Policy Review
Energy requirement for COVID-19 vaccine-cold chain and logistics

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1. Introduction

COVID-19 has disturbed almost every sector as well as associated activities across the globe, imposed partial and full lockdowns, limited the travelling and transportation services and forced people to maintain physical distancing. Although many countries have limited the infection rate, the pandemic still looms large across the globe. The resulting impacts appear to be even more catastrophic that will force people to extreme poverty, food insecurity, health and educational crisis, etc.

Preventive measures taken by economies have limited the impact of the pandemic but still, the use of vaccines has been identified as the most critical aspect to get countries back on track, especially the low and middle-income countries. An efficient distribution and supply chain in middle-income and high-income countries may save up to 61% and 33% of subsequent deaths respectively (Peters and Hartley 2020). Hence, developing and supplying vaccines is amongst the topmost global priority. As of today, many vaccines are commercially available and have achieved regulatory approvals. Hence, the pharmaceutical companies, manufacturers, and distributors have to face significant logistic challenges to ensure their effective transfer and storage.

Now, due to specific requirements of vaccines to be cooled and stored at a very low temperature, an equitable distribution relies on developing cold chains (Cold Chain and Refrigeration 2021). These requirements of supply chains might underpin an equitable distribution across the globe. Even today, a major focus is still on developing vaccines and their distribution techniques and requirements have been overshadowed. To achieve even herd-immunity, around 60-70% of the population will need access to the vaccine, which estimates to around 10 billion people (Peters and Hartley 2020).

A cold supply chain has many components, including pre-cooling, cold storage, refrigeration, and then a temperature-maintained transport service. Although a cold supply chain is not something that is entirely linked with only COVID vaccines, different medicines, blood products and a range of health services also require cold storage (World Health Organization 2020). Now, there is a sudden increase in demand at a time when a contagious virus has posed a major challenge even to the developed countries. For developing and under-developed countries, a lack of functioning and fully integrated supply chain is even a bigger hurdle due to insufficient capacity and infrastructure, unreliable cooling process, poor maintenance, lack of skills in handling, electricity access, and a sustainable financial model. Unless these issues are addressed at an accelerating rate, there is a major change that the cumulative effect of the above-mentioned challenges will lead to an inefficient immunization program. Figure 1 represents a cold chain supply of vaccines for effective outreach.

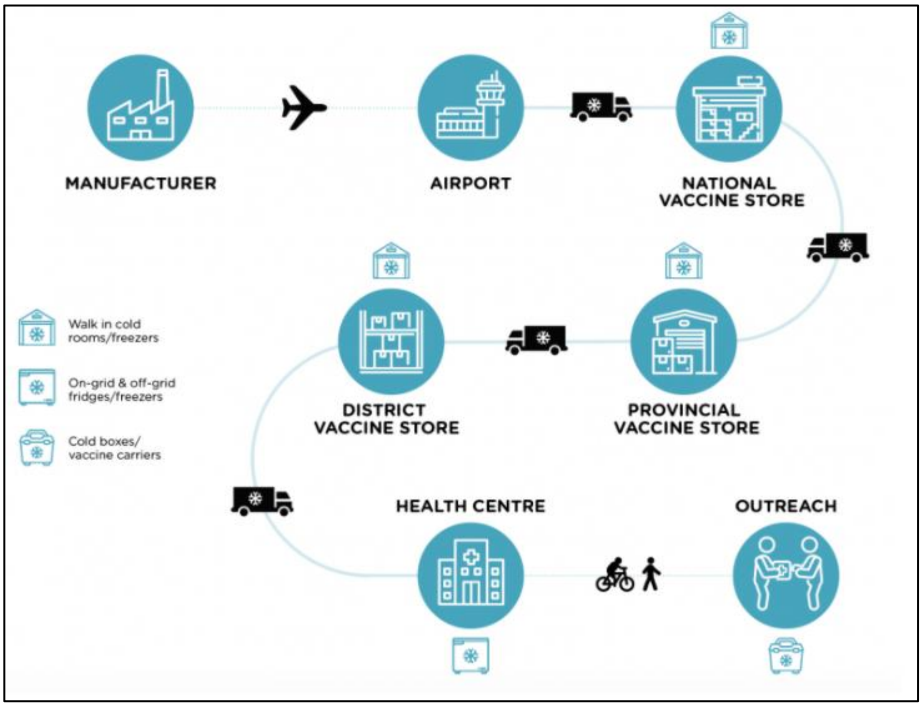

Figure 1: Cold supply chain of vaccine in a routine immunization program (Peters and Hartley 2020)

Based on the above-mentioned requirements, a sustainable supply of energy and electricity is the most fundamental pre-requisite for the efficient distribution of vaccines. This report signifies the energy requirements and challenges faced by a cold chain supply and logistics for COVID vaccines. As of today, over 900 million world population is living without electricity (Ritchie and Roser 2021). A much larger portion that does have electricity is incapable of having cold-chain equipment. Moreover, a large population in developing and under-developed countries live in rural areas where immunization is performed through an outreach programme.

1.1. Scope and objectives of the study

Since the outreach of a cold chain in remote areas will require abundant energy availability, the immunization process will face critical challenges and limitations. This study identifies the energy requirements for a sustainable cold chain and its logistics, and what will be its implications on the environment. Key objectives of the study are:

- Analyzing the energy requirements of a complete cold chain during production, transportation, and storage of COVID vaccines.
- Identifying the major challenges of the energy sector for an effective outreach of immunization programme of COVID.
- Analyzing the environmental implications of a sustainable cold chain from the perspective of Sustainable Development Goals (SDGs).

2. Energy requirements of a sustainable cold chain

3.1. Vaccine Stability

The first pre-requisite of any vaccine is constant cooling and maintaining of a very low temperature. Immunization success is highly dependent on maintaining cold chains since vaccines lose their integrity if exposed to a high temperature for long durations (Weintraub, Yadav and Berkley, 2020). As of today, more than 250 vaccines for battling COVID have been developed, but only around 10 of them are at commercial or final testing state (Werner, 2020). Each vaccine requires a different number of doses and has different temperature requirements for shipment and storage. Some vaccines are kept frozen while some lose their integrity in case of accidental freezing.

Table 1 lists the major vaccines available and their temperature requirements over long and short terms (Diop 2021).

Table 1: Leading vaccines in their late development stages along with cooling requirements

Sr. No	Vaccine/Company	Required doses / Time	Temperature requirements for shipment and long-term storage	Duration of storage at 8-12 °C
1	BioNTECH/Pfizer	Two with an interval of 28 days	-70 to -80 degree centigrade	5 days
2	Moderna/NIAID	Two with an interval of 28 days	-20 degree centigrade	10 days
3	AstraZeneca	One dose	2-8 degree centigrade	N/A
4	CanSino	One dose	2-8 degree centigrade	N/A
5	Gamaleya	Two with an interval of 21 days	2-8 degree centigrade	N/A
6	Jannsen	Two with an interval of 56 days	2-8 degree centigrade	N/A
7	Sinovac	Two with an interval of 14 days	2-8 degree centigrade	N/A
8	Sinopharm-Beijing	Two with an interval of 14 days	2-8 degree centigrade	N/A
9	Novavex	Two with an interval of 21 days	2-8 degree centigrade	N/A
10	Sinopharm-Wuhan	Two with an interval of 14 days	2-8 degree centigrade	N/A

Based on the table mentioned above, most of the vaccines will require a temperature between 2-8 °C while some even require up to -80 °C. This will require a new cold chain for lower economies and the strengthening of already existing ones in middle-income economies. Hence the two major challenges for delivering a COVID vaccine are mentioned in figure 2.

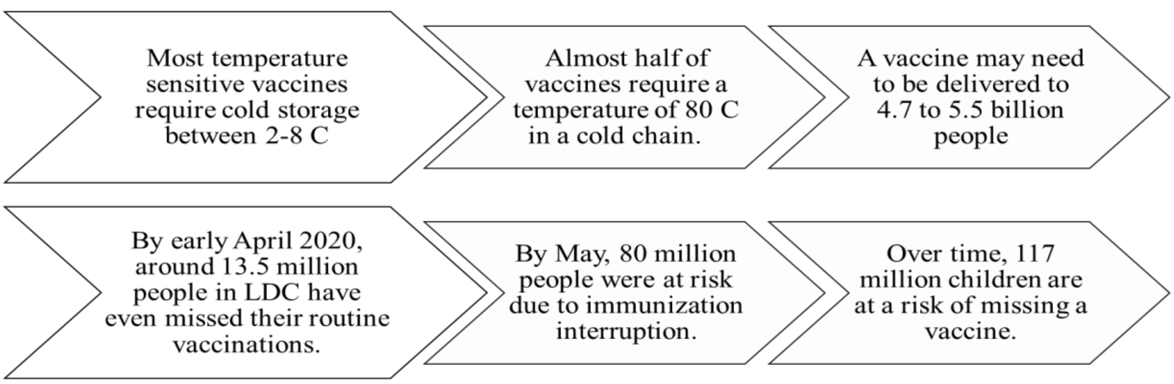

Figure 2: Two major challenges for delivering a COVID vaccine

Now, the basic reason for the lack of outreach is the cooling requirements for storage in remote areas due to the unavailability of energy sources. Even prior to COVID-19, there was an inadequate distribution of vaccines for other diseases that require vaccines to be stored at around 2-8 °C. The global outreach of such vaccines as of 2018 was 86%, which means that around 20 million children were left unvaccinated against those diseases (UNICEF and WHO, 2019). Furthermore, the lockdown situation imposed by COVID had compounded the delivery of many vaccines. As per UNICEF, approximately 13.5 million people in LDCs have missed routine vaccinations (as of April 2020). If the supply remains on cold chain capacity as well, the challenges will be further compounded.

3.2. Cold Chain Requirements and Initiatives

Delivering vaccines to around 5-6 billion people will require a massive expansion of the cold chains. This infrastructure build-up must be done to serve on-going pandemic needs while some vaccines are under testing and others are being distributed on a commercial scale in developed countries. Many technologies used today for ensuring the efficient functioning of cold chains are inefficient and poses a risk of technology lock-in. Therefore countries and their development institutes must utilize procurement standards that prioritize cheap, efficient equipment powered by green energy sources. Cold Chain Equipment Optimisation Platform(CCEOP) has already committed $250 million and delivered over 60,000 new pieces of cold-chain equipment in the last two years (Weintraub, Yadav and Berkley 2020).

Further, there is also a need to invest in the monitoring of the supply chain to find out the scope of cold chain gaps and what are the potential points where they can break down. The human resource and skills required to maintain the equipment must also be sorted out. Gavi launched an INFUSE (Inclusive finance for the underserved economy) (INFUSE, 2016) to focus on innovations that have a high impact on addressing country-level needs and address the data integration along with Gavi-linked countries. Now all these cooling efforts must be aligned with the strategies dealing with energy access, including stimulus for better recovery. Medical clinics, hospitals, and other modes in a supply chain must have a guaranteed energy supply for powering the additional cooling needs.

For an efficient supply and storage of vaccines, a large quantity of cold chain equipment will be required (as shown in figure 3) and hence these refrigerators are currently referred to as the most important medical equipment in the chain. Bulk storage at different levels requires walk-in cold rooms (WICs) and walk-in freezer rooms (WIFs). Both pieces of equipment consume a significant amount of electricity from an on-grid or an off-grid system. Further, they also need standby generators to overcome the threat of a power outage (CLASP 2020). Each piece of equipment mentioned in figure 3 below can attain temperature up to a certain limit based on the refrigerant present and its use. Hence a resilient and efficient energy supply system is critical as previously mentioned.

Despite the above-mentioned aspects pertaining to the indispensability of electricity in this supply chain, many health care centers in developing and under-developed countries have a limited supply of electricity, and some that are present in rural areas do not even have connections to the national grid. Many facilities across the world have unreliable energy supply to be an integral part of vaccine distribution (World Health Organization 2020)

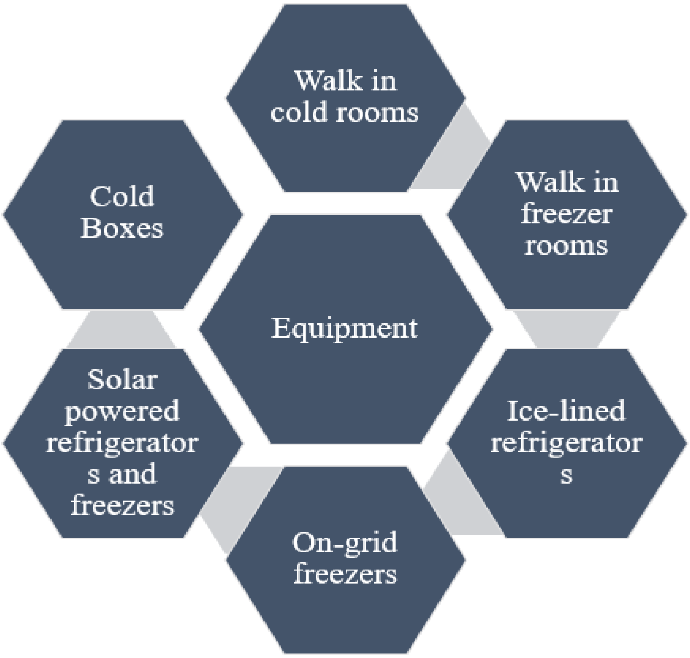

Figure 3: Cooling equipment involved at different stages of a cold supply chain

Efficient and clean technologies exist and have the potential to address many challenges faced by different supply chains in developing countries. Ranging from management systems to control stocks, vaccine flow in supply lines to cold storage like refrigerators with ice-lining, all need a guaranteed energy supply. Although in the past decade, the situation had improved, the is no way near the pace that is currently required to counter the COVID situation, and hence the challenge still looms. Servitization, Cooling as a Service (CaaS), and strengthening market-based business models have appeared to have an accelerating and sustainable impact (Weintraub, Yadav and Berkley 2020).

UNEP is also partnering with governments and the Africa Centre of Excellence for Sustainable Cooling and Cold Chain (ACES) for developing cutting-edge cold chains. This coalition is bringing together experts from industries and academics to help countries establish sustainable cold chains that are fit for vaccines (Noronha 2020). Arizona State University (ASU) came up with recent innovations to counter the extensive use of energy through the use of phase change materials. These materials absorb the heat and then keep temperatures lower for a sufficiently long period (Werner 2020). Ignite Energy Africa has recommended innovative energy technologies and distribution channels to help tackle the major issues (Aghoghovbia and Contributor 2019). Remote areas can have low-powered off-grid solar refrigerators with climate-friendly refrigerants for better outreach of vaccine and its storage. UNICEF also aims to have 65,000 cold refrigerators powered by solar in low-income countries. However, for its effective utilization, a collaboration between government, private sector, and academic partners will be crucial for effective execution. Q-tec from Germany is also working on improving cooling techniques for maintaining the -70 °C temperature of the Pfizer vaccine (Wehrmann, 2020) . Pharmaceutical refrigerators and biomedical freezers developed by PHCbi offer a very comprehensive selection of storage solutions for high-valued vaccines. These devices are based on high-performance refrigeration platforms engineered for reliability, temperature uniformity, fast temperature recovery, and tolerance for real-world conditions (Corporation 2021).

3.3. Energy poverty and Rural development

Most of the operations as mentioned above are high energy-intensive processes and hence will require sufficient capital for their adoption which requires the procurement processes to consider this cost factor as well. The absence of this equipment and the absence of energy efficiency standards might lead to wastage of vaccines and a poorly functioning supply chain. Apart from them, energy is required to power the rest of the medical facility, energy drives the heavy transport trucks, and energy is also used in the production process. Based on these heavy requirements, energy requirements of the cold supply chain hence must be kept as low as possible.

The major challenge however still lies with the rural communities and the issue of energy poverty. To counter this global pandemic, even the remotest of areas will require access to reliable and sustainable energy (Diop, 2020). Based on the above-mentioned statistics, there will be a significant increase in energy demand from cooling applications, and this will require accelerated actions. As of today, the capability of developing countries is based on an unreliable supply of grid electricity or using costly diesel trucks and generators. Although it might appear as the most feasible short-term solution, a long-term plan must further be defined with cost-effective solutions to ensure affordability and reliability (No Weak Links: Effective Cold Chain Management for Distribution of COVID-19 Vaccines 2021).

The world bank has initiated a multi-sectoral technical assistance program, "The ESMAP Efficient, Clean Cooling Program" for accelerating the penetration of energy-efficient cooling and refrigeration devices in developing and under-developed countries (Diop, 2020). Further, efforts in response to COVID-19 are also being made to electrify the health facilities with solar PV solutions. This will also assist in the transfer of chilled vaccines to remote areas. Hence, the critical role of "energy" as an enabler of health care delivery should be realized and how it strengthens the nexus between SDG 7 (energy) and SDG 3 (health).

Failing to deliver sustainable cooling also has other detrimental impacts on economic development. International Labour Organization (ILO) has estimated that by 2030 the global economy would suffer a loss of around $2.4 trillion due to heat stress. The heat stress in rural areas will further impact the GDPs since a significant portion comes from their activity.

3.4. Environmental considerations of the cold chain

Despite being a critical aspect for fighting a pandemic, cold chains do have an environmental cost in the form of both indirect emissions and leakage of refrigerant gases. Even before the global pandemic, the health sector was responsible for almost 5% of global emissions, including refrigerants. Cold chains individually also contribute to around 3-3.5% of total emissions. Indirect emissions result from energy consumption in cooling and other processes. This can be controlled by adopting energy-efficient systems with low carbon content and using an ongrid energy supply that is generated from renewable energy resources. Apart from this, the indirect emissions also include pollution caused by transporting vehicles, polluting diesel systems and sub-optimized delays on the roads. The direct emissions in the form of refrigerant leakages can be avoided by replacing old and outdated technologies with natural or synthetic refrigerants.

As per the reports of WHO, Chlorofluorocarbons are still being used across 81 different countries who need to ensure that their inventories don't promote incentives to replace such systems with ones that are up to the standards. A constantly increasing need for refrigerants also provides an opportunity to replace conventional refrigerants with new ones. Furthermore, instead of increasing the grid transmission that is harnessing electricity from thermal or carbon-intensive sources, decentralized solar systems can be established that can fulfil the electricity needs, and will promote sustainability at the same time.

The vaccination programmes against COVID are considered to be the inflection point that ought to determine how these cold chains will be handled in the coming decade. If the economies opt for short-term and energy inefficient solutions, then we might encounter the same problems ahead. There is a dire need to ensure that such events do not occur, and even in case they do, both low and middle-income countries should also be fully prepared for them. Many developing countries lack technological capability and the experts believe that COVID demand can lead to long-neglected investments.

3. Policy Recommendations

For successfully implementing a cold chain and logistic for COVID 19 vaccine, the following recommendations should be implemented.

- **Energy-Health nexus:** For efficient functioning of a cold chain and logistic for medical applications, electricity is an indispensable parameter, and hence the critical role of "energy" as an enabler of health care delivery should be realized and how it strengthens the nexus between SDG 7 (energy), SDG 3 (health) and SDG 13 (environment).
- **Rebuilding and strengthening of cold chains:** A complete outreach of COVID vaccines will require strengthening the existing cold chains and building additional ones, especially for the rural economies. Based on the limited energy availability and affordability, the vaccine and technology importing countries should ensure that the imported techniques are not highly energy-intensive or have an adverse environmental impact.
- **Sustainable cold chains for remote areas:** The biggest challenge for an equitable distribution of vaccines would be in remote areas mainly due to limited outreach programmes and more importantly due to the absence of energy infrastructure to create a stable energy vaccine transport and storage unit. Hence, any urgent expansion of a cold chain in such remote areas should also take ensure energy availability in those areas. In short-term plan where immediate and urgent electricity access is required, grid extensions and large diesel generators can be used (despite being an unsustainable approach). However, the same devices at a later stage can be complemented with cost-saving options to generate affordable hybrid systems. The government must also prepare these areas against similar upcoming threats by adopting renewable and stand-alone generation systems.
- **Environment mitigation and climate control:** Despite being an integral part, cold chains do have environmental impact in the form of indirect emissions that are generated from energy consumption at various stages and direct emissions that are linked with refrigerant leakage. The former challenge can be controlled through decentralized solar PV systems and the latter can be controlled by replacing the traditional refrigerants with natural and synthetic refrigerants. Proper monitoring should also be done to ensure that the CFC inventories do not promote illegal trade and provide incentives for their replacing.

- **Need for energy efficiency standards:** Estimates suggest that a large portion (25%) of vaccines is degraded by the time they reach their destination due to lack of compliance standards, sub-par technologies, inefficient management, and sometimes due to absence of required energy. Hence, the path to an efficient cold chain will require energy efficiency standards and policies for various appliances, transportation, and storage processes.
- **Financial support mechanisms:** Even after excluding the non-vaccine parameters, vaccination of a single person costs around $25-$45. In the context of productivity gains, immunization schemes are cost-effective, but to achieve this financial sustainability, considerable investments are required in energy-efficient cold chain solutions. For most countries, these investments have to be mobilized locally and mostly from the private sector. New, investments can be generated through business models, providing incentives, and through financial supporting mechanisms.
- **Controlling the energy demand:** Energy requirements of the cold supply chain hence must be kept as low as possible by adopting demand-side management techniques. Such techniques can reduce energy consumption through efficient cooling, better insulations, off-grid DC refrigerators, solar cooling, and other similar measures.

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