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Assessing the sustainable alignment of a sensor-based connected health system with SDGs: an evaluation model and case study

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Abstract

Purpose – The main objective of the study is to address the lack of sustainability assessments of smart connected health systems in the academic literature by presenting an assessment model to determine the alignment of these systems with the 17 Sustainable Development Goals (SDGs) proposed in the 2030 Agenda.
Design/methodology/approach – An evaluation model based on decision analysis is proposed that includes three phases: alignment framework, information gathering and assessment. This model measures the alignment of the connected health system with each of the 17 SDGs, identifying the goals and criteria associated with each SDG that the system achieves to satisfy.
Findings – The analysis reveals that the system has achieved more than 24% of the targets among the 17 SDGs. In addition, it identifies four sustainability challenges that the system potentially addresses in relation to the SDGs, providing valuable guidance for researchers and practitioners interested in sustainable health technology development.
Practical implications – The study's results have significant implications for policymakers and stakeholders in the health and technology sectors.
Originality/value – The originality of this study lies in its comprehensive approach to assessing the sustainability of connected health systems in the context of the SDGs, filling an important gap in the existing literature.

Keywords Sensor devices, Internet of things, Artificial intelligence, Sustainable Development Goals, Healthcare technology, Sustainability challenges

Paper type Research paper

1. Introduction

The World Health Organization report states that in the Decade of Healthy Aging 2020–2030, there is a healthy ageing needs to be promoted, as it will lead to improved overall services for society, an improved economy in all sectors, significant advances in social equality, and will

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generally help to drive progress in education, health, resource management and environmental protection (World Health Organization, 2021).

The number of people aged 60 years or older is expected to increase significantly by 2030, with one in every six people worldwide falling into this category (UN Department of Economic and Social Affairs, 2019). By 2050, the global population of individuals aged 60 and over is projected to reach 2.1 billion, representing a doubling of current levels. Additionally, the population of individuals aged 80 and above is expected to triple between 2020 and 2050, ultimately reaching 426 million by mid-century (World Health Organization, 2022).

In recent decades, there have been significant advances in healthcare and improvements to people's quality of life. This century has witnessed exponential growth in innovative ideas, proposals and intelligent developments that have the potential to transform global health outcomes (Masud *et al.*, 2022; Sun *et al.*, 2022). Some of the key advancements involve the Internet of things (IoT) (Qadri *et al.*, 2020), smart cities (Poongodi *et al.*, 2021), intelligent health systems (IHSs) (Priya and Rajinikanth, 2021) and artificial intelligence (Guo *et al.*, 2020), among others (Tian *et al.*, 2019).

IoT has opened up new opportunities for remote monitoring and tracking of patient health, which can enable early detection of potential health issues and improve disease management. IHSs integrate multiple technologies to create intelligent and interconnected healthcare systems that can provide personalized and efficient care to patients. Smart cities utilize advanced technologies to improve public health, safety and sustainability. Artificial Intelligence (AI) has the potential to revolutionize healthcare by enabling accurate diagnosis, prediction and prevention of diseases, as well as improving medical research and drug discovery.

These advancements hold great promise for improving global health outcomes, but they also pose significant challenges, including ethical considerations, data privacy and security concerns. Therefore, further research is needed to address these issues and ensure that these technologies are deployed in a safe, ethical and effective manner.

The adoption of IoT in IHSs is of relevant importance, as it offers the possibility to improve people's health by continuously monitoring and adapting connected intelligent healthcare systems (Khatoon *et al.*, 2020; Sadoughi *et al.*, 2020; Singh *et al.*, 2022). With the potential to revolutionize healthcare, IoT technology allows for seamless and uninterrupted monitoring of patients' health, thus enabling early detection and prevention of diseases. This technology has immense perspective to significantly increase the quality of healthcare and contribute to better patient outcomes.

Connected health systems are an integrated platform that brings together IHSs and the delocalization of these, combining health management, monitoring, diagnosis and data review in remote locations, such as a hospital or district health centre, into a single system.

Overall, IHSs have the potential to revolutionize healthcare delivery by improving efficiency, accuracy and patient engagement. As healthcare continues to face challenges such as rising costs and increasing demand, the IHSs offer a promising solution to meet these challenges and improve healthcare outcomes. There are still challenges to be addressed, such as increasing sustainability (Espinosa *et al.*, 2021), interoperability (Saripalle, 2019) and data security (Butpheng *et al.*, 2020).

The alignment of sensor-based connected health systems with the Sustainable Development Goals (SDGs) has become a crucial issue in recent years (Sachs *et al.*, 2019), particularly in terms of sustainability. In September 2015, the United Nations agreed the SDG Agenda, consisting of 17 goals and 169 targets (ONU, 2020). Despite this, no systematic study has been conducted to evaluate the extent to which connected health systems collaborate to the achievement of the SDGs in terms of sustainability. This research gap is significant, considering that these systems are increasingly being integrated into healthcare due to the aging population, and their use has a profound impact on the ability to achieve the SDGs. Addressing this gap is crucial to accelerate progress towards sustainable development and meet the challenges that lie ahead.

This paper proposes an evaluation model based on decision analysis (Clemen, 1996) for the alignment of a healthcare system with the 17 SDGs and their associated targets (Verdejo *et al.*, 2022). It includes three phases: (1) alignment framework, where the structure of the alignment process is established, (2) gathering information, where the system is analysed for each SDG objective and its associated criteria, and (3) rating value, where the percentage of target achievement is computed. The results of the analysis can help identify areas for improvement in the healthcare system's alignment with the SDGs.

The system proposed in the research is a home activity monitoring solution that reports on people's routine through a system of sensors integrated in the environment and also ubiquitous, through a computer application that can be controlled on a smartphone, tablet or computer. The system also consists of a central device connected to the electrical grid or individual power supplies that provide autonomy and efficiency to the set of devices. Further details can be found in Section 2 of the document.

Furthermore, an evaluation of the alignment between a sensor-based connected health systems designed for primary care professionals and the SDGs, which monitors patients' healthy aging at home through activity recognition by sensor devices is presented. The assessment explores how an activity recognition system can either enable or impede the attainment of every goal of the 17 goals represented in this agenda using the proposed evaluation model. Addressing a significant research gap, this assessment provides valuable insights into the potential of sensor-based connected health systems in promoting sustainable development.

Finally, identifying sustainability challenges and improvement areas in the proposed sensor-based connected health systems provides valuable guidance for researchers and professionals interested in sustainable healthcare technology development. The improvement areas identified can guide future research and development efforts towards enhancing the user experience and system efficiency. Therefore, this study not only contributes to understanding the sustainability of sensor-based connected health systems but also provides practical guidance for the design and implementation of more sustainable and user-centered technologies.

This paper provides significant knowledge regarding the alignment between sensor-based connected health systems and the SDGs, emphasizing significant obstacles with key challenges that must be confronted in the future to enhance this alignment. Overcoming these challenges can accelerate global progress towards achieving the SDGs and promoting sustainable development. These findings have important implications for policymakers and stakeholders in the health and technology sectors, emphasizing the need for continued efforts to enhance the alignment between sensor-based connected health systems and the SDGs.

The structure of the paper is as follows: In Section 2, we introduce a new sensor-based connected health system that monitors healthy ageing at home. Section 3 presents the evaluation model based on decision analysis of the alignment of the SDGs in healthcare systems. Section 4 evaluates the system's alignment with the SDGs according to the proposed evaluation model. In Section 5, results obtained from the assessment are discussed, their implications and future challenges. Finally, Section 6 presents the conclusions of the paper.

2. Sensor-based connected health system for the home

In this section, we present a real home-based healthy ageing monitoring system as an example of a sensor-based connected health systems aimed at primary care professionals. This system will be analysed in Section 4 in terms of the extent to which it aligns with the 17 SDGs.

The healthy ageing monitoring system is an activity monitoring solution that reports on a patient's healthy habits at home, based on the approach proposed in López-Medina *et al.* (2020). This system is capable of performing this type of detection in multiple-occupancy

contexts, since it can distinguish which person is carrying out the activity, thanks to an indoor location system that uses wrist-worn wearable devices (Albín-Rodríguez *et al.*, 2021). In addition, the system performs monitoring and recognition of activities transparently and follows a device-free approach that frees the user from having to interact directly with the devices (Hussain *et al.*, 2020).

The system can be used to detect a set of pre-defined activities in any sector of the population. However, it has been designed primarily to support older adults in ageing healthily at home under monitoring by their family doctor. In this case, its main objective is to carry out a personalized follow-up of the patient, monitoring healthy habits and providing feedback to healthcare professionals. In order to perform this type of monitoring, an agreement has been reached with the healthcare professionals to recognize only a certain set of healthy habits. These habits set out in Table 1.

The monitoring system consists of a central device in each patient's home, which is responsible for collecting all the data from both the sensor devices as well as the wrist device. The data from these devices are sent to the central device through the Message Queuing Telemetry Transport (MQTT) protocol that maintains communication between all the devices in the home (Babangida *et al.*, 2022). Table 2 presents types of sensor devices and the associated data for location and healthy habit detection.

The central device sends all the sensor data generated every minute to the system server. The system server integrates the classification model that locates the patient within the enclosed space of each home. In this way, the major problem of multi-occupancy is solved by the method proposed in Albín-Rodríguez *et al.*, (2021). Furthermore, an activity detection model based on protoforms and fuzzy logic is established (López-Medina *et al.*, 2020) to detect the proposed habits.

The system includes a web application accessible from any browser, through which the healthcare professionals monitor compliance with the healthy habits established with the patient. The web-based system includes a main view of each patient's current status.

Table 1.
Habits detected by the healthy ageing monitoring system for the home

Healthy habits per day	Area
Brush teeth	Bathroom
Take a shower	Bathroom
Exercise for a specific period of time	Outside
Eat in the morning	Kitchen/Living room
Eat in the afternoon	Kitchen/Living room
Eat in the evening	Kitchen/Living room
Sleep a certain number of hours	Bedroom

Source(s): Created by the authors

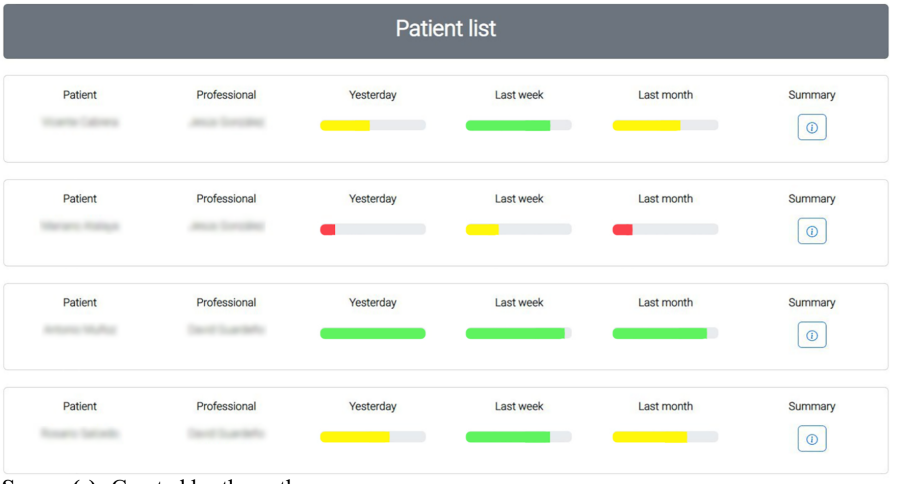
Table 2.
Summary of sensor devices in the system and the type of value returning

Type sensor	Type data	Value
Motion sensor	Motion	True
	No motion	False
Open/close sensor	Open	True
	Close	False
Ambient sensor	Temperature	[−10, 45] °C
	Relative humidity	[0, 95] %
RSSI scanner	Received Signal Strength Indicator (location)	[0, −200] dBm
Activity wristband	Steps	Positive integer

Source(s): Created by the authors

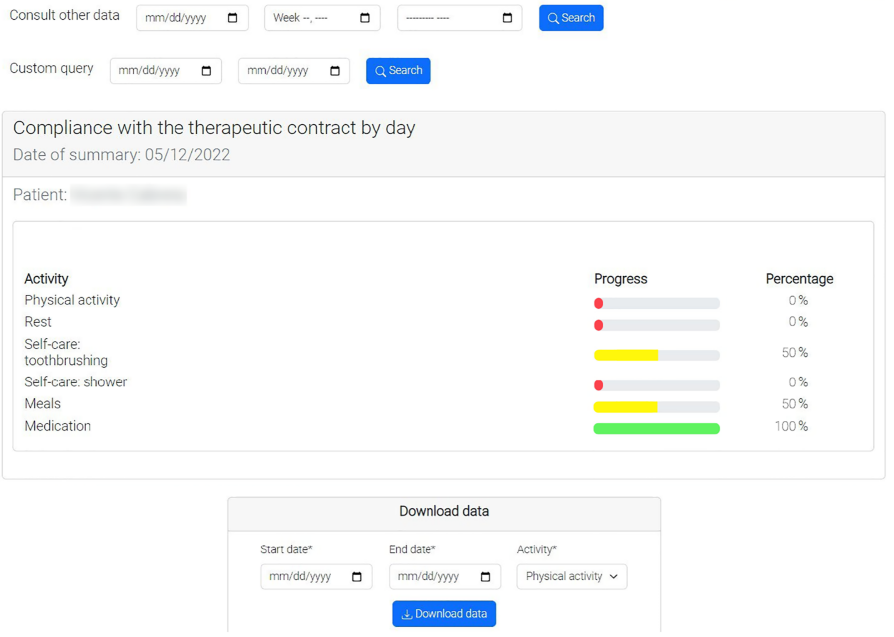
An overview of the healthy habits of the previous day and an average of the last week and the last month are provided for each patient (see Figure 1).

Moreover, a detailed report for each patient can be accessed to display the compliance percentage per type of activity (see Figure 2). The web-based system is able to display specific days or variable time periods, as well as provide a download of the raw data.



Source(s): Created by the authors

Figure 1. Main view of patient's healthy habits the day before, and average over the last week and month



Source(s): Created by the authors

Figure 2. Detailed view of a patient

3. Evaluation model of the alignment of the SDGs in healthcare systems

Decision analysis (Clemen, 1996) is a field within decision theory that has been widely used in various evaluation contexts (Campos-Guzmán *et al.*, 2019; Gupta *et al.*, 2021; Espinilla *et al.*, 2013). To generate an overall assessment of each evaluated element, the evaluation procedure involves calculating an overall score that synthesizes the information gathered and provides valuable insights into each evaluated element. To achieve this, it is necessary to establish an evaluation framework that assesses the elements, collects the relevant information, and finally calculates an overall score for each evaluated element.

Decision analysis is a highly effective theory for evaluating the alignment of the SDGs in healthcare systems, taking into account all the pertinent indicators assessed in each SDG. In this paper, we propose an evaluation model based on this theory to measure the level of compliance of healthcare systems with the taxonomy proposed in Espinosa *et al.* (2021), which establishes a set of indicators assessed for each SDG to be evaluated (ONU, 2020).

Figure 3 illustrates the general scheme of the model that offers a comprehensive quantitative analysis of each SDG indicator. Subsequently, the phases are listed and described as follows:

(1) *Alignment framework*: During this phase, the evaluation model establishes the structure of the alignment process that includes the Health System, the 17 SDGs and their corresponding indicators according to Espinosa *et al.* (2021); ONU (2020).

(2) *Information gathering*: This phase examines the Health System for each of the SDGs with a detailed analysis of the indicators for each goal. The assessment determines whether the system addresses each indicator and provides a justification.

(3) *Rating value*: Finally, this phase calculates the percentage of validated indicators for each SDG. The number of indicators achieved is divided by the total number of indicators set for each SDG. The validated indicator measures progress towards achieving the desired indicators and can help identify areas for improvement.

It should be noted that this method assumes that all criteria have equal weight or importance. However, in cases where certain criteria hold greater significance than others, a weighted average should be computed to determine the overall percentage of target achievement.

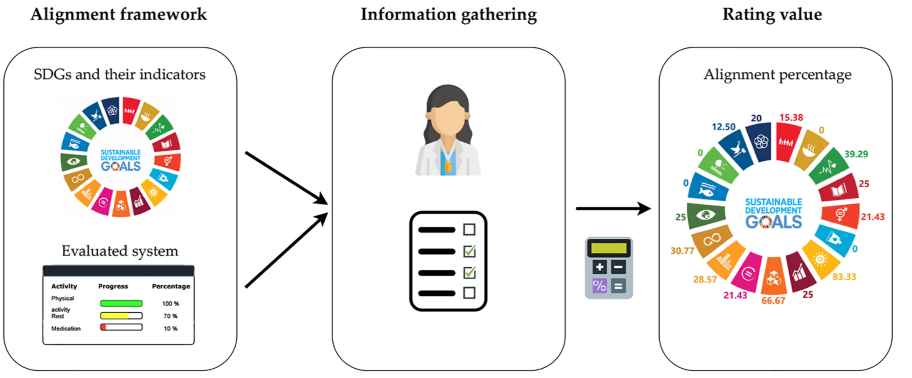


Figure 3.
Scheme of the evaluation model of the alignment of the SDGs

Source(s): Created by the authors

4. Alignment of the proposed monitoring system with the SGDs

The assessment of the alignment between the proposed system in Section 2 and the SDGs has been carried out by analysing the percentage impact of each factor using the assessment model proposed in Section 3.

The evaluation model identifies the objectives and indicators that the proposed system has successfully achieved and those that require improvement.

Subsequently, an assessment is provided for each goal. The indicators considered to be aligned with the system, the quantification of the evaluation conducted and the justification for compliance are indicated for each SDG.

SDG 1. No poverty

Source(s): United Nations, "SDG 1. No poverty"

SDG 1 aims to eradicate all forms of poverty, promote shared prosperity and establish social protection systems to ensure a decent standard of living for everyone. It also seeks to empower the most vulnerable individuals, promote equality, and provide access to natural and economic resources, including technology.

Indicators assessed: 1.a.2.; 1.b.1.

Quantification of the proposed system:

(1) Indicator compliance: 2 of 13.

(2) Indicators validated: 15.38%.

Justification of compliance (Dlodlo and Kalezhi, 2015; Din *et al.*, 2019; Espinosa *et al.*, 2021; Verma, 2021; Tamasiga *et al.*, 2023):

(1) Empowering people out of poverty is ensured through access to technology.

(2) Comprehensive, advanced and preventive healthcare is one of the means to eliminate poverty.

(3) IoT systems applied to health services can be developed in a wide range of settings and territories.

(4) Public expenditure on health systems will be reduced over time with home-based health IoT applications.

(5) Monitoring for health prevention will lead to a decrease in public expenditure on healthcare.

(6) Energy savings and efficiency are demonstrated by access to integral health technologies used at home, cutting down on travel and energy consumption in healthcare centres.

(7) Agriculture, being a crucial element in the reduction of poverty, stands to gain considerable benefits from the incorporation of advanced technologies and intelligent systems.

(8) Technological systems and the use of sensors, IoT, artificial intelligence, etc., will close the technological gap of the poorest territories and achieve health, social and energy-related improvements.

SDG 3. Good health and well-being

Source(s): United Nations, "SDG 3. Good health and well-being"

SDG 3 strives to enhance and safeguard the health and well-being of individuals, prevent the spread of epidemics and diseases, and promote the overall welfare of society. This goal indicates the importance of the environment and how it affects health. It also promotes good health coverage for the whole of society, accessible vaccines and improved health research. Technology is always present in this objective, as it is part of research and health capacity building.

Indicators assessed: 3.4.1.; 3.8.1.; 3.8.2.; 3.9.3.; 3.a.1.; 3.b.1.; 3.b.2.; 3.b.3.; 3.c.1.; 3.c.2. and 3.d.2.

Quantification of the proposed system:

(1) Indicator compliance: 11 of 28.

(2) Indicators validated: 39.29%.

Justification of compliance (Solanas *et al.*, 2014; Bouchabou *et al.*, 2021; Qian *et al.*, 2021; Espinosa *et al.*, 2021; Eisazadeh *et al.*, 2024):

(1) Ensuring people's health and well-being means improving the quality of their healthcare, and technology is a fundamental part of making this care effective.

(2) The reduction of risk factors for some diseases, such as diabetes and cardiovascular diseases, will come about through the technological adaptation of IoT devices, sensors and smart systems that are used together with conventional ones in multiple areas.

(3) Smart health systems will drive progress by creating healthcare synergies between more developed and less developed territories.

(4) IoT technology systems and their applications play a crucial role in disease research, prevention and control, especially during pandemics, in addition to their use in vaccine and drug manufacturing efficiency, logistics, population vaccination planning and management, data management and patient monitoring at home, among other endeavours.

(5) Technology applied to healthcare is a key factor today and will be a key factor in the future for healthcare around the world. Access to healthcare in all territories will be a reality, thanks to Internet systems, sensors and artificial intelligence, among other technologies.

SDG 4. Quality education

Source(s): United Nations, "SDG 4. Quality education"

SDG 4 is focused on achieving equal and quality education for all people, and endeavours to enhance the number of young individuals and adults equipped with relevant skills to pursue employment, decent work and entrepreneurship opportunities. The goal also involves eliminating gender and income-based disparities in educational access. The acquisition of literacy, knowledge and skills essential for promoting sustainable development is considered a critical step in empowering individuals to lead self-sufficient, healthy and sustainable lives.

Indicators assessed: 4.4.1.; 4.5.1. and 4.7.1.

Quantification of the proposed system:

(1) Indicator compliance: 3 of 12.

(2) Indicators validated: 25.00%.

Justification of compliance (Chaniaud *et al.*, 2021; Chen *et al.*, 2021; Elayan *et al.*, 2021; Abulibdeh *et al.*, 2024):

(1) The main justification for SDG 4 in the proposed system is the promotion and enhancement of educational, technological and other competencies that empower the population and their need for understanding, adapting and managing sensor-based connected health systems that are adapted to their diseases, resources and knowledge.

(2) It has been demonstrated that quality education must offer training in technologies, both in early childhood and higher education. The design of intelligent systems, computer applications, the use of scientific knowledge and its dissemination will be fundamental to develop and enhance talent. Fragile areas, territories in conflict and vulnerable populations use technology to provide anytime, anywhere education. In the war against Ukraine, technological resources are being used to deliver educational content to children in shelters and remote areas.

SDG 5. Gender equality

Source(s): United Nations, "SDG 5. Gender equality"

SDG 5 is focused on empowering women and girls around the world and achieving gender equality. To this end, this goal strives to erase all avenues of discrimination, harmful

practices and violence against them. The goal emphasizes the significance of prevention, education and awareness-raising on sexual and reproductive health and rights. Additionally, SDG 5 advocates for equal opportunities for women in education, employment, healthcare, technology and leadership positions. It recognizes the crucial role of women in achieving sustainable development and encourages the removal of gender-based barriers and stereotypes.

Indicators assessed: 5.4.1.; 5.b.1. and 5.c.1.

Quantification of the proposed system:

(1) Indicator compliance: 3 of 14.

(2) Indicators validated: 21.43%.

Justification of compliance (Sharma *et al.*, 2016; Amanullah *et al.*, 2020; Ali *et al.*, 2021; Miranda Calero *et al.*, 2022):

(1) The analysis of gender equality must factor into all studies, reports and research carried out, with the aim of making the role of women and girls visible, hidden in science and productive work for hundreds of years. This objective aims to highlight and support scientific and other developments that support gender equality.

(2) Specifically, the proposed sensor-based connected health system uses technology, IoT and sensors to promote the independence and quality of life of people with chronic diseases. Scientific studies show that most of the care for older adults, dependent, sick and disabled people, as well as minors, is a job mainly done by women, so we cannot ignore the validation of SDG 5 in this research.

(3) Enhancing the education of girls and women around the world is a need that affects many areas. This objective is justified by the pressing need that girls all over the world have for education in technical and scientific fields, regardless of their race, religion, social status or place of birth.

SDG 7. Affordable and clean energy

Source(s): United Nations, "SDG 7. Affordable and clean energy"

SDG 7 focuses on expanding and ensuring access to reliable, modern energy services and affordable while increasing the use of renewable energy sources and energy efficiency. This goal seeks to transition towards a more sustainable and self-sufficient energy model that strengthens energy systems. As clean energy becomes increasingly vital, research and technology play a key role in supporting this transition.

Indicators assessed: 7.1.1.; 7.1.2.; 7.2.1.; 7.a.1. and 7.b.1.

Quantification of the proposed system:

(1) Indicator compliance: 5 of 6.

(2) Indicators validated: 83.33%.

Justification of compliance (Roldan-Fernandez *et al.*, 2021; Montero *et al.*, 2022; Jha *et al.*, 2024):

(1) The use of clean and efficient energy technology is essential in any engineering development or, in this case, in the design of a system whose power supply will be electrical. Renewable energies used in distributed energy systems and in the homes of the system users will represent an advance in the use of high-quality electrical energy and self-consumption.

(2) The electricity supply of the proposed system is a crucial aspect that can greatly impact its energy efficiency. Incorporating renewable or hybrid energy systems can be a breakthrough in achieving sustainability goals. The utilization of intelligent systems and IoT innovations within the energy industry has the potential to enhance efficiency and sustainability, resulting in direct advantages for individuals and the environment. To ensure quality and protection of the installation, energy systems must be equipped with remote control systems, automation, and sensors to monitor pressure, temperature and heat. The use of data management, as well as domotic and inmotic systems, can further enhance the efficiency and effectiveness of the energy systems.

SDG 8. Decent work and economic growth

Source(s): United Nations, "SDG 8. Decent work and economic growth"

SDG 8 recognizes the value of sustainable economic growth, with the promotion of quality jobs. In addition, it seeks equal employment opportunities, decent and secure jobs. It also promotes international cooperation to support trade and youth employment around the world.

Indicators assessed: 8.3.1.; 8.5.1.; 8.5.2. and 8.b.1.

Quantification of the proposed system:

(1) Indicator compliance: 4 of 16.

(2) Indicators validated: 25.00%.

Justification of compliance (Albahri *et al.*, 2018; Ahad *et al.*, 2019; Kaplan and Haenlein, 2020; Soo *et al.*, 2023):

(1) Four indicators are validated through the implementation of high-quality jobs related to health service technology systems. This objective aims to align the proposed system by strengthening the economy. Sustainability and the application of advanced technological systems entail economic, social and health progress.

(2) The promotion of medical specialist work and training in IoT systems and technology is increasingly important, as there is a need for multidisciplinary teams and attracting a sector of the population that is young and has high expectations in the world of work.

(3) In addition, health monitoring and health prevention systems in the home enable the creation of new jobs, new specialities and emerging sectors. Economic

investment is needed in territories that are vulnerable, in conflict, and have high poverty rates. The integration of smart devices in healthcare or other areas will lead to progress in working conditions and the business environment and structure.

SDG 9. Industry, innovation and infrastructure

Source(s): United Nations, "SDG 9. Industry, innovation and infrastructure"

SDG 9 focuses on building sustainable, resilient and adaptable buildings and infrastructure. It seeks an inclusive, innovative industry that promotes sustainability and quality of life for society and the territory.

In addition, it recognizes the need to promote an environmental technology that is accessible, inclusive and adaptable and adapted to changes in society. It reinforces the challenges towards technological progress and innovation that seeks scientific research and empowers all industrial, financial, small business, etc. agents. In addition, it calls on the most advanced countries to support more vulnerable countries in accessing technology for the improvement of industry and infrastructure.

Indicators assessed: 9.1.1.; 9.3.1.; 9.4.1.; 9.5.1.; 9.5.2.; 9.a.1.; 9.b.1 and 9.c.1.

Quantification of the proposed system:

(1) Indicator compliance: 8 of 12.

(2) Indicators validated: 66.67%.

Justification of compliance (Rastogi *et al.*, 2020; Chakraborty *et al.*, 2021; Rahman *et al.*, 2021; Teo *et al.*, 2024):

(1) The proposed system aims to not only enhance the standard of living of individuals experiencing chronic illnesses but also to enhance their access to healthcare centers by reducing transportation barriers. Additionally, the system will contribute to direct energy savings by decreasing the need for travel. This will lower greenhouse gas emissions directly and indirectly. Intelligent system technologies, applied to health and society, will improve the business infrastructures associated with these areas.

(2) In line with SDG 9, companies working directly or indirectly in the technological sector and its applications to healthcare will adapt, new industries associated with this field will be created and innovation and competitiveness will be fostered.

(3) The innovation of healthcare infrastructures is essential for the digital transformation of hospitals and other healthcare facilities, as it is a key factor in enhancing environmental sustainability, encouraging the efficient use of energy and promoting the adoption of renewable energy sources.

SDG 10. Reduced inequalities

Source(s): United Nations, "SDG 10. Reduced inequalities"

SDG 10 promotes the reduction of inequalities across various dimensions, including income, gender, ethnicity, religion, race, class, age, disability, and opportunities, through the implementation of policies and laws. It also aims to enhance market regulations and control to ensure equal opportunities for all individuals, regardless of their background.

Development assistance and investment in vulnerable regions should be encouraged. The goal is to advance worldwide social integration through the facilitation of secure, well-organized, and consistent migration.

Indicators assessed: 10.4.1.; 10.5.1. and 10.b.1.

Quantification of the proposed system:

(1) Indicator compliance: 3 of 14.

(2) Indicators validated: 21.43%.

Justification of compliance (Lazaroiu and Roscia, 2018; Parise *et al.*, 2018; Maina and Singh, 2019; Tsekleves and Cooper, 2021; Ciubotaru *et al.*, 2023; Zhu *et al.*, 2023):

(1) The proposed system will be implemented in Europe, but according to SDG 10, advances in technology and its applications should be replicated and exported to more disadvantaged areas of the planet. This sensor-based connected health system should be adapted and transferred to other vulnerable environments, thus contributing to the reduction of inequalities.

(2) However, even in European territories and other developed countries there are population movements from rural to urban areas and vice versa, which sometimes lead to a deterioration in people's health.

(3) Developing low-cost applications, with flexible implementation and adaptable to public and private health systems, is a step forward in reducing inequalities.

SDG 11. Sustainable cities and communities

Source(s): United Nations, "SDG 11. Sustainable cities and communities"

SDG 11 strives for the modernization of urban and rural areas to ensure that they are livable and sustainable for all. This goal focuses on improving access to basic services such as

energy, water, housing, public spaces, and transportation, while reducing the environmental impact of these services.

The goal is to elevate the worth of rural areas, foster innovation and increase access to technology. Additionally, it advocates for safeguarding cultural spaces, natural and historical heritage, and fostering harmonious relationships between urban areas and agricultural and natural landscapes.

Indicators assessed: 11.1.1.; 11.2.1.; 11.3.2.; 11.a.1.

Quantification of the proposed system:

(1) Indicator compliance: 4 of 14.

(2) Indicators validated: 28.57%.

Justification of compliance (Allam and Dhunny, 2019; Almalki *et al.*, 2021; Shehab *et al.*, 2022; Wan, 2024):

(1) Compliance and validation of SDG 11 in the proposed system is justified by the population improvements brought about by smart health applications. In addition, environmental protection can be validated as any sensor IoT and monitoring applications use low-power devices and can be powered by the grid from renewable energy sources. Moreover, their implementation saves costs for people travelling to health centres, thus reducing indirect pollution. Creating smart human communities requires the integration of smart grid strategies, sustainable cities, and smart cities.

(2) City and territory planning must integrate sensor systems and IoT technology that will result in numerous designs for sustainability and energy efficiency. In addition, the integration and use of data will improve the quality of human health, mobility, consumption, and other areas.

SDG 12. Responsible consumption and production

Source(s): United Nations, "SDG 12. Responsible consumption and production"

The objective of SDG 12 is to encourage the adoption of efficient energy sources and renewable through the implementation of decarbonization plans. It promotes sustainable lifestyles that respect the natural environment, integrate the use of technology for environmental protection and improve synergies between researchers, scientists, politicians and businessmen for the common good.

It aims to make consumption more efficient in a complex world, in addition to reducing waste. It considers it very important to reinforce scientific and technological research in all the countries of the world and the promotion of alignment tools with the SDGs.

Indicators assessed: 12.1.1.; 12.7.1.; 12.8. and 12.a.1.

Quantification of the proposed system:

(1) Indicator compliance: 4 of 13.

(2) Indicators validated: 30.77%.

Justification of compliance (Garrido-Hidalgo *et al.*, 2018; Sheikh *et al.*, 2021; Trocin *et al.*, 2021; Xie *et al.*, 2023):

(1) Responsible consumption must include the implementation of smart systems and technical solutions in healthcare in order to improve people's quality of life and protect the environment. Healthcare systems and sensor technology, IoT and energy efficiency are closely linked and will lead to reduced travel-related pollution and waste.

(2) The implementation of sensors and advanced technology will improve knowledge, control and data management for disaster response, prevention and use of production and waste management.

(3) Education and sustainable development are integrated into the rise and validation of smart health devices, and if powered by renewable energy systems, they can verify compliance with this objective.

SDG 13. Climate action

Source(s): United Nations, "SDG 13. Climate action"

SDG 13 promotes the strengthening of relations between countries around Action on Climate Change. Its goal is to improve all aspects of environmental protection to prevent natural disasters and mitigate future risks. It also intends to promote education and environmental awareness in schools and educational institutions and of all kinds.

Indicators assessed: 13.2.2. and 13.3.1.

Quantification of the proposed system:

(1) Indicator compliance: 2 of 8.

(2) Indicators validated: 25.00%.

Justification of compliance (Motlagh *et al.*, 2020; Tuysuz and Trestian, 2020; Anderson *et al.*, 2021; Javaid and Khan, 2021; Gao *et al.*, 2022; Fahim *et al.*, 2023; Khurshudov, 2024):

(1) Intelligent systems applied to health have wide-ranging indirect effects on climate change, as their implementation reduces the use of polluting vehicles and other more energy intensive systems.

(2) An analysis of climate change from a technological and scientific perspective is crucial, with the mitigation of specific pollutants, such as carbon dioxide (CO_2) emissions, being a vital area of focus. Effectively addressing these issues is necessary to make significant progress and achieve satisfactory results in the fight against climate change in the years ahead. The installation of sensors and pollution monitoring systems in cities will allow real-time monitoring of greenhouse gas emissions and guide action to improve health outcomes and environmental protection.

SDG 16. Peace, justice and strong institutions

Source(s): United Nations, "SDG 16. Peace, justice and strong institutions"

SDG 16 underscores the criticality of fostering peaceful and inclusive societies that uphold human rights and protect the most vulnerable. It strives to strengthen democratic institutions, promote transparency and accountability, and guarantee that everyone has the same access to justice. Preventing violence in all its forms, including terrorism and crime, and combatting corruption and bribery is the aim of this goal. In addition, it aims to safeguard essential liberties, promote the rule of law and ensure protection of fundamental freedoms, such as freedom of peaceful assembly, association and speech. To build robust, resilient and fair societies, an alliance involving all pertinent stakeholders, such as non-governmental organizations, the business community and civil society, working together in unison., is necessary to achieve SDG 16.

Indicators assessed: 16.6.2.; 16.7.2. and 16.10.2.

Quantification of the proposed system:

(1) Indicator compliance: 3 of 24.

(2) Indicators validated: 12.50%.

Justification of compliance (Rodríguez-Rodríguez *et al.*, 2019; Sourbati and Behrendt, 2020; Zidaru *et al.*, 2021; Yaqoob *et al.*, 2023):

(1) Applications of technology systems, sensors, AI, IoT, electrical engineering, telecommunications, among others, are changing the world order. If their use is consistent, they will promote peace and justice in the world, although we cannot forget that such technologies are also used for war.

(2) Technology helps to resolve conflicts and crime, and is fundamental in helping older adults and people with disabilities. In policing, it has driven great advances in the search for missing persons. More broadly, it has brought about improvements in multiple areas in work and personal life. Specifically, the system proposed in this work is designed to help older adults, vulnerable and sick people to have an independent and healthier life.

SDG 17. Partnerships for the goals

Source(s): United Nations, "SDG 17. Partnerships for the goals"

SDG 17 recognizes the importance of advocating for an inclusive, rules-based, transparent, impartial and fair trading system. It is crucial to foster a global trading system that is rules-based, accessible, impartial and fair and benefits all stakeholders. It highlights the relevance of global macroeconomic stability and supporting developing countries in achieving long-term debt sustainability. This goal emphasizes the requirement for international collaboration and partnership to gather the necessary means and achieve sustainable development. It also aims to enhance the transfer of technology, promote innovation and capacity building, and encourage private sector engagement in sustainable development. Ultimately, SDG 17 strives to create a strong and inclusive global economy that benefits all people, regardless of their socio-economic status or geographic location.

A science and technology-based capacity-building mechanism for developing countries should be provided. Training in innovation and development, especially in electrical engineering, electronics, information technology and telecommunications, should be increased.

Indicators assessed: 17.6.1.; 17.7.1.; 17.8.1.; 17.14.1. and 17.18.1.

Quantification of the proposed system:

(1) Indicator compliance: 5 of 25.

(2) Indicators validated: 20.00%.

Justification of compliance (Bayram *et al.*, 2020; Espinosa *et al.*, 2020; Vinuesa *et al.*, 2020; Raval *et al.*, 2024):

(1) This goal prioritizes a global vision of the planet, governance and the application of the SDGs in a multi-disciplinary manner. The implementation of technology is prioritized as an essential system for compliance and to drive strategies for global progress.

(2) The system proposed here satisfies several indicators that promote coherence and progress in health systems and users through the use of sensor technology, IoT and advanced medical and preventive health systems. Strengthening ties between countries and institutions is fundamental to enhance cohesion and drive advances in society and the environment. With good political management, technology and intelligent systems will help foster ties in global governance. Information technology, electronics, electrical and other related areas are fundamental to integrate science and improve international cooperation. For example, these ties have been crucial in the management of COVID-19, with the exchange of information on vaccines and advanced production technology.

(3) For progress in AI, ties between countries and collaboration between scientific groups from all parts of the world will be essential. Likewise, open, transparent and universal business management will improve economic transactions, and this will lead to enhanced health protection and other social improvements.

(4) Alliances in scientific knowledge and production of machinery and devices will achieve a continuous improvement of the planet. Data management and transfer for a common good will help drive progress.

5. Results analysis and future challenges

This section begins with an overview of the alignment of the SDGs and the validation of the proposed sensor-based connected health system. Afterwards, we will discuss the challenges that connected health systems and the SDGs may face in the future.

5.1 Results analysis

Figure 4 provides a summary of the system's percentage of compliance with the SDGs analysed above, so that we can see its SDG alignment. It can be observed that it is aligned with 13 of the 17 total SDGs, and 57 indicators have been validated out of a total of 232, offering an overall compliance rate of 24.37%.

SDGs 2, 6, 14 and 15 are not aligned with the system, so their assessment is 0. For this reason, they have not been taken into account in the previous analysis.

The system proposed in this research does not provide clear answers to some of the SDGs, either quantitatively or qualitatively, which is why an assessment of some of the omitted goals has not been carried out. For example, some of these unaligned goals, such as SDG 2, are intended to explain how smart health systems affect the alleviation of global hunger. Although we will be able to align with some of its targets, such as 2.2, which deals with processes to improve nutritional health through technological systems, we have chosen not to include this indicator as it involves a very specific and complex review that is beyond the scope of this work.

Similarly, for the remaining objectives not covered by this study: 2, 6, 14 and 15, we have carried out the same analysis; due to their complexity and subjectivity, we have left them out of the alignment with the associated health systems.

In our research, we have conducted a comprehensive assessment of several important areas related to sensor-based connected health systems and their alignment with the SDGs. Our aim is to provide a tool that can assess health systems based on their level of alignment with the SDGs. This will enable us to identify areas where improvements can be made in future healthcare and energy efficiency.

In the alignment of the SDGs with respect to smart health systems and the integration of IoT in the field of sustainability, we cannot forget the importance of energy efficiency and the application of clean energy sources. For this reason, even if it is not a priority topic in this research, it is an obligatory analysis, as sustainability is transversally linked to energy efficiency.

A crucial aspect that we have identified is the encouragement of using renewable energy in the context of promoting healthy ageing. As populations around the world continue to age, there is an urgent need to develop health systems that can support the growing demands for healthcare services while also promoting sustainable energy practices. Encouraging the adoption of alternative energy sources in healthcare facilities can help lessen our dependence on fossil fuels and promote a sustainable future.

Source(s): Created by the authors

Figure 4.
System's compliance percentage for each SDGs

We have also highlighted the most significant results of the sustainability assessment that we conducted on the proposed system. Our findings indicate that innovation and research in technologies, sensor devices, IoT and human activity recognition are essential for driving continuous improvement of health systems and society. These technologies can enhance the ability of healthcare providers to monitor patients' health status more efficiently and make better-informed decisions regarding treatment and care.

Another important aspect of our research is the monitoring of human environments as a solution for institutional management and governance, while also protecting privacy and cybersecurity. By leveraging technologies such as IoT sensors and AI algorithms, we can create more efficient and effective healthcare systems that are better equipped to handle the growing demands of the future.

Finally, we have found that the use of high-efficiency technological systems can significantly reduce energy consumption, especially when integrated with renewable energies. This has significant implications for the sustainability of healthcare systems, as reducing energy consumption can help to minimize the environmental impact of healthcare services while also reducing costs and improving efficiency. Overall, our research provides important insights into the key areas that need to be addressed to create more sustainable and effective healthcare systems in the future.

5.2 Future challenges

After conducting a thorough analysis using the proposed evaluation model to assess the alignment of the proposed system with the sustainable objectives, it is crucial to identify and describe the challenges that the system may face in terms of the SDGs. This analysis would provide valuable insights into the gaps that need to be addressed to ensure the system's effective contribution to sustainable development.

Firstly, a protocol should be designed to analyse the alignment of any research with the SDGs, both in the technological field and in other areas. For example, if an application focused on people with disabilities in the field of mobility is developed, SDGs 3, 7, 9, 10, 11 and 16 can be applied. This alignment can provide the work and projects with a quality label, which would be very useful for obtaining funding.

In some funding initiatives for international projects, such as the European Union lines, one of the vectors and evaluation parameters is sustainability and alignment with the SDGs. For this reason, we consider it interesting that any research should be based on and aligned with sustainability objectives. For example, in Spain, the calls for the next generation of EU funds require the justification of the impact of each project at the local level and its alignment with the SDGs.

Secondly, a review of the technical and economic feasibility of the research would be useful in order to assess and economically quantify the pilot projects and their actual implementation, particularly in the field of intelligent systems applied to healthcare for individuals and institutions.

Our third proposal is to encourage the replication of this research in any validated topic and its implementation in other territories or vulnerable environments that are less developed or have greater health, social or technological needs. By applying these sensor-based connected health systems to different contexts, we can address various global health challenges and ensure that no one is left behind.

Finally, our fourth proposal emphasizes the need to enhance energy efficiency and mitigate climate change, which is mainly aligned with SDGs 7 and 13 in a multidisciplinary manner. By prioritizing sustainable energy practices and integrating renewable energy sources into healthcare systems, we can reduce our carbon footprint and promote a more sustainable future for all.

6. Conclusions

In this paper, we have aimed to provide a detailed and practical perspective on assessing the alignment of SDGs in sensor-based connected health systems. Specifically, we have proposed an evaluation model based on decision analysis for the alignment of a healthcare system with SDGs and their associated targets is proposed. This analysis can help identify areas for improvement in the healthcare system's alignment with the SDGs.

Furthermore, we have evaluated the SDG alignment of a sensor-based connected health system, which uses sensor devices for activity recognition, designed for primary care professionals. The results of this assessment, along with the alignment of SDG indicators and targets, will drive the commitment to technological integration worldwide, leading to progress in any territory and ultimately achieving equality and environmental protection. We have presented and discussed how the proposed system can either support or obstruct the accomplishment of the 17 SDGs and their corresponding targets as stated in the 2030 Agenda, in order to attain these objectives. Based on a comprehensive quantitative analysis of each SDG indicator, we found that the system has achieved more than 24% compliance.

From our qualitative analysis, we have drawn three main conclusions. Firstly, greater economic progress will be driven by innovation and research in information and communication technologies, as well as activity recognition. Secondly, human monitoring is a suitable solution in health contexts, but it is important to consider privacy and cybersecurity concerns. Thirdly, the implementation of this kind of system promotes low energy consumption and the integration of renewable energies.

Finally, we have identified and described four sustainability challenges that future connected health systems may encounter in aligning with the SDGs. These challenges offer valuable insights for researchers and professionals who are interested in advancing the development of sustainable healthcare technology. First, designing a protocol to analyse the alignment of any research with the SDGs, both in technological and non-technological fields. Second, conducting a review of the technical and economic feasibility of the research to assess and quantify pilot projects and their actual implementation. Third, encouraging the replication of validated research in other territories or vulnerable environments with greater health, social or technological needs. Fourth, enhancing energy efficiency and climate change mitigation in a multidisciplinary manner, aligned with SDGs 7 and 13.

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Supplementary material

The supplementary material for this article can be found online.

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