. *Front. Cardiovasc. Med.* 10. <https://doi.org/10.3389/fcvm.2023.1231000>.
- Lokmic-Tomkins, Z., Davies, S., Block, L.J., et al., 2022. Assessing the carbon footprint of digital health interventions: a scoping review. *J. Am. Med. Inform. Assoc.* 29, 2128–2139. <https://doi.org/10.1093/jamia/ocac196>.
- Ma, Y., Zhao, C., Zhao, Y., et al., 2022. Telemedicine application in patients with chronic disease: a systematic review and meta-analysis. *BMC Med. Inform. Decis. Mak.* 22, 105. <https://doi.org/10.1186/s12911-022-01845-2>.
- McDonagh, T.A., Metra, M., Adamo, M., et al., 2021. 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur. Heart J.* 42, 3599–3726. <https://doi.org/10.1093/eurheartj/ehab368>.
- Morcillo Serra, C., Aroca Tanarro, A., Cummings, C.M., et al., 2022. Impact on the reduction of CO2 emissions due to the use of telemedicine. *Sci. Rep.* 12, 12507. <https://doi.org/10.1038/s41598-022-16864-2>.
- Nguyen, O.T., Alishahi Tabriz, A., Huo, J., et al., 2021. Impact of asynchronous electronic communication-based visits on clinical outcomes and health care delivery: systematic review. *J. Med. Internet Res.* 23, e27531. <https://doi.org/10.2196/27531>.
- Or, Z., Seppänen, A.-V., 2024. The role of the health sector in tackling climate change: a narrative review. *Health Policy (New York)* 143, 105053. <https://doi.org/10.1016/j.healthpol.2024.105053>.
- Padilla-Rivera, A., Russo-Garrido, S., Merveille, N., 2020. Addressing the social aspects of a circular economy: a systematic literature review. *Sustainability* 12, 7912. <https://doi.org/10.3390/su12197912>.
- Petkovic, J., Magwood, O., Lytvyn, L., et al., 2023. Key issues for stakeholder engagement in the development of health and healthcare guidelines. *Res. Involv. Engagem.* 9, 27. <https://doi.org/10.1186/s40900-023-00433-6>.
- Priescu, I., Oncioiu, I., 2022. Measuring the impact of virtual communities on the intention to use telemedicine services. *Healthcare* 10, 1685. <https://doi.org/10.3390/healthcare10091685>.
- Rabin, A.S., Lai, P.S., Maximous, S.I., Shankar, H.M., 2024. Reducing the climate impact of critical care. *CHEST Crit Care* 2, 100037. <https://doi.org/10.1016/j.chstcc.2023.100037>.
- Rasheed, F.N., Baddley, J., Prabhakaran, P., et al., 2021. Decarbonising healthcare in low and middle income countries: potential pathways to net zero emissions. *BMJ* n1284. <https://doi.org/10.1136/bmj.n1284>.
- Ravindrane, R., Patel, J., 2022. Infrastructure: the environmental impacts of telemedicine in place of face-to-face patient care: a systematic review. *Futur. Healthc. J.* 9, 28–33. <https://doi.org/10.7861/fhj.2021-0148>.
- Richie, C., 2021. Environmental sustainability and the carbon emissions of pharmaceuticals. *J. Med. Ethics Medeth.* 2020, 106842. <https://doi.org/10.1136/medethics-2020-106842>.
- Rocha, J., Oliveira, S., Viana, C.M., Ribeiro, A.I., 2022. Climate change and its impacts on health, environment and economy. In: *One Health*. Elsevier, pp. 253–279.
- Rocque, R.J., Beaudoin, C., Ndjaboue, R., et al., 2021. Health effects of climate change: an overview of systematic reviews. *BMJ Open* 11, e046333. <https://doi.org/10.1136/bmjopen-2020-046333>.
- Rodler, S., Ramacciotti, L.S., Maas, M., et al., 2023. The impact of telemedicine in reducing the carbon footprint in health care: a systematic review and cumulative analysis of 68 million clinical consultations. *Eur. Urol. Focus* 9, 873–887. <https://doi.org/10.1016/j.euf.2023.11.013>.
- Roesch, A., Sala, S., Jungbluth, N., 2020. Normalization and weighting: the open challenge in LCA. *Int. J. Life Cycle Assess.* 25, 1859–1865. <https://doi.org/10.1007/s11367-020-01790-0>.
- Sapna, F., Raveena, F., Chandio, M., et al., 2023. Advancements in heart failure management: a comprehensive narrative review of emerging therapies. *Cureus*. <https://doi.org/10.7759/cureus.46486>.
- Savoldelli, A., Landi, D., Rizzi, C., 2023. Sustainability in Healthcare: Methods and Tools for the Assessment.
- Savoldelli, A., Regazzoni, V., Rizzola, G., et al., 2024a. Telemedicine and remote Management of Patients with heart failure: from theory to daily practice. *Telemed e-Health*. <https://doi.org/10.1089/tmj.2024.0067>.
- Savoldelli, A., Landi, D., Rizzi, C., 2024b. Exploring quantitative methodologies for assessing the environmental, social, and economic impacts of telemedicine: a literature review. *Sustainability* 16, 2438. <https://doi.org/10.3390/su16062438>.
- Savoldelli, A., Landi, D., Rizzi, C., 2024c. Exploring the Environmental Impact of Telemedicine: A Life Cycle Assessment.
- Sijm-Eeken, M., Jaspers, M., Peute, L., 2023. Identifying environmental impact factors for sustainable healthcare: a scoping review. *Int. J. Environ. Res. Public Health* 20, 6747. <https://doi.org/10.3390/ijerph20186747>.
- Sillcox, R., Gitonga, B., Meiklejohn, D.A., et al., 2023. The environmental impact of surgical telemedicine: life cycle assessment of virtual vs. in-person preoperative evaluations for benign foregut disease. *Surg. Endosc.* 37, 5696–5702. <https://doi.org/10.1007/s00464-023-10131-9>.
- Smith, M.W., O'Shea, A.M.J., Wray, C.M., 2023. Health care and climate change—telemedicine's role in environmental stewardship. *JAMA Netw. Open* 6, e2253794. <https://doi.org/10.1001/jamanetworkopen.2022.53794>.
- Spitaleri, G., Lupón, J., Domingo, M., et al., 2021. Mortality trends in an ambulatory multidisciplinary heart failure unit from 2001 to 2018. *Sci. Rep.* 11, 732. <https://doi.org/10.1038/s41598-020-79926-3>.
- Sten-Gahmberg, S., Pedersen, K., Harsheim, I.G., et al., 2024. Experiences with telemedicine-based follow-up of chronic conditions: the views of patients and health personnel enrolled in a pragmatic randomized controlled trial. *BMC Health Serv. Res.* 24, 341. <https://doi.org/10.1186/s12913-024-10732-7>.
- Telemedicine: A Guide to Assessing Telecommunications in Health Care, 2025.
- Thiel, C.L., Mehta, N., Sejo, C.S., et al., 2023. Telemedicine and the environment: life cycle environmental emissions from in-person and virtual clinic visits. *NPJ Digit Med.* 6, 87. <https://doi.org/10.1038/s41746-023-00818-7>.
- Tozour, J.N., Bandremer, S., Patberg, E., et al., 2021. Application of telemedicine video visits in a maternal-fetal medicine practice at the epicenter of the COVID-19 pandemic. *Am. J. Obstet. Gynecol. MFM* 3, 100469. <https://doi.org/10.1016/j.ajogmf.2021.100469>.
- Transforming Our World, 2025. The 2030 Agenda for Sustainable Development. <https://sdgs.un.org/2030agenda>.
- Williams, C., Shang, D., 2024. Telehealth for chronic disease management among vulnerable populations. *J. Racial Ethn. Health Disparities* 11, 1089–1096. <https://doi.org/10.1007/s40615-023-01588-4>.