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Review

Exploring Quantitative Methodologies for Assessing the Environmental, Social, and Economic Impacts of Telemedicine: A Literature Review

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Abstract: The significant consumption of resources within the healthcare sector underscores the need to address both efficiency and sustainability concerns. Telemedicine has been identified as one of the most promising pathways for reducing the environmental impacts of the healthcare sector. However, a comprehensive sustainability assessment is still required. The main aim of the present study is to conduct a systematic literature review to explore approaches and methodologies employed for quantifying the environmental, social, and economic impacts of telemedicine. Moreover, the research seeks to determine whether the approaches focus on a single aspect or whether they allow for a comprehensive assessment including all three sustainability pillars. The searching phase was conducted in the Scopus and PubMed databases, considering last 10 years (i.e., 2013–2023). Keywords were related to remote care and sustainability impact fields. Following the PRISMA framework, out of 477 articles, 91 studies were included in the analysis. Primary findings highlighted that studies on telemedicine impacts predominantly focus on transport-related aspects, emphasizing direct emissions and associated costs that are avoided and time savings. Televisit emerged as the most investigated remote care activity. Database and conversion factors were mainly employed for analysis, while other methodologies were sporadically mentioned in the literature. Despite numerous papers addressing these issues, a standardized and comprehensive methodology still appears to be lacking. Future works should consider the entire life cycle process, including more stakeholders. A defined approach will be fundamental to move beyond theoretical discussions and provide actionable insights for healthcare practitioners, policymakers, and researchers.

Keywords: telemedicine; healthcare sector; environmental and public health; sustainable development

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1. Introduction

Sustainable healthcare is an essential concept encompassing a well-structured medical care system that not only addresses the immediate health needs of the present population but also considers the preservation of environmental, economic, and social resources for the benefit of future generations [1]. At the moment, health promotion and sustainable development strategies are not declared to be sufficiently well integrated [2]. This disparity is most evident in the excessive use of resources, such as energy, water, and materials, as well as the extensive waste produced, which includes medical disposables, hazardous materials, and emissions. This behavior has not only a negative environmental impact but also places a heavy economic burden on healthcare systems, contributing to rising healthcare costs [3]. Moreover, in our current healthcare landscape, the integration of health promotion and sustainable development strategies is often lacking. Healthcare systems mainly focus on treating illnesses rather than promoting holistic health and wellbeing. Emerging technologies and innovative healthcare practices have the potential to optimize resource utilization, reduce waste, and enhance the overall quality of care [4].

Telemedicine involves using information and communication technologies to offer care services at a distance [5], allowing the share of medical information among different stakeholders. It enables healthcare providers to evaluate, diagnose, and treat patients without a face-to-face interaction. Indeed, patients can communicate with clinicians from their home using personal technology or specific medical devices. It has a wide range of uses, including online patient consultations, remote control, telehealth nursing, and remote physical and psychiatry rehabilitation. Telemedicine adoption has been trending upward recently, with particular growth in the past two years, following the COVID-19 pandemic [6]. Telemedicine has proven to be a prompt and effective response, allowing the continuity of healthcare despite the restrictions imposed by the need for social distancing [7]. Thanks to this technology, patients have been able to receive medical consultations and monitor their conditions without the need to physically move to a medical facility, thus minimizing the risk of exposure to the virus.

Telemedicine has emerged as a powerful tool to enhance the accessibility of care for patients residing in remote or rural areas where conventional healthcare services may be scarce or entirely unavailable [5]. Remote care can bridge geographical gaps, reducing the need for patients and healthcare professionals to travel long distances to receive or provide medical care. For this reason, the adoption of these technologies is currently cited in the literature as an option to make the healthcare sector greener [8]. However, for a more realistic understanding of the impacts generated by these new technologies, a broader assessment is needed. As such, it is crucial to identify the methodologies and indicators relevant to the environmental, social, and economic dimensions. These dimensions play a pivotal role in establishing measures and standards for the application of a sustainable development framework in the context of telemedicine. To achieve this result, the various stakeholders involved in the telemedicine process are required. Their perspectives make it possible to generate a more comprehensive perspective of potential impacts [9].

Based on this context, the main aim of the present study is to comprehensively explore approaches and methodologies employed in the literature to quantify the sustainability impacts of telemedicine activities. Therefore, the following section introduces a scientific background for understanding how sustainability pillars are estimated in the healthcare field, with a particular attention to remote care. The search strategy is proposed, and the article selection process and analysis are presented. Finally, discussions and conclusions are drawn.

2. Scientific Background

Global interest in sustainable healthcare has been growing, implying the need for healthcare systems with better environmental, social, and economic impacts [10]. The health element has been introduced as the third point of the Sustainable Development Goals (SDGs) defined by the World Health Organization (WHO) in the 2030 Agenda [11]. This goal has been further subdivided into 13 specific targets, to ensure a comprehensive and multifaceted approach to healthcare sustainability. On the other hand, as declared by the WHO, the other 16 SDGs have direct or indirect linkages with health, defining a web of interconnecting goals for a sustainable development framework [12]. As described by Charlesworth K.E. et al. [13], a systemic perspective is required due to the complexity of health's context. The full range of its stakeholders and their different perspectives have to be considered in order to perform a complete analysis and support decisions with lasting and positive effects.

Sustainability concepts have partially been investigated in the healthcare field. The high impact generated by healthcare systems on the environment is already well known [14]. One of the main reasons why hospitals are considered the main contributors to environmental damage concerns greenhouse gas (GHG) emissions. The 2022 Lancet Countdown Report showed an increase in healthcare emissions to 2.7 Gt of CO2 equivalent (CO2eq), which accounts for 5.2% of global emissions [15]. On the other hand, healthcare facilities generate a large amount of waste, including hazardous and non-hazardous waste, responsible for negative impacts on the environment and public health [16]. To ensure better management, it is essential to measure the pressures of healthcare activities on the environment [14], with a primary focus on reducing carbon emissions, minimizing waste, and optimizing energy consumption, preferably from renewable sources [1,17]. A previous study conducted a literature review to identify the methodologies applied for the quantification of environmental impact in the healthcare field [18]. As included in the review, a significant portion of studies has centered on the analysis of devices and instruments used in clinical practice. In these studies, single-use and reusable devices have been investigated, applying the standardized Life Cycle Assessment (LCA) approach. In contrast, a systematic and standardized methodology for assessing the environmental impact of hospital care processes and clinical activities has not been identified yet.

Social sustainability plays a key role in pursuing patient welfare and increasing the quality of care delivered. In order to reach this goal, healthcare systems have to mobilize and allocate sufficient and appropriate resources (human, technology, information, and finance) to meet individual and public health needs [19]. Mehra R. et al. [20] have highlighted the presence of many social indicators that are extrapolated by several techniques, strategies, and practices. They concern, for example, patients' satisfaction, the workforce, education and training, and accessibility. On the other hand, Kaur Rattan T. et al. [21] have defined a multidimensional framework composed of seven dimensions to determine the sustainability level of healthcare services. They also include topics such as performance reporting and budgeting, while also considering economic aspects. Indeed, an economic impact assessment cannot be ignored, as this can allow the solution to be adopted and maintained over time.

Telemedicine has been identified as one of the most promising avenues for investment in reducing the environmental impacts of the healthcare sector, primarily due to its potential to mitigate the physical transportation of individuals. Ramyadevi Ravindrane et al. [22] found telemedicine to have an environmental benefit versus face-to-face consultations, with reduced greenhouse gas emissions. Pickard Strange M. et al. [23] concluded that all of the papers included in their literature review estimated that virtual consulting significantly reduced carbon emissions. Nevertheless, the amount of total carbon emissions saved varied significantly, due to the different service and healthcare delivery model under consideration. Lenzen M. et al. [15] suggest that the environmental impact of healthcare varies across these indicators and is not confined to greenhouse gas emissions, as previously found. The limited consideration of wider factors related to the adoption, use, and spread of these technologies has been highlighted [23]; hence, a comprehensive evaluation is required, extending the environmental viewpoint to a sustainable development framework.

The social aspect of telemedicine plays a fundamental role in delivering high-quality services, always placing a human-centered design at its core. As highlighted by Papavero et al. [24], it is essential to conduct assessments that consider not only the patient but also other stakeholders, such as caregivers, who interact with the patient and can benefit from telemedicine. However, the fragmentation and lack of consistency across studies make it challenging to approach this important topic and evaluate the generated impacts. Given the interest in the topic, several studies in the literature have attempted to define methods for the quantitative assessment of the sustainability of telemedicine activities. The difficulty in achieving a systematized approach is largely due to the complexity of the healthcare sector, the involvement of various stakeholders, and the challenges associated with data acquisition [25]. There is a clear need for a systematic assessment that includes all stakeholders involved. To gain a general overview and identify the methods and indicators for assessing the overall impact of telemedicine, in-depth analyses are required. This will enable the integration of these findings into a systemic and reproducible vision of the field, thereby contributing to improving the quality of telemedicine services and optimizing the benefits for all stakeholders.

In the defined context, the present research aims to conduct a systematic literature review to comprehend how the environmental, social, and economic impacts of telemedicine are currently assessed. Specifically, the research questions guiding the review are:

1. Which aspects are investigated to estimate the sustainability impacts of telemedicine and how are they combined for comprehensive evaluation?
2. Which methodologies are applied to perform a quantitative evaluation of telemedicine's impacts?
3. Have methodologies allowed single-aspect assessments or reached more sustainability pillars, aligning with sustainable development?

Hence, the existing gaps that still need to be integrated for a comprehensive evaluation are discussed.

3. Research Methodology

A systematic literature review is intended to collect and analyze data from a wide range of articles, allowing clearly stated and extensive coverage of a specific topic. A research protocol has been defined for the systematic identification and inclusion of the articles into the review. At this stage, the protocol has not been registered.

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework was chosen due to its completeness and reproducibility. In particular, the PRISMA methodology formalizes the research and tracks the process of article selection. It helps to ensure the quality of the review, mitigating the risk of bias [26] by means of its 4 standard phases: identification, screening, eligibility, and article inclusion.

3.1. Search Strategy

The Scopus and PubMed databases were chosen for article selection due to their completeness regarding the interested topic. An initial screening process was carried out to determine the keywords to be used in the search. Specifically, the research aims to conduct a comprehensive investigation that encompasses all three pillars of sustainability, in order to investigate their eventual correlation. For this reason, the search strategy was applied, utilizing keywords related to environmental, social, and economic sustainability concepts combined with telemedicine topics.

The list of selected keywords is shown in Figure 1. In addition to "telemedicine", the word "ehealth" was used to extract articles related to digital care. Indeed, the terms are sometimes used interchangeably, even if they have slightly different meanings [27]. Moreover, terms indicating specific telemedicine activities were used, such as "teleconsultation," "telemonitoring," and "televisit". The terms related to the environmental pillar have been extrapolated from published literature reviews related to the sustainability of the healthcare field [18,23,28]. To improve the research, the terms "energy efficiency" and "energy measurement" have been added to the queries. Finally, the remaining two sustainability pillars, "social sustainability", "soci* impact" have been searched because these are very present in the literature [29,30]. In addition, the term "cost–benefit" was included because it allows for the inclusion of not only economic but also social aspects. Moreover, it was employed to perform integrated and comprehensive impact analysis [31]. While terms within each category were correlated with Boolean OR logic, Boolean AND logic was used between categories (Figure 1). The research was conducted by searching the selected terms in the title, abstract, and keywords of articles.

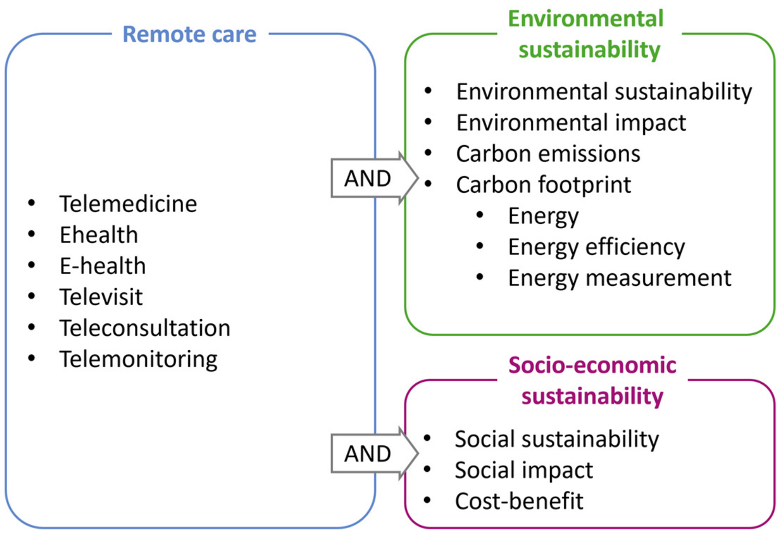

Figure 1. Definition of searching queries, combining the selected keywords using the Boolean logics.

3.2. Inclusion and Exclusion Criteria

A set of inclusion and exclusion criteria have been defined in order to only select articles relevant to the research. Specifically, articles were included based on the following criteria:

- Peer-reviewed, full-text papers presenting original studies;
- Papers designed as a prospective study, retrospective study, cross-sectional study, survey study, case study, quasi-experimental study, randomized controlled trial, pilot study, observational study, exploratory study, or multi-stage model;
- Papers reporting telemedicine activities (i.e., televisits, telemonitoring, teleconsultation, . . .) or its instrumentation (i.e., mobile apps, ICT, AI. . .);
- Papers with the aim of quantifying at least one sustainability impact (i.e., environmental, social, or economic impact) that telemedicine has on care processes;
- Papers that consider the perspective of patients or other stakeholders involved in telemedicine processes (medical personnel, public health, environment, society).

On the other hand, the following were excluded:

- Papers where telemedicine is used only partially;
- Papers concerning telemedicine where sustainability impacts were not assessed;
- Papers not reported in English;
- Papers that do not satisfy all inclusion criteria.

The review investigates the evolution of the topic during the last decade; hence, papers published between 2013 and 2023 were, included. This selection provides a comprehensive analysis of the influence of the COVID-19 pandemic, the increasing prevalence of telemedicine initiatives, and the growing interest in sustainability-related subjects in recent years.

3.3. Selection Process, Data Collection, and Synthesis

Papers identified via the databases were imported into an Excel table and duplicates were manually removed. The screening procedure allows one to select only pertinent studies by means of an initial analysis of the title and abstract. During the eligibility phase, all remaining articles were reviewed, applying the inclusion and exclusion criteria defined in the protocol. Then, the selected articles were included in a final list, for later analysis.

Because of the novelty of the research topic, at this primary stage no constraints on the quality of the articles have been imposed, with the aim of providing a more comprehensive and general overview. As proposed by Pickard Strange M et al. [23], no articles were excluded on the basis of quality appraisal, due to the lack of reference checklists. The employment of specific databases (i.e., Scopus and PubMed), was the unique quality filter for the inclusion in the search phase.

In addition to general information, during results analysis, a mapping of the most commonly used telemedicine techniques (i.e., televisit, telemonitoring. . .) was performed. Additionally, the included medical specialties and the types of treated patients were examined. Furthermore, considering the focus of the research on sustainability estimations, we explored whether the articles addressed one or more pillars in their evaluations.

The last part of the analysis involved a deeper investigation to understand the predominant themes within each pillar of sustainability. Hence, the methods and tools used to quantify the impacts of the aspects have been highlighted. The results are discussed below to understand their benefits and limitations, as well as their comprehensiveness.

4. Results

4.1. Article Selection

Systematic research was conducted in late 2022 and updated during 2023 to incorporate the latest developments in this emerging topic. Conducting the research twice allowed previously identified studies to be cross-checked; eventual inconstancies were thus evaluated and resolved. The searching process and the article selection phase are detailed in Figure 2. The search in the Scopus and Pubmed databases was conducted in two distinct phases, initially focusing on environmental aspects, and subsequently extending to other sustainability dimensions. During the identification phase, 477 articles were initially found by applying the search strategy and keywords as outlined in the protocol. Among these preliminary results, 120 studies were identified as duplicates by a researcher, who read and manually removed them. Consequently, they were excluded, leaving 357 articles for the screening process. In the following phase, 99 studies were deemed irrelevant to the designated topic and eliminated. The remaining 258 articles were subjected to a rigorous evaluation based on the inclusion and exclusion criteria. During the eligibility phase, 167 articles were considered ineligible for different reasons. Specifically, 33 papers with the wrong context did not analyze telemedicine or only mentioned it. On the other hand, 48 papers with a wrong aim investigated other aspects of telemedicine, not including sustainability. Nine papers were excluded because they were not in English. Additionally, 77 papers with reviews and qualitative and general descriptions were not considered because our attention is directed at real case studies and applications. Consequently, 91 articles that aimed to quantitatively assess the sustainability of telemedicine were included in the review and subjected to the subsequent analysis process.

4.2. Descriptive Results

The data included in Figure 3 confirm the growing interest in this research topic. Specifically, a noticeable increase was recorded after the publication of the 2030 Agenda and after the call for a greater emphasis on sustainable development themes by the WHO. The positive trend has also been confirmed in the last year, considering also that a portion of the articles has not been published yet.

By investigating the countries involved in the selected articles, a clear predominance was observed in the United States, accounting for 32% of the results (Figure 4). Other countries actively involved in these topics were Spain and the United Kingdom, each with eight published articles. Finally, Australia, Canada, and Italy contributed six and five publications, respectively. The remaining articles are distributed among various countries across the world.

The systematic review included articles from various journals, categorized into specific fields. As illustrated in Figure 5, approximately 47% of the articles (n = 43) were published in medical journals. Another substantial portion can be found in health informatics journals, comprising 25% of the total (n = 23). Additionally, 10% (n = 9) were included in the environmental health field and 6.6% (n = 6) in health policy journals. A minority number of studies were exclusively published in journals closely associated with environmental, energy, and engineering sciences. The most prevalent journals are dedicated to topics in environmental health and health informatics, such as the "International Journal of Environmental Research and Public Health", "Telemedicine Journal and e-Health", and "Journal of Medical Internet Research". On the other hand, several medical journals were involved, but with only a limited number of publications related to sustainability themes.

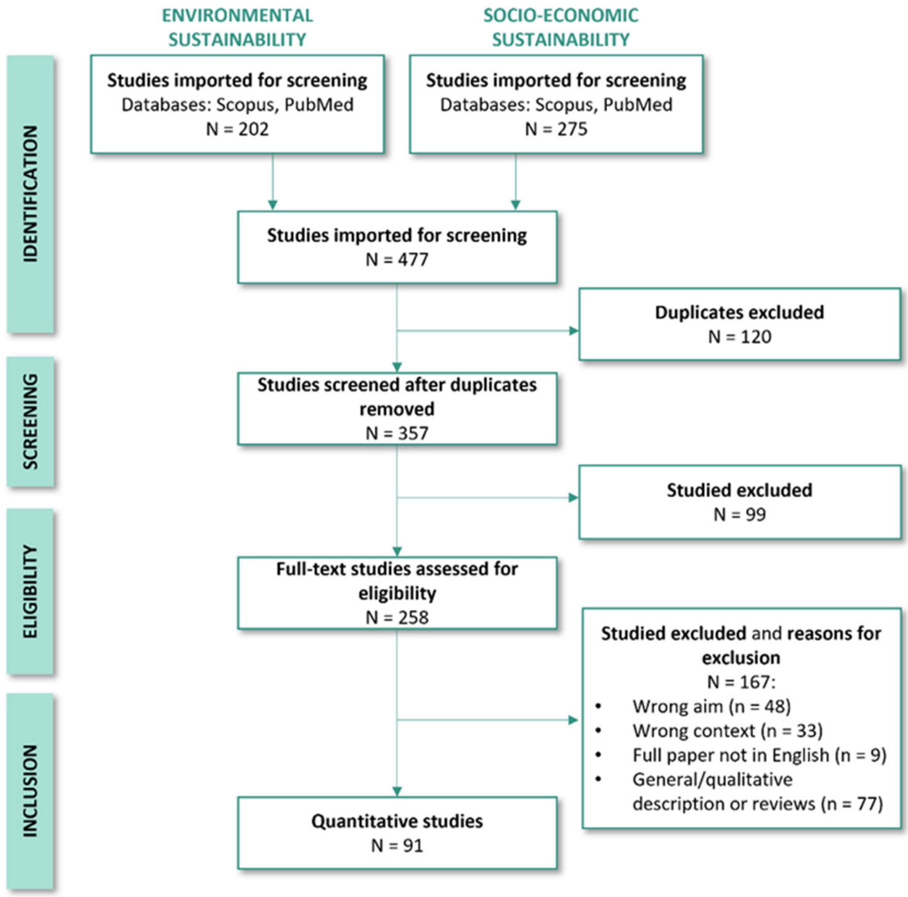

Figure 2. PRISMA diagram resulting from the process of article selection.

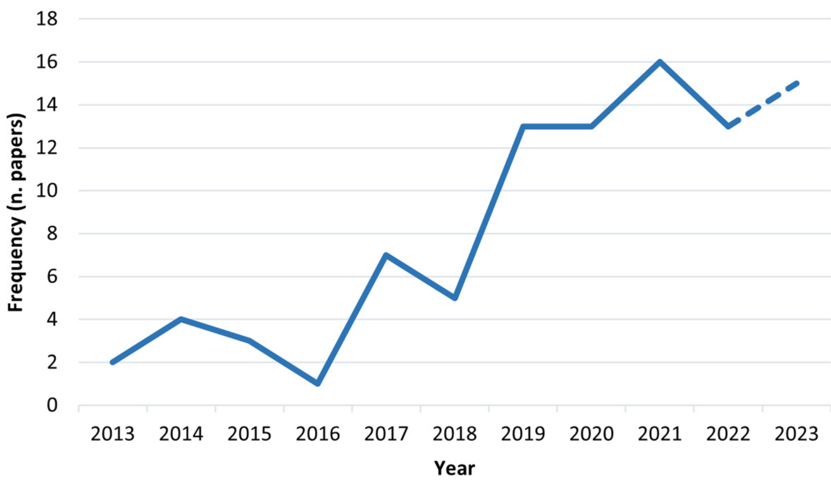

Figure 3. Number of publications included in the review over the last 10 years.

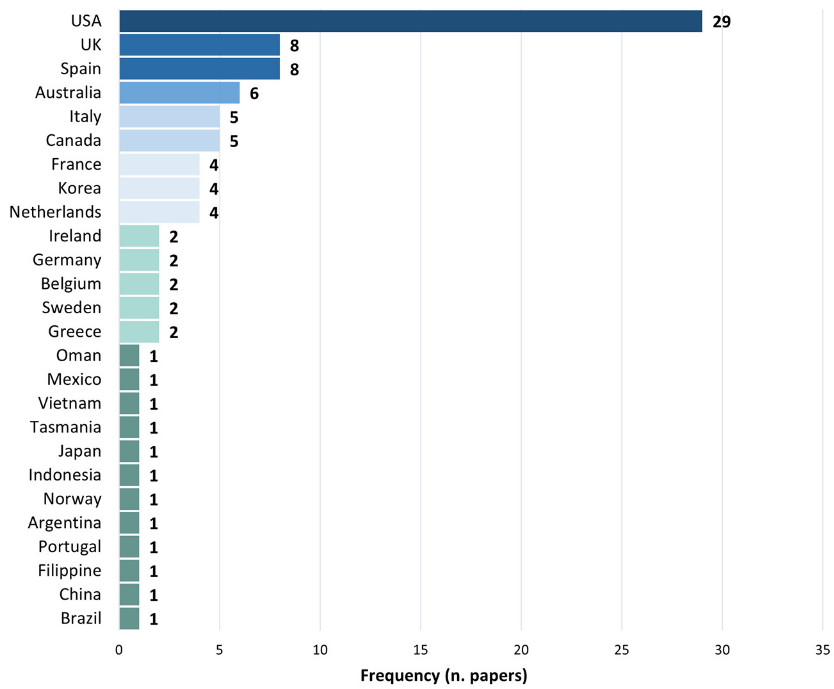

Figure 4. Location of study development.

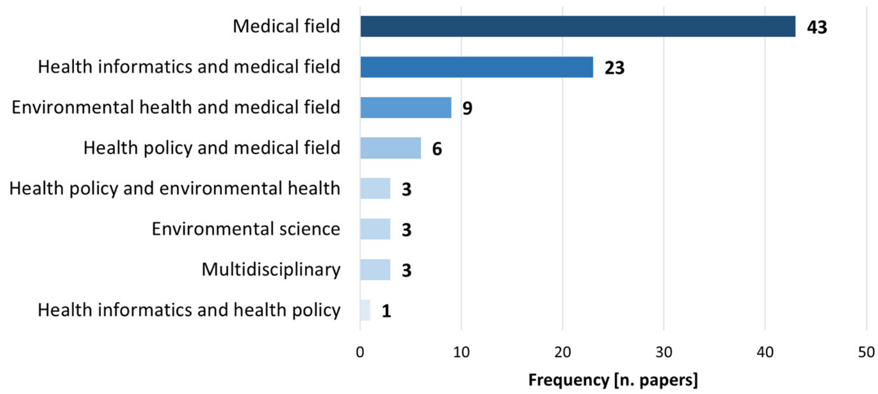

Figure 5. Main research field of international journals included in the systematic review.

The most examined telemedicine activities in the selected articles are presented in Figure 6. It was found that the 51.6% of the studies (n = 47) discussed televisit case studies to quantify generated savings and impacts. Also, telemonitoring studies are very frequent; the results show that 20 studies were dedicated to this subject. In nine cases, the specific equipment used for telemedicine was not detailed. Other studies explored different forms of remote care, such as telerehabilitation and teleconsultation, though their occurrence is relatively sporadic. Similarly, the most investigated medical specialties and their frequency were analyzed. As illustrated in Figure 7, a substantial portion of the studies did not specify a particular medical specialty but instead conducted a cross-sectional analysis across various medical units, involving more than one specialty. The remaining papers did not exhibit a specific medical specialty with significant prevalence. A higher number of studies were focused on patients with cardiovascular conditions, totaling 12 papers. In all other instances, there were no more than six articles per disease group. Lastly, an initial analysis provided a comprehensive overview of the sustainability topics examined most often in the selected articles. As represented in Figure 8, each of the three pillars contains single-topic studies, with 11 papers addressing social sustainability, 14 concentrating on environmental sustainability, and 15 delving into economic sustainability. On the other hand, numerous studies aimed to integrate these pillars, conducting more comprehensive analyses. Specifically, seven studies encompassed both social and environmental aspects, while twenty-eight papers incorporated socio-economic dimensions. Finally, 16 articles explored themes encompassing all three sustainability impacts, taking a broader approach to the subject matter.

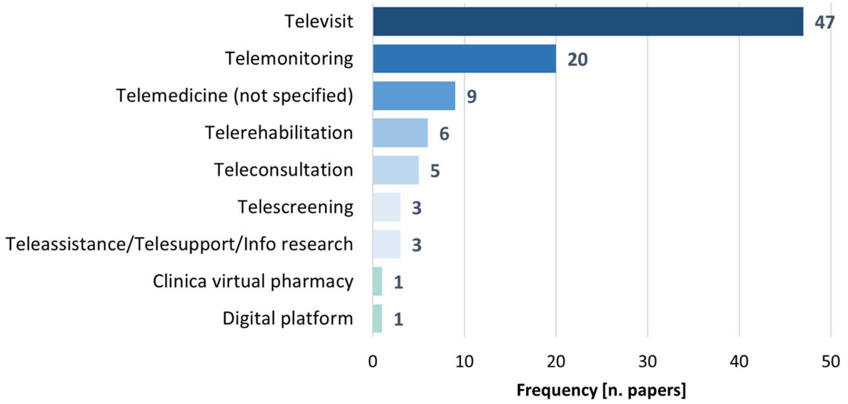

Figure 6. Number of telemedicine activities analyzed in the articles included in the literature review.

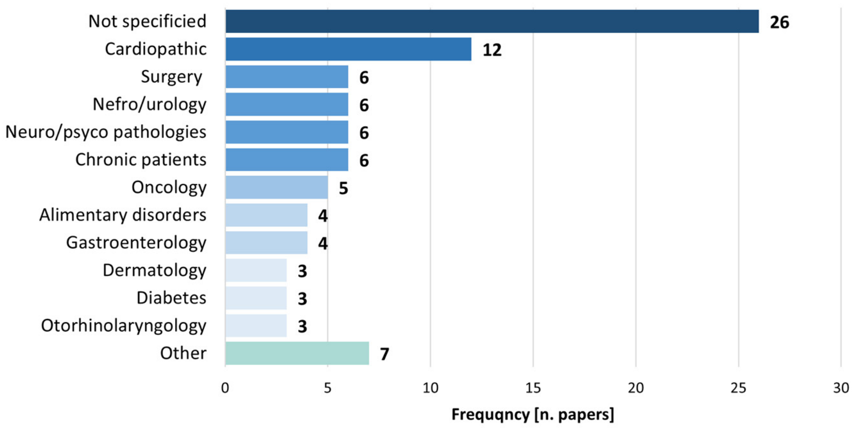

Figure 7. Medical specialties studied in the selected articles.

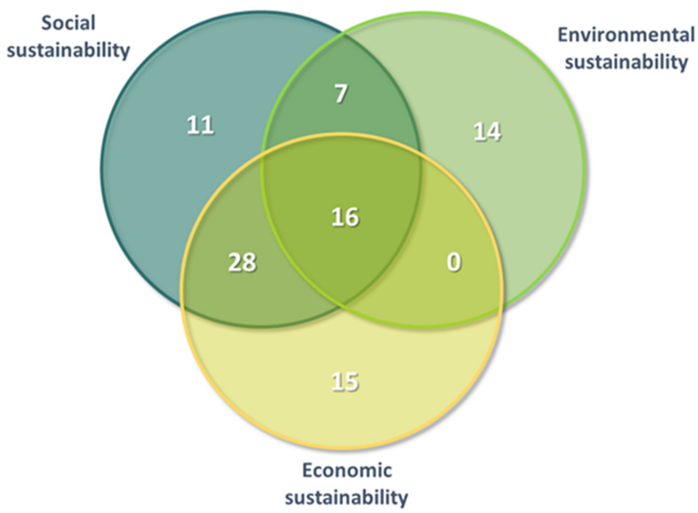

Figure 8. Number of sustainability pillars investigated in selected studies.

4.3. Findings on Applied Methodologies

In order to answer the first research question, the parameters used to quantify the sustainability of telemedicine activities were extrapolated from each selected article. Therefore, a synthesis of the impacts studied in the literature was created, focusing on environmental, social, and economic aspects. The investigation concerned whether a specific parameter was present in studies exclusively dedicated to a single sustainability pillar or derived from a paper integrating two or three sustainability aspects. The results of this primary analysis are reported in Table 1.

Table 1. Investigation of the environmental (A), social (B), and economic (C) sustainability parameters employed in the selected studies and an analysis of their correlation.

		Sustainability Studies					
		Environmental	***Social***	***Economic***	***Socio-Environmental***	***Socio-Economic***	***Socio-Eco-Environmental***
(A)	Travel reduction	✓			✓		✓
	Energy consumption	✓			✓		
	Embodied energy	✓					
	Data transmission	✓					
	Waste management	✓					
(B)	User experience		✓		✓	✓	✓
	Quality of life		✓			✓	
	Medical outcome		✓		✓	✓	✓
	Security		✓				
	Acceptability		✓				
	Digital literacy		✓				
	Time savings		✓		✓	✓	✓
	Accessibility					✓	
	Workload					✓	
	Avoided car collisions						✓
(C)	Medical activity costs			✓		✓	✓
	Technology costs			✓		✓	
	Travel costs			✓		✓	✓
	Patients' avoided costs			✓			✓
	New hub investments			✓			
	Productivity loss					✓	✓
	Training costs			✓		✓	
	Environmental costs						✓

Among the examined environmental aspects, travel reduction and energy consumption emerged as cross-cutting themes across multiple sustainability aspects. Specifically, the analysis of the reduction in environmental impacts related to reducing travel appeared in articles addressing all three sustainability aspects. In contrast, more technical and specific investigations, such as the quantification of embodied energy, data transmission, and waste management, were only present in studies specifically focused on ecological topics. A greater number of parameters are used to evaluate the social field. Some specific themes, such as service acceptability, safety, and digital literacy, were predominantly included in studies related to the quantification of single social impacts. Other topics, such as user experience, quality of life, medical outcomes, and time savings were employed for integrated assessments. While user experience and medical outcome evaluation were present in a greater number of cross-sectional studies, workload and avoided traffic incidents only appeared in socio-economic and socio-economic-environmental studies, respectively. Finally, in economic evaluations, the considered costs are often similar, and they have appeared in articles focused solely on economic assessments, as well as in more comprehensive studies.

Only the parameter related to the costs incurred for investing in a new hub were found exclusively in economic studies.

A further investigation assessed the frequency with which specific parameters were employed to quantify the sustainability impact of telemedicine solutions. Following the same clusters as the previous analysis, the parameters are categorized and included in Table 2.

Table 2. Analysis of the combination of indicators used to quantify impacts related to one or more sustainability issues of telemedicine.

Sustainability Pillars	**Investigated Aspects**		
	Environment	**Society**	**Economy**
Environmental (n = 14)	- Travel reduction (n = 7); - Energy consumption (n = 1); - Embodied energy, energy consumption (n = 1); - Travel reduction, energy consumption, data transmission, waste management (n = 4); - Travel reduction, energy consumption (n = 1).	-	-
Social (n = 11)	-	- User experience (n = 1); - User experience, time savings (n = 1); - User experience, quality of life, medical outcome (n = 2); - Medical outcome, quality of life (n = 1); - Medical outcome (n = 2); - Medical outcome/quality of life, security (n = 2); - Acceptability (n = 1); - Digital literacy (n = 1).	-
Economic (n = 15)	-	-	- Medical activity costs (n = 6); - Medical activity and technology costs (n = 2); - Medical activity and travel costs (n = 2); - Training costs (n = 1); - Medical activity, technology, and patients' avoided costs (n = 1); - Medical activity, travel, patients' avoided costs (n = 1); - New hub investments, patients' avoided costs (n = 1).
Socio-environmental (n = 7)	- Travel reduction (n = 4); - Energy consumption (n = 1); - Travel reduction, energy consumption (n = 2).	- User experience (n = 3); - Medical outcome (n = 2); - Time savings (n = 1); - User experience, time savings (n = 1).	-

Table 2. *Cont.*

Sustainability Pillars	Investigated Aspects		
	Environment	Society	Economy
Socio-economic (n = 28)	-	- Quality of life (n = 12); - User experience (n = 4); - Medical outcome, user experience/accessibility (n = 3); - Medical outcome (n = 2); - Productivity (n = 1); - Accessibility (n = 1); - Quality of life, user experience (n = 1); - Medical outcome, quality of life, user experience (n = 1); - Medical outcome, time saving, user experience (n = 1); - User experience, workload, time saving (n = 1); - Quality of life, user experience, workload, security (n = 1).	- Medical activity costs (n = 9); - Medical activity and technology costs (n = 5); - Medical activity cost, production loss (n = 5); - Medical activity and travel costs (n = 3); - Travel costs (n = 2); - Training and technology costs (n = 2); - Training costs (n = 1); - Technology costs (n = 1).
Socio-eco-environmental (n = 16)	- Travel reduction (n = 16)	- Time saving (n = 10); - Time saving, user experience (n = 3); - Medical outcome (n = 1); - Medical outcome, user experience (n = 1); - Time saved, avoided car collisions (n = 1).	- Travel cost (n = 9); - Travel cost, waiting time/production loss costs, environmental costs (n = 1); - Travel cost, activities cost (n = 1); - Average person cost (not defined) (n = 1); - Medical activity cost (n = 1); - Travel cost, production loss cost (n = 3).

Specifically, reduction in transport-related emissions emerged as the most investigated aspect in articles focusing on environmental sustainability, appearing either independently (n = 6) or in conjunction with other factors (n = 5). Within this specific domain, this parameter was frequently expanded through an assessment of energy consumption, data transmission, and waste management, providing a comprehensive evaluation (n = 4). Simultaneously, transport reduction was the most extensively studied even in articles addressing socio-environmental topics, appearing four times as a single parameter and twice in combination with energy efficiency. Conversely, this parameter was the sole focus in papers investigating socio-economic-environmental aspects (n = 16). Parameters used for environmental sustainability assessment are often combined in various ways without a clear dominance. Among the key aspects investigated are user experience and the evaluation of medical outcomes, albeit combined differently with other factors. Similarly, in articles related to socio-environmental themes, no dominance was observed. In contrast, socio-economic studies demonstrated a strong emphasis on quality of life, either as a singular theme (n = 12) or combined with other aspects (n = 3). The second most frequent parameter is user experience, often combined with other sustainability parameters (n = 8). Conversely, in studies spanning all sustainability pillars, time savings are predominantly evaluated, mainly as a single social parameter (n = 10), or in combination with user experience (n = 3) and avoided road accidents (n = 1). Finally, the most utilized economic parameter is the cost associated with medical activities, both in studies specifically focused on economic sustainability (n = 6) and socio-economic sustainability (n = 9). In the latter case, these are frequently paired with technology costs (n = 5), production loss (n = 5), and travel costs (n = 3). Travel cost is the most common parameter in studies transcending all three sustainability aspects, appearing in nearly all articles in this cluster either independently (n = 9) or combined with more specific aspects (n = 5).

The final section concerns the second and third research questions; the results show the specific methodologies applied to quantify the impacts of telemedicine activities. Information and references were collected for each of the previously investigated parameters and are presented in Table 3.

Within the selected list of papers, 24 articles utilized official national databases to obtain specific conversion factors, enabling the quantification of environmental impacts, with a primary focus on reducing transportation. In particular, the United States Environmental Protection Agency (US EPA)'s conversion factors have emerged as the most frequently employed, featuring in nine distinct studies [32–40]. The determination of physical distances between patients' residences and healthcare provider locations involved the utilization of tools such as Google Maps, zip codes, or other geospatial data tools. In three articles [41–43], the same approach was also applied to assess impacts related to both transportation and energy consumption. Online carbon calculators were employed in three cases. Also, the standardized LCA approach was identified in three articles [44–46], in which the environmental impacts of travel reduction, embodied and consumed energy, waste management, and in one case internet data were quantified. Other methodologies were applied only to specific single cases. For instance, the Framework for Energy Efficiency Testing to Improve eNvironmental Goals of the Software (FEETINGS) method has enabled the assessment of energy consumption, performing the power consumption measurements [47]. The Carbon Trust Method, on the other hand, has allowed for a more comprehensive evaluation focused on travel reduction, energy consumption, data transmission, and waste management [48]. Another study conducted a similar analysis but involving average values [49]. In one case, energy consumption was measured using specific instrumentation [50], while in another case, information on reductions came from interviews [51].

For the evaluation of social aspects, standardized questionnaires, structured interviews, and surveys were identified as the most frequent methods, appearing 25 times. This approach was primarily used to gather information related to patients' user experience. To obtain results, several different questionnaire forms were detected, highlighting a missing common approach. For example, the Telemedicine Usability Questionnaire (TUQ) [36], the Telemedicine Satisfaction Survey (TeSS) [35], the System Usability Scale (SUS) [52,53], and the Telemedicine Satisfaction and Usefulness Questionnaire (TSUQ) [54,55] were identified in the selected articles. These assessments were often integrated with [56] other parameters related to medical outcomes, quality of life, and time saved. Specific standardized questionnaires, such as the five-level EQ-5D (EQ-5D-5L) [57–60], were applied to assess patient quality of life. More specific impacts, such as digital literacy, were investigated using ad hoc designed structured interviews [61]. On the other hand, information acquisition was performed via patients' medical records in seven articles [37,39,43,51,54,62,63] in order to analyze medical outcomes, time saved, and in one case, user experience related to time saved. The Markov simulation model was used twice for quantifying quality of life [60,64] and, in a single case, for evaluating medical outcomes and user experience [65]. In contrast, retrospective and statistical analysis were applied three times for the detection of quality of life [66], acceptability [67], and an integrated evaluation of medical outcomes, quality of life, and safety [68]. Official national databases and documents were primarily used to assess time saved, emerging six times to integrate the evaluation with environmental and economic impacts [38,55,56,69–71]. Other methodologies appeared only in individual articles. For example, the Nielsen Usability Heuristics were used once to evaluate user experience [50]. The Morisky scale combined with HRQoL was used for the assessment of quality of life [72,73]. Momentum's 18 critical criteria and Kingdon's framework were involved in assessing service accessibility in one article [74].

Various methodologies have been employed to collect information and conduct specific analyses. Specifically, within the socio-economic article cluster, two papers implemented cost–utility analyses [75,76], eight studies employed cost-effectiveness surveys [52,58,60,64,77–80], eight conducted cost–benefit analyses [57,74,81–85], and one utilized the classic cost accounting technique [56]. Cost–benefit analyses were also detected in articles included in the economic cluster [86–93]. In this case, costs and benefits were defined in monetary terms, including via the Net Present Value (NPV), Internal Rate of Return (IRR), and Quality of Service (QoS). This approach was identified in eight papers. However, despite the potential for integrated assessments, these methodologies were not identified in cross-sectional analyses across all three sustainability pillars in this review. Other methodologies were employed for quantifying economic impacts and applied to individual case studies, such as time series [94], cost analysis [95], and EBIT and WACC evaluation [96].

Table 3. Methods and tools used to quantify specific parameters and to perform sustainability analyses of telemedicine activities.

Investigated Aspects			Methods and Tools	Source
Environment	Society	Economy		
Travel reduction	-	-	• Retrospective analysis and definition of KPIs; • Greenhouse Gas Protocol, NHS Carbon Footprint Plus and UK Government; • Google Maps, US EPA GHG conversion factors; • Zip codes, Alteryx's analytic platform (geospatial data), US EPA conversion factors; • Oman MoH National HIMS; • Online carbon calculators.	[97] [98] [32] [33] [99] [41,42]
Energy consumption	-	-	• Framework for Energy Efficiency Testing to Improve eNvironmental Goals of the Software (FEETINGS).	[47]
Embody energy, energy consumption			• LCA, sensitivity analysis.	[44]
Travel reduction, energy consumption, waste			• LCA, sensitivity analysis.	[45]
Travel reduction, energy consumption, data transmission, waste management	-	-	• Carbon Trust Method; • Geodesic distance, average values of consumption, unadjusted Poisson regression; • LCA, Monte Carlo analysis.	[48] [49] [46]
Travel reduction, energy consumption	-	-	• ArcGIS, US EPA conversion factors.	[34]
-	User experience	-	• Questionnaires, multiple linear regression analysis.	[100]
-	User experience, quality of life, medical outcome	-	• Questionnaires, modified Morisky scale, patient assessment; • Qualitative interviews.	[72] [101]
-	Medical outcome, quality of life	-	• Korean version of the HRQoL, Korean version of the modified Morisky scale (secondary data).	[73]
-	Medical outcome/quality of life, security	-	• Estimation of retrospective analysis; • Online survey and correlation analysis.	[68] [102]
-	Medical outcome	-	• Patients' records; • Structured questionnaires.	[62] [103]
-	Acceptability	-	• Statistical analysis of access (R software (version 4.0.0)).	[67]

Table 3. *Cont.*

Investigated Aspects			Methods and Tools	Source
Environment	Society	Economy		
-	Digital literacy	-	• Questionnaires (internet health information-seeking behaviors, eHealth Literacy Scale, Social Support Scale, Self-Rated Abilities for Health Practices Scale, Health-Promoting Lifestyle Profile II).	[61]
	User experience, time savings		• Google Maps, telephone questionnaires.	[104]
-	-	Medical activity costs	• Time series analysis; • Cost–benefit analysis; • Economic approach (EBIT, WACC); • Prospective observational study, survey, sensitivity analysis; • Prospective analysis, generalized estimating equation models; • Health economic (Markov) model, ROI.	[105] [86] [96] [106] [107] [108]
-	-	Medical activity and technology costs	• Cost–benefit analysis (NPV, IRR, QoS) (n = 2).	[87,88]
-	-	Medical activity and travel costs	• Cost analysis (transfer cost, face-to-face appoint cost, telemedicine cost); • Cost–benefit analysis, NPV, IRR, payback period; • Cost–benefit analysis.	[95] [89] [90]
-	-	Training costs	• Cost–benefit analysis.	[91]
-	-	Medical activity, technology, and patients' avoided costs	• Cost–benefit analysis.	[92]
-	-	Medical activity, travel, and patients' avoided costs	• Economic analysis (cross-sectional design and collection of secondary data in electronic media).	[109]
-	-	New hub investments, patients' avoided costs	• "Patient benefit" cost savings, "peripheral site benefit" cost analysis.	[93]
Travel reduction.	User experience	-	• EPA conversion factors—Telemedicine Satisfaction Survey (TeSS); • US EPA conversion factors, Telemedicine usability questionnaire (TUQ).	[35] [36]
Travel reduction.	Time savings	-	• US EPA conversion factors, medical records.	[37]
Travel reduction.	User experience, time savings	-	• German Federal Environment Agency, questionnaire.	[110]
Energy consumption	User experience	-	• Energy consumption measuring equipment, Nielsen usability heuristics.	[50]
Travel reduction, energy consumption	Medical outcome	-	• Conversion factors, patients' records, and clinicians' interview; • Google Maps, annual report produced by The Department for Business, Energy, and Industrial Strategy, GraphPad, Prism and SPSS Statistics 20.	[51] [111]
-	Quality of life	Technology and training costs	• Cost–utility analysis; • Cost-effectiveness analysis (Markov Model), sensitivity analysis.	[75] [64]
-	Quality of life	Medical activity and production loss costs	• Cost effectiveness (Eating Disorder Examination Questionnaire global scores, EQ-5D-5L, ICECAP-A); • Cost–benefit analysis; • Modelled cost–utility analysis, sensitivity analysis.	[57] [112] [76]

Table 3. *Cont.*

Investigated Aspects			Methods and Tools	Source
Environment	Society	Economy		
-	Quality of life	Medical activity costs	• Cost-effectiveness analysis (n = 2); • Cost-effectiveness (EQ-5D-5L questionnaires, focus groups, physical tests); • Cost–benefit analysis.	[77,78] [58] [81]
-	Medical outcome, user experience	Medical activity costs	• Markov cohort-level simulation (MOS SF-36 and PEQ questionnaires); • Survey on patient demographics, referral information, session outcomes, costs and patient and T-SP satisfaction.	[65] [63]
-	User experience	Travel costs	• Cost–benefit analysis.	[82]
-	User experience	Technology, production loss costs	• Technical, clinical feasibility, cost-effectiveness (SUS, TAM, time spent, adherence, interviews).	[52]
-	Medical outcome, quality of life, user experience	Medical activity and technology costs	• Cost effectiveness (Patients medical outcomes, CCI, SF-12, EuroQoL-5D), TSUQ.	[54]
-	Medical outcome, user experience, time saving	Medical activity costs	• Cost–benefit analysis, treatment adherence, patient satisfaction, time spent, and cost.	[83]
-	Quality of life, user experience, security, workload	Medical activity and technology costs	• Mini-Mental State Examination (MMSE), the clock drawing test, and the five-level EQ-5D (EQ-5D-5L). Semi structured interviews with patients and healthcare professionals. Costs from databases.	[59]
-	User experience, time saving, workload	Medical activity costs	• Telephonic EDAD questionnaires and "replacement cost method".	[113]
-	Productivity	Medical activity and production loss costs	• Cost–benefit analysis, Bayesian approach.	[84]
-	User experience	Medical activities costs	• Cost-effectiveness (PREMS survey), cost–benefit analysis, Monte Carlo analysis.	[79]
-	Medical outcome, user experience	Medical activity and production loss costs	• Pain Disability Index, iMTA Medical Cost Questionnaire, SF-12, PSEQ, IPQ-K [DLV], GPE, SUS, system usage data, intervention reporting.	[53]
-	Quality of life	Medical activity and technology costs	• Cost-effectiveness (Markov patient-level simulation model, EQ-5D-5L) sensitivity analysis.	[60]
-	Quality of life	Training costs	• Regression approach ("Meta- and cost-effectiveness analysis of commercial weight loss strategies") and sensitivity analysis.	[66]
-	Accessibility	Medical activity and travel costs	• Cost–benefit, Momentum's 18 critical criteria, Kingdon's "three process streams" framework.	[74]
-	Quality of life, user experience	Medical activity and, technology costs	• Epidemiological survey and trial (standardized and customized questionnaires).	[114]
-	Quality of life, medical outcome	Medical activity and travel costs	• Cost-effectiveness (36-Item Short Form Health Survey), Geriatric Depression Scale, Beck Depression Inventory, and Structured Clinical Interview for DSM-IV.	[80]
-	Medical outcome	Travel costs	• Survey to patients.	[94]
-	Medical outcome	Medical activity and travel costs	• Cost–benefit analysis.	[85]

Table 3. *Cont.*

Investigated Aspects			Methods and Tools	Source
Environment	Society	Economy		
-	User experience	Medical activity and technology cost	• Traditional cost-accounting method—patient interview.	[115]
Travel reduction	Time saving	Travel costs	• Google Maps, French National Environmental calculator conversion factor. Diesel and public transport cost; • AA Route Planner© and Google Maps, online carbon calculator (Carbon Footprint LtD), patients reports; • Google Maps, conversion factors • Retrospective analysis; • MapPoint 2013, MP Mileage 2.5, US national conversion factors; • Zip codes, US Department of Energy average.	[69] [116] [117] [118] [70] [38]
Travel reduction	Time saving, user experience	Travel costs	• Google Maps, EPA, questionnaires; • Google Maps, 2020 Federal Standard Mileage rate, TSUQ, patients reports.	[39] [55]
Travel reduction	Time saving	Travel cost, production loss costs	• AA mileage calculator, internet-based tool Map My Emissions, Office for National Statistics (web-based resources); • Google Maps, Statistical software.	[56] [24]
Travel reduction	Time saving, user experience	Travel cost, production loss costs	• PSQ-18 Satisfaction questionnaire, Canada Revenue Agency's official deduction rates.	[71]
Travel reduction	Time saving	Travel cost, waiting time/production loss costs, environmental costs	• Recommendations for empirical standard costs, evaluation approach, average gross hourly wage. German Federal Environment Agency. sensitivity analysis.	[119]
Travel reduction	Time saving	Travel cost, activity cost	• Google Maps + EPA + Bureau of Labor Statistics.	[40]
Travel reduction	Medical outcome	Average person cost (not def)	• National Tariff workbook, Google Maps and Carbon Footprint calculator, patients' records.	[43]
Travel reduction	Medical outcome, user experience	Activities cost	• Semi structured interviews. Surveys.	[120]
Travel reduction	Time saving	Avoided car collisions	• Round-trip distance, Internal Revenue Services' (IRS) 2022 standard mileage reimbursement rates, national motor vehicle crash data, vehicle emissions rate.	[45]

5. Discussion

5.1. Key Findings

The present article has examined the parameters and the methodologies applied in the literature to quantify environmental, social, and economic sustainability related to the introduction of telemedicine solutions within care pathways.

The papers included in the study represented numerous countries from diverse regions worldwide, each adopting methodologies to quantify the sustainability impacts related to telemedicine activities. The increasing trend observed in this field is reflected in the growing number of articles included in this systematic review. Indeed, an important portion of the papers were excluded during the revision process because they provided only general descriptions, without including practical case studies. For example, 15 papers exclusively related to the year 2023 were excluded during the eligibility phase. They qualitatively defined telemedicine as a means to lead the healthcare system towards sustainable development, without providing a quantification of its impacts. However, they confirm the increasing interest in extending sustainability aspects into a broader framework, encompassing not only technical but also medical fields.

The healthcare sector is experiencing the introduction and testing of new remote care approaches, with the aim of ensuring greater benefits and improving people's quality of life. As included in the review, several medical specialties have been involved in telemedicine evaluation. Despite being present in a small number of studies, heart diseases emerged as the most analyzed in these studies. Given their frailty and chronic conditions, these patients necessitate increased access to healthcare services. Hence, as they constitute a substantial portion of the current healthcare market, a more effective management approach holds the potential for significant benefits, including a reduction in impacts and enhancement of sustainability.

As evidenced by the results, televisit is the most predominant telemedicine activity highlighted in the present systematic review. Articles concerning televisit activities encompassed a variety of analyses and employed different parameters to quantify their sustainability impacts. At the same time, televisit was analyzed in the majority of articles that addressed environmental, social, and economic aspects at the same time. Specifically, 15 out of 16 selected articles (i.e., 94%) employed televisit case studies to apply methodologies and quantify impacts. In only one case out of the 16 (i.e., 6%), the telemedicine technique was not specified. While these analyses considered all three sustainability aspects, they still lack a comprehensive and broad-spectrum evaluation. Specifically, the studies predominantly concerned transport-related aspects, reduced through the adoption of remote care. In these instances, the environmental impact of televisit has been solely defined in terms of the reduction in direct emissions resulting from people's travel. Information regarding the use of devices and their life cycle and the utilization of data for information transmission remains absent in these cases. Simultaneously, the investigated social aspects were largely related to transportation, appearing as time saved in travel in 14 articles, combined occasionally with information on medical outcomes and user experience. These analyses were mainly focused on patients' perspectives, due to their central role in the healthcare supply chain. On the other hand, the inclusion of other stakeholders involved in telemedicine processes appears to be lacking. However, a comprehensive quantification of social impacts will be difficult to achieve if the role of other stakeholders is overlooked [121]. Similarly, in complete papers, the assessment of economic aspects also focused on transportation, principally including travel costs (n = 14) and related issues, such as the loss of productivity. Given the frameworks of these studies, conversion factors and national databases are often employed to perform the analysis and quantify impacts.

5.2. Contribution to the Current Literature

The increased focus on the concept of sustainable development outlined in the United Nations' Agenda 2030 has generated widespread interest on the international stage. Some nations have defined specific projects aimed at mitigating the impacts generated by healthcare systems. For instance, in June 2022, Stanford Medicine promised to reduce climate-warming emissions by 50% by 2030 and achieve net-zero emissions by 2050 [45]. Similarly, the UK National Health Service has committed to becoming a net-zero emitter by 2040, with an ambitious target of an 80% reduction between 2028 and 2032 [51]. In other cases, such as in Australia, the promotion of telehealth services is incentivized due to its potential to enhance patient accessibility, reaching even remote areas [76]. Hence, the present review has addressed the common interest in search approaches to formalize and standardize the assessment of impacts generated. As highlighted in the literature, telemedicine is perceived as an opportunity to transition towards environmental sustainability and beyond, mitigating the significant impacts generated by healthcare systems. However, while the Sustainable Development Goals (SDGs) offer a qualitative framework for impact assessment, it is crucial to understand how to operationalize and develop quantitative analyses for concrete evaluations [18]. For this reason, a clear overview of the state of this field will play a crucial role in addressing the heterogeneity of studies that have applied methodologies for a quantitative assessment of the sustainability of telemedicine solutions.

Currently, there is a lack of clarity in the literature regarding the presence of a formalized approach to addressing this issue and quantifying the benefits derived from the introduction of these new solutions. In alignment with Pickard Strange et al. [23], the evaluation of the environmental impacts of telemedicine primarily focuses on reducing transportation, with alternative methodologies being applied in only a few isolated cases. This review provides an integrated perspective compared to previous investigations, exploring not only environmental aspects but also social and economic facets. Additionally, it investigates how different sustainability aspects have been integrated, offering a more comprehensive approach within the framework of sustainable development. In particular, limited information was available regarding the concept of social sustainability. However, as revealed by the review, the exploration of social sustainability in the context of telemedicine is still in its preliminary phase. Many trials have observed and are currently demonstrating the effectiveness of telemedicine in enhancing various medical and social aspects, particularly those related to patients. The assessment of social impacts primarily focuses on user experience, quality of life, medical outcomes, and time saved due to reduced travel.

Furthermore, the review illustrates that, in the current landscape, the theme of sustainability in the healthcare sector has emerged prominently, gaining significant attention within the healthcare industry. This is evident, for example, in the topics of scientific journals included in the study. Despite the demonstrated medical benefits, there is currently a noted limited integration with knowledge related to engineering and environmental sectors. This underscores the difficulty in defining and employing objective methodologies to quantify the opportunities presented by telemedicine within the context of sustainable development. A formalized approach is still lacking, primarily due to the complexity of the system and the uncertainty of information. However, the development of an objective and comprehensive impact assessment is fundamental to designing healthcare services that efficiently utilize limited resources. Hence, additional steps should be performed, allowing a reduction in the fragmentation of approaches and a systematized, shared approach.

6. Conclusions

Sustainable healthcare requires a comprehensive approach that considers the interconnections among social, environmental, and economic factors, with the primary goal of establishing a secure, effective, and equitable system for patients and communities. The formulation and adoption of systematic methodologies enable the objective quantification of impacts, facilitating more efficient resource management to enhance sustainability. Telemedicine, as a means of providing remote care and assistance, has experienced wide adoption, with televisits emerging as the most extensively explored activity within sustainability research. The present study performed a comprehensive literature review to investigate the indicators and methodologies applied in prior research for quantifying the environmental, social, and economic impacts of telemedicine activities.

To answer the first research question, a set of indicators were presented to define the most commonly used approaches aimed to quantify impacts. The numerous indicators, particularly in the social and economic domains, have underscored the presence of several approaches, which often differ according to the research article. The lack of standardization is evident, highlighting a need for uniformity. Furthermore, it has been shown how these indicators were combined to conduct integrated assessments covering multiple aspects of sustainability. A considerable number of studies have endeavored to address environmental, social, and economic aspects concurrently, striving for a comprehensive assessment. Nevertheless, these evaluations mainly focus on travel-related aspects, including the avoidance of direct travel emissions, time savings, user experience, and transportation costs.

As shown in the investigation of the second and third research questions, several methodologies have been employed to estimate the impacts of telemedicine activities. Further work is required to systematize and define a reproducible approach. More standardized methodologies are beginning to be utilized to investigate the individual aspects of sustainability. For example, the LCA can be applied for environmental evaluation; however, it is still underutilized in telemedicine field because the uncertainty of data. On the other hand, user experience analysis is commonly used for the social aspect. Although a more in-depth analysis can be carried out in these cases, there is a lack of a systematic approach capable of comprehensively addressing the entire process.

Future Implications

In conclusion, this research serves as an initial exploration of the existing works on the subject. Future steps could consider the findings from this literature review, aiming to combine indicators and methodologies to establish a systematic and reproducible approach across various studies. Given the persisting challenges in clinical practice concerning the acquisition and quality of information for analysis, future studies could firstly focus on an individual sustainability pillar. Hence, as preliminary result, it can be possible to integrate into the analysis more equally significant aspects currently overlooked or disregarded. As a second step, it will be essential to integrate assessments across different sustainability domains, as they cannot be considered in isolation to align with the concept of sustainable development. The challenge in practice lies in applying sustainability expertise to the specific field of telemedicine, which is increasingly gaining importance over the years. Bridging the medical and engineering domains will be crucial to overcome qualitative and theoretical assessments and develop quantitative analyses. Through integrated working groups, these analyses can provide insights for healthcare practitioners, policymakers, and researchers to address the complexities of sustainable telemedicine practices. Therefore, the review can facilitate the selection of optimal solutions to support a sustainable development trajectory, reducing environmental footprints and improving the sustainability.

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