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Review

Solar Energy Implementation for Health-Care Facilities in Developing and Underdeveloped Countries: Overview, Opportunities, and Challenges

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Abstract: Developing and underdeveloped countries face innumerable problems related to the accessibility and quality of energy that put the lives of patients, health-care infrastructures, and health workers at risk. Current approaches, such as grid power, unsustainable energy sources such as diesel or gas, and mobile health clinics, have proven insufficient to address this issue. In response, access to reliable health care and electricity has undergone multiple transformations in the last decade, especially in remote and rural areas. Good health and clean energy are two of the 17 United Nations Sustainable Development Goals, originally designed to be a "shared blueprint for peace and prosperity for people and the planet, now and into the future." Unfortunately, little is known about the interaction between health-care access and energy access in developing and underdeveloped countries, mainly in remote or rural areas. For this reason, this study conducts a review of the literature, including current approaches, challenges, and opportunities for the implementation of solar energy in health centers. As a result, several challenges and opportunities in three impact areas are presented: (1) operational, (2) environmental, and (3) economic. This study delivers detailed information that allows the implementation of solar energy in the health-care sector (in a more effective manner) by sharing best practices.

Keywords: solar energy; health-care facilities; PV systems; developing countries; underdeveloped countries; renewable energy

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1. Introduction

1.1. Problem Identification

In the last decade, there has been a drastic transformation in the health-care system, mainly in rural areas [1]. This is primarily due to changes in resources, financing, technology, and the clustering of health systems. However, despite these changes, resources for rural health systems remain relatively insufficient, especially in developing or underdeveloped countries [2]. In these countries, a significant percentage of the population still resides in rural areas, where access to health-care benefits is deficient and in some cases nonexistent. This is a problem, given that the Rio Declaration on Environment and Development states that all people are a fundamental part of sustainable development and have the right to live a healthy life [3]. Reliable access to energy plays a fundamental role in the sustainability and effectiveness of health-care facilities. Without energy, the facilities face several consequences, such as the risk of deterioration of vaccines, ineffective sterilization of equipment, poor lighting, communication problems with providers and

other health-care centers, inability to perform laboratory tests, and delays and interruptions of services, among others [4].

Conventional energy resources (fossil fuels) generate harmful emissions for the environment and for the population. Pollutants generated by fossil fuels degrade the environment, water, land, and wildlife and risk the population's health. For this reason, in recent years, incorporating renewable energies has become essential to cover the energy demand. In particular, solar energy plays a fundamental role in this energy transition since it is emission-free, utilizes an infinite resource, and is available mostly everywhere [5]. In this way, having access to renewable energy resources, such as solar energy, has the potential to positively impact health-care facilities as a long-term strategy [4].

However, underdeveloped and developing countries face a problem due to the growing demand for quality, cost-effective, timely health care and available supply [6]. In underdeveloped and developing countries, health care relies heavily on financial and logistical support from local governments, nongovernmental agencies, and international aid. Together with the help of these organizations, the health systems can provide medical supplies, medical personnel, and health services [7].

There are many needs in health-care facilities, which generally cannot be covered by the aforementioned efforts, particularly in rural and remote areas [7]. Statistics show that many remote health centers in underdeveloped or developing countries often do not have access to electricity, e.g., in Uganda and Tanzania, 58% and 50% of health centers do not have access to electricity [8]. This indicates that they do not have lighting for childbirth, emergency night care, refrigeration for vaccines, or sterilization devices [8]. The abovementioned are fundamental and critical needs for the operation of health establishments [8].

In addition, the health-care business is under pressure to enhance patient safety, operate more effectively, minimize medical mistakes, and give reliable access to accurate information while reducing costs, maintaining patient privacy, and adhering to regulatory and legal obligations [9]. The energy cost has increased exponentially in recent years, which has negatively impacted the operation of health establishments, since its costs increase, reaching up to 3% of hospital budgets [10]. This implies that the resources being spent on energy could have been used to cover critical needs to improve the quality and safety of medical care [10].

In summary, there is a problem with access to clean, quality, affordable and reliable energy in health-care facilities in underdeveloped and developing countries, a problem that intensifies in remote areas.

1.2. Proposed Solution

The proposed solution to this problem is the utilization of photovoltaic solar energy in health-care facilities. Solar energy plays a vital role in improving energy infrastructure for health if adequately integrated [7]. Solar energy is an abundant resource, and studies have shown that the electricity produced can generate a reliable supply for health-care facilities. This electrical power supply can support the operation of essential medical equipment in health-care facilities [7]. In addition, it allows its implementation in remote places where access to the electrical network is nonexistent and access to fuel for the operation of the generators is limited [11].

The purpose of this study is to provide a literature review on the overview, challenges, and opportunities of solar energy applications in underdeveloped and developing countries with a specific focus on health-care facilities. This effort will contribute to the literature by identifying and unifying opportunities and challenges in three main areas: (1) operational, (2) environmental, and (3) economic. In this way, it will be possible to have access to detailed information on the implementation of solar energy in health-care facilities, interventions, and programs to encourage the adoption of solar energy by sharing best practices related to the topic.

2. Literature Review

2.1. Current Electricity Concerns in Undeveloped and Underdeveloped Countries

This section provides a summary of three core concerns related to electricity access and usage in undeveloped and underdeveloped countries.

First, for health establishments that can be connected to the existing electrical network, this is the classic way of supplying electricity to any health center [8]. The electrical network provides energy sources based mainly on fossil fuels, and generally the facilities have a backup system of generators. However, there are some gaps in this approach. Power outage, mainly in periods of peak demand, is a problem even in developed countries and is even more frequent in undeveloped and developing countries without electricity supply or depending on backup generators [8]. Additionally, generators have low reliability, and there is limited power generation capacity [8]. Additionally, the generators have low operating efficiency, due to which they produce significant waste heat. Generators that work with fossil fuels will generate emissions that are harmful to people's health, such as particulate matter, CO_2, and other polluting gases [8]. Access to the electrical network does not reduce the dependence on backup generators, since—by regulation—health-care facilities delivering emergency care, delivery rooms, and surgical procedures require a backup power system [8].

Second, a widely used approach in places without access to the electricity grid is using fossil fuels to generate electrical energy, refrigeration, and lighting [8]. However, this approach has some limitations. Generators are primarily used in emergencies and not as a constant power supply due to their costly operation, and in some cases, limited access to fuel. Refrigerators powered by propane or kerosene are used to refrigerate vaccines and other supplies. However, studies have shown that refrigerators powered by kerosene, the most widely used, do not always provide adequate cooling [7]. Additionally, remote areas' access to propane and kerosene is limited and unreliable. Moreover, high dependence on fossil fuels contributes to greenhouse gas emissions and negatively impacts climate change and air pollution [10].

Third, mobile clinics provide primary health care in some hard-to-reach rural areas, which can be especially beneficial for geriatric patients, pregnant women, and children [12]. Mobile clinics provide a primary care service that can sometimes be specialized, depending on the complexity. This service is beneficial, since patients can access these mobile clinics regardless of geographical location. However, these types of services have some challenges. Mobile clinics depend highly on public policies that allow the creation and financing of these initiatives, which in some countries are nonexistent [12]. Additionally, time is limited. Mobile clinics generally visit an area from a couple of times a week to a couple of times a month. For the same reason, mobile clinics cannot attend emergencies. Finally, they depend on diesel and gasoline generators to run medical equipment [12].

2.2. Topic Area 1—Operational Impact

2.2.1. Overview

Operational impact relates to productivity and reliability. This section provides an overview of productivity and reliability concerns within solar energy applications in underdeveloped and developing countries with a specific focus on health-care facilities.

Operational impact refers to evaluating interruptions or improvements in various aspects of a health-care facility's operations. A reliable electricity supply system can differentiate life and death in developing countries. According to studies, implementing more robust emergency care electrical supply systems in hospitals in low- and middle-income countries might affect 45% of deaths and 36% of disability-adjusted life years (DALYs) [13,14]. Lack of energy access at health-care institutions can result in a variety of issues. Some of these issues include the inability to provide clinical care after sunset, inadequate lighting for operations, poor sterilizing facilities, inadequate refrigeration for drugs and vaccines, trouble in obtaining power for laboratory equipment used to diagnose

diseases, difficulty in getting in touch with medical personnel, and difficulties in arranging transportation to an institution with a higher degree of specialty [15–17].

According to the United States Department of Energy, health-care institutions consume up to twice the energy that the average commercial facility consumes [18]. Solar energy has the potential to provide high-quality health care, a reliable system, and low-cost electricity to rural and remote areas [19]. Health-care facilities have many operational components critical to patients' functioning and necessary medical treatment.

2.2.2. Challenges and Opportunities

Challenges and opportunities discussed in this section include operational lighting, communication systems, refrigeration, sterilization, and medical equipment.

Operational Lighting: The operational lighting component accounts for 19% of hospital energy consumption [20]. Potential alternatives and proposals for reducing energy consumption from lighting in buildings have been developed, utilizing more efficient technologies and renewable energy sources. Among these suggestions related to energy efficiency are improving the quality of luminaries in energy efficiency and lighting modeling before the construction of buildings [21]. Improving the quality of luminaires, such as implementing LEDs, can reduce energy consumption by approximately 50% compared to fluorescent lighting [22]. The implementation of lighting modeling can estimate and approximate the light needed for each space and time in the building and mechanisms to reduce that energy consumption before construction [23]. Lighting in health-care institutions is an essential component for providing appropriate health-care services. Lack of illumination affects the safety of invasive medical procedures and access to medical services at night. According to studies, providing minimal light and electric power to surgical equipment might cut maternal mortality by 70% [24]. The main suggestion related to renewable energies is integrating renewable energy in buildings [21]. Integrating renewable energy is essential for the building sector, since in places like Europe, this sector represents 40–45% of the total energy consumption [25].

Communication Systems: Health-care facilities have various types of equipment crucial to their operation, including communication systems. Communication systems provide quick access to information, efficient information management among doctors and health-care workers, and the ability to call other specialized institutions to transfer patients. This last point is crucial to maintaining communication between the health-care institution and larger health-care facilities that may provide more specialized services not offered by smaller hospitals or hospitals located in remote places [24]. According to the World Health Organization (WHO), developing nations are short of 4.3 million health-care workers. Due to a scarcity of health-care professionals and a lack of professional development, rural hospitals must treat a more significant number of patients [26,27]. Solar energy can provide long-term sustainability to communication equipment while allowing access to systems such as telemedicine to improve service efficiency [28,29]. Telemedicine has been used to overcome obstacles in health-care facilities in developing countries, such as geographic access, availability, and affordability [30].

Refrigeration: Health-care institutions use supplies and services that require proper refrigeration, such as vaccines, medicines, and blood, which are critical to their operation. Studies have shown that incorrect refrigeration practices cause vaccines for snake bites to lose effectiveness. Lack of access to refrigeration equipment forces some developing countries to go to other cities to get ice to provide unregulated refrigeration to the vaccines [31]. Additionally, it has been observed that 50% of vaccinations delivered to developing countries ends up being lost, since they are not kept in proper refrigeration [32]. Previous studies have revealed how low-cost renewable energy systems, such as solar energy, may provide refrigeration for developing countries that do not have access to dependable electricity or no access to electricity at all [33].

Sterilization: Sterilization is crucial in preventing infections in health-care facilities and keeping patients safe. Without stable electricity, health-care institutions use non-

WHO-approved sterilizing methods for surgical equipment, which fail to eliminate 100% of microbes. Around 50–60 million people worldwide suffer from wounds, and 20% of patients get a postoperative infection [32].

Medical Equipment: Electricity is crucial for powering medical equipment such as ultrasounds, X-ray machines, and incubators, which allow for improved medical diagnostic services. Studies have shown that using electric incubators for newborns in Kenyan health institutions reduced neonatal death rates from 40% to 28% [32]. Other studies have shown how renewable energy sources such as solar energy can provide reliable energy to medical equipment for diagnosis or treatment that is vital for prompt emergency response [34].

2.2.3. Summary

In summary, access to electricity is crucial for health-care facilities to operate appropriately. A lack of reliable electricity can impact such elements as operational lighting, communication systems, refrigeration, sterilization, and medical equipment. Operational issues have the potential to negatively impact health-care quality, vaccination efficacy, infection rates, neonatal mortality, and surgical procedure outcomes. Because hospitals are energy-intensive commercial buildings, it is necessary to examine the influence of solar energy on operations [35]. Opportunities exist in that solar energy applications can be used to generate electricity for the entire building and/or to generate electricity for individual pieces of equipment, yet challenges exist in that solar energy only works during daylight, batteries can be an expensive storage option for non-daylight hours, and finding skilled workers to maintain solar energy applications is difficult.

2.3. Topic Area 2—Environmental Impact

2.3.1. Overview

Environmental impact relates to emissions, pollution, water treatment, sanitation, and climate change, particularly when there is limited to no electricity available. This section will provide an overview of these environmental impact concerns within solar energy applications in underdeveloped and developing countries with a specific focus on health-care facilities.

According to studies, using hybrid renewable energy systems (renewable energy sources combined with traditional energy generators) has a more positive environmental impact and is a viable approach for rural electrification [4]. Solar energy generation continues to provide one of the most compelling incentives for its incorporation into health-care facilities, reducing air pollution and as a result improving human health quality, which is its primary goal [36]. This section discusses the environmental impact of the integration of solar applications in health-care facilities to provide an overview of related topics.

2.3.2. Challenges and Opportunities

Challenges and opportunities discussed in this section include water resources and treatment, HVAC, greenhouse gas emissions, air pollution, environmental regulations, waste management, land and space concerns, and wildlife protection.

Water Resources and Treatment: Water scarcity or lack of access to clean water is still a significant issue in many parts of the world and has been identified as one of the largest global risks for the next decade [37]. Some studies indicate that 25% of the population in the world does not have access to safe drinking water [38,39]. Clean and safe water is vital and has many applications in health-care facilities, such as bathroom operation, cooling and heating, medical equipment, landscaping, laundry, and kitchen [40,41]. A crucial surgical procedure's efficiency and outcome may be impacted if there is no consistent water availability. This might cause delays in medical treatments [42]. By offering alternative water treatment processes and providing clean water to health-care institutions, solar energy may be used to lessen the impact of water shortage [43]. Health-care facilities are major wastewater sources, including pharmaceutical, chemical, biological, and radioactive waste [44]. Due to the contamination and scarcity of water resources in health-care facilities,

implementing mechanisms and technologies for water treatment has become vital. An example of the alternatives that have shown efficiency in removing bacteria and viruses in the water treatment process is membrane bioreactor technology (MBR) [45]. Low-energy consumption technology such as MBR can benefit from implementing solar energy. Solar energy can access solar desalination and photocatalysis technologies as maturing alternatives for water treatment processes [43].

Heating, Ventilation, and Air-Conditioning (HVAC): According to previous research, air-conditioning components account for 50% of the energy consumed by health-care facilities [20]. HVAC systems are crucial in health-care facilities because they provide heating, ventilation, temperature control, air filtration, and prevent the transmission of viruses and germs [46]. Studies have shown that heating and cooling systems have an impact on the reliability of the energy system. Because of the influence of HVAC systems on energy supply, solar energy systems are critical for meeting this demand, especially in remote areas with limited grid access [47]. Solar heating, solar cooling, and photovoltaic (e.g., solar electric) systems can minimize buildings' energy consumption and greenhouse gas emissions [48].

Greenhouse Gas Emissions: The use of renewable energies, including solar energy, has been demonstrated in the literature as an effective strategy for reducing greenhouse gas emissions and as a result minimizing hazardous environmental impacts on human health [49]. Health-care facilities are one of the biggest electricity consumers in countries such as China, the US, Japan, India, and Germany [50]. Thus, in most countries, the health-care sector is the largest service sector in terms of carbon footprint [50]. Considering the urgent need to shift to clean energy, transitioning the health-care sector into renewables, such as solar, presents a profound opportunity to reduce greenhouse gas emissions globally [51,52].

Air Pollution: In 2013, the health-care sector in the United States was responsible for a significant portion of national air pollution, including acid rain (12%), greenhouse gas emissions (10%), smog formation (10%), criteria air pollutants (9%), stratospheric ozone depletion (1%) and air toxics (1–2%) [35]. Solar energy provides a viable option to reduce air pollution and improve national health.

Environmental Regulations: A country's environmental policies and regulations are relevant when considering hazardous impacts on human health. Developing countries tend to have more flexible emission regulations. An example is India's concentrations of suspended particulate matter standard [53]. As a result, substantial health effects are associated with the air quality in these countries. In other words, environmental policies fail to establish necessary environmental standards, adversely affecting human health. Solar energy, on the other hand, reduces carbon dioxide emissions and increases the likelihood of avoiding premature deaths in east China, resulting in air-quality health-related benefits [54].

Waste Management: Clean energy generation has the advantage of the absence or minimum production of waste products during its operation and the sun's endless harnessing capacity [55]. Regarding energy generation, current common energy sources (fossil fuels) necessitate extensive refining, which consumes additional resources and generates extra waste. In contrast, solar energy is drawn from a renewable source, and no source is depleted during the process, resulting in minimal waste since the processing is minor [56]. Minimal waste is a huge benefit for health-care facilities in remote locations, since the population's health is protected. Moreover, solar energy has endless harnessing capacity. For instance, the abundant solar energy sources in Hong Kong contribute to the energy supply and help improve environmental issues [57]. However, renewable energy consumption positively and significantly impacts environmental degradation [58]. Because solar energy is a renewable resource, its use does not deplete the environment. Other studies have stated that the everyday use of electricity generated by solar panels avoids consuming resources and degrading the environment, which supports the positive impact that energy generated from solar has [59].

Land and Space Concerns: The intensive land use required for photovoltaic system implementation is a challenge. Solar deployment could potentially interfere with produc-

tively used areas for other purposes, including food production [60]. A possible strategy to mitigate potential conflicts over land use for solar deployment is co-locating food production with solar panels or utilizing land unsuitable for agriculture [60]. On the other hand, the amount of land used for solar plants will be directly proportional to the size of the building and its requirements—in our case, health-care facilities. Due to the intensive land use, an additional impact on the environment is its aesthetic and visual aspects. For example, recently, California placed solar energy plants in land out of bounds to minimize recreational and visual impacts [61].

Wildlife Protection: Moreover, the placement and design of numerous solar energy plants can create a conflict in terms of wildlife displacement. The relationship between wildlife protection and solar energy development in the US has been examined, and authors have suggested that, among other things, using spatial decision support tools can help mitigate the effects of solar and wind energy development [62]. An example of this current issue is the controversy solar projects in the southwest of the United States have generated due to the disruption to wildlife and habitat [61]. However, a possible solution to manage solar energy integration's impact on wildlife is to locate panels in already disturbed environments, such as rooftops in urban areas or industrial sites [62]. The size of health-care facilities is more constrained in developing nations. As a result, the area taken up by the solar panels will be smaller because there are fewer of them. Alternative placement options, such as rooftops, can also be considered to minimize the impact.

2.3.3. Summary

In summary, benefits associated with solar generated energy include reduced greenhouse gas emissions, minimal hazardous impacts on human health, electrification of remote locations, reduced waste products, and the limitless harnessing capacity solar energy provides. Nevertheless, some of the current challenges the integration of solar energy plants is facing are intensive land-use, wildlife displacement, and habitat alteration. Health-care facilities in urban and rural areas can be electrified using solar power, which is an environmentally favorable choice. Solar energy is a feasible solution as the primary electricity generator, backup generator, or the sole option in islands or remote places to supply energy to health-care facilities, since it provides a more flexible, conscientious method of generating electricity. Opportunities exist in that solar energy applications can be used as a clean energy source, yet challenges exist in the sourcing, manufacturing, and transportation of solar energy components and systems. Thus, although the solar panels themselves result in limited environmental impact in comparison to fossil fuels, there is the potential for carbon footprint costs to negate the potential benefit of clean energy.

2.4. Topic Area 3—Economic Impact

2.4.1. Overview

Economic impact relates to sustainability, return on investment, and economic efficiency. This section provides an overview of these economic impact concerns within solar energy applications in underdeveloped and developing countries with a specific focus on health-care facilities.

Economic impact is one of the most critical factors when evaluating any project. Economic impacts are actions that can generate an impact that can be assessed monetarily at a local or global level and include the impact on the community. Energy is a pivotal and critical factor in every country. Currently, electricity is no longer a commodity, but a vital necessity, and its importance is directly related to a country's economic development [63]. A central key point to ensure the progress of a country's economy is a balance between energy supply and demand [64]. Incorporating solar applications into health-care facilities has numerous economic implications for consumers and a country's economy. Replacing fossil fuels with renewable energy benefits health-care facilities by lowering premature mortality rates, lost workdays, and overall costs [65].

2.4.2. Challenges and Opportunities

Challenges and opportunities discussed in this section include independent and reliable energy sources, cost of diseases, technological innovation, and employment and GDP.

Independent and Reliable Energy Sources: Solar energy has the potential to provide a reliable and low-cost electricity system to health-care facilities located in rural and remote areas [19]. In West African countries where rural electricity reaches only 40%, off-grid systems have gained significant attention and become more widespread in recent years, reaching more than 30 MW of installed capacity in solar power [66]. Solar applications may reduce both consumer utility bills and reliance on foreign energy sources. After the initial investment and installation of a solar energy system, electricity costs will be reduced [67]. Geographical locations of health-care facilities that are somewhat remote have limited access to electricity from a central grid. If any access exists, grid stability is not always optimal. Studies have focused on implementing integrated solutions using distributed energy sources, battery storage, and smart grids to improve the supply and reliability of energy in the islands [68]. The integration of solar systems can have huge implications in maintaining a reliable power supply, ensuring reliable grid stability, and reducing the need for expensive diesel generators for electricity use on islands [52,69]. Thus, health-care facilities in isolated geographical locations can benefit both environmentally and economically from using solar systems for electricity generation. On-site energy generation enables remote or rural areas to establish their own independent and reliable health-care facilities without relying on the local grid, which is not always an option. Literature has shown that integrating solar systems provides constant power and is environmentally sustainable [70]. Hence, integrating solar energy systems can accelerate rural electrification in an environmentally sustainable way. Furthermore, the expansion of renewable energy, such as solar, will reduce reliance on foreign energy sources and exposure to volatile fossil fuel market prices [71]. The city of Al-Tafilah in Jordan has shown that a hybrid renewable energy system (wind, solar, and hydro) can meet 100% of the city's electricity demand [72].

Cost of Diseases: Inaccessibility to reliable energy in remote locations, such as Africa, jeopardizes community access to necessary medication, safe childbirth, and other health treatments [73]. According to the World Health Organization (WHO), the African continent loses US$2.4 trillion annually to disease and inadequate health-care systems [73]. However, many African countries, such as Malia and Zambia, have put measures in place to reduce investment risks and increase the deployment of photovoltaic systems in health infrastructure [74]. Besides requiring a high initial investment, no significant resource or technical barriers have been found for the integration of solar systems into rural health-care facilities [74]. As a result, the reliable electrification of health-care facilities in developing and underdeveloped countries' rural or remote areas is a pressing issue considering the high and hidden costs of health care. According to findings from another study, a PV energy system is a more cost-effective and environmentally friendly energy source for outlying medical facilities [75]. In addition, given that solar energy is becoming more economically competitive in the energy market by the year, it is expected that it will help provide adequate care and extend the lives of many developing and underdeveloped country residents [76].

Technological Innovation: The integration of solar technologies in developing and undeveloped countries promotes technological innovation. According to studies, the solar energy market in China remains suboptimal due to several challenges faced by the industry, such as (1) poor connectivity in innovation networks, (2) unaligned competitive entities, and (3) a lack of market supervision [77]. These challenges currently provide opportunities for the innovation sector to grow and thrive. In other words, they are boosting technology innovation. As the solar energy market expands, new technological challenges emerge on a daily basis. The need to electrify remote health-care facilities has prompted a number of public, private, and nongovernmental initiatives, such as WE CARE Solar, a social innovation venture that proposes the development of portable solar suitcases to address the issue of intermittent electricity in hospitals in developing

countries lacking modern health-care facilities [73]. Projects like the one mentioned above only highlight the critical need for innovations in the health-care sector, particularly in developing countries, in order to provide quality care to a country's population. In addition, the development and diffusion of renewable energy technologies have been primarily associated with technological innovation systems studies and their establishment (TIS) [78]. Furthermore, solar applications drive technological innovation and create opportunities for entrepreneurs, promoting employment generation.

Employment and GDP: The integration of solar systems into community buildings, such as health-care facilities, provides employment generation benefits and increases a country's gross domestic product (GDP). Solar energy-based technologies and projects will stimulate business development, thereby creating jobs for unemployed youth [79], which is important considering young people in developing and underdeveloped countries seek employment to support themselves [80]. Expanding the solar power generation industry brings several new opportunities for entrepreneurs. No technical degree or background will be necessary to take advantage of these new opportunities in the industry. Positions will instead become available throughout the entire value chain [81]. However, as solar applications expand, new opportunities and uses emerge. It should be noted that employment will rise in a country if its GDP exceeds growth in labor productivity. According to a Moroccan study, the simulated economic impact on GDP by 2040 ranges between 1.21% and 1.99%, with potential employment ranging between 269,252 and 499,000 [82]. A study performed on Saudi Arabia stated that the integration of renewable energies, such as wind and solar, could help achieve sustainability and diversify the country's GDP [83]. Access to solar energy in rural areas promotes rural industrialization. As a result, health-care facilities can grow and develop more productively. Moreover, a positive correlation has been shown between health improvements and a country's GDP [84]. To summarize, solar applications can benefit a country's GDP by increasing employment opportunities.

2.4.3. Summary

Given the importance of electricity in our daily lives, there is a direct relationship between growth in the energy sector and a country's economic development. Some of the advantages of incorporating solar applications include promoting innovative technology development, increasing employment generation, improving the country's GDP, lowering consumer utility bills, and reducing a country's dependence on foreign energy sources. More specifically, health-care facilities can benefit from the use of solar energy in their operations while also contributing to the economic development of their country. In many cases, if they have access to the central grid, their utility bills will be reduced or, in the best-case scenario, they will be able to work independently of the central grid. This enables health-care facilities to provide dependable, high-quality patient care while lowering costs.

The introduction of renewable energies impacts a country's economy in multiple sectors, such as technology innovation, employment opportunities, and consumers' utility bills [63,82,85]. The integration of solar plants has meaningful benefits in terms of social welfare: in addition to environmental benefits, they also contribute to increasing a country's GDP, reducing foreign dependence, and employment generation [86]. Opportunities exist in that solar energy applications can be used in a modular fashion, scaling as funds become available. In addition, solar energy applications benefit from economies of scale: the more panels purchased, the cheaper the price. Although solar is scalable, it is still expensive, especially considering the large up-front costs for the individual components (e.g., inverter, battery, etc.). The high costs have the potential to result in health-care facilities becoming dependent upon NGOs or government for sustainability.

3. Discussion

The lack of accessibility and the intensive use of energy in the health industry is a relevant issue and one of the biggest challenges in the industry in developing and underdeveloped countries. Developing and underdeveloped countries face innumerable

problems related to the accessibility and quality of energy that put the lives of patients, health-care infrastructures, and health workers at risk. Current approaches such as grid power, unsustainable energy sources such as diesel or gas, and mobile health clinics have proven insufficient to address this issue. Those approaches have raised numerous operational, logistical, environmental, and economic concerns.

This study found that integrating solar energy in health facilities can provide innumerable opportunities. However, these opportunities are not without associated challenges. Table 1 summarizes the opportunities and challenges in each of the focus areas related to operational impacts. Table 2 shows a summary of the opportunities and challenges in each of the focus areas studied on the topic of environmental impacts. Table 3 summarizes the challenges and opportunities in economic impacts, specifying four main focus areas.

Table 1. Summary of opportunities and challenges for the use of solar energy in health facilities—operational impacts.

Operational Impacts		
Focus Area	**Opportunities**	**Challenges**
Operational Lighting	Utilization of more efficient technologies and solar energy.	Solar energy doesn't work at night, and batteries are expensive.
Communication Systems	Solar energy to operate communication equipment.	Lack of specialized workers. The use of batteries is expensive.
Refrigeration	Low-cost solar energy systems, such as solar power to provide refrigeration.	Intermittence of electricity generation. It only works during the day. The use of batteries increases the cost.
Sterilization	WHO-approved sterilizing methods.	High implementation cost.
Medical Equipment	Solar energy can provide reliable power to medical equipment.	Intermittence of electricity generation. It only works during the day. The use of batteries increases the cost. Optimize electrical load.

Table 2. Summary of opportunities and challenges for the use of solar energy in health facilities—environmental impacts.

Environmental Impacts		
Focus Area	**Opportunities**	**Challenges**
Water Resources and Treatment	Implementation of low energy consumption technologies for water treatment.	High implementation cost. Lack of specialized workers.
HVAC	Solar heating, solar cooling, and photovoltaic systems.	Lack of specialized workers. Optimize electrical load.
Greenhouse Gas Emissions	Solar energy transition to reduce GHG emissions	GHG emission from the manufacturing process of clean energies.
Air Pollution	Use of solar energy for the reduction of air pollution	The carbon footprint from the manufacturing and transportation of solar systems.
Environmental Regulations	Increased use of solar energy has health-related benefits for the population.	Make it a priority for governments to create environmental policies
Waste Management	Minimization of waste production by generating electricity with solar systems	Waste production from the manufacturing and transportation of solar systems.
Land and Space Concerns	Creation of new regulations on land use for renewable energies.	Make it a priority for governments to create land use regulations. Intensive land use.
Wildlife Protection	Minimize the impact of wildfire by installing solar systems in already disturbed environments.	Limitation of the areas where solar panels can be installed. Wildfire displacement and habitat disturbance.

Table 3. Summary of opportunities and challenges for the use of solar energy in health facilities—economic impacts.

Economic Impacts		
Focus Area	**Opportunities**	**Challenges**
Independent and Reliable Energy Sources	Solar energy has the potential to provide high-quality health care, a reliable system, and low-cost electricity to remote areas.	The high initial cost of systems and batteries. High dependence on NGOs and government subsidies.
Cost of Diseases	Expand access to the health system in rural and remote sectors.	The scalability of using solar energy due to its high initial cost.
Technological Innovation	Solar applications drive technological innovation and create opportunities for entrepreneurs.	Poor connectivity in innovation networks, unaligned competitive entities, and a lack of market supervision.
Employment and GDP	Solar energy-based technologies and projects will stimulate business development, thereby creating jobs for the unemployed youth.	Specialized solar energy workers are limited. Lack of policies that incentivize solar energy.

3.1. Opportunities

The implementation of solar energy in health-care facilities in rural or remote areas presents several opportunities in the operational area, which are summarized in Table 1. Operational lighting is an essential resource in health-care centers that can be used more efficiently with the implementation of new technologies and solar energy. Advances in telemedicine in recent years have been enormous, from routine medical consultations to complex surgeries. Telemedicine has been utilized to overcome barriers in undeveloped and developing countries' health-care institutions, such as geographic access, availability, and affordability [30]. Access to telemedicine in remote areas is an excellent opportunity to improve and expand health services, which would be possible with feasible access to energy and an internet connection. Medical equipment is crucial for the operation of health-care facilities, such as refrigeration, sterilization, X-rays, and incubators. For example, studies have shown that in some developing countries, 50% of the vacation is lost due to a lack of adequate refrigeration [32]. Additionally, electric incubators can reduce the risk of death of newborns by up to 40% [32]. Access to electrical energy is crucial to power the medical equipment in the facilities. In this way, solar energy can provide the power for the stable and reliable operation of essential medical equipment.

Another topic investigated in this study is the environmental opportunities presented by using solar energy in health-care facilities, which are summarized in Table 2. Water scarcity, or a lack of access to clean water, is a major concern in many regions of the world, and it has been highlighted as one of the most critical global challenges for the next decade [37]. Water is essential in health-care facilities for various reasons, including bathroom operation, cooling and heating, medical equipment, and laundry [40,41]. Due to this problem of contamination and water scarcity, implementing mechanisms and technologies for water treatment has become a vital need in health-care facilities that can be supported with solar energy generation in remote areas. There is also an opportunity to upgrade HVAC systems, accounting for up to 50% of energy consumption in health-care facilities. HVAC electrical systems are more efficient and have less energy loss than systems that use fossil fuels, which would generate savings in facility costs. The health-care sector is responsible for a significant part of environmental pollution. For example, in the United States the health-care sector is responsible for 12% of acid rain, 10% of greenhouse gas emissions, 10% of smog formation, and 10% of other air pollutants [35]. The use of solar energy in health-care facilities will help to significantly reduce greenhouse gas emissions due to the reduction of dependence on fossil fuels in energy generation. In this way, it helps protect the environment's degradation and people's health. Another benefit is that solar energy has a minimal impact on people's health compared to fossil fuels since the components produced by fossil fuels can cause premature death and respiratory diseases,

among others [54]. In addition, solar energy does not generate toxic waste like other energy sources. Countries have the sovereign right to use their natural resources [3]. It is essential to consider that the use of resources must be aligned with environmental regulations and policies, which allow the care of wildlife and protected spaces. Due to the massive energy transition occurring, the opportunity has been created to modify and make the environmental policies and regulations that allow the coexistence of the rapid development of solar energy and land and wildlife protection.

Finally, there are invaluable economic opportunities for implementing solar power in health-care facilities, which are summarized in Table 3. Providing electricity to remote areas that do not have a connection to the electricity grid is one of the main opportunities for solar energy. Some areas are remote due to their geographical location and difficult access, such as mountains, deserts, jungles, or islands. In some cases, extending the electricity grid in these locations is costly, so solar energy is presented as the best viable alternative. Accessing electricity through solar energy is essential for operating these areas' health-care facilities. Most underdeveloped and developing countries have a lot of power outages due to unreliable grids or natural disasters. This situation is even worse in remote areas. Health-care facilities with on-site photovoltaic systems have a unique opportunity to continue operating even during power outages, helping in this way to improve the stability of the grid in the face of this type of event [52,69]. Energy is critical in all countries, and its importance is directly tied to a country's economic development [63]. One of the main benefits of implementing solar energy is the reduction in electricity costs. This cost reduction would provide budgetary flexibility for health-care facilities, allowing them to reallocate expenses and invest in improving infrastructure and equipment or cover other more immediate needs, such as medicines and vaccines. Renewable energy implementation also positively impacts a country's local economy. In particular, integrating solar technologies in the health-care sector will promote technological innovation [77]. This positively impacts the generation of jobs and the creation of new businesses in the energy sector [81]. New business development will finally positively increase GDP. Added to the economic impact on the country's GDP, it will reduce its dependence on foreign fossil fuels. In conclusion, implementing solar energy in the health sector presents opportunities for the health sector and the entire supply chain, positively impacting various sectors of a country's economy. According to the Rio Declaration on Environment and Development, the citizens of each country must cooperate to eradicate poverty and reduce differences in living standards and access to essential services such as health-care centers [3].

3.2. Challenges

The implementation of solar energy in health-care facilities is not without its challenges. Tables 1–3 summarize the challenges in each of the three areas analyzed in the paper: (1) operational, (2) environmental, and (3) economic. The high initial investment is a critical factor in adopting solar energy [87]. These costs can vary significantly from country to country, and (depending on the size of the PV systems) the costs can easily be doubled if a battery backup system is considered. Additionally, solar generation depends greatly on geographic location and factors such as solar irradiance, sunny days, cloudy days, rain, and snow [87]. The dependence on multiple variables makes solar energy generation highly variable and sometimes unstable. Predicting this variability is an important challenge for installation in health-care facilities [7]. Due to the high variability in solar energy during the day and by season, it is essential to quantify and optimize electrical loads in facilities adequately. To this must be added another variability related to emergencies that can occur in a health-care facility. Emergencies are directly related to the increase in energy consumption at certain times. Additionally, there is a challenge due to the lack of specialized workers for installing and maintaining solar systems.

The use of solar energy also creates environmental challenges, which are summarized in Table 2. The energy needed to power large health-care facilities, such as regional hospitals, requires intensive land use, which can also lead to wildfire displacement and habitat

disturbance. Reducing this type of impact on the environment is one of the challenges of implementing solar energy in health centers. These impacts can intensify when protected areas of flora and fauna exist. There is also a challenge such that it becomes a priority for governments to create regulations that allow the sustained development of the solar industry, considering the potential environmental, flora, and fauna damage. Although solar panels do not pollute most during the operation phase, there is a challenge in how to reduce the carbon footprint and GHG emissions from the manufacturing and transportation of solar systems.

The high investment cost for photovoltaic systems is the main challenge associated with economic impacts (see Table 3). Additionally, there are costs related to the failure of the solar systems. This is due to a lack of predicted and real-time maintenance of the photovoltaic systems [88]. Investments in the health-care sector depend primarily on the public sector and NGOs, so there may be financing problems in some underdeveloped or developing countries to invest in solar energy. In addition, governments may have other more urgent priorities in the health sector. Furthermore, the development of solar application technology innovation may be undermined by a lack of market oversight and collaborative innovation networks. In the same way, the potential for employment and GDP growth can be reduced due to the mismatch between the growth of the solar industry and the specialization of workers in the field. Finally, one of the critical factors related to the adoption of solar energy is the lack of public policies that encourage the use of solar energy—programs such as net metering, peer-to-peer, tax reduction, or subsidies [89].

4. Conclusions

4.1. Main Takeaways

Solar energy is a reliable and long-term solution to electricity deficiency and accessibility in health-care facilities in underdeveloped and developing countries. The integration of solar energy in the health industry indicates a modernization of medical care and a decrease in dependence on fossil fuels, which will help a smooth energy transition. With the implementation of solar energy, patients in remote areas, often left behind, will have the opportunity to have access to quality health care. In addition, solar energy reduces much of the energy intensity in the facilities, making it more economical and respectful of the environment. Solar power can take the accessibility and quality of health care to new levels of ease and safety that have not been seen and cannot be replicated with other forms of technology.

4.2. Contribution to Literature

The general contribution of this paper is providing a holistic perspective of the challenges and opportunities of solar energy as a relevant actor in improving the energy infrastructure in rural or remote health centers. The literature review revealed three impact areas to consider: (1) operational, (2) environmental, and (3) economic. Researchers can use the findings in this review as a basis for new investigations at the intersection of solar energy and health-care facilities in developing and undeveloped countries. Additionally, it provides an overview that policymakers can use for policies and regulations that should be considered in the topic. Finally, this study offers a variety of interventions and programs that encourage the use of solar energy by sharing best practices.

4.3. Limitations and Future Research

This article is not without limitations. The study has focused on an isolated topic: the use of solar energy in health-care facilities in developed and underdeveloped countries. Articles on other facilities have not been included. Additionally, the incorporation of studies focused on developed countries was limited. Also, studies focused on different types of renewable energy, other than solar, were not considered. Finally, this study is a qualitative literature review. Unlike systematic reviews, this study lacks an established

strategy for searching for articles, so the number of selected papers is broader. At the same time, it lacks statistical analysis, as in the case of meta-analyses.

There is a need for future research to generate more reliable resources on the topic studied. More research is needed on variations in solar panel performance and power load optimization, as well as how they can affect the functionality of a health-care facility. Implementing the system requires more information about optimal performance in some remote areas where other limitations may exist. There is also a need to analyze and quantify the costs and benefits of implementing solar systems in rural or remote health centers. Finally, it is also necessary to analyze and review the public policies that promote the use of solar energy and investigate specific regulations that intertwine health-care facilities and solar power.

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