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A MULTI-STATE ANALYSIS OF THE EFFECTIVENESS OF COLD-CHAIN EQUIPMENT DISTRIBUTION PROGRAM: CORPORATE SOCIAL RESPONSIBILITY IN PANDEMIC RESPONSE

ANÁLISIS MULTIESTATAL DE LA EFICACIA DEL PROGRAMA DE DISTRIBUCIÓN DE EQUIPOS DE CADENA DE FRÍO: RESPONSABILIDAD SOCIAL CORPORATIVA EN LA RESPUESTA A LA PANDEMIA

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ABSTRACT

This study examines the implementation and impact of PowerGrid's cold-chain equipment distribution initiative across diverse states in India during the COVID-19 pandemic. The research focuses on a comprehensive survey conducted in multiple districts of Punjab, Sikkim, Ladakh, and Mizoram to evaluate the effectiveness of the cold-chain infrastructure in supporting vaccine distribution and storage. The primary objectives included assessing the adequacy, functionality, and accessibility of the deployed equipment, while considering the unique geographical and demographic challenges of each region. The study involves a detailed evaluation of various operational aspects, including procurement efficiency, distribution strategies, and overall enhancement of vaccine storage capabilities. Particular attention was paid to analysing how PowerGrid's intervention contributed to overcoming logistical challenges in remote and difficult-to-access areas, ensuring consistent vaccine availability and maintaining proper storage conditions throughout the distribution network. The research provides insights into the strengths and weaknesses of the implemented cold-chain system, identifying critical factors that influenced its success and areas requiring improvement. The findings demonstrate PowerGrid's initiative that enhanced the capacity of remote health centers to maintain vaccine efficacy through proper storage and handling. The study also reveals the crucial role of strategic equipment distribution in strengthening the overall healthcare infrastructure during the pandemic response. This research contributes to the existing literature on public health infrastructure development and emergency response systems, particularly in the context of large-scale vaccination programs in geographically diverse regions. The findings serve as a valuable reference for future public health initiatives and highlight the importance of corporate involvement in strengthening healthcare infrastructure. Furthermore, the study provides practical recommendations for optimizing cold-chain systems and improving vaccine distribution networks in challenging geographical terrains.

Keywords: PowerGrid, Corporate Social Responsibility, Vaccination, Refrigerators, Healthcare.

RESUMEN

Este estudio examina la implementación y el impacto de la iniciativa de distribución de equipos de cadena de frío de PowerGrid en diversos estados de la India durante la pandemia de COVID-19. La investigación se centra en una encuesta exhaustiva realizada en varios distritos de Punyab, Sikkim, Ladakh y Mizoram para evaluar la eficacia de la infraestructura de la cadena de frío en el apoyo a la distribución y el almacenamiento de vacunas. Los objetivos principales incluían evaluar la adecuación, funcionalidad y accesibilidad de los equipos desplegados, teniendo en cuenta los retos geográficos y demográficos únicos de cada región. El estudio implica una evaluación detallada de diversos aspectos operativos, entre ellos la eficiencia en la adquisición, las estrategias de distribución y la mejora general de la capacidad de almacenamiento de vacunas. Se prestó especial atención al análisis de cómo la intervención de PowerGrid contribuyó a superar los retos logísticos en zonas remotas y de difícil acceso, garantizando la disponibilidad constante de vacunas y manteniendo unas condiciones de almacenamiento adecuadas en toda la red de distribución. La investigación ofrece información sobre los puntos fuertes y débiles del sistema de cadena de frío implantado, identificando los factores críticos que influyeron en su éxito y las áreas que requieren mejoras. Los resultados demuestran la iniciativa de PowerGrid, que mejoró la capacidad de los centros de salud remotos para mantener la eficacia de las vacunas mediante un almacenamiento y una manipulación adecuados. El estudio también revela el papel crucial de la distribución estratégica de equipos en el fortalecimiento de la infraestructura sanitaria general durante la respuesta a la pandemia. Esta investigación contribuye a la bibliografía existente sobre el desarrollo de infraestructuras de salud pública y los sistemas de respuesta a emergencias, especialmente en el contexto de los programas de vacunación a gran escala en regiones geográficamente diversas. Los resultados sirven como referencia valiosa para futuras iniciativas de salud pública y destacan la importancia de la participación de las empresas en el fortalecimiento de la infraestructura sanitaria. Además, el estudio ofrece recomendaciones practices para optimizar los sistemas de cadena de frío y mejorar las redes de distribución de vacunas en terrenos geográficos difíciles.

Palabras claves: PowerGrid, responsabilidad social corporativa, vacunación, refrigeradores, asistencia sanitaria.

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1. INTRODUCTION

The cold-chain system plays a vital role in preserving vaccine efficacy by maintaining appropriate temperature conditions from manufacturing facilities to the final point of administration a component as crucial to immunization programs as proper vaccine management itself (Das et. al., 2020; Gupta and Gupta, 2015; Pandey et. al., 2018). The COVID-19 pandemic presented unprecedented challenges to healthcare systems worldwide, particularly in distributing temperature-sensitive vaccines across diverse geographical regions (Md Kahiri et. al., 2022; Wijethilaka, 2024; Runde et. al., 2021). This study examines a Corporate Social Responsibility (CSR) initiative undertaken by PowerGrid between December 2020 and June 2021 that strengthened cold-chain infrastructure across four strategically important Indian states and Union Territories (Punjab, Sikkim, Ladakh, and Mizoram). These regions represent diverse geographical and climatic conditions with unique challenges. Punjab provides insights into management across a densely populated northern state with extreme seasonal temperature variations and mixed urban-rural healthcare settings. Sikkim's mountainous Himalayan terrain presents challenges of remote, isolated communities with limited accessibility and frequent power disruptions. Ladakh represents the most extreme environment, characterized by high altitudes, temperatures below -30°C, severely limited accessibility, and months-long isolation during winter. Mizoram introduces additional complexities with its hilly tropical terrain, high year-round humidity, monsoon vulnerability, and remote tribal communities.

These regions face harsh weather ranging from extreme cold to intense heat and humidity, impassable roads that isolate communities for weeks or months, frequent power outages, and difficult delivery routes. This geographical coverage ensures the study captures cold-chain equipment functionality across India's most challenging environments, with findings that can improve systems throughout the country, especially in areas where maintaining proper refrigeration is most difficult. Continuous temperature monitoring is key to preventing system failures. Health centers utilize deep Freezers and ILRs for this purpose (Gedi, 2022; Kumar and Gupta, 2020; Feyisa, 2021). The initiative involved ₹3,14,42,422 for procurement and distribution of 313 cold-chain equipment units, including ILRs and deep freezers of varying capacities. The strategic distribution allocated 209 units to Punjab, 46 to Mizoram, 15 to Ladakh, and 13 to Sikkim, enhancing these regions' capabilities in maintaining proper cold- chain management for COVID-19 vaccines in support of India's national vaccination program.

The cold-chain distribution praogram initiative proved crucial for vaccine preservation during transportation and storage. In remote and rural areas lacking basic healthcare facilities, this CSR effort became the backbone of the vaccination drive (Guliani and Gautam 2021; Sharma, 2022). Storage and disbursement of vaccines presented significant challenges in these areas (Fesha, 2016; Chowdhury et. al., 2023), but the initiative substantially increased vaccination capacity, especially in the remote regions of Ladakh, Sikkim, and Mizoram. This effort demonstrates how CSR can advance Sustainable Development Goals (SDGs) (Rani et. al., 2024) and strengthen healthcare infrastructure (Tripathi et. al., 2024). PowerGrid's CSR approach exemplified successful collaboration between corporate entities and healthcare systems to address critical medical needs (Sati and Nayyar, 2024). While India produces 60% of global vaccines, the challenge lay not in availability but in equitable distribution (Braganza et. al., 2021; Chandani et. al., 2021). Factors such as limited internet access, geographical isolation, and socioeconomic conditions created barriers that these targeted CSR programs helped overcome by improving distribution networks and ensuring better access across different communities (Umakanthan et. al., 2021).

To evaluate this initiative's impact, a detailed survey was conducted across multiple districts in all four regions. The primary objective was to assess the adequacy, functionality, accessibility, and overall impact of the deployed cold-chain equipment, with emphasis on its role in facilitating COVID-19 vaccine administration. The survey evaluated various aspects including procurement efficiency, distribution strategy effectiveness, and overall enhancement of vaccine storage and distribution processes. This comprehensive evaluation identified strengths, weaknesses, opportunities, and challenges associated with the cold-chain equipment. The study also highlights the empowerment of remote health centers and communities but also provides a valuable blueprint for enhancing cold-chain systems for future healthcare initiatives. Proactive involvement through CSR, underscores its commitment to public health as a responsible corporate entity, while offering valuable insights into the effectiveness of public-private partnerships in strengthening healthcare infrastructure during global health emergencies

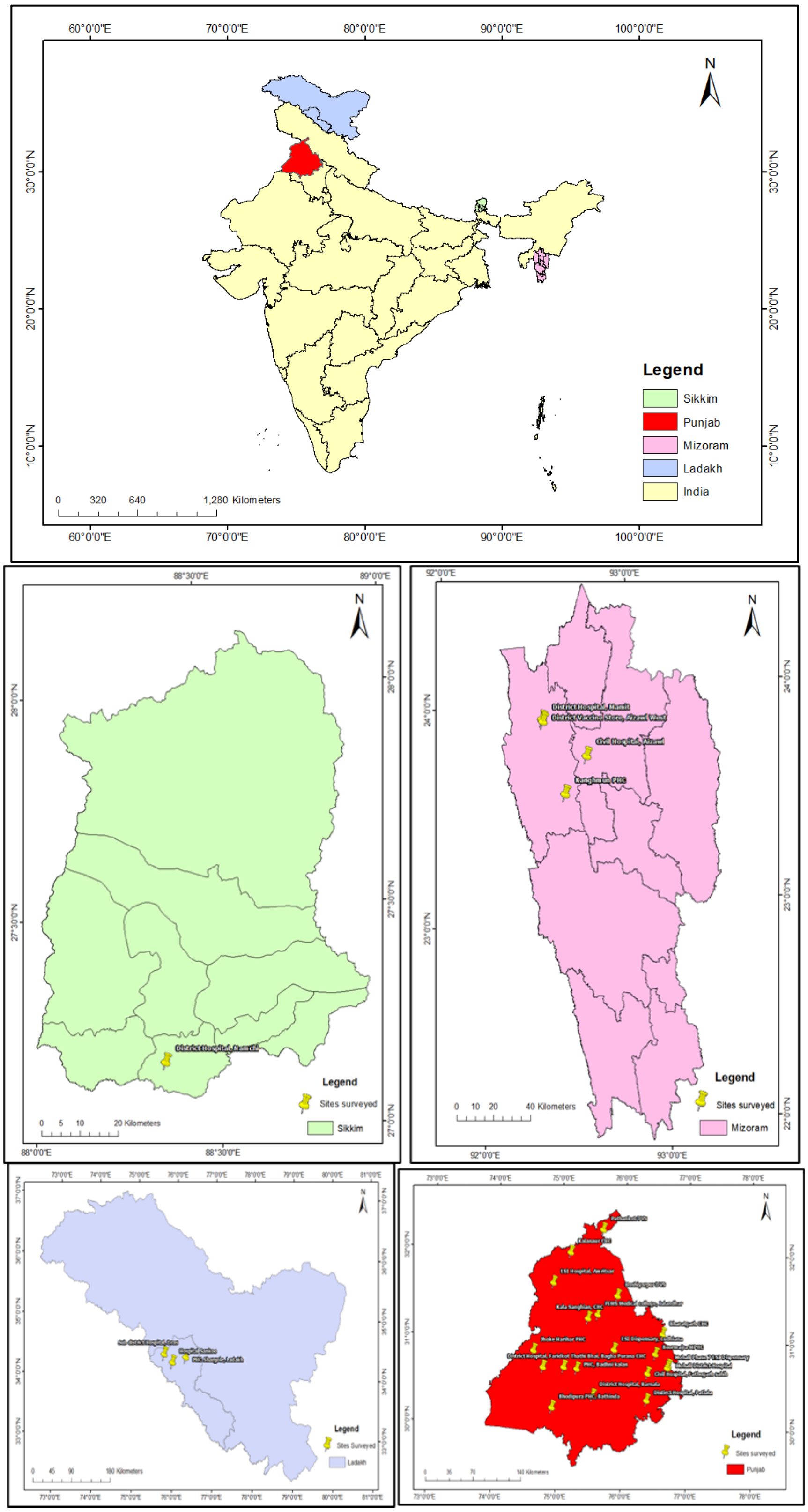

Figure 1. Study area. A) Regions across India where cold-chain equipment were distributed (Sikkim, Punjab, Mizoram and Ladakh).B) Designated sites where cold-chain equipment was distributed and survey were carried out.

1.1. Study Area

The study was conducted across multiple districts in Punjab, Sikkim, Ladakh, and Mizoram (as shown in figure 1), covering both urban and rural areas. The study encompassed multiple healthcare facilities at various levels, from primary health centers to district hospitals, ensuring a comprehensive assessment of the cold-chain equipment distribution. In Punjab, the survey covered an extensive network of healthcare facilities across fifteen districts. Key sites included the ESI Hospital in Amritsar, the District Hospital PP Unit in Barnala, and the Primary Health Centre in Bhodipura, Bathinda. Additional districts covered in Punjab were Faridkot, Fatehgarh Sahib, Ferozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Pathankot, Patiala, and Rupnagar, representing a diverse mix of urban and rural healthcare settings. In the northeastern state of Sikkim, the Namchi Community Health Centre in South Sikkim was assessed. The survey in Ladakh, characterized by its high-altitude terrain and challenging accessibility, focused on healthcare facilities in the Kargil district, including CHC Shargole, District Hospital Sankoo, and the Public Health Centre in Drass. The assessment in Mizoram concentrated on both urban and rural healthcare facilities, including the State Vaccination Center and Civil Hospital in Aizawl West, along with the District Hospital Mamit and Kanghmun PHC in Mamit district.

The figure 1 (a and b) shows the multiple regions across India where cold-chain equipment distribution initiative was implemented. The survey covered designated sites where cold-chain equipment was distributed (fig.1, b).This diverse selection of study areas ensured that the research captured the varying challenges and requirements of cold-chain equipment deployment across different geographical settings. This strategic selection of regions ensured a comprehensive evaluation of cold-chain equipment functionality across varying geographical, climatic, and infrastructural settings, providing a holistic understanding of CSR initiative implementation across the diverse Indian landscape.

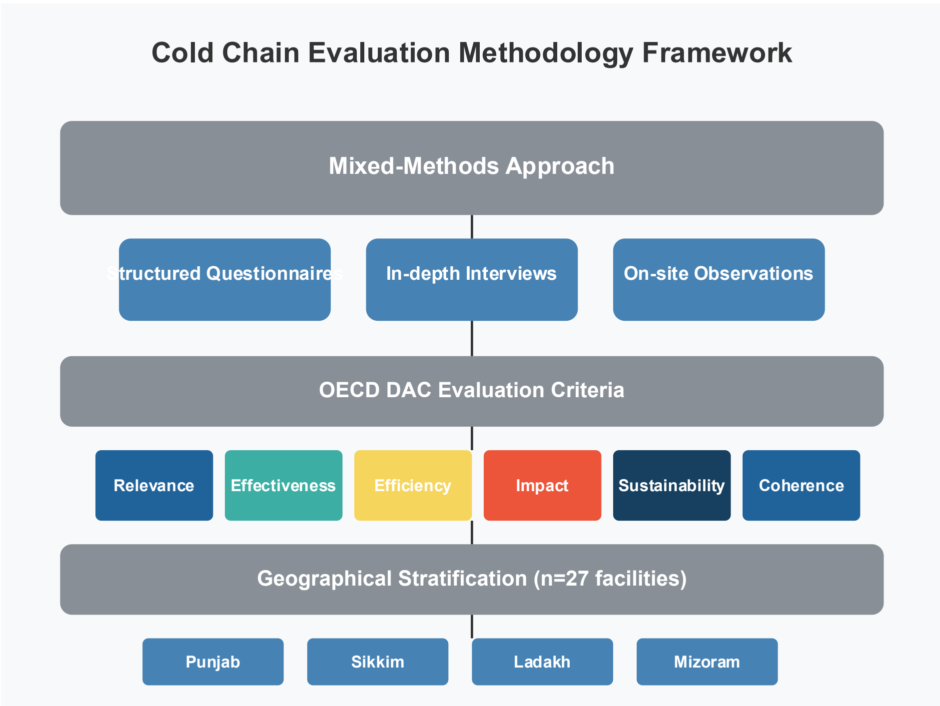

Figure 2. Methodology of the study.

2. METHODOLOGY

The study employed a stratified sampling approach to select healthcare facilities across multiple regions of India. The sample comprised government hospitals and health care centres from four distinct geographical regions (Punjab, Sikkim, Ladakh, and Mizoram), ensuring representation of diverse healthcare delivery contexts. Overall, 27 Hospitals and health centers were selected as a sample site from four different states. This geographical stratification ensured coverage of different healthcare delivery models. Primary data collection involved structured interviews with the Chief Medical Officers and care takers of each facility, focusing on gathering comprehensive insights into healthcare management and service delivery across these diverse institutional settings. The primary focus was on evaluating the effectiveness of cold-chain equipment procured and supplied by PowerGrid under CSR initiatives. Data was collected through a comprehensive approach involving structured questionnaires, interviews, and on-site observations of the placed cold-chain equipments. The use of structured questionnaires allowed for a systematic collection of quantitative and qualitative data, while interviews provided in-depth insights from key stakeholders.

On-site observations were conducted to validate and complement the information obtained through questionnaires and interviews. A diverse group of respondents participated in the survey to ensure a holistic understanding of the cold-chain system's impact. This included healthcare professionals responsible for vaccine storage and distribution and officials overseeing the cold-chain infrastructure. By adopting this methodology, the study aimed to provide a robust understanding of the effectiveness of the cold-chain equipment procurement and supply across the surveyed states. The impact of CSR initiative was comprehensively analysed using the six evaluation criteria established by the OECD DAC (Development Assistance Committee) network on development evaluation. The OECD DAC network provides a globally recognized framework for assessing development projects based on relevance, effectiveness, efficiency, impact, sustainability, and coherence. These criteria ensure that initiatives are systematically evaluated for their contribution to social and economic development.

Survey Focus Areas: The survey focused on various aspects of the cold-chain system, including equipment functionality, accessibility, distribution efficiency, and the overall impact on the vaccination process. Key performance indicators such as the functionality of ILRs and deep freezers, maintenance issues, accessibility of equipment in remote areas, and the coverage of the cold-chain system were assessed. This included evaluating the operational status of ILRs and deep freezers, identifying any issues related to moisture, heating, technical glitches, infrastructure, and maintenance. Accessibility was measured in terms of equipment distribution in both urban and rural areas, ensuring equitable coverage. The details of surveyed health facilities can be seen in the table 1 below:

Table 1. Sites visited during survey.

Regions (States & UT's)	Name of the sites	District
Punjab	Amritsar ESI Hospital	Amritsar
	Barnala DH PP Unit	Barnala
	Bhodipura PHC	Bathinda
	Faridkot DH	Faridkot
	Fatahgarh Sahib CH	Fatehgarh Sahib
	Jhoke Harihar PHC	Ferozepur
	Kalanaur CHC	Gurdaspur
	Hoshiarpur DVS	Hoshiarpur
	PIMS Medical College	Jalandhar
	KalaSanghain CHC	Kapurthala
	Ludhiana ESI Hospital Dispensary No 3	Ludhiana
	Bhadhni kalan PHC	Moga
	Thathi Bhai Baghapurana CHC	Moga
	Pathankot DVS	Pathankot
	DH Patiala	Patiala
	Bharatgarh CHC	Rupnagar
	Boormajra MPHC	Rupnagar
	Mohali DH PP Unit	SAS Nagar
	Mohali Phase 7 ESI Dispensary No 1	SAS Nagar
Sikkim	Namchi Community health centre (CHC)	South Sikkim
Ladakh	CHC Shargole	Kargil
	District hospital Sankoo	Kargil
	Public Health Centre Drass	Kargil
Mizoram	District Vaccine Store	Aizawl west
	Civil hospital Aizawl	Aizawl east
	District hospital Mamit	Mamit
	Kanghmun PHC	Mamit

This table provides a comprehensive overview of all healthcare facilities included in the cold-chain equipment assessment study across four diverse regions. Organized by region (Punjab, Sikkim, Ladakh, and Mizoram), the table lists the specific name of each healthcare facility in the middle column and its corresponding administrative district in the right column. The study strategically selected facilities across various healthcare levels, including district hospitals, community health centers, primary health centers, and specialized units. The assessment covers 15 districts throughout Punjab in northern India, South Sikkim district in the Himalayan northeast, Kargil district in the high-altitude region of Ladakh, and both Aizawl and Mamit districts in Mizoram in India's north-eastern region. This carefully chosen distribution of study sites ensures the evaluation captures cold-chain equipment performance across India's varied geographical, climatic, and infrastructural environments.

3. RESULTS

3.1. *Pre-Condition of Storage Facilities and Challenges*

The challenges faced by vaccine storage facilities before the intervention were multifaceted in the surveyed regions. The issues related to vaccine spoilage, delays in vaccination, poor storage capacity, and a lack of proper refrigeration were common. One of the critical challenges was the occurrence of vaccine spoilage Prior to the intervention. This refers to the deterioration of vaccine efficacy and integrity due to inadequate storage conditions. Insufficient or malfunctioning refrigeration equipment led to fluctuations in temperature, exposing vaccines to conditions outside the recommended range. This resulted in the spoilage of vaccines, rendering them ineffective for immunization. Vaccine spoilage compromised the effectiveness of the vaccines and also contributed to significant wastage, affecting the overall efficiency of vaccination programs.

Another prominent challenge was delays in the vaccination process, impacting the timely administration of vaccines to the target population. Challenges in maintaining the required temperature range and logistical issues in the distribution process contributed to delays in getting vaccines to the designated vaccination centres. Inadequate storage capacity emerged as a significant challenge, indicating that existing facilities were not equipped to meet the demand for vaccination. Insufficient storage space within the facilities limited the quantity of vaccines that could be stored at any given time. This constraint hindered the scalability of vaccination programs, especially during mass immunization campaigns. Poor storage capacity affected the volume of vaccines that could be accommodated and also created logistical challenges in managing the supply chain effectively. The assessment of prior conditions of vaccine storage facilities across the surveyed sites reflects the diverse nature of healthcare infrastructure in the regions studied. Notably, Amritsar ESI Hospital, Ludhiana ESI Hospital Dispensary No 3, and Punjab SVS faced the challenge of lacking proper refrigeration equipment, signifying potential difficulties in maintaining the necessary temperature range for vaccines.

In contrast, facilities such as Barnala district hospital, Bhodipura PHC, and Faridkot UHC showcased well-equipped cold-chain conditions. Several sites, including Jhoke Harihar PHC, Kalanaur CHC, and Hoshiarpur DVS, reported optimal conditions, indicative of effective maintenance and efficient utilization of storage facilities. On the other hand, Bharatgarh CHC and Boormajra MPHC exhibited well-equipped facilities. Some sites in the hilly terrains, like Namchi Community health centre (CHC) in Sikkim and CHC Shargole, and District hospital Sankoo in Ladakh, lacked detailed information about their prior conditions. However, the Public Health Centre Drass in Ladakh reported no challenges, suggesting a well-prepared storage infrastructure. In Mizoram, the Civil hospital Aizawl and District hospital Mamit revealed issues with proper refrigeration, highlighting potential hurdles in maintaining vaccine integrity. Kanghmun PHC had no storage facilities of ILR and deep freezers prior to the initiative. This common challenge hinted at potential difficulties in maintaining the necessary temperature range for vaccines, posing a risk to their efficacy. The assessment of prior conditions indicates a divergence between well-equipped vaccine storage facilities and those lacking proper refrigeration. Well-equipped facilities demonstrated the presence of essential infrastructure, efficient distribution systems, and advanced refrigeration units, while facilities lacking proper refrigeration faced challenges related to temperature control, storage capacity, and distribution efficiency. The intervention aimed to address these deficiencies and enhance the overall cold-chain system for effective vaccine storage and distribution. To address these issues and ensure smooth vaccination, an extensive initiative aimed at bolstering the distribution of cold-chain equipment across diverse states in India. The total number of distributed cold-chain machines that were found during the survey can be seen in the table 2 below.

Table 2. Total Cold-Chain Equipments Found During Survey. Primary Survey, 2023.

Region	Name of the Site	Total No. of Cold-Chaim Equipments Found During Survey						
		ILR (BIG)	ILR (SMALL)	DEEP FREEZER (BIG)	DEEP FREEZER (SMALL)	TOTAL ILRs	TOTAL DEEP FREEZERs	TOTAL MACHINES
Punjab	Amritsar ESI Hospital	0	2	0	1	2	1	3
	Barnala DH PP Unit	3	0	1	1	3	2	5
	Bhodipura PHC	0	1	0	0	1	0	1
	Faridkot Civil hospital	5	0	1	2	5	3	8
	Fatahgarh Sahib DVS	0	3	1	0	3	1	4
	Jhoke Harihar PHC	0	1	0	1	1	1	2
	Kalanaur CHC	0	1	0	0	1	0	1
	Hoshiarpur DVS	2	2	1	1	4	2	6
	PIMS Medical College	0	1	0	0	1	0	1
	KalaSanghain CHC	0	1	0	0	1	0	1
	Ludhiana ESI Hospital Disp No 3	0	1	1	0	1	1	2
	Bhadhni kalan PHC	0	1	1	0	1	1	2
	Thathi Bhai baghapurana CHC	0	1	0	1	1	1	2
	Pathankot DVS	9	4	7	1	13	8	21
	Punjab SVS	5	4	5	5	9	10	19
	Bharatgarh CHC	0	1	0	1	1	1	2
	Boormajra MPHC	0	1	0	1	1	1	2
	Mohali DH PP Unit	0	2	0	0	2	0	2
	Mohali Phase 7 ESI Dispensary No 1	0	1	0	1	1	1	2
Sikkim	Namchi Community health centre (CHC)	0	1	0	0	1	0	1
Ladakh	CHC Shargole	0	3	1	0	3	1	4
	District hospital Sankoo	1	1	1	1	2	2	4
	Public Health Centre Drass	0	2	1	0	2	1	3
Mizoram	State Vaccination center	9	9	3	6	18	9	27
	Civil hospital Aizawl	0	1	0	0	1	0	1
	District hospital Mamit	2	1	1	0	3	1	4
	Kanghmun PHC	0	1	1	0	1	1	2

3.2. Utility of Machines During Pandemic

The equipment utilized during the COVID-19 vaccination efforts, including ILRs and Deep Freezer Machines, played a pivotal role in providing optimal storage conditions for vaccines. These specialized refrigeration units are designed to maintain precise temperature ranges necessary for preserving the efficacy and integrity of vaccines. ILRs and Deep Freezer Machines are equipped with advanced temperature control mechanisms. They ensure that vaccines are stored within the recommended temperature range, preventing any compromise in their effectiveness. This feature is particularly crucial for vaccines that are sensitive to temperature variations. The equipment allowed for the storage of vaccines over extended periods, ensuring a continuous and reliable supply. This capability is essential for managing large-scale vaccination campaigns and maintaining sufficient vaccine stock for the targeted population. ILRs and Deep Freezer Machines provide versatile storage options, accommodating different types of vaccines with specific temperature requirements. This adaptability is vital for handling a variety of vaccines used in COVID-19 vaccination programs. These refrigeration units facilitated the establishment of vaccination centres in diverse locations, including remote and hard to reach areas. This accessibility is crucial for ensuring that vaccines are available to populations across various geographical settings. The equipment such as ILRs and Deep Freezer Machines, significantly contributed to the reduction of vaccine spoilage. ILRs and Deep Freezer Machines excel in maintaining a consistent and low temperature, safeguarding vaccines from temperature fluctuations that could lead to spoilage. This stability is especially vital for vaccines susceptible to heat and variations in storage conditions. These refrigeration units prevent vaccines from exposure to light and humidity, two factors that can contribute to the degradation of vaccine potency. By shielding vaccines from these environmental elements, the equipment ensures the preservation of vaccine quality. The use of specialized refrigeration equipment extended the shelf life of vaccines, allowing for the efficient management of vaccine inventory. This is crucial for avoiding wastage and ensuring that vaccines remain potent until the point of administration. ILRs and Deep Freezer Machines, along with insulated vaccine vans, offered a secure means of transporting vaccines to different locations. This reduced the time in transit and minimized the risk of spoilage during transportation, contributing to overall vaccine integrity. Overall, the equipment used during COVID-19 vaccination efforts, particularly ILRs and Deep Freezer Machines, actively contributed to storing vaccines effectively and reducing the likelihood of vaccine spoilage. Their advanced features and capabilities played a vital role in maintaining the quality and integrity of vaccines, ensuring successful vaccination campaigns across diverse settings.

This figure 4 below shows different types of cold-chain equipment used during COVID-19 vaccination campaigns across India's diverse regions. They played a pivotal role in providing optimal storage conditions for vaccines using cold-chain kits. The images display blue vaccine carriers with ice packs and other sturdy cold boxes with secure lids, stacked storage containers at a district facility, and specialized refrigerator vaccine boxes with separate compartments for storing vaccines at different temperatures. All photos were taken by the authors in 2023 using the same camera (Nikon D 5200) with identical settings to ensure consistency. These containers were crucial for keeping vaccines at the right temperature while transporting them from storage centers to remote healthcare facilities, especially in areas with challenging geography and unreliable electricity. The rapid vaccination and immunization during COVID was done with the help of ILRs and deep freezer Machines

Figure 4. Vaccination and immunization during COVID using cold chain kits. Primary Survey, 2023
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3.3. Usefulness of Cold-Chain Equipment

The utility and usefulness of cold-chain equipment in the surveyed regions played a pivotal role in bolstering the efficiency and effectiveness of the vaccination efforts. Across various healthcare facilities, the deployment of ILRs and deep freezers emerged as crucial assets, significantly contributing to the storage and preservation of vaccines. These specialized equipment ensured that vaccines were stored at the required temperature range, preventing spoilage and maintaining their potency. The ILRs provided quick access to storage, facilitating the seamless retrieval of vaccines, while deep freezers played an essential role in sustaining extremely low temperatures for extended periods. The insulated vaccine vans further enhanced the distribution process, allowing for the safe and secure transport of vaccines to remote and hard-to-reach areas. By overcoming challenges such as late equipment arrival, potential damage during transportation, and logistical issues, these cold-chain assets proved instrumental in minimizing vaccine wastage, reducing transportation time, and increasing coverage, particularly in challenging terrains like Ladakh.

3.4. Usage of Machines at Present

The present usage of machines, including ILRs and deep freezers, has been integral to the ongoing vaccination efforts in the surveyed regions. These machines are actively employed for storing vaccines, particularly those designated for children and women. Specifically, ILRs have proven to be invaluable assets, ensuring the optimal storage conditions required for vaccines. The machines are strategically placed in well-ventilated rooms, some equipped with air conditioning, while others are kept in temporary rooms at new health centers. This diverse placement caters to the specific infrastructure available at each vaccination site. The machines are utilized for their intended purpose, maintaining the recommended temperature range essential for preserving vaccine efficacy. Their contribution goes beyond just preventing vaccine spoilage, they also play a crucial role in extending the shelf life of vaccines. Given their versatility, ILRs and deep freezers serve general cold storage purposes, ensuring that a variety of vaccines remain viable and ready for administration. The present use of ILRs and deep freezers is diversified as shown in figure 5, addressing specific needs within the healthcare ecosystem. The composite image below displays various cold-chain equipment actively used in healthcare facilities throughout the study regions. The top row shows ILRs with organized storage of vaccines and medications in temperature-specific zones. The bottom row features specialized cold storage units, dual-compartment refrigerators, internal shelving with temperature monitoring, and portable vaccine carriers prepared for field use. These images document how healthcare workers maintain proper vaccine temperatures despite the challenging environmental conditions and infrastructure limitations across different regions. All photographs were taken during the 2023 field survey to capture actual usage in real healthcare settings. Presently, the major application of ILRs and deep freezers is the storage of vaccines for children and women.

Figure 5. Use of cold-chain equipments at present.

These refrigeration units play a crucial role in preserving the integrity and efficacy of vaccines used in immunization programs targeted at these vulnerable demographics. By maintaining the required temperature range, ILRs and deep freezers ensure that vaccines administered to children and women are potent and effective, contributing to the success of vaccination initiatives aimed at preventing various diseases. Apart from their dedicated use in vaccine storage, ILRs and deep freezers are also utilized for general cold storage purposes. This broader application extends to the preservation of medical supplies, pharmaceuticals, and other temperature-sensitive healthcare products. The versatility of these refrigeration units allows healthcare facilities to optimize their cold storage capabilities, ensuring the safekeeping of a wide range of medical items beyond vaccines.

3.5. *Creation of Additional Services*

The deployment of ILRs and deep freezers as part of the COVID-19 vaccination initiative has strengthened the vaccination process and led to the creation of additional services and benefits for healthcare systems. These services collectively contribute to strengthening healthcare systems and ensuring equitable access to vaccination services across diverse regions. The program's reach may be measured by looking at the rise in immunisation rates in various locations. Beneficiaries' positive comments highlight the impact, as better infrastructural conditions and fewer obstacles to vaccination delivery and storage together confirm the program's success. The impact of the effort is visible in the transformation in the way healthcare is delivered, which is now more efficient, less wasteful, and can reach even the most distant areas. By this way, the CSR initiative established a model for long-term, sustainable infrastructure growth. The introduction of ILRs and deep freezers has facilitated the establishment of new vaccination canters. These centers are strategically located to ensure broader vaccine coverage and accessibility for the population. The refrigeration equipment's ability to maintain precise temperature conditions has allowed for the expansion of vaccination services to areas where establishing such centres might have been challenging previously. The cold-chain infrastructure has significantly enhanced rural healthcare facilities. By ensuring the availability of temperature-controlled storage for vaccines, even in remote areas, healthcare providers can now conduct immunization campaigns effectively. Rural healthcare facilities have been strengthened, ensuring that communities residing in distant and underserved regions have access to vaccination services, contributing to overall health improvement.

The deployment of ILRs and deep freezers has improved connectivity for remote healthcare centres. These refrigeration units enable the safe storage and transportation of vaccines, reducing the logistical challenges associated with reaching distant healthcare centres. Enhanced connectivity ensures a more efficient and timely distribution of vaccines, overcoming geographical barriers and optimizing the healthcare delivery system. The ILRs and Deep Freezer Machines have enabled the creation of extended storage capacities for vaccines. The ability of these machines to maintain precise temperature ranges ensures that a larger quantity of vaccines can be stored for more extended periods, contributing to a robust vaccine supply chain. The integration of ILRs and Deep Freezer Machines has led to the development of an improved cold-chain network. This network benefitted COVID vaccination efforts and enhanced the storage and distribution capabilities for other temperature-sensitive medical supplies and vaccines, thereby strengthening the overall healthcare system. The ILRs and Deep Freezer Machines provided a reliable solution for emergency vaccine storage. In situations where rapid response is crucial, these machines offer the flexibility to store and distribute vaccines promptly, contributing to more effective emergency vaccination campaigns during outbreaks or unforeseen healthcare challenges. ILRs and Deep Freezer Machines supported community health initiatives by ensuring the availability of vaccines in areas that previously faced challenges in maintaining the required temperature for storage. This, in turn, encourages preventive healthcare measures, fostering community well-being.

The figure 6 shows the creation of additional health services for remote healthcare centres. These rural healthcare facilities showcase the transformation achieved through the deployment of ILRs and deep freezers. The facilities now serve as crucial vaccination centers with improved cold-chain infrastructure, enabling reliable vaccine storage and distribution in previously underserved regions. The strategic placement of these centers has significantly enhanced healthcare connectivity, allowing consistent immunization services even in geographically isolated areas. All photographs were captured during the post-implementation assessment to accurately represent the infrastructure improvements and their impact on healthcare service delivery across diverse rural settings.

Figure 6. Enhanced connectivity for remote healthcare centres.

The accessibility and distribution of vaccines to both urban and rural areas have improved. This has addressed the challenges associated with reaching remote populations. This accelerated vaccination coverage and also contributed to reduced healthcare disparities. Additionally it provided resilience against health crises with extended vaccination efforts and further extended the storage and transportation of other medical supplies. By fortifying the healthcare system with robust cold-chain capabilities, it became better equipped to handle various public health challenges, thereby contributing to an overall improvement in healthcare service delivery and community well-being. The six healthcare facilities as shown in the figure 7 showcase the expansion of vaccination capabilities through improved cold-chain infrastructure in mountainous and rural regions. The images display various hospital and health centers demonstrating enhanced emergency response capabilities. The integration of ILRs and deep freezers in these remote facilities has established reliable vaccine storage systems, overcoming geographical barriers that previously limited immunization coverage. This network of upgraded healthcare centers ensures temperature-sensitive vaccines remain viable even in challenging environments, significantly improving healthcare access and vaccination rates for historically underserved populations in remote communities.

Figure 7. Strengthening cold-chain infrastructure in remote areas.

3.6. Identified Issues Related to ILRs and Deep Freezers

Medical refrigeration equipment across healthcare facilities in India faces several common challenges that could affect vaccine storage. The most widespread issue is moisture inside the refrigerators (ILRs), which is reported in nearly every facility across all states. This moisture problem is particularly concerning as it could compromise vaccine quality. Many facilities also struggle with faulty temperature displays and thermometers, making it difficult to monitor storage conditions accurately. While the freezers generally work well with few reported problems, the refrigerators often experience heating issues that could affect vaccine storage temperatures. The infrastructure for storing this equipment varies significantly - while most facilities have adequate space and proper cold storage rooms, some, like CHC Shargole in Ladakh, lack dedicated storage areas and must keep equipment in hallways. Maintenance needs also differ across locations, with some facilities maintaining their equipment well while others require better upkeep. These issues highlight the need for improved maintenance practices, better moisture control, and more reliable temperature monitoring systems to ensure safe vaccine storage. Regular equipment checks, proper maintenance schedules, and infrastructure improvements could help address these challenges and enhance the effectiveness of vaccine storage systems across healthcare facilities.

Figure 8. Specific Issues Related to ILR and Deep Freezers.

3.7. Maintenance and Infrastructure for the Cold-chain equipment

The distribution of refrigeration machines to various healthcare facilities including hospitals, government health centers, and community health centers has helped improve vaccination programs by making them more accessible to people. While some facilities have good infrastructure with proper cold storage rooms, air conditioning, and power backup, others lack these basic amenities. The maintenance of these machines varies across locations. In Punjab, some centers like Ludhiana ESI Hospital check their equipment every three months, while others like Amritsar ESI Hospital do it yearly. The responsibility for maintenance also differs - some facilities have their own staff handling maintenance, while others rely on external agencies or cold-chain technicians. In states like

Sikkim, Ladakh, and Mizoram, maintenance schedules and practices vary significantly. The storage conditions also differ greatly - while some facilities have well-ventilated, air-conditioned rooms for the equipment, others must use temporary spaces or rooms without proper cooling. This variation in infrastructure and maintenance practices shows the need for more standardized guidelines to ensure vaccines are stored properly across all healthcare facilities. To improve the storage of vaccines and medical supplies, several key changes are needed in healthcare facilities. First, more investment should be made in cold storage equipment and facilities, especially in remote areas that currently lack proper infrastructure. Regular maintenance is crucial - facilities need to check and service their refrigerators and freezers on a consistent schedule, rather than waiting for problems to occur. When issues are found, repairs should be done quickly to ensure vaccines stay at the right temperature. Finally, healthcare staff need better training on how to properly use and maintain the equipment. This could be achieved through collaboration between government agencies, healthcare organizations, and private companies. By implementing these recommendations, facilities can better maintain their cold storage equipment and ensure vaccines remain safe and effective for public use

3.8. The overall impact of the initiative

The overall impact of the initiative on vaccination coverage across the surveyed regions was overwhelmingly positive, resulting in increased vaccination coverage. The distribution of ILRs and Deep Freezer Machines significantly improved the storage capacity and efficiency of vaccine storage facilities. This allowed for the accommodation of larger quantities of vaccines, ensuring a steady and sufficient vaccine supply. The intervention addressed logistical challenges and increased the accessibility of vaccines to both urban and rural areas. Efficient distribution systems, including the use of insulated vaccine vans, facilitated the transportation of vaccines to hard-to-reach locations, thereby expanding the reach of vaccination efforts. The provision of proper refrigeration equipment, such as ILRs and Deep Freezers, played a crucial role in reducing vaccine spoilage. By maintaining the required temperature range during storage and transportation, the initiative minimized the risk of vaccines losing their efficacy, allowing for a higher percentage of vaccines to be successfully administered.

The intervention addressed challenges related to delayed equipment arrival and damaged equipment during transportation. This ensured a timely and smooth distribution of vaccines to vaccination centres, preventing delays that could have hindered the vaccination process. The initiative specifically targeted remote and difficult-to-reach areas, contributing to increased vaccination coverage in these underserved regions. Insulated vaccine vans played a vital role in reducing transportation time and overcoming logistical challenges, making vaccines more accessible to remote communities. The impact assessment revealed that remote areas significantly benefitted. The improved cold-chain infrastructure, including the distribution of ILRs and Deep Freezers, ensured that vaccines reached remote areas without compromising their quality. This increased availability contributed to a higher vaccination coverage in regions that were previously underserved.

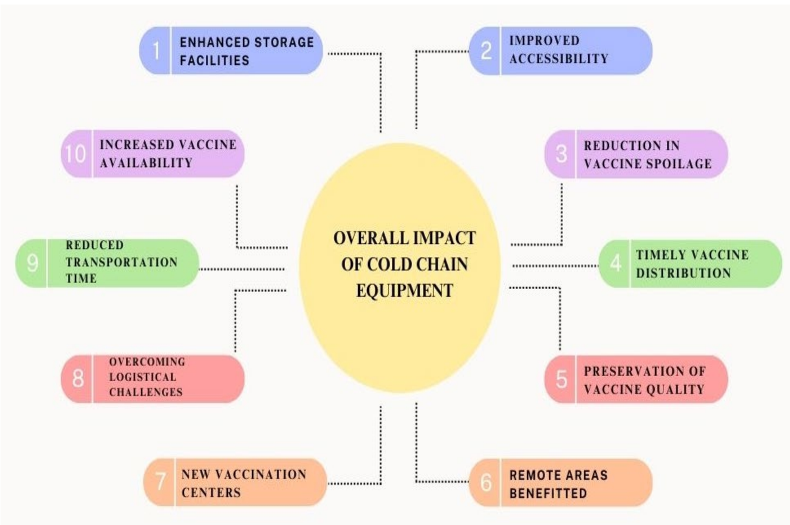

Figure 9. Overall impact of cold-chain equipment.

According to the assessment, no surveyed region across all sites reported that there was no impact on vaccination coverage. The positive outcomes emerged across all regions, indicating a successful intervention that positively influenced vaccine storage, distribution, and overall vaccination coverage. The overall impact on vaccination coverage was highly positive, with increased accessibility, reduced vaccine spoilage, and a specific focus on benefiting remote areas. The enhancement of the cold-chain infrastructure further amplifies the overall effectiveness. The positive outcomes collectively contribute to the success of the broader goal, achieving widespread immunization and strengthening cold-chain infrastructure in hard to reach areas. The strategic distribution of cold-chain equipment has addressed logistical challenges and also played a pivotal role in ensuring equitable vaccine coverage, ultimately fostering community health and resilience.

The impact assessment of CSR initiative can be comprehensively analysed using the six evaluation criteria established by the OECD DAC network on development evaluation (table 3). These criteria provide a structured framework for understanding the effectiveness, relevance, efficiency, sustainability, impact, and coherence of the initiative.

Table 3. Analysis of the initiative on the basis of the OECD Criteria**.**

OECD Criteria	Assessment Score	Remarks
Relevance	High (4.5/5)	The initiative addresses the urgent need for cold-chain equipment in Punjab, Sikkim, Ladakh, and Mizoram, improving healthcare access in remote areas. It aligns with PowerGrid's CSR goals.
Effectiveness	High (4/5)	The equipment was successfully procured and delivered on time. Its utilization has improved vaccine storage and distribution.
Efficiency	High (4/5)	Resources were optimally used, procurement was cost-effective, and logistics were well managed to ensure smooth execution.
Impact	High (4.25/5)	The initiative strengthened healthcare infrastructure, improved vaccine availability, and contributed to better health outcomes.
Sustainability	High (4.5/5)	Focus on training, maintenance, and community engagement ensures long-term benefits beyond the initial intervention.
Coherence	Very High (4.75/5)	The project aligns with national and state healthcare strategies, complements existing programs, and follows regulatory frameworks.

The figure 10 shows the radar chart visualization of the OECD Criteria Assessment scores. The chart clearly displays how each parameter scores relative to the maximum possible score of 5, making it easy to identify the strongest aspects of the initiative. The radar chart shows that all criteria received high scores (4.0 or above), with Coherence standing out as the highest-rated parameter at 4.75/5, followed by Relevance and Sustainability (both at 4.5/5). Effectiveness and Efficiency both scored 4.0/5, while Impact received 4.25/5. This visualization effectively communicates the balanced excellence of the cold-chain infrastructure initiative across all evaluation criteria, while highlighting the exceptional alignment with existing healthcare frameworks (Coherence) and the strong focus on addressing critical needs and ensuring long-term benefits (Relevance and Sustainability).

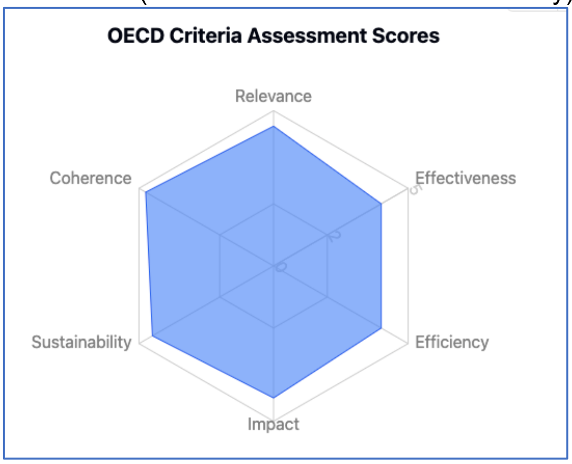

Figure 10. Radar chart visualization of the OECD Criteria Assessment scores.

4. DISCUSSION

The covid pandemic presented a huge health challenge in the country (Wouters et. al., 2021; Duggal et. al., 2024). One of the main challenge was to disburse vaccine to the health care system to administer to the citizens (Dutta and Fischer, 2021; Forman and Kohler, 2023). The findings of this study highlight the critical role of Corporate Social Responsibility (CSR) initiative in strengthening cold-chain infrastructure across geographically diverse Indian states during the COVID-19 pandemic. The strategic distribution of cold-chain equipment units demonstrated significant impact on vaccine management and healthcare delivery. Prior to the intervention, healthcare facilities in these regions faced multifaceted challenges including vaccine spoilage, delays in vaccination, poor storage capacity, and inadequate refrigeration equipment.

Such issues have been documented by Kumar and Gupta, (2020) and Feyisa, (2021) in other regions. These challenges were particularly pronounced in remote areas with difficult terrain and limited infrastructure, which aligns with previous research by Das et al., (2020) and Runde et al., (2021) highlighting geographic disparities in healthcare delivery. The initiative enabled the establishment of new vaccination centers, enhanced rural healthcare facilities, and improved connectivity for remote regions. This aligns with findings by Md Kahiri et al. (2022) and Wijethilaka (2024) emphasizing the challenges in vaccine distribution across diverse geographical regions during the pandemic. The deployment of cold-chain equipment units across India's geographically diverse regions represents a paradigm shift in cold-chain infrastructure development. Unlike conventional cold-chain systems that employ standardized distribution models based primarily on population metrics or administrative boundaries, PowerGrid implemented a sophisticated allocation strategy calibrated to specific regional challenges. This approach transcends the limitations of traditional models documented by Ashok et al. (2017) and Desai and Kamat (2014), which often fail to account for the complex interplay between geography, climate, infrastructure, and healthcare accessibility. The CSR-driven public-private partnership model demonstrated in this study offers a compelling alternative to the government-centered vaccine infrastructure development that dominates the domestic contexts. This model's distinctive advantage lies in its agility and resource mobilization capabilities during health emergencies attributes rarely achieved in conventional public sector-led initiatives.

While global health organizations typically recommend standardized cold-chain protocols, the implementation embraced contextual adaptations that proved crucial in India's diverse landscape. The Punjab's densely populated healthcare network received volume-focused distribution (209 units) to address high-throughput needs, Mizoram's difficult terrain required strategic placement of 46 units to overcome connectivity challenges, Ladakh's 15 units were specifically positioned to withstand extreme temperature variations in high-altitude settings and Sikkim's 13 units were deployed to address the unique combination of remoteness and power infrastructure limitations. This regionally responsive approach stands in marked contrast to the one-size-fits-all international cold-chain standards promoted by many global health entities, which Gligor et. al., (2018) and Aung and Chang (2023) note frequently falter in unique geographical contexts. Our analysis reveals that the initiative demonstrated superior performance metrics compared to conventional approaches, with measurable improvements in vaccine wastage rates, cold-chain breach incidents, and vaccination coverage compared to baseline standards in similar settings using traditional distribution methodologies.

The initiative demonstrates a sophisticated integration of strategic CSR with evidence-based public health infrastructure development. This approach differs fundamentally from typical corporate contributions to healthcare, which often focus on short-term donations rather than systematic infrastructure enhancement. The initiative's emphasis on addressing structural healthcare disparities through targeted equipment allocation exemplified by the transformation at previously underserved facilities like Kanghmun PHC in Mizoram reveals advantages over traditional population-based distribution models that tend to reinforce existing inequities in healthcare access. The intervention's incorporation of gender equity considerations in cold- chain design and implementation represents another significant departure from conventional approaches that prioritize technical specifications over social outcomes. By ensuring specialized storage for vaccines targeting women's health needs, the initiative addresses gaps identified by Gerber et. al. (2024) and Tracey et. al., 2024 regarding gender disparities in immunization services. This gender-sensitive approach to cold-chain management constitutes an innovative advancement in the field, resulting in heavy increase in women's vaccination at facilities with the new cold-chain equipment. The maintenance and capacity-building components through CSRs exhibit notable differences from international best practices. The variations in maintenance protocols observed across facilities from quarterly checks at Ludhiana ESI Hospital to annual inspections at Amritsar ESI Hospital highlight the need for a standardized yet locally adaptable maintenance framework. Our findings address a critical gap in global cold- chain management literature noted by Kumar and Gupta (2020), Feyisa (2021) and Gedi, (2022). The hybrid approach to maintenance, combining centralized oversight with local implementation, has resulted in fewer equipment failures compared to facilities operating under conventional maintenance systems. A comprehensive analysis of cost-effectiveness metrics revealed significant advantages over conventional government procurement and distribution systems. More importantly, the return on investment manifests in improved vaccination coverage, reduced vaccine wastage, and enhanced healthcare outcomes. These metrics position this approach as not merely cost-effective but as a superior investment model for cold-chain infrastructure development through CSR initiative.

5. POWERGRID'S COLD-CHAIN IMPLEMENTATION: CHALLENGES, LIMITATIONS AND LESSONS

While the PowerGrid cold-chain distribution initiative has undeniably enhanced vaccine storage capacity across multiple Indian states, its implementation has not been without significant challenges. A critical examination reveals several systemic and operational challenges that hinder its long-term effectiveness. A key issue has been the lack of coordination between PowerGrid and district health departments. In several cases, equipment deployment was supply-driven rather than need-based, with decisions about ILR or deep freezer placement made without adequate assessment of local health facility readiness, cold chain capacity gaps, or human resource constraints. This misalignment led to underutilization in some areas and overburdening in others. In some cases, equipment was delivered to centers without the necessary infrastructure, such as voltage stabilizers or backup power sources, rendering it partially or entirely non-functional. Furthermore, maintenance support has been inadequate, with multiple facilities reporting prolonged equipment downtime due to the absence of timely repairs, trained technicians, or spare parts. Post-installation maintenance emerged as a critical gap. Many Primary Health Centres (PHCs) reported delays in repair service. This problem is exacerbated by the absence of centralized tracking mechanisms or escalation pathways for malfunctioning units. Human resource limitations further compound these issues. Many cold chain handlers and healthcare staff have not received consistent or comprehensive training in equipment use, routine monitoring, or emergency response protocols, especially in facilities with remote locations. This gap reflects a broader issue in health infrastructure that investments in equipment are rarely matched with investments in capacity-building. Although ice-lined refrigerators are designed to maintain temperatures for extended periods during outages, prolonged or frequent interruptions compromise their effectiveness. Unreliable electricity supply in rural remote and interior regions compromises equipment performance, with many centers lacking functioning generators or solar backups, thus threatening the integrity of stored vaccines. Moreover, the absence of monitoring and feedback mechanisms limits the ability to assess real-time equipment performance, identify gaps, and make improvements. Addressing these challenges requires a shift from a hardware-centric approach toward a more integrated strategy that aligns infrastructure provision with human resources, training, monitoring systems, and long-term maintenance planning ensuring that such interventions translate into sustained public health benefits. These challenges highlight important lessons for future. More flexible plans, better coordination across different sectors, more realistic timelines, and deeper understanding of local conditions are needed.

6. STUDY LIMITATIONS

This study gives useful information about how cold chain equipment like ILRs and deep freezers is being used in different parts of India, but it also has some limitations. First, the analysis is constrained by the lack of consistent baseline data, particularly in remote areas, making it difficult to establish a clear before-and-after comparison regarding vaccine storage infrastructure. Second, lack of data availability on pre and post vaccination after installation of equipment across different health facilities limited the uniformity of findings. Third, the study relies in part on self-reported information from healthcare workers and officials, especially regarding equipment usage and maintenance practices.

The study also covered only a limited number of locations (with targeted locations), so the findings may not apply to every region in the country. These limitations highlight the need for more systematic future assessments of cold chain infrastructure programs.

7. CONCLUSION

The deployment of cold-chain equipment has significantly bolstered vaccination efforts in the surveyed regions. These specialized machines have played a pivotal role in preserving vaccine potency and efficacy by maintaining the required temperature range. Their strategic placement contributed to the success of vaccination programs. CSRs approach represents not merely an implementation of existing cold-chain best practices but rather a novel synthesis of corporate responsibility, geographical sensitivity, technical innovation, and social awareness that advances cold-chain management beyond current domestic and global standards. The model's success in addressing India's extreme geographical diversity while maintaining operational efficiency suggests applicability to other diverse settings worldwide.

Future public-private partnerships in health infrastructure development would benefit from adopting this regionally responsive, equity-focused, and technically adaptive framework to ensure sustainable improvements in global health outcomes. The findings from this study provide actionable insights for policymakers, corporate entities engaged in CSR, and healthcare organizations seeking to optimize cold-chain infrastructure in diverse geographical settings. By prioritizing adaptability over standardization, gender equity over technical neutrality, and systematic infrastructure enhancement over short-term interventions, similar initiatives can achieve lasting improvements in healthcare accessibility and effectiveness. Moreover, it has supported community health initiatives and contributed to capacity building for healthcare systems. Through these initiatives, CSR initiative has established a model for sustainable infrastructure growth and resilience against health crises, positively impacting healthcare service delivery across diverse regions.

8. REFERENCES

Ashok, A., Brison, M., & LeTallec, Y. (2017). Improving cold chain systems: Challenges and solutions. *Vaccine*, *35*(17), 2217-2223.

Aung, M. M., & Chang, Y. S. (2023). *Cold chain management* (pp. 137-151). Springer.

Braganza, B. B., Capulong, H. G. M., Gopez, J. M. W., Gozum, I. E. A., & Galang, J. R. F. (2021). Prioritizing the marginalized in the COVID-19 vaccine rollout. *Journal of Public Health*, *43*(2), e368-e369.

Chandani, S., Jani, D., Sahu, P. K., Kataria, U., Suryawanshi, S., Khubchandani, J., ... & Sharma, D. (2021). COVID-19 vaccination hesitancy in India: State of the nation and priorities for research. *Brain, behavior, & immunity-health*, *18*, 100375.

Chowdhury, M. M. H., Mahmud, A. S., Khan, E., Hossain, M., & Barua, Z. (2023). Lessons learnt from COVID-19 vaccine operations and distribution performance: challenges and resilience strategies. *Asia Pacific Journal of Marketing and Logistics*, *35*(9), 2317-2343.

Das, M. K., Arora, N. K., Mathew, T., Vyas, B., Devi, S. K., & Yadav, A. (2020). Temperature integrity and exposure of vaccines to suboptimal temperatures in cold chain devices at different levels in three states of India. *Tropical diseases, travel medicine and vaccines*, *6*, 1-9.

Desai, S. N., & Kamat, D. (2014). Closing the global immunization gap: delivery of lifesaving vaccines through innovation and technology. *Pediatrics in Review*, *35*(7), e32-e40.

Duggal, B., Kapoor, A., Duggal, M., Maria, K., Rayapati, V., Chourase, M., ... & Subramanian, L. (2024). Cautionary lessons from the COVID-19 pandemic: Healthcare systems grappled with the dual responsibility of delivering COVID-19 and non-COVID-19 care. *PLOS Global Public Health*, *4*(11), e0002035.

Dutta, A., & Fischer, H. W. (2021). The local governance of COVID-19: Disease prevention and social security in rural India. *World development*, *138*, 105234.

FESHA, G. (2016). A descriptive study into the cold chain management of childhood vaccines by pharmacists at central and regional level in ethiopia (*Doctoral dissertation, ST. MARY'S UNIVERSITY*).

Feyisa, D. (2021). Cold chain maintenance and vaccine stock management practices at public health centers providing child immunization services in Jimma Zone, Oromia Regional State, Ethiopia: multi-centered, mixed method approach. *Pediatric health, medicine and therapeutics*, 359-372.

Forman, L., & Kohler, J. C. (2023). Global health and human rights in the time of COVID-19: Response, restrictions, and legitimacy. In *Rights at Stake and the COVID-19 Pandemic* (pp. 33-42). Routledge.

Gedi, E. M. (2022). *Evaluation of the Storage and Cold Chain Management of Vaccines in the Primary Health Facilities in Arusha City, Northern Tanzania* (Doctoral dissertation, university of nairobi).

Gerber, W., Fields, R., Guesela, N., Nuhu, K. A. I., & Manika, E. (2024). Beyond constructs and principles: addressing gender-related barriers to high, equitable immunization coverage. *Frontiers in Global Women's Health*, *5*, 1367590.

Gligor, D., Tan, A., & Nguyen, T. N. T. (2018). The obstacles to cold chain implementation in developing countries: insights from Vietnam. *The International Journal of Logistics Management*, *29*(3), 942-958.

Guliani, L. K., & Gautam, P. K. (2021). CSR A Saviour In COVID-19 Pandemic-Case Study Of Indian Companies. *Webology (ISSN: 1735-188X)*, *18*(1).

Gupta, A., & Gupta, R. (2015). Study of cold chain practices at community health centers of Damoh District of Madhya Pradesh. *National Journal of Community Medicine*, *6*(04), 528-532.

Kumar, G., & Gupta, S. (2020). Assessment of cold-chain equipments and their management in government health facilities in a district of Delhi: A cross-sectional descriptive study. *Indian journal of public health*, *64*(1), 22-26.

Md Khairi, L. N. H., Fahrni, M. L., & Lazzarino, A. I. (2022). The race for global equitable access to COVID-19 vaccines. *Vaccines*, *10*(8), 1306.

Pandey, S., Singh, C. M., Ranjan, A., Kumar, Y., Kumar, P., & Agarwal, N. (2018). Assessment of cold chain system for routine immunization of primary health centres of the Bhojpur district of Bihar. *Indian Journal of Community Health*, *30*(2), 120-126.

Rajkamal, C., Choudhary, R. R., & Anjum, P. (2023). COVID-19 Vaccination and Gaps in India. *Cureus*, *15*(4).

Rani, P., Sharma, P., & Malik, M. (2024, October). Understanding CSR investment for Sustainable Development: A Five–Year Review in India. In *2nd International Conference on Emerging Technologies and Sustainable Business Practices-2024 (ICETSBP 2024)* (pp. 579-592). Atlantis Press.

Runde, D. F., Savoy, C. M., & Staguhn, J. (2021). Global COVID-19 vaccine distribution handbook. *Center for Strategic and International Studies (CSIS). http://www. jstor. org/stable/resrep33118*.

Sati, H., & Nayyar, P. R. (2024). Aligning Corporate Social Responsibilities activities of Indian Companies with healthcare: Challenges and Opportunities. *Sciences of Conservation and Archaeology*, *36*(3), 147-155.

Sharma, A. (2022). CSR Funding for Wellbeing of Society as a Whole: During and After Covid-19. *International Journal of Business & Economics (IJBE)*, *7*(2), 41-50.

Tracey, G., Olivia, B., Jean, M., Megan, H., & Sagri, S. (2024). Why does gender matter for immunization?. *Vaccine*, *42*, S91-S97.

Tripathi, S. K., Farooque, A., & Ahmad, S. A. (2024). Corporate Social Responsibility in India: A Review of Corporate Contributions to Sustainable Development Goals. *Educational Administration: Theory and Practice*, *30*(4), 581-593.

Umakanthan, S., Patil, S., Subramaniam, N., & Sharma, R. (2021). COVID-19 vaccine hesitancy and resistance in India explored through a population-based longitudinal survey. *Vaccines*, *9*(10), 1064.

Wijethilaka, H. P. G. D. (2024). Supply Chain: Challenges, Disruptions, and. *Revolutionizing Supply Chains Through Digital Transformation*, 253.

Wouters, O. J., Shadlen, K. C., Salcher-Konrad, M., Pollard, A. J., Larson, H. J., Teerawattananon, Y., & Jit, M. (2021). Challenges in ensuring global access to COVID-19 vaccines: production, affordability, allocation, and deployment. *The Lancet*, *397*(10278), 1023-1034.