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An Integrated Solution for Solar Cold Chain Portfolio Management using Internet of Things

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ABSTRACT

The Cold Chain system includes a range of systems, such as 'thermal' and 'refrigerated packaging' strategies for moving temperature-sensitive goods along a supply chain, and logistical preparation to ensure shipment integrity. Cold Chain products, including refrigerated trucks and railcars, container ships, reefers, and air freight, are shipped in many different ways. The basic elements of the system are Cooling Systems, Cold, Cold Transport and Cold Processing and Distribution. The 'cold' element of the system, i.e. refrigerators powered by gas or kerosene, has been considered the most suitable choice in areas without reliable energy sources such as electricity. Nevertheless, numerous problems with these tools have made it both difficult and costly to maintain temperatures within the safe range. In the 1980s, solar refrigerators powered by batteries were introduced as a solution to those problems. But the batteries they relied on required regular maintenance, had a lifespan of only three to five years, and replacements of quality were costly and sometimes hard to get. A new solution with solar power has emerged in recent years by avoiding unreliable energy storage which is also expensive. This new solar-powered system freezes the material and keeps the tank frozen when there is no sunlight. The new IoT technology offers greater visibility and control over the entire cold chain network operated by the solar. Using data in real-time, IoT will allow quicker, more appropriate reactions as well as much more informed decisions. Nonetheless, the issue is that most IoT solutions aren't considered primetime ready. IoT has tremendous potential to play a pivotal role in turning the Solar Cold Chain System into Smarter one. This literature analysis is created by revising a good number of papers published in peer-reviewed journals and online sources using the secondary data obtained. The goal of the study is to explain the use of IoT in the Solar-powered Cold Chain System, the future of IoT in this area, find research gaps and finally list the research agenda.

Keywords: Solar Energy, Cold Chain, IoT, Cloud Computing, AI, Big Data, Cloud Storage, Smart Sensors, Energy Grid, Bluetooth, WiFi.

1. INTRODUCTION :

With technology, the distance between the two parts of the world is being reduced even if the physical distance is kept the same. The shock or vibrations may cause damage to the items that were delivered using the cold chain, but excessive temperature sometimes broke them too. During transport time, the quality of a range of products considered to be perishable objects, such as good products, maybe reduced because they sustain chemical reactions that can often be mitigated under unstable temperature conditions. Reliable freight management involves effective time-consuming planning which has invariably negative effects, particularly if such a shipment is perishable. Depending on the cold chain, food, pharmaceutical and medical industries deliver an unacceptable cargo service guarantee. The transport of goods requiring sensitivity for temperature through a supply chain with methods of packaging such as thermal and cooling is referred to as cold chain. In order to safeguard products in shipping, it needs a good logistic planning of shipments. There are various modes of transport, such as

refrigerated freight ships, air, rail and trucks, with the cold chain [1].
The success of an effective 'Cold Chain' system solely depends on the performance of the critical element 'Cold'. The type of container and the cooling system used on shipments for a long period of time are therefore important. 20% of energy is used for container cooling only in most of the cold chain logistics operation [1]. Factors such as transit time, shipment size, and observed ambient or external temperatures are critical when determining what form of packaging is needed and the related energy consumption level. These may vary from a tiny box that requires dry ice or spray, rolling containers to an electrically refreshing big reefer. For many years, the 'Cold' element of the system, that is, refrigerators, powered by kerosene, gas or diesel was considered the most suitable choice for areas with no stable energy sources such as electricity. Nevertheless, numerous problems with these tools have made it both difficult and costly to maintain temperatures within the safe range [2]. In the 1980s, solar refrigerators powered by batteries were introduced as a solution to those problems. But the batteries they relied on required regular maintenance, had a lifespan of only three to five years, and replacements of quality were costly and sometimes hard to get. A new solution has emerged in recent years, the design of a solar refrigerator, deleting the energy storage battery requirement used for power solar refrigerators for expensive and unreliable. This model uses solar energy for directly freeze storage materials to keep the refrigerator cold at night and rainy days afterward the power in the frozen bank [3].
The ICT offers greater visibility and control over the entire solar-operated cold-chain system. ICT's use of data in real-time would allow quicker, more effective reactions as well as much more informed decisions. Recent technologies such as smart sensors, cloud platforms, GPS devices, network gateways, big data analytics tools, wireless networking solutions, and customized user interfaces [4] can simplify the system's integrated operation such as tracking, aggregating, monitoring, delivery, reporting, analytics and sharing [5].
The typical integrated Solar Powered Cold Chain Portfolio Management System includes - Smart Sensors such as automotive, chemical, moisture, flow, weather, humidity, sound, temperature, that detects physical environmental conditions, procedure and changes them into the signal. They have integrated microcontrollers and broadcasting capabilities to automatically capture, pre-process and transmit data. For the collection of data obtained by these sensors, different IoT devices are used [6].
IoT Systems includes numerous boards of developers including Arduino, Beagle Bone, ARM, RaspberryPi, Intel Edison, Intel Galileo, etc. The gateway is used to communicate with the IoT node through protocols like ZigBee, BLE, Z-wave, GPS, Bluetooth, Wi-Fi and mobile portals. Usually, protocols like CoAP, MQTT, and XMPP communicate the data from the gateway to the cloud [7], [8]. Cloud infrastructure provides a platform for quick, easy and complex processing of events in real-time needed to perform advanced sensor data analytics. Cloud computing technology harnesses a Big Data platform which allows large amounts of data to be stored in a decentralized location, ensuring easy data access, data protection, and reduced storage costs. Notable cloud platforms are Amazon Web Services, Microsoft Azure, VMWare, and Google Cloud. The Cloud Platform offers a suite of tools for collecting, processing and storing data [9].Machine learning and artificial intelligence software, such as Google Cloud ML, Amazon Machine Learning (AML) and Google ML Kit for Mobile Azure Machine Learning Lab, make it possible to discover knowledge and to create insights to provide analytical solutions that are essential to enhance the efficiency and profit of energy plants.
The system would increase the quality and effectiveness of food, pharmaceutical, and other perishable supply chains over long distances. The "cold chain" or temperature-controlled supply chain, is now gradually integrating digital technological systems, stable cloud infrastructure, and open architecture rather than pure freezers and freight trains. Besides, the integration of eco-friendly renewable solar energy instead of non-renewable eco-unfriendly fossil energy controlled and managed by ICT results in a more intelligent solar-powered cold chain system that provides managers with live temperature and location data, minimizing any problems along the chain before they occur [10].

2. RESEARCH AIM AND METHODOLOGY :

This paper mainly focuses on the role of Information and Communication Technology (ICT) in improving and finding integrated solutions for Solar Cold Chain Portfolio management. The main objectives of this research article are listed below:

- To know the development in Cold Chain operation and Management.
- To understand the role of Solar Energy for the Cold element of the Cold Chain.
- To envision the future of ICT in Solar Cold Chain.
- To draw a review model on ICT in Solar Cold Chain.

This paper makes use of secondary data from journal articles, magazines, and some official websites. In this paper, a real attempt is made to know the research carried out in the area of Solar Cold Chain Operation and management. The role of Solar Energy for the Cold element of the Cold Chain also reviewed. The applications of ICT in Solar Cold Chain also studied. The ICT system consists of many recent technologies such as smart sensors, cloud platforms, GPS devices, network gateways, big data analytics tools, wireless networking solutions, and customized user interfaces. This literature analysis is created by revising a good number of papers published in peer-reviewed journals and online sources using the secondary data obtained. The paper also analyses the research agenda. Finally, this paper tries to put forward some suggestions to implement Research Activities according to the proposal.

3. LITERATURE REVIEW :

In recent years a considerable extent of growth and development had been established in the field of Cold Chain, Solar-powered Cold Chain, and ICT. A significant number of published papers on the Solar Cold Chain perspective have been reviewed and examined in this paper in the peer-reviewed Journals and on the Internet for the last 15 years (2005-2020). The analysis, made the literature section classified into three subdivisions. Primarily, the emphasis is on finding development in the Cold Chain sector Operation and its Management. This later discusses the role of Solar Energy in managing the 'Cold' element of the Cold Chain. This also outlines the different investigations on ICT technology and how it affects the Solar Energy-powered Cold Chain Portfolio Management.

3.1 DEVELOPMENT IN COLD CHAIN OPERATION & MANAGEMENT :

Manufacturers use ‘Cold Chain' to deliver environmentally sensitive goods. Frozen items require the regulated temperature to ensure that the same 'quality' product is supplied to the customer from the manufacturer. According to WHO, "a drug should be evaluated under storage conditions its thermal stability". Before 1987, "manufacturers are responsible for shipping and maintaining the required temperature in the supply chain" as per the Food and Drug Distribution Act (FDA). The act was amended in 1897 as "for the effective distribution of temperature-sensitive products, all producers and distributors will work together"

Management of supply chain involves packaging, labeling, determining the mode of transportation (air, road or ship), shipping the product and maintaining shipping evidence. The entire shipping cycle is done at a controlled temperature. The temperature-critical items can be checked for quality and stability at any time or any given location if necessary (Bishra, 2006) [11].

Oliva & Revetria (2008) [12] developed a model for efficient transportation of temperature-sensitive items. According to them, some items such as food are facing a major loss of quality as they have a very short shelf-life. To maintain quality, they are to be frozen. The frozen elements get contaminated due to inadequate packaging and transportation. Despite the Hazard Analysis of Critical Control Point (HACCP), which is the formulation of food and health regulations, food-borne diseases are most prevalent in Europe. Cold Chain Management (CCM) is implemented for effective control of the supply chain. This means that the heat is to be maintained in the supply chain. Protection to ‘cold items’ must be assured from manufacturer to customer.

Good cold chain management involves cross-docking to reduce inventory rates, consolidating for efficient delivery and temperature assessment to ensure quality. The authors suggest a model for CCM that would replace an outdated conventional FIFO. The item which is manufactured first in the FIFO system will be packed first. The new model is called Safety Monitoring and Assurance System (SMAS) with Time Temperature Integrators (TTI) are small, inexpensive devices for measuring time-temperature-dependent changes in the quality of items. In this model, instead of FIFO, items are graded as First Grade, Second Grade, etc. To ensure high quality the ideal temperature condition and shelf-life must be recorded on every pack of food.

Fig.1: Cold Chain Management (Oliva & Revetria, 2008) [12].

The HACCP Act ensures quality, hygiene, and safety of the cold items. The act is necessary to recognize hazards and risks associated with the distribution of items using the cold chain, to evaluate critical points, to create quality assurance monitoring and controls, to take action if quality requirements are not met, to check cold chain operations and to maintain records necessary. Food, beverages, and cosmetics have a very short life span. Efficient monitoring and tracking should, therefore, be done to mitigate the possible losses. On every single packet of the product, the manufacturer must record the raw materials used, ideal temperature condition and shelf-life. To ensure maximum profit effective supply chain planning and execution are proposed (Fu *et al.,* 2008) [13].

Products supplied using Clod Chain experience transit conditions during the loading and unloading process. The required temperature cannot be preserved if the transport vehicle doors are open for long periods during the loading or unloading process. The heat produced inside the vehicle during the transportation process can also be the reason for the variation in the temperature. During the transportation process, a sudden interruption can occur in the refrigeration system. A model is proposed to manage such circumstances. The model proposed uses temperature control technology and produces alert messages if the temperature drops (Carullo *et al.,* 2009) [14].

Rollo & Gnoni (2010) [15] propose a CCM model. This includes four parties, namely production, management of inventories, distribution, and end-consumer. "Intelligent packaging" is to be performed during manufacturing to ensure that the product quality is not compromised due to the packaging. When shipping different items using the cold chain it is important to maintain different temperatures. If the proper temperature is not preserved, the shelf-life of 'cold products' can be reduced. Therefore "intelligent shipping" is required. First Expired First Out is the strategy that is more successful than FIFO. Distribution is achieved in most cases by the outsourcing of the cold chain. At this point, the performance depends on things, containers, transit time, etc. The end customer is the last party in the Cold Chain. Temperature regulation at this point is very difficult because it depends on the performance of the consumer's refrigerator. In the case of reverse flow, which is from the customer to the cold chain, precaution must be taken to ensure the quality of products.

Not only does the cold chain include 'Cold materials on wheels.' People are a vital part of the chain for the proper execution of all required procedures. In the case of any problem or unforeseen circumstance, people need to take appropriate measures (Vesper *et al.,* 2010) [16].

Liu & Gia (2010) [17] developed the e^3-V approach for effective cold chain management. It involves actors, value activity, and value object value port and value interface. The key actors are buyers and sellers. The value operation is the use of technology to manage the Cold Chain effectively. The object of interest is the one that is exchanged between the producer and the consumer; it may be in terms of goods, services or money. The port of value is where goods are traded. The value system ensures Cold Chain is handled properly. The customer gets shipped goods or services only when he pays for the same. Value activity means that the seller uses technology to ensure goods are delivered properly, and the buyer uses technology to ensure payment.

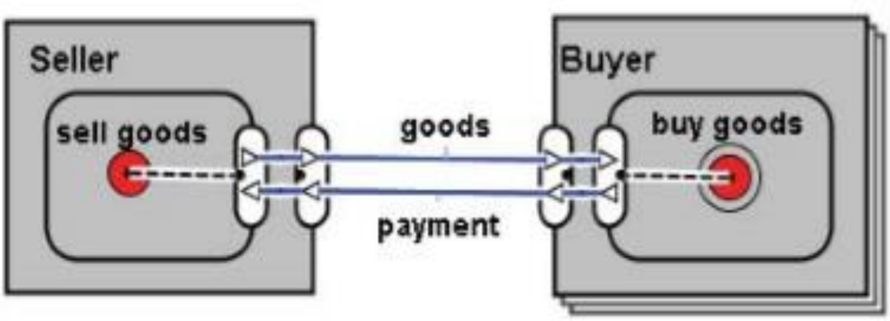


Fig. 2: Example of the e3-Value model (Liu &Gia, 2010) [17].

Gui *et al.* (2010) [18] introduced a model called the Multi-Echelon stochastic inventory model to satisfy customers 'unpredictable demands and maintain optimal inventory levels. In general, the cold chain comprises three stages, namely production delivery, and distribution. This model is perfect for getting maximum gain and overcoming the loss due to surplus stock. For the three cold storage units, it assumes a convergence branch structure as shown in figure-3. The first level includes cold storage at the manufacturing plant, processing unit, and packaging unit, the second level is cold storage on wheels and the third level is cold storage at various distortion units. The stock levels are determined by demand.

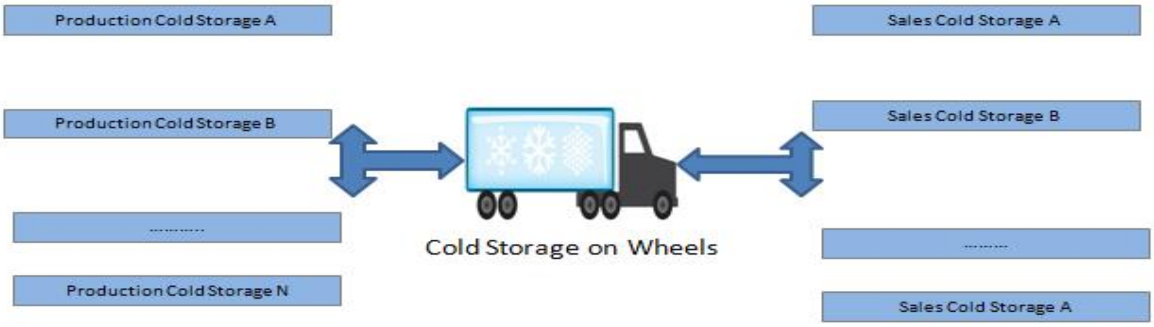


Fig. 3: Multi-echelon stochastic model (Gue *et al.*, 2010) [18]

Ying *et al.* (2010) [19] suggested a model called Optimum Distribution System for the efficient distribution of Cold Chain products. Carrying and storage are seen as two of the Cold Chain's main components. 'Cold material' is supplied to the user without wasting resources. Since the quality of the 'Cold items' degrades due to temperature change, the ship of the goods is to be performed with the utmost care.

Continuous electricity supply is needed for maintaining the desired temperature in the cold chain. Previously, battery-powered refrigerators were used. Such batteries have a very short lifespan of 3-5 years. That would then result in enormous replacement costs. Solar refrigerators that use flat-plate evacuated tubes are used to overcome this situation (Kurian 2012) [20].

Many products delivered using the Cold Chain are consumables. The ideal temperature required for these products should be maintained, from production to consumption. By shipping goods using Cold Chain, care must be taken on the 'quality' and 'safety' of the goods delivered across the supply chain is maintained. To ensure maximum benefit, it is necessary to forecast the demand for the items to store the items on high demand in adequate quantities. Likewise, to mitigate the potential loss, the stock of non-moving objects must be reduced. In CCM this approach is called 'demand forecasting.' It is primarily used by warehouse owners to overcome out of stock and surplus stock situations (Lan & Tialn, 2013) [21].

When thermal sensitive items that get perished easily are shipped through the cold chain, care must be taken to maintain the required temperature from the manufacturer to the distributor or consumer. The

Perishable Product Export Control Board (PPECCB) suggests the use of reefers to transport the items. When 'cold items' are transported, there is a possibility of container rain. When the container is cooled before loading of 'cold items', due to hot air outside the container, moisture gets condensed on the roof walls. As quickly perishing thermally sensitive products are transported via the cold chain, care must be taken to keep the appropriate temperature from the supplier to the distributor or user. The Perishable Product Export Control Board (PPECB) recommends that the products be transported using reefers. When the 'cold objects' are transported, container rain is likely. Once the container is cooled before loading 'cold products,' due to hot atmosphere outside the container, humidity is condensed on the walls of the roof. That would then result in enormous replacement costs. Solar refrigerators that use flat-evacuated tubes are used to overcome this situation. This is called container rain. It will harm the quality of shipped goods. To avoid this continuous electricity is to be supplied to the containers once loaded with items. The aim here is to hold the ideal temperature during adverse weather, such as hot summer (Freiboth *et al.*, 2013) [22].

Liu & Liu (2013) [23] introduce a 2-hub cold supply chain model. There are three forms of information flow between various nodes within a cold supply chain, namely logistic information, business information, and capital flow. Cold supply chain 2-hub model is implemented to bridge the gap related to the flow of information between different nodes. For transportation, the cold supply chain uses third-party logistics (TPL), but it uses technology to control information flow between various nodes.

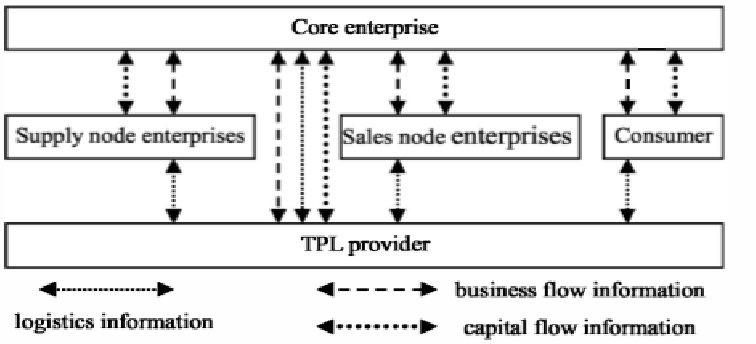


Fig. 4: 2-Hub model for cold supply chain using TPL (Liu &Liu 2013) [23].

Yang *et al.* (2013) [24] demonstrate how the cold supply chain progresses from third-party logistics (3PL) to fourth-party logistics (4PL) using technology. Full cold supply chain automation is realized using 4PL technology.

Using the Cold Supply Chain, utmost care must be taken when transporting temperature and vibration-sensitive objects. Many of the abnormal incidents happen during the process of transportation. Therefore, complete monitoring of the cold supply chain is much needed. The entire supply chain is monitored for detecting temperature anomalies, detecting theft and detecting any obstacles during transport or detecting the location. Multidimensional Cold Chain Logistics Information Sensing Surveillance (MISS) uses technology to track the entire cold supply chain, thus ensuring the protection of shipped products (Ding *et al.*, 2013) [25].

Safety and reliability are the two quantitative elements that are to be handled to optimize the cold supply chain. To minimize loss during transportation, using a heuristic algorithm, the safety and reliability of items to be delivered are measured. The cost of transportation of items using the cold chain also involves a cost to ensure the safety and reliability of items to be delivered (Zou *et al.*,2013) [26].

The efficient transport of thermally sensitive items is a worldwide challenge. The cold supply chain covers production, processing, shipping, and sales. The continuous flow of information will occur among the four. The use of 3PL breaks the connection as the services of third parties are used for the transport. Using ubiquitous technology, real-time monitoring is used to bridge that gap. It ensures the safety and quality of shipped goods using the Cold Chain (Zang & Chen, 2014) [27].

Liolissia (2015) [28] developed a new paradigm to ensure that products are distributed effectively using the Cold Supply Chain. This paradigm is called an Integrated Cold Supply Network consisting of goods, origin/destination, distribution, conditional demand, the integrity of the load and integrity of the transport. The product must be delivered according to conditional demand. When the product is packed, ideal temperature and humidity levels are to be recorded on each unit needed to maintain its quality. Source and destination are critical aspects of measuring temperature-sensitive object quality. The ideal temperature should be preserved during transport. The integrity of transport ensures the specified temperature of the products is preserved during the shipping process. Load integrity ensures that every unit is kept at the required temperature.

Singh *et al.* (2017) [29] proposed a conceptual model for the assessment of Cold Chain sustainability. Sustainability is a key factor in any business. The model analyzes the sustainability contributing factors. The factors ensuring the sustainability of the cold chain are a selection of manufacturer/supplier, knowledge of environmental conditions, the close association among various Cold Chain stakeholders. The Cold Chain should be measured based on production costs, distribution costs, waste rate, energy use and performance in transport. The obstacles to sustainability are insufficient facilities, inefficient mechanisms, and inappropriate deployment of Cold Chain centers and lack of expertise. Reduced risks and costs, optimal inventory levels, increased flexibility, and improved quality are the supporting factors.

To delay the biological deterioration of perishable goods transported using the Cold Chain, time-temperature constraints need to be critically evaluated at each significant stage of the cold chain. Failure to maintain the desired temperature condition reduces cold chain performance. Depending on time and temperature the shelf-life of products delivered using cold chains should be determined. The objects will perish before the specified time if the appropriate temperature is not maintained. Therefore, the time-temperature history of the products should be used to evaluate the quality (Mercier *et al.*, 2017) [30].

Low-temperature conditions, unreliable shelf-life printed on the pack of goods are the key cause of the wastage of temperature-sensitive products delivered using cold chain. The cold chain will not stop with the convenience store. It goes on until the consumer. But on the customer side, the refrigeration level would be different compared to the manufacturing stage. 'Intelligent packing' is achieved using 'smart technology' to ensure the quality of the items. Intelligent packaging is "a packaging system capable of performing smart functions to promote decision-making to extend shelf life, improve safety, improve quality, provide details and warn about possible problems." The quality check can be done by using Time Temperature Indicators (TTI) and smart devices (Stergiou, 2018) [31].

A reliable way to confirm and verify that goods have been stored within a permitted range of temperature is needed at any node of the cold chain. To check the consistency of items supplied, a distributed ledger system is used in cold chain management. This uses intelligent devices to test the quality of products delivered using a cold chain (Hulea & Miron, 2018) [32].

The use of solar refrigerators, innovations in transportations, real-time monitoring and temperature maintenance throughout the cold chain are factors that have a major impact on the performance of the cold chain. There are several Critical Control Points (CCPs) between producer and customer on the cold chain. The quality and temperature of the products must be tested at any critical point using real-time technology (Compos & Villa, 2018) [33].

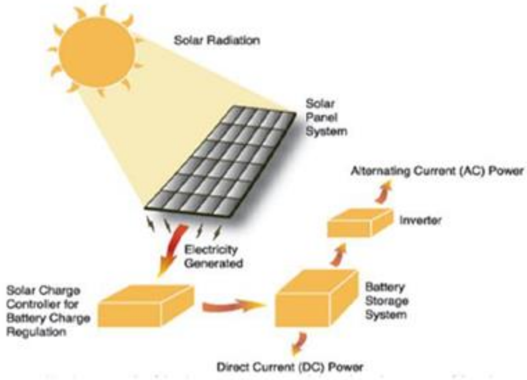
Table 1: Development in Cold Chain Operation & Management (2005-2020).

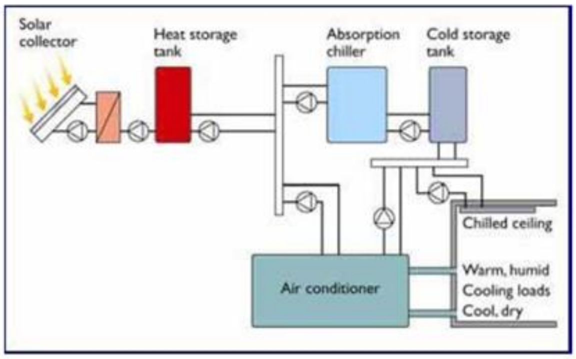
Sl.No	Authors	Year	Inventions/Findings/Results
1	Bishra [11]	2006	Manufacturers and retailers alike and not just the manufacturer take responsibility for the successful management of the cold chain.
2	Oliva & Revetria [12]	2008	Instead of conventional FIFO, SAMS model is proposed for CCM. SAMS model includes TTI for measuring the quality of the shipped products.
3	Fu *et al.* [13]	2008	For effective CCM, supply chain planning and execution is a must. For effective tracking of items can be done by using technology
4	Carullo *et al.* [14]	2009	For efficient CCM, an alert mechanism using some technology is implemented in unexpected circumstances where the temperature cannot be maintained
5	Rollo & Gnoni [15]	2010	“Intelligent packing”, “intelligent shipping”, FEFO strategies make CCM more effective

6	Vesper *et al.* [16]	2010	People are an essential part of the cold chain.
7	Liu & Gia [17]	2010	e^3 V methodology for CCM
8	Gui *et al.* [18]	2010	Multi-echelon stochastic model for CCM is developed to meet the ransom demands of customers
9	Ying *et al.* [19]	2010	Model is developed for effective transportation of 'Cold things'
10	Kurian [20]	2012	Use of Solar Cold Chain
11	Lan & Tialn [21]	2013	The demand must be forecasted when maintaining cold products stock to ensure maximum gain
12	Freiboth *et al.* [22]	2013	The quality of products should not be deteriorated when they are distributed using the cold chain during adverse weather conditions such as Summer
13	Liu & Liu [23]	2013	Two hub model for the effective flow of information using technology
14	Yang *et al.* [24]	2013	Use of technology to create 4PL
15	Ding *et al.* [25]	2013	Multi-dimensional Information Sensing Surveillance for Cold Chain Logistics using technology to ensure the safety of items shipped using Cold Supply Chain
16	Zou *et al.* [26]	2013	Heuristic algorithm to ensure safety and reliability of items delivered using Cold Supply Chain
17	Zang & Chen [27]	2014	Real-time monitoring of Cold chain to guarantee the quality and safety of items
18	Liolissa [28]	2015	Design of a new paradigm called integrated cold chain to make sure the quality of items delivered
19	Singh *et al.* [29]	2017	Main reasons for achieving the sustainability of the cold supply chain, activities to be adopted to ensure sustainability and main performance metrics for sustainability evaluation are identified
20	Mercier *et al.* [30]	2017	Quality and stability of items depends not only on temperature but also on time-temperature conditions
21	Stergiou [31]	2018	To ensure the better shelf-life of items, 'intelligent packing' is done using 'smart devices and TTI
22	Hulea & Miron [32]	2018	Use of distributed ledger technologies to verify the quality of items delivered using Cold Chain
23	Compos & Villa [33]	2018	At every Critical Control Point (CCP) temperature is to be checked using technology to ensure the quality of items

3.2 SOLAR ENERGY FOR THE 'COLD' ELEMENT OF THE COLD CHAIN :

Solar cooling includes two forms in theory. One is the use of photovoltaic technology-translation of solar energy into electricity first, and then this produced electric energy is used for cooling and refrigeration, such as photovoltaic refrigeration and thermoelectric refrigeration. The use of solar collectors is another technique. First, solar energy is transformed to heat, and heat is used to drive cooling energy, such as absorption cooling, adsorption cooling, and jet cooling. 2 key factors are driving the implementation of the solar cooling technology, one being the solar cooling capacity and the other being the high solar energy costs. Solar refrigerator costs are based solely on the technology employed. Costs will range from $1,200 US to $7,000 US (Liu, 2010) [17].





(a) (b)

Fig. 5: Basic principles of (a) solar light - electricity conversion refrigeration and (b) solar absorption refrigeration [34].

A current alternative to raising the peak of energy use is the potential use of renewable energies such as wind, biogas, hydro, ocean waves, and solar radiation, etc., have played a major role in reforming the natural balance and creating increasing demand for the population. Clean and renewable energy, solar energy, is today one of the most distributed sources of energy in the world. Likely, the availability of the excessive amount of solar radiation provides the opportunity to use solar thermal technology for summer cooling and summer cooling. The challenge is to choose effective and sufficient technologies to take advantage of the full heat from the sun to meet the demand for electricity. Solar energy is the most environmentally sustainable choice for cooling from any angle including potential for Ozone depletion, the potential for global warming and primary energy use.

Balaras *et al.* (2007) [34], in Europe, surveyed more than50 projects on solar-powered cooling systems to determine the potential needs of solar refrigeration technology. In the US state of Indiana, the world's first solar-powered single-effect Lithium Bromide refrigerator was placed into commercial service, and this created widespread interest in the solar refrigeration market. Coefficient of Performance (COP) is used to calculate the efficacy of the refrigeration system. This is the ratio of useful work to energy input. The system's efficiency will be calculated with a high COP value.

The refrigerator with solar adsorption consists primarily of a collector holding the adsorbent, an evaporator, and a condenser. It uses the performance of the adsorbent – refrigerant pair in the refrigerator process during adsorption and desorption. Performances in 14 consecutive days are assessed. Also, on cloudy and rainy days, the device generates cold air. The COP (cooling energy / solar energy) contained in average ambient temperature between 14 and 18°C for irradiation between 12,000 and 27,000 kJ/m^{2}was 5 to 8 percent. COP was small, but it was noiseless and polite to the environment (Lemmini & Errougani, 2005) [35].

With wireless sensor nodes, photodiodes and storage capacitors implemented using 0.35 μm CMOS logic process, solar energy can be used as a power source for harvesting and storage. Integrated vertical plate condensers allow for dense energy storage without restricting optical efficiency. It is possible to generate power of 225 μW / mm^2 as output by a 20k LUX light with intensity. Photodiodes convert light energy into electrical energy while electromechanical transducers convert vibrations into electrical energy. A digital-analog converter (ADC) sampling the sensor data, an RF transceiver and a DSP core, are the major parts of the sensor node (Guilar *et al*. 2006) [36].

In the Faculty of Sciences, Rabat, Laboratory of Solar experimented with solar adsorption refrigerator using pairs of activated carbon-methanol fluids. It was composed of an adsorbent (collector), an evaporator, and a condenser. Even at rainy and cloudy weather temperatures, with very high irradiation, it can produce cold less than -11^{0}C during days. For irradiation with range 12,000 and 28,000 kJm^{-2} and each day ambient surrounding heat around 20°C, the COP was ranging from 0.05 to 0.08. The results show that the unit performs well in Rabat, Mediterranean climate (Lemmin & Errougani, 2007) [37].

Ogueke & Anyanwu (2008) [38] analyzed the solid adsorption refrigerator performance. They were observed and tested during the collector's cool down and evaporation processes. They found that if the initial concentration of adsorbents decreased from 0.29 to 0.21 kg/kg, then the adsorbed concentration

rose from 55 to 98%. For the same difference in the initial adsorbent concentration, the mass of ice produced is increased from 0 kg of ice/kg of adsorbent to 0.4 kg of ice/kg of the same.
Peltier effect (the principles of a thermoelectric module) can be used to design the solar-powered refrigerator, to store and transport perishable items, medicines, and biological materials at low temperatures. By producing temperature 5°C from 27°C in approximately 44mins, it had proven its performance, and calculated COP would be 0.16. The refrigerator's main aim is to be ideal for use by Bedouins living in remote areas of Oman where electricity is a dream (Wahab *et al.*, 2009) [39].
A new model named solar adsorption refrigerator was developed using fuzzy clustering techniques based on the ANFIS architecture. They used it for commercial as well as domestic purposes. The evaporating, condensing and generating temperatures are 0^0C, 35^0C and 107^0C respectively are used here to produce a COP of 0.616 (Tashtoush *et al*., 2011) [40].
Activated carbon prepared by coconut shell is considered better to provide the lowest temperature than palm seed and charcoal as an adsorber. It has been proven to inflate plate cooling powered by sunlight energy during daytime and night temperatures (Tashtoush *et al.*, 2012) [41].
Chien *et al.* (2013) [42] found that after 160 minutes, the increase in solar irradiance from 550 to 700W / m^2 and 500ml ambient temperature water as the cooling load would hold the cooling at $5–8^0$C. The working fluids used here are NH_3-H_2O which produces around 0.25 COPs. This may be used in transportation to desert areas for vaccination or food cooling. One way of cooling is by using solar power to compress the vapor.
Sunlight, Photovoltaic panel transforms the source of energy into DC. A DC drives a compressor to extract heat from the insulated field, and extracted heat acts as a heat sink in the absence of sunlight to preserve the insulation temperature. Inside the insulated region, the thermal reservoir also includes a substance for phase shift. (Ewert *et al.*, 2013) [43].
An alternative to the fuel-driven movers was developed using solar panels as a transport refrigeration system. It consisted of a compressor (electric motor to provide the compressor with motive force), fans, solar PV electrical power source and a power management controller to supply electrical power to the two motors (Blasko *et al.*, 2013) [44].
The solar adsorption ice makers are invented in sustaining the cold chain in third world countries. They are also used for the storage of vaccines. To develop these ice makers, the activated carbon/methanol pair were used. They could produce 5 kg of ice and COP of about 0.08 with the whole next day. At dimension 1.7 x 1.5 x 0.95 m the prototype has experimented. A solar collector with a 1.2m^2 exposed area was used to gather solar radiation (Santori *et al*., 2014) [45].
The model uses heat coupled with thermo-acoustic cooler to generate an acoustic function that was developed to turn the acoustic energy into cooling power. The solar-driven thermo-acoustic cooler is built with PCM. This PCM is rapidly crystallized throughout the day with high solar irradiation to achieve a low temperature of approximately -35 ° C was possible. (Muzet *et al.*, 2014) [46].
Throughout the daytime, the solar PV panel mounted on the top of the roof can be used to prepare cold storage. This design could reach a minimum temperature of 2-3 degrees during the daytime and slowly rise to a maximum temperature of 7-8 degrees at night. This cold storage system has made it ideal for growers of vegetables and fruits to store products for 2 weeks. It avoided costs and rotting by at least 10 to 15 percent. (Khan &Iqbal, 2014) [47].
The project includes solar panels for charging a Lead Acid Battery (12V, 1.2Amp hrs), and a Peltier thermoelectric device for cooling on one side and heat dissipation on the other. Heat dissipation from the sink is cooled by a fan. The system creates quick chilling in just a few seconds as the plate heats up. They are the alternatives to the regular refrigerators that emit CFC and HCFC, making the environment free from pollution (Reddy & Basha, 2015) [48].
The need for electricity can be reduced by using photovoltaic, renewable sources. Depending on the building's position, construction and load, 21 to 70 percent of the electricity requirement can be saved by the solar thermal refrigeration. (Eicker *et al.*, 2015) [49].
The process called Ocean Thermal Energy Conversion used solar energy absorbed in the upper layer of the water. It is a device for producing electricity, and its power is based on OTEC solar assistance. This provided electricity used for electricity and fish storage. (Yuan *et al.*, 2015) [50].
The new design of a solar refrigerator has the irreversibility effect on the performance of the machines.

The fall in heat source temperature causes the COP value to decrease. (Betouche *et al.*, 2016) [51].
Tracking is done primarily through the use of electric motors, sensors, microcontrollers, PLC and many other methods where some input is given to it. This paper takes an approach to the use as a source of a refrigerant such as R744 (CO_2), FREON 12, Ammonia, FREON 22, and FREON 135. An automatic machine is designed and fabricated based on the pressure variation of the refrigerants. The tracking system is used as the working medium with a refrigerant to rotate the device concerning rotation from the sun. Energy output power generation increases as a result of continuous extraction and minimal light utilization (Kumar 2016) [52].
The invention is the portable refrigerator that can transition between a functional mode for use in food and drink cold storage and a collapsed mode of transport. A chiller circuit cooled the food storage space, which can be powered by one or more solar panels (Trotter *et al.*,2016) [53].
The 109 m^3 cold room is refrigerated with an ammonia-absorbing machine. A cold room is driven by a solar absorption system intended for storing fruit and vegetables, especially dates in southern Tunisia. It is important to pay attention to the cooling load, moisture, and ventilation in the room to avoid the perishability of the food and to preserve the nutritional value, quality, and color. Authors propose a model that uses vacuum tube collectors, to provide the required heat thermally from the sun. To accomplish the solar cold room work, at least 21m^2 of solar collectors are required. Several technologies are available such as copper absorber vacuum collectors, and glass absorber vacuum collectors. The fruits are first pre-cooled in an adjacent space at 6°C indoor temperature, and then processed at 2°C in the cold room to avoid product shock. The Solar collector area calculation depends on the global radiation available. Solar collector design requires either a numerical model like the Eufrat model, the Capderou model or the Brichambaut model or direct data from stations in the region (Hmida *et al.*, 2017) [54].
A solar adsorption refrigerator is designed to conserve pharmaceutical products, using the zeolite/water pair. The test was to calculate solar radiation on the collector-adsorber, the temperature of all collector-adsorber, condenser, evaporator, and storage tank components. The SCOP value and total energy obtained by refrigeration with solar adsorption range from 0.09 to 0.185 and 15 to19 MJ respectively. (Tubreoumya *et al.*, 2017) [55].
When using solar arrays in Solar Direct Drive systems, the decreased solar irradiance during rainy weather has surmounted. The energy harvesting system aims to determine the priority of the electricity demand before supplying it to the needy. Consequently, once the basic needs are met and excess energy is allocated to other devices, such as health facility lighting, appliance data loggers, diagnostic equipment and cell phone chargers, etc (Myers *et al*., 2017) [56].
Simulation of the solar air conditioning system was performed and tested with $LiNO_3$-NH_3working fluids to achieve optimum COP performance. Here the energy was saved over other commercial air conditioning by up over 98.95 percent. (Sutikno *et al*., 2018) [57].
Vapor absorption cooling system gives scope to use low-grade energy source i.e. solar panel to generate cooling effect dominated by compression technology driven by high-grade energy. The absorption refrigeration system offers great potential to reduce environmental heat pollution (Narale *et al.*, 2018) [58].
The cooler was designed and powered by a solar hybrid wind system. The photovoltaic solar array is installed at the top of the truck to transform DC output alternating with Current using an inverter. A charge controller is mounted to track the charge stored on the battery. To observe its efficiency, AI is implemented too. As the vehicle is moving, this wind energy is used for amplification by wind turbines installed at the truck's speed. Now, this energy is combined with the photovoltaic solar system and is used for cooling purposes. (Njoroge *et al*., 2018) [59].
Coefficient of Performance (COP) is used to calculate the efficacy of the refrigeration system. The system's efficiency will be calculated with a high COP value. Comparisons of some COP with varieties of solar-powered refrigerators are shown below:

Table 2: Comparisons of some COP with varieties of solar-powered refrigerators

Author(s)	Year	Type	Working Fluids	COP
Lemmini & Errougani [35]	2005	Solar Adsorption Refrigerator	carbon AC35-methanol	0.05-0.08
Lemmini & Errougani	2007	Solar Adsorption	Methanol-Carbon	0.05-0.08

[37]		Refrigerator	(AC35)	
Wahab *et al.* [39]	2009	Thermoelectric Refrigerator	Crystalline silicon solar cell	0.16
Tashtoush *et al.* [41]	2012	Solar Adsorption Refrigerator	Carbon (coconut shell)-methanol	0.31
Chien*et al.* [42]	2013	Solar Adsorption Refrigerator	NH_3-H_2O	0.25
Santori *et. al.* [45]	2014	Solar Adsorption Refrigerator	Carbon-methanol	0.08
Muzet *et al.* [46]	2014	Solar Thermoacoustic refrigerator	-	0.21
Yuan *et al.* [50]	2015	Solar-assisted combined cycle	Ammonia-water	0.18
Tubreoumya *et al.* [55]	2017	Solar Adsorption Refrigerator	zeolite-water	*0.09 to 0.185*
Sutikno *et al.* [57]	2018	Solar Adsorption Refrigerator	NH_3-$LiNO_3$	0.743 to 0.824
Narale *et al.* [58]	2018	Solar Adsorption Refrigerator	R-717 - water	0.74

4. INTEGRATED SOLUTION FOR SOLAR COLD CHAIN MANAGEMENT :

The term integration means "the making up or composition of a whole by adding together or combining the separate parts or elements". A Cold Chain usually consisting of a chain of activities from supplier to seller, or from producer to customer, describing a business process that links supplier/manufacturer, transport logistics service provider, and consumers. Since the process viewpoint is the main component, the addition or combination of activities and processes can be seen as an overall element for the integration of the supply chain. Functionally a solar cold chain can be seen as the close association between four technologies:

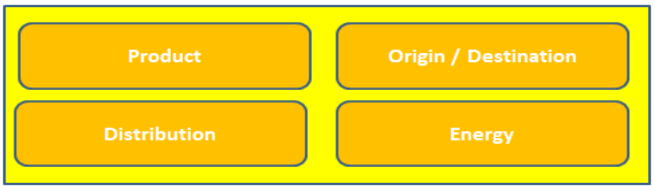


Fig. 6: Technologies associated with the Solar Cold Chain System.

- **Product-** A product has physical attributes that require different conditions of temperature and humidity. Such requirements govern its movement, which must take place in a way that does not compromise its physical integrity to a degree considered unacceptable. Such physical characteristics include how fresh and delicate a product can be; how it manages the cycle of the cold chain. Otherwise, the commodity may be completely or partially losing its market value.
- **Origin / Destination -** The respective locations where they produce and consume a temperature-sensitive commodity. This illustrates the complexity of making a product accessible at a market from where it is made, which can be a major restriction. Because of developments in cold chain logistics, the use of increasingly distant procurement techniques, some of which span the globe, became possible.
- **Distribution-** The available methods and facilities for transporting a commodity inside a temperature-controlled climate. They can include temperature controlled containers (refers), trucks, and equipment for warehousing.
- **Energy -** Control of temperature is a function of almost every stage of the cold chain. By utilizing low-energy technology, the sector will become less dependent on fossil fuels. In cold-chain systems, renewable energies such as wind, bio-energy, solar, hydro and geothermal can be used as a replacement for fossil fuels to produce electricity for use in refrigerating and supply

chain operations. Solar power is one of the best solutions in tropical countries for running small, cold storage systems. (Rodriguez, 2019) [60].

5. THE RESEARCH MODEL :

A research model is built based on an analysis of literature inside solar cold chain integration and the effects of ICT. The model is shown below in Figure 6. The purpose of this model is to dynamically integrate the relationship between ICT and control of the solar cold chain. It will be the starting point for empirical analysis. Besides, it suggests a collection of areas considered important to consider when discussing the effect of ICT on process integration. The model advocates predominantly an overall exploratory approach and is mostly applicable to rigorous qualitative studies.

1. Intelligent Packaging: Cold chain products such as food or pharmaceuticals are fabricated or processed in explicit services. When a manufactured good is ready for shipping, various types of packaging techniques are available to help preserve the quality of its temperature as well as protect it from damage. Most versatile among them is Intelligent Packaging. It is primarily used during transport and storage to track the condition of a packaged product and to collect and provide information about the nature of the packaged goods quality. The system consists of hardware components such as time-temperature indicators, gas detection systems, freshness and/or ripening indicators, and radio frequency indicators. It is capable of monitoring and acting upon changes in a product or its environment. This can track and manage a package's environment actively, and interact with an external interface. Intelligent packaging with smart sensors can monitor time and temperature and can include a product's background of partial or complete temperature. In the supply chain, sensor-based RFID technology can be incorporated into the product packaging to monitor and trace the origin of the product and any sources of contamination or interference.

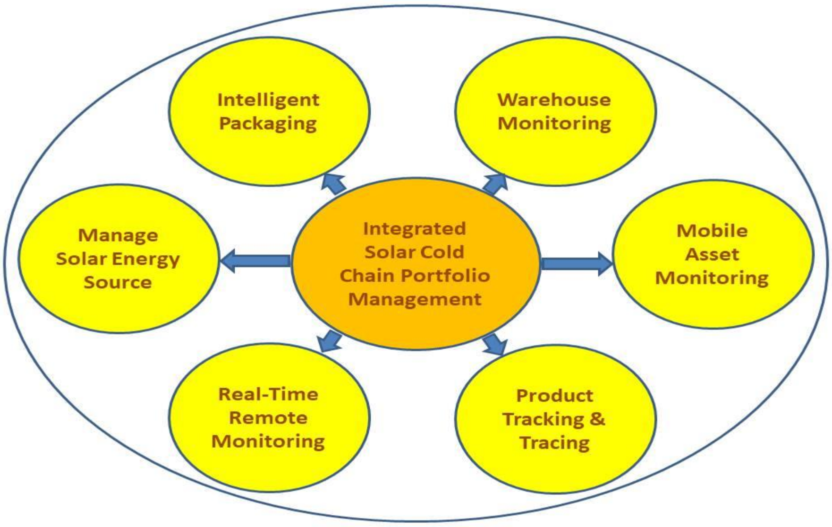


Fig. 7: Integrated Solar Cold Chain Portfolio Management Model

2. Warehouse Monitoring: While the most vulnerable process of end-to-end cold chain management is cooled container transport in cold chain logistics. The important components of this logistics are the security monitoring, refrigerated storehouse distribution conditions and other cold storage facilities. Better temperature control in refrigerated warehouses may help to minimize waste as temperatures that are either too high or too low can lead to loss as it is generally accepted that temperature is an essential environmental attribute regarding product spoilage. RFID sensors are capable of collecting location and temperature and transmitting this information back to a more computationally driven device that can measure parameters such as approximate remaining shelf life. Usually, WSN systems have more sensors than RFID and have incorporated members but are also more costly. RFID and WSN systems are typically limited to one per pallet, but fairly extensive data collection may be involved. Thermal imaging may be used to decrease the number of specific sensors used inside a storage system (RFID or WSN). Computational fluid dynamics technique used to study airflow during the cooling process which can be used to determine the optimal ventilation for containers, pallet distribution, and other variables within the cold storage.

3. Mobile Asset Monitoring: Provides tracking and monitoring of temperature-controlled vehicles used in the Cold Chain in real-time. It keeps track of the cargo temperature and humidity in the truck, reporting shocks and tracking the fuel level and location of the vehicle. The data collected is sent to the cloud application regularly to record, monitor, evaluate and produce various alerts based on alarm conditions and help cold-sensitive products manufacturers enhance operational efficiency and ensure compliance with legal safety initiatives. The system addresses out of band temperature inside the container, stealing/siphoning/adulteration of goods from the carrier, unauthorized stops or routes of the carrier, deviation in fuel consumption & schedule adherence and driving patterns of the driver.

4. Product Tracking & Tracing: Tracking and tracing systems are very useful in the design or setup of a cold chain passive cooling system where thermal or insulated packaging systems are used to maintain the temperature of sensitive time-temperature items. A tracking and tracing system can be introduced to monitor the location and service status of the thermal packaging device at any time, and the tracking system can be used to establish a product quality management system for the packaged product. The combination of IoT and Blockchain provides mechanisms to collect, store and share data with all of the partners in the Cold Chain – securely and in real-time. In Cold Chain, IoT linked sensors help to evaluate and verify the source of the component materials and their compliance with regulations. It stores output metrics for tracking and recording deviations in process efficiency. Embedded goods sensors track items and alert supply chain stakeholders to issues such as temperature anomalies or harm to the products. Smart sensors provide data at each point of the Cold Chain that draws a complete image of a product from raw materials to final distribution and with appropriate granularity to perform root-cause analysis, assess liability in the event of an accident and obtain any number or form of insight.

5. Real-Time Remote Monitoring refers to devices and systems capable of tracking the Cold Chain's environmental state in all of the stages involved, such as temperature, humidity, gas, voltage, vibration, etc. It will provide an account of the Cold Chain's integrity, and help recognize possible vulnerabilities. Wireless smart sensors, such as temperature sensors, moisture sensors, thermocouple sensors, water rope sensors, water detectors, door open/close sensors, accelerometers, current detectors, etc., continuously and automatically monitor environmental conditions around the clock, perform mobility gages, track moisture levels to ensure proper storage, identify coolant leakage or other potential issues.

6. Manage Solar Energy Source: While, with advancements in conversion technology, solar power generation becomes cheaper, the need for the hour is to make the device open to monitoring at the customer level. The Solar PV system consistently generates enough electricity, and its output needs to be tracked in real-time. Smart sensors including voltage sensors, current sensors, and temperature sensor are sensing the essential solar photovoltaic device parameters. Such sensors are integrated with the Solar System sense environmental conditions and transmit generated data with the help of wireless communication medium to the Cloud. The data so accumulated and collected and evaluated for automated decision-making by the Manage and Control applications.

6. DISCUSSION & FUTURE WORK :

In this work, an analysis of the growth of Cold Chain logistics and development in Solar Energy as the cause of energy to the 'Cold' element of Cold Chain in the last 15 years was carried out. The contributions of various authors in the field were discussed in chronological order with a view of recording milestones achieved. The Cold Chain has been found to include many processes such as cold storage, cold transportation, packing, cold warehouse, inventory monitoring & tracing, and distribution. Authors viewed the need to incorporate ICT with the Cold Chain System to simplify processes and make the system more efficient. With the introduction of new technology with diversified uses and functionalities, everything can be leveraged to make the Cold Chain System flexible and competitive. There is also significant progress in the field of Solar as the source energy to meet the Cold Chain's power requirements for both – providing current to refrigeration systems, and making them self-reliable. Solar driven Cold Chain has a bright future and the sector is in its nascent stage. Authors expect researchers to explore the potential and build heterogeneous solutions that address all of the Solar Cold Chain's requirements. Prospective is widely accessible integrating cloud computing, Bigdata, Blockchain, Artificial Intelligence, Machine Learning with powerful cross-platform sensors and unique actuators.

This article introduced the Integrated Solar Cold Chain Portfolio Management Conceptual Model. The model contains six major processes that only provided the theoretical analysis. The model was created by uniting the ideas that various contributors put forward in the field. Future research to be built in the Solar Cold Chain will combine these processes with emerging technologies. We can also use predictive control models to assess perishable products' temperature and relative moisture sharing. They may also contribute to the knowledge of the time of delivery of perishable goods along the chain and their expiry in case of a cold loss or disruption of the system. Another important thing would be measuring the energy costs required to maintain the fresh product's proper temperature at each point of the cold chain.

7. CONCLUSION :

IoT has emerged as a revolutionary technology, capable of enhancing the process flow of the Cold Chain. However, the impact of IoT on system integration and the output, in turn, is not yet empirically explored. The cross-sectional literature review analysis shows a strong and powerful relationship between IoT adoption and the impact it can have on manufacturers, suppliers, logistics managers, retailers, and customers. It is perceived that the coexistence of IoT capabilities in conjunction with ICT technology has substantial process change as well as sustainable service efficiency. This study leads to the integration of processes in the Solar Cold Chain. The adoption of IoT from an organizational capability theory perspective helps to attain the potential for organizational integration.

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