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Renewable Energy Integration in Sustainable Healthcare Systems

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Abstract: The increased availability and affordability of renewable energy sources have evoked considerable interest. Hospitals and healthcare facilities, specifically, are now looking for clean and renewable energy alternatives to contain energy expenses, avoid price volatility, and safeguard public health. Yet, precise load estimation and techno-economic analysis are imperative to achieve optimum performance and dependability of renewable energy systems. This research will explore load estimation and techno-economic analysis for a remote hospital to determine the potential value of renewable energy in terms of energy generation, cost savings, and environmental benefits. Additionally, this research assesses the viability of having a renewable energy system installed at the hospital. By utilizing two clean energy management software tools, HOMER PRO and RETScreen Expert, this research compares the hybrid (PV/Wind/Battery/Converter/Grid) system under proposal with the current system regarding cost savings, optimal system configuration, and environmental impact. The findings show that the proposed hybrid system is a more cost-effective, reliable, environmentally friendly, and efficient solution. Additionally, the reduction of grid load and the annualized generation and consumption of energy are computed. The suggested ideal system is validated by comparing the results of the two software applications. Other local businesses wishing to adopt solar and wind energy may find the techno-economic assessment of the suggested system to be a helpful guide.

Keywords: Renewable Energy; Effectiveness, Energy Systems; Healthcare Systems.

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1. Introduction

Energy efficiency and sustainability need to be considered and integrated into long-term strategic planning because healthcare technologies are developing quickly. The idea of energy-efficient healthcare has acquired a lot of popularity as hospitals and trusts struggle with the dual issues of improving medical care and reducing environmental impact. From the incorporation of cutting-edge technologies and therapies to the creation of ecologically friendly facilities, the future of sustainable healthcare encompasses the various aspects of energy efficiency in the medical industry (Dion et al., 2023). The design and construction (or retrofitting) of facilities that promote sustainability is the first step towards providing healthcare that is energy-efficient. Hospitals can also curtail their carbon footprint by adopting green building practices, including using renewable materials, energy-efficient lighting, and well-maintained heating, ventilation, and air conditioning systems. Healthcare buildings can also produce environmentally friendly settings by using smart building technologies and efficient insulation measures. To find a balance between state-of-the-art technology and energy efficiency, hospitals and clinics are reevaluating their method of medical equipment.

Advanced medical equipment is manufactured with energy efficiency in mind, such as through automatic shutdown, low-power mode, and sophisticated power management (Sethi & Caemmerer, 2024). In addition, recycling and renovating medical devices can facilitate a circular economy by minimizing waste and prolonging the life of important healthcare assets, especially in emerging economies (Olatomiwa et al., 2022). Another crucial step in reaching sustainability and a net-zero healthcare system is the incorporation of renewable energy sources into healthcare facilities. Utilizing clean energy sources such as geothermal systems, heat pumps, wind turbines, and solar panels can lessen dependency on conventional power grids. In addition to saving money, progressive hospitals are making investments in on-site CHP and renewable energy infrastructure to help reduce greenhouse gas emissions overall (Eshiet & Iji, 2024).

2. Review of Literature

The foundations of human resource quality and the determinant of every nation's growth strategy are good health and welfare. The close and intimate relationship between environment and health is widely known (Soto et al., 2022). The environment should be safeguarded and maintained as a component of excellent health and wellbeing. Planning is crucial, especially for urban health, as a result of the expanding urban areas brought about by the growing population of cities.

Despite the fact that there were success stories about lowering death rates, increasing life expectancy, and controlling disease-specific deaths, the committee raised concerns about the availability and accessibility of healthcare services. Primary health centres (PHCs) lacked adequate staffing and equipment, medical professionals were in short supply, and healthcare facilities urgently needed to be upgraded (Albarsha et al., 2024).

The NHP draft was released to the public on the eve of the ninth plan, and feedback was requested. The NHP paper was ultimately released in 2002 with the goal of achieving acceptable standards for the health of the Indian population, decentralization, equity, accessibility to healthcare, and the availability of reasonably priced private healthcare. The policy also recognized the importance of traditional remedies.

After 14 years, the National Health Policy of 2017 was released, and as a result, the health context underwent numerous changes. The 2017 policy has been influenced by the emergence of the private sector, the number of infectious and non-communicable diseases, the increase in health spending, and the expansion of the economy, which has improved fiscal capacity (Naveed et al., 2024).

Since social security and growth depend heavily on health care, the Indian government wants to see "health for all." According to the Constitution, hospitals, dispensaries, public health, and sanitation are listed under the state list (Entry 6, State List II), whereas family planning and population control are listed under the concurrent list (Entry 20 A, List III).

3. Methodology

The vast potential for renewable energy in the region has been highlighted by a thorough investigation of the solar and wind energy resources that are accessible at the site. In light of these findings, the case study's recommended methodology is based on sustainable energy sources including solar and wind power. The study does a thorough examination of resource availability and cost estimation using the HOMER PRO and RET Screen Expert tools.

3.1. Case Study

The electric load and overall equipment of the building are the main topics of this study's feasibility analysis of implementing a hybrid power system. The building now uses grid power, which is somewhat costly. The study uses HOMER Pro and RET Screen Expert, clean energy management programs frequently used for hybrid renewable energy system design, to address this. To identify the best options based on the lowest COE and NPC, a variety of viable solutions are examined, and various scenarios involving generated energy systems are examined. When established, renewable energy sources are less expensive to run than conventional fossil fuels. Long-term energy bill savings can balance the initial investment in renewable energy infrastructure. The financial case for healthcare facilities is further strengthened by the fact that numerous governments provide incentives for renewable energy installations (Ahmed & Areebah, 2024).

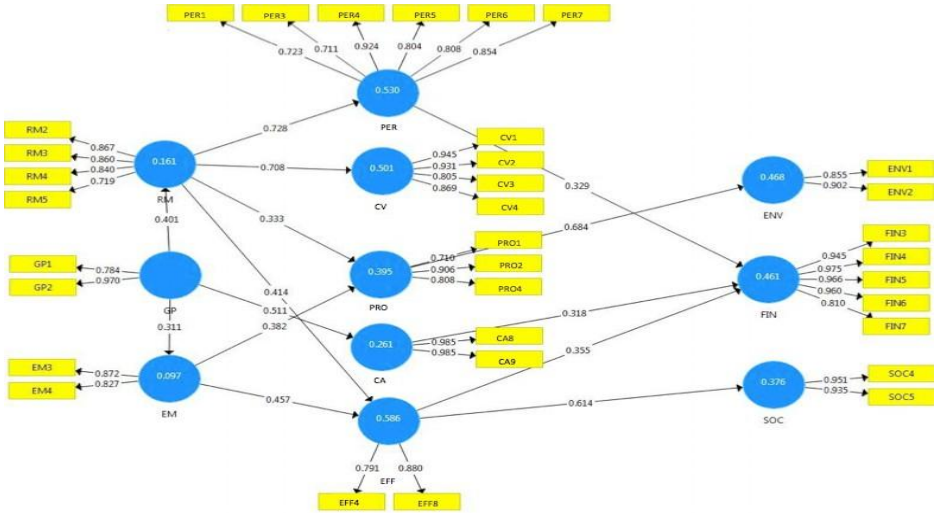

Figure 1: The Results of the Measurement Model

3.2.Enhancing Public Health

Healthcare institutions can significantly contribute to better public health outcomes by lowering their use on fossil fuels. Asthma, heart disease, and other illnesses made worse by poor air quality are less common when air pollution levels drop. Furthermore, the healthcare industry's dedication to safeguarding and improving community health outside of its buildings is demonstrated by sustainable energy practices in healthcare settings. Leading software for planning and analysing hybrid power systems, which can include a mix of WTs, solar panels, batteries, and other power generation and storage devices, is HOMER Pro, created by HOMER Energy. Important characteristics include:

1 **Optimization and sensitivity analysis:** HOMER Pro is particularly well-known for its capacity to sort through thousands of options and identify the best dependable and economical system configuration for a given application.
2 **Component modelling:** Users can use it to simulate how specific parts will behave, including their technical and financial traits.
3 **Grid modelling:** HOMER can analyse the economic effects of grid failures and the interactions between variable generation resources and loads in grid-connected systems.
4 **Economic analysis:** It calculates factors like net present value, payback period, and levelized cost of electricity to give comprehensive economic feasibility evaluations.

Multi-year simulation: HOMER Pro evaluates the long-term viability of the system by running thousands of simulations over several years.

On the other hand, Natural Resources Canada is the developer and distributor of the well-known renewable energy management software program RET Screen Expert. The software aims at enabling discovery, evaluation, and implementation of prospects for cogeneration, energy savings, and renewable energy opportunities. Its essential properties and functionality entail:

1**. Feasibility analysis**: Availing the end-users with holistic knowledge on whether renewable energy initiatives are economically as well as technologically viable or not.

2**. Performance analysis**: Enabling experts to check actual performance within facilities and put it alongside modelled results.

3. **Analysis of emissions**: Facilitating the assessment of reductions in greenhouse gas emissions, important for programs advocating environmental conservation and sustainability.

4. **Database**: Providing a vast repository of climatic information, equipment data, and project examples, of benefit to users.

Both computer programs are used to perform energy, economic, and environmental analysis of the planned system, the outcomes being compared to confirm conclusions.

3.3.Solar Energy in Healthcare Facilities

The incorporation of solar power in healthcare facilities is a critical element of shifting to sustainable and resilient healthcare infrastructure. Through solar photovoltaic (PV) systems and solar thermal systems, healthcare facilities can effectively lower their energy usage and environmental footprint. Solar PV systems transform sunlight into electricity via semiconductor cells, offering considerable amounts of the electrical power required for air conditioning, medical devices, and lighting. Because they are scalable, solar PV systems can be arranged in different configurations such as ground-mounted arrays, rooftop installations, and solar carports to meet a facility's unique requirements. Solar PV systems have advantages, including saving energy costs and lowering grid dependence, making the facility more resilient to power outages and energy price spikes.

Solar thermal systems utilize the sun's radiation to produce heat, which can be used in hospitals for space heating, hot water, and cooling by means of absorption chillers. By using solar thermal technologies, healthcare centers can drastically lower their gas or electricity usage for these ends. As a consequence, solar thermal systems represent a precious potential for hospitals to reduce greenhouse gas emissions and save energy, enabling a more environmentally friendly and sustainable operation.

The use of solar energy systems in health care facilities is not without difficulty. The main hurdles are the up-front capital and the extensive space needed for solar installations. But strategic design and planning can solve these problems. For example, retrofitting of existing buildings or incorporating solar PV panels in new building design can maximize space efficiency and energy generating capacity. In addition, incentives in the form of subsidies, tax credits, and renewable energy certificates can decrease initial costs, making solar power projects more viable and attractive.

Table 1: Results summary for Reflective measurement models

Latent Variable	Elements that the indicator capture	Outer Loadings	Indicator Reliability	Composite Reliability	AVE
PRO	PRO1	0.710	0.504	0.852	0.659
	PRO2	0.906	0.820		
	PRO4	0.808	0.652		
CA	CA8	0.985	0.970	0.985	0.970
	CA9	0.985	0.970		
CV	CV1	0.945	0.893	0.938	0.791
	CV2	0.931	0.866		
	CV3	0.805	0.648		
	CV4	0.869	0.755		
EM	EM3	0.872	0.760	0.838	0.722
	EM4	0.827	0.760		
ENV	ENV1	0.855	0.731	0.871	0.772
	ENV2	0.902	0.813		
FIN	FIN3	0.945	0.893	0.971	0.871
	FIN4	0.975	0.950		
	FIN5	0.966	0.933		
	FIN6	0.960	0.921		
	FIN7	0.810	0.656		
GP	GP1	0.784	0.614	0.874	0.778
	GP2	0.970	0.940		
	PER1	0.723	0.522		
	PER3	0.711	0.505		

PER	PER4	0.924	0.853	0.918	0.652
	PER5	0.804	0.643		
	PER6	0.808	0.652		
	PER7	0.854	0.729		
EFF	EFF4	0.791	0.625	0.823	0.700
	EFF8	0.880	0.774		
RM	RM2	0.867	0.751	0.894	0.679
	RM3	0.860	0.739		
	RM4	0.840	0.705		
	RM5	0.719	0.516		
SOC	SOC4	0.951	0.904	0.941	0.889
	SOC5	0.935	0.874		

Numerous medical facilities across the globe are models of sustainable healthcare design because they have effectively incorporated solar energy into their operations. These institutions show leadership in environmental management in addition to reporting notable energy cost reductions. For example, hospitals with solar carports improve the overall sustainability and user comfort of the facility by producing clean electricity and offering staff and patients shaded parking.

Table 2: Effect Sizes of Coefficient of Determination and Predictive Relevance

	f2 effect size			**q2 effect size**		
	ENV	**FIN**	**SOC**	**ENV**	**FIN**	**SOC**
GP	0.468	0.460	0.376	0.323	0.362	0.341
PRO	NA	0.461	0.377	NA	0.363	0.311
CA	0.468	0.359	0.376	0.323	0.286	0.311
CV	0.468	0.461	0.376	0.323	0.363	0.311
EM	0.461	0.461	0.377	0.317	0.363	0.311
PER	0.468	0.383	0.376	0.323	0.303	0.311
EFF	0.468	0.375	NA	0.323	0.291	NA
RM	0.472	0.472	0.376	0.326	0.372	0.311

The use of solar energy in healthcare is expected to increase much further as costs come down and technology advances. The intermittent nature of solar power can be mitigated by integrating battery storage systems with solar PV installations, guaranteeing a consistent and dependable energy source. Furthermore, the development of building-integrated photovoltaics (BIPV) and improvements in solar panel efficiency present promising paths for integrating solar energy into healthcare facility architecture in a seamless manner.

Table 3: Total Effects and Index Values of Latent Constructs

Latent constructs	**Importance (Total effects)**	**Performance (Index values)**
ENVIRONMENTAL BENEFITS		
PRO	0.684	76.692
EM	0.261	57.610
GP	0.173	69.929
RM	0.228	60.698
FINANCIAL BENEFITS		
CA	0.318	62.642
EM	0.162	57.610
GP	0.368	69.929
PER	0.329	49.028
EFF	0.355	57.199
RM	0.386	60.698
SOCIAL BENEFITS		
EM	0.280	57.610
GP	0.189	69.929
EFF	0.614	57.199
RM	0.254	60.698

India's renewable energy industry has played a significant role in expanding the nation's grid-connected power generation capacity, addressing the country's energy scarcity, and promoting sustainable growth. It

has been acknowledged that India as a country can provide solutions for the country's power problems through renewable energy sources. Renewable energy will be crucial to planning energy processes and guaranteeing energy security in the years to come. With global energy demand growing faster than existing production capacity, the globe is experiencing an energy deficit. As a result, there is less supply, which drives up prices. Improving energy generation capacities is essential to maintaining global industrial, demographic, and economic growth, guaranteeing a consistent and effective supply of energy to satisfy rising needs.

4. Conclusion

Encouraging an awareness and responsibility culture among health professionals is fundamental to attaining energy efficiency within the sector. Employee training schemes can enable workers to embrace energy-saving practices, including turning equipment off when idle, maximizing lighting, and executing energy-efficient practices. By enabling health professionals with the means to become sustainability champions, a team-based environment is fostered where all contribute to the common cause of energy efficiency. The advent of telemedicine and remote patient monitoring has also transformed healthcare delivery, providing greater accessibility and energy efficiency. These technologies minimize energy usage related to travel and on-site healthcare services by avoiding the necessity for in-person visits. In addition, remote monitoring and virtual medical consultations are also in line with wider sustainability goals, illustrating how technology can promote energy efficiency in the healthcare sector. Governments and regulatory agencies have a significant influence on how energy-efficient healthcare is developed. Change in the healthcare sector can be sparked by enforcing strict energy efficiency regulations, incentives, and subsidies. Policymakers can motivate healthcare providers to give energy efficiency top priority in their operations by establishing a regulatory framework that incentivizes ecologically responsible behaviour.

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